Marine Analyst Service Handbook

Caterpillar
Service Training

January 2004 - 6th Edition

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This book contains a list of formulas and terms for use by a qualified Caterpillar Marine Analyst. Many of the formulas are “Rules of Thumb” but they do provide guidance in their respective areas. These formulas are generally accepted in the marine field. This book is intended as an aid to the Marine Analyst and ***NOT*** a replacement for professional ship design personnel.

Table of Contents

Engine Performance

Application Guidelines

Knowledge of the engine's operating requirements is essential to establish a proper match of engine rating to boat operating requirements. To help determine the acceptability of a rating for a particular boat's application, the following parameters should be considered:

1. Time at full throttle
2. Annual operating hours
3. Propeller match

Time at Full Throttle

Time at full throttle is the amount of time the engine is operated at rated rpm without load cycling during a normal duty cycle. This is normally specified in terms of percent of total cycle time or in minutes per hour.

Annual Operating Hours

The annual operation hours are based on the accumulated service meter units* during a 12-month period.

Propeller Match

The propeller must be sized to allow the engine to operate slightly above rated rpm under the boat's most severe load conditions: full fuel and water tanks, stores aboard for extended voyaging, and adverse sea conditions.

*Clock hours are the same as Service Meter Units on all Caterpillar Engines using electric service meters. Some Caterpillar Engines (D399, D398, D379 and earlier engines) used service meters which "counted" engine revolutions. One service meter unit on those engines, corresponds to a clock hour only when the engine is operating at rated speed (rpm). The ratio between clock hours and service meter units is proportional to engine speed.

Ratings

Ratings are statements of the engines' power and speed capability under specified load conditions. The Caterpillar rating system simply matches engines to particular applications. It consists of the following standard ratings.

Continuous A Rating

For heavy-duty service in ocean-going displacement hulls such as freighters, tugboats, bottom-drag trawlers, and deep river towboats when the engine is operated at rated load and speed up to 100% of the time without interruption or load cycling. Expected usage should be from 5000 to 8000 hours per year.

Medium Duty B Rating

For use in midwater and shrimp trawlers, purse seiners, crew and supply boats, ferry boats with trips longer than one hour, and towboats in rivers where locks, sandbars, curves, or traffic dictate frequent slowing and engine load is constant with some cycling. Full power operation to be limited to 80% of operation time. Expected usage should be from 3000 to 5000 hours per year.

Intermittent C Rating

For use in yachts with displacement hulls as well as ferries with trips of less than one hour, fishing boats moving at higher speed out and back (e.g. lobster, crayfish, and tuna), and short trip coastal freighters where engine load and speed are cyclical. Full power operation to be limited to 50% of operation time. Expected usage should be from 2000 to 4000 hours per year.

Patrol Craft D Rating

Continuous power for use in patrol, customs, police, and some fire boats. Full power limited to 16% of operation. Expected usage should be from 1000 to 3000 hours per year.

High Performance E Rating

For use in pleasure craft with planing hulls as well as for pilot, harbor patrol, and harbormaster boats. Full power operation to be limited to 8% of operation time. Expected usage should be from 200 to 1000 hours per year.

Rating Conditions

Ratings are based on SAE J1128/ISO 8665 standard ambient conditions of 29.61 in. of Hg (100 kPa) and 77° F (25° C). Ratings also apply at AS1501, BS5514, DIN6271 and ISO 3046/1 standard conditions of 29.61 in. of Hg (100 kPa), 81° F (27° C) and 60% relative humidity.

Power is based on a 35° API [60° F (16° C)] fuel having a LHV of 18,390 B/lb (42,780 kJ/kg) used at 85° F (29° C) with a density of 7.001 lb/U.S. gal (838.9 g/L).

Ratings are gross output ratings: i.e., total output capability of the engine equipped with standard accessories: lube oil, fuel oil and jacket water pumps. Power to drive auxiliaries must be deducted from the gross output to arrive at the net power available for the external (flywheel) load. Typical auxiliaries include cooling fans, air compressors, charging alternators, marine gears, and sea water pumps.

Marine Engine Ratings to DIN Standards

The DIN (Deutsche Industrie Norme) 6270 Standard covers rated output data for internal combustion engines in general applications. When required, DIN 6270 main propulsion ratings can be quoted according to the following stipulations.

Continuous Output A
This is the published Caterpillar “Continuous ‘A’ Rating” rating in kW units. No additional reference is necessary*.

Output B
Output B is defined as the maximum useful output that the engine can deliver for a definite time limit corresponding to the engine application. The fuel setting is pre-set such that output B cannot be exceeded, so no overload capability need be demonstrated.

On the basis of this definition, we can offer two output B ratings with kW values corresponding to Caterpillar’s Medium Duty B Rating or Caterpillar’s Intermittent C Rating.

In each case, it is mandatory that reference be made to the applicable rating definitions.

General Comments

DIN 6270 conditions are slightly different from the SAE conditions used in the U.S. We believe that they are virtually equivalent for all practical purposes. No correction to ratings should be made to account for the slightly different reference conditions.

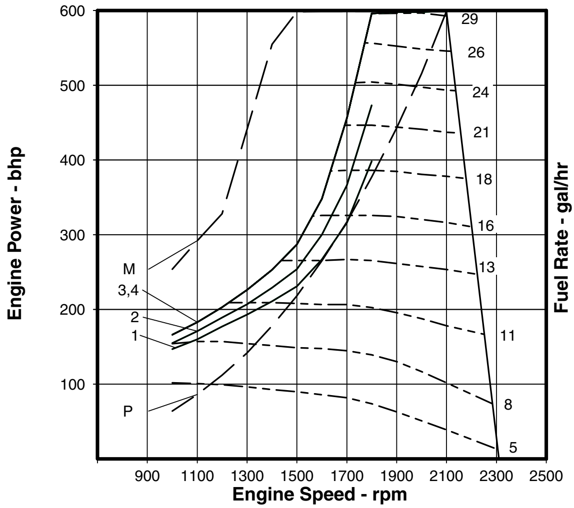
Useful output as described under DIN 6270 is defined as the output available to drive the load after suitable deductions are made for engine driven accessories. This is equivalent to the net rating. Caterpillar ratings indicate gross output. At the kW requirement to drive such accessories as charging alternator and sea water pump are low and well within our rating tolerance, no deductions for main propulsion engine driven accessory loads need to be made.

*A condition in the "Continuous Output A" definition is that the output limiting device must be set to provide a margin of extra capacity. This overload capability can be demonstrated, if required, by increasing the fuel setting from the factory-set continuous output value to the value corresponding to our "B" rating level. With a few exceptions, this increased fuel setting will correspond to an overload capability of approximately 10%. The propeller should be sized for the continuous rating with the appropriate safety margins the Technical Marketing Information File (TMI). The fuel setting must be readjusted to the name-plate value upon completion of the demonstration test.

Performance Curve Format

Caterpillar Performance Curves follow the following format:

Engine Performance – MAR – C Rating
3406 DITA DM6120-00



ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in. Hg- Gauge	Air Flow cfm	Exh Temp F	Exh Flow cfm
Curve 1	1800	398	0.334	19.0	276.7	809	735	1894
	1600	267	0.347	13.4	134.4	544	759	1301
	1400	211	0.354	10.7	78.2	417	761	1000
	1200	177	0.354	9.0	53.2	332	757	788
	1000	147	0.359	7.6	38.4	265	763	633
Curve 2	1800	473	0.329	22.3	36.2	937	746	2202
	1600	300	0.344	14.7	16.0	576	791	1414
	1400	229	0.352	11.5	9.0	431	795	1060
	1200	189	0.354	9.5	6.0	339	793	827
	1000	155	0.359	8.0	4.4	269	799	661
Curve 3	2100	599	0.342	29.4	59.6	1446	648	3121
	1900	598	0.339	29.0	56.2	1262	708	2905
	1700	456	0.334	21.8	32.9	845	804	2071
	1500	287	0.346	14.2	14.1	523	838	1325
	1300	226	0.352	11.4	8.6	392	835	1004
	1100	183	0.355	9.4	5.9	307	836	785
Curve 4	2100	599	0.342	29.4	59.6	1446	648	3121
	1900	598	0.339	29.0	56.2	1262	708	2905
	1700	456	0.334	21.8	32.9	845	804	2071
	1500	287	0.346	14.2	14.1	523	838	1325
	1300	226	0.352	11.4	8.6	392	835	1004
	1100	183	0.355	9.4	5.9	307	836	785

MAXIMUM POWER DATA

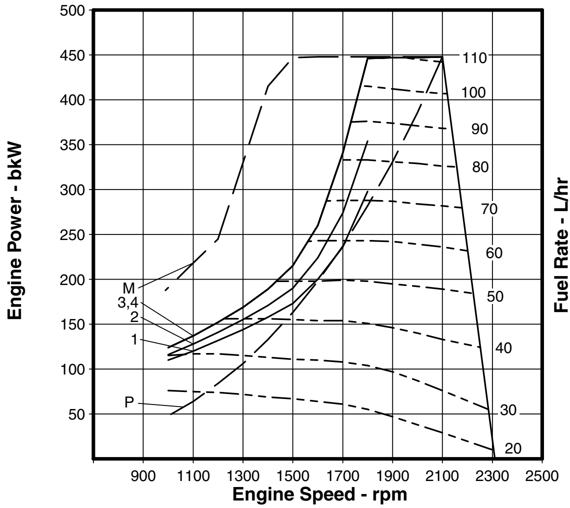
Engine Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in. Hg-Gauge	Air Flow cfm	Exh Temp F	Exh Flow cfm
2100	599	0.342	29.4	59.6	1446	648	3121
1900	599	0.339	29.0	56.2	1262	708	2909
1700	599	0.334	28.6	53.9	1124	799	2743
1500	598	0.336	28.7	48.2	930	966	2594
1300	441	0.352	22.3	31.1	636	1208	2011
1100	292	0.380	15.9	16.3	403	1181	1301

PROPELLER DEMAND DATA

Engine Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in. Hg-Gauge	Air Flow cfm	Exh Temp F	Exh Flow cfm
2100	599	0.342	29.4	59.6	1446	648	3121
1900	443	0.334	21.2	34.2	951	697	2152
1700	317	0.342	15.5	18.7	647	752	1534
1500	218	0.354	11.1	8.8	459	748	1078
1300	142	0.364	7.4	3.6	343	625	725
1100	86	0.375	4.6	1.0	265	486	488

Brake Mean Effective Pressure . . . . 35 kPa

Heat Rejection to Coolant (total) . . . . 99 293 kW



ZONE LIMIT DATA

	Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp C	Exh Flow cu m/ min
Curve 1	1800	298	203	71.9	934.8	22.9	390	53.6
	1600	200	211	50.5	453.9	15.4	403	36.8
	1400	158	215	40.4	264.2	11.8	404	28.3
	1200	132	215	33.9	179.6	9.4	402	22.3
	1000	110	218	28.6	129.9	7.5	405	17.9
Curve 2	1800	354	200	84.3	122.3	26.5	396	62.3
	1600	224	209	55.7	54.0	16.3	420	40.0
	1400	171	214	43.6	30.5	12.2	422	30.0
	1200	141	215	36.1	20.4	9.6	421	23.4
	1000	116	218	30.2	14.7	7.6	424	18.7
Curve 3	2100	448	208	111.1	201.3	40.9	344	88.3
	1900	447	206	109.7	189.7	35.7	376	82.2
	1700	341	203	82.5	111.0	23.9	427	58.6
	1500	215	210	53.7	47.5	14.8	445	37.5
	1300	169	214	43.0	29.0	11.1	443	28.4
	1100	137	216	35.4	20.0	8.7	444	22.2
Curve 4	2100	448	208	111.1	201.3	40.9	344	88.3
	1900	447	206	109.7	189.7	35.7	376	82.2
	1700	341	203	82.5	111.0	23.9	427	58.6
	1500	215	210	53.7	47.5	14.8	445	37.5
	1300	169	214	43.0	29.0	11.1	443	28.4
	1100	137	216	35.4	20.0	8.7	444	22.2

MAXIMUM POWER DATA

Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp C	Exh Flow cu m/ min
2100	448	208	111.1	201.3	40.9	344	88.3
1900	448	206	109.8	189.7	35.7	376	82.3
1700	448	203	108.3	182.2	31.8	424	77.6
1500	447	204	108.7	162.7	26.3	513	73.4
1300	330	214	84.3	105.2	18.0	641	56.9
1100	218	231	60.1	55.1	11.4	627	36.8

PROPELLER DEMAND DATA

Engine Speed rpm	Engine Power bkW	Fuel Cons g/ kW-hr	Fuel Rate L/hr	Boost Press kPa Gauge	Air Flow cu m/ min	Exh Temp C	Exh Flow cu m/ min
2100	448	208	111.1	201.3	40.9	344	88.3
1900	331	203	80.1	115.7	26.9	370	60.9
1700	237	208	58.7	63.3	18.3	399	43.4
1500	163	215	41.9	29.8	13.0	397	30.5
1300	106	221	27.9	12.0	9.7	332	20.5
1100	64	228	17.5	3.3	7.5	258	13.8

Brake Mean Effective Pressure . . . . 239 kPa
Heat Rejection to Coolant (total) . . . . 1746 kW

Features of the Performance Curve:

Vertical Axis [left side] . . . Graduated in units of Power [Brake kW or Brake Horsepower]

Horizontal Axis . . . Graduated in units of Engine Speed [Revolutions per Minute]

Curve P . . . Propeller Demand Curve, describes the power demanded by a fixed pitch propeller used in a displacement hull. Semi-displacement and planing hulls will have higher load demand than shown in the “P” curve. Each semi-displacement and planing hull has different demand, which makes it impossible to show the load demand for each hull. Semi-displacement and planing hulls will need to be sea trialed with fuel measurements taken at different engine speeds to determine actual fuel and load demand.

Curve 1 . . . Continuous Limit Line, describes the upper limit of continuous operation, without interruption or load cycling.

Zone 1-2 . . . Zone 1-2 is located between Curve 1 and Curve 2. It is the zone within which operation is permitted for periods up to 4 hours, followed by a one hour period at combination of power and speed on or under Line 1.

Zone 2-3 . . . Zone 2-3 is located between Curve 2 and Curve 3. It is the zone within which operation is permitted for periods up to 1 hour, followed by a one hour period at combinations of power and speed on or under Line 1.

Zone 3-4 . . . Zone 3-4 is located between Curve 3 and Curve 4. It is the zone within which operation is permitted for periods up to five (5) minutes, followed by a one hour period at combinations of power and speed on or under Line 1.

Curve 4…Maximum Limit Curve, the maximum power available within the rating development limits (cylinder pressure, turbo speed, exhaust temperature).

Curve M…Maximum Power Data, the maximum power capability of the engine without regard to the rating development limits.

Fuel Rate Lines . . . Parallel, slightly curving, dotted lines, with graduations on their right ends, are lines of constant fuel rate. [gal/hr or L/hr]

The most efficient engine rpm to generate any given amount of power will be found directly under the high point of the fuel rate line nearest the required power. This will be most useful in those applications which can vary the engine speed at which power is extracted, such as controllable pitch propellers.

The graphical representation of the engine performance is accompanied by a full set of tabular information. Included is intake manifold pressure, exhaust stack temperature, combustion air flow, exhaust gas flow, fuel rate, engine power and engine speed, and fuel efficiency for all the curves shown.

Each standard rating of the engines will have its performance documented as shown above. There can be a delay of the formal version of the data in the case of new ratings or engine configurations.

Engine Configuration Effects on Ratings

Engine configurations can be altered to allow efficient use of larger amounts of fuel. This is done by increasing the amount of air which can be utilized in an engine. Air flow through an engine is called aspiration. Caterpillar engines have one of the following methods of aspiration:

Naturally Aspirated

In a naturally aspirated engine, the volume of air drawn into each cylinder is moderate, since only atmospheric pressure is forcing air through the cylinder's intake valve. There is no pressurization of the engine's intake manifold by an external device and engine intake manifold pressure is always a partial vacuum.

Turbocharged

Greater amounts of air can be forced into an engine's cylinders by installing a turbocharger. Turbochargers are turbine-like devices which use exhaust energy (which naturally aspirated engines waste) to compress outside air and force it into the intake manifold. The increased amount of air flowing through turbocharged engines does two good things:

1. The greater flow of air cools the valves, piston crowns and cylinder walls, making them better able to resist the firing forces.
2. Fuel can be burned more efficiently, due to the increased amount of air for combustion.

This makes the engine more powerful. Compression does increase the temperature of the intake air, however. It is very useful to remove the heat-of-compression from the intake air, upstream of the combustion chambers. Cooling the air before it enters the combustion chambers makes the air more dense and increases cooling of the combustion chamber components.

Turbocharged/Aftercooled

An air-cooling heat exchanger (aftercooler) is installed between the turbocharger and the combustion chamber on Turbocharged/Aftercooled engines. The aftercooler cools the incoming air, carrying the heat away with a flow of water. The water can come from two sources. If jacket water (the same water that cools the cylinder head and block) is used in the aftercooler, then the air can only be cooled to approximately 200° F (93° C). Jacket water temperature is thermostatically controlled at approximately 180° F (82° C). Even cooler air can be obtained by cooling the aftercooler with water from a separate circuit, such as sea water or some other circuit, with colder water than the engine jacket water.

Lower aftercooler water temperatures permit higher engine ratings because cooler, denser air permits burning more fuel.

Extended Periods of Low Load

Prolonged low load operation should be followed by periodic operation at higher load to consume exhaust deposits. Low load operation is defined as below approximately 20% load. The engine should be operated above 40% load periodically to consume the exhaust deposits. Caterpillar engines can be run well over 24 hours before exhaust slobber becomes significant. The amount of additional time depends upon the engine configuration, water temperature to the aftercooler, inlet air temperature to the engine and type of fuel.

Auxiliary Engine Ratings

Marine engines used for auxiliary power are of the same general configuration as propulsion engines. Their power output is limited by the same design factors. Horsepower ratings are also determined by the type of aspiration, the aftercooling system and by engine application.

Caterpillar prime power ratings are used for marine generator sets when applied as ship-board power and as emergency power at both 60 Hz and 50 Hz. The engine is set at the factory to provide 110% of rated output as required by Marine Classification Societies (MCS).

Normally, other auxiliary power requirements, such as hydraulic pumps, winches, fire and cargo pumps, and compressors, are applied at a rating based on their duty cycle and load factor.

Boat Performance

The performance of the boat is the result of a complex interaction of all three aspects of the installation; the engine, the hull, and the propeller.

Tolerances on Hull, Propeller and Engine

Proper component sizing is very important to the life and performance of the entire propulsion system. There are tolerances in several aspects of the propulsion system. In worst-case conditions, the result can be short life and/or unsatisfactory performance. For example: the effect of these tolerances is shown below in Figure 1.1:

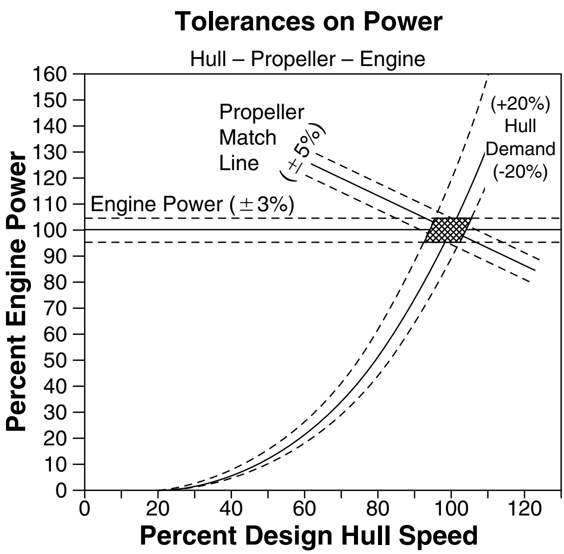


FIGURE 1.1

The engine power may be expected to vary due to manufacturing tolerance by as much as 3% on either side of its rated or 100% power.

The propeller power absorption may be as much as 5% higher, or lower, than originally expected. This could result from manufacturing tolerance in pitch, surface finish, and blade profile.

The hull resistance may vary as much as 20% from calculated values or previous experience due to inevitable differences in weight and shape.

Propeller Sizing

The propeller is as important as the hull or the engine to the performance of the boat.

The propeller directly influences: top speed, fuel efficiency, and engine life.

General Information

While many operators will choose to operate at reduced throttle settings while cruising, the engine must be able to reach its rated speed (rpm) when the boat is ready for sea; fully loaded with fuel, water, and stores. For the ultimate in engine life and economy, expected engine operating speeds during sea trials should be approximately 1-3% over full load rated engine speed (rpm). This is done to compensate for anticipated boat loading and hull fouling.

Table of Engine rpm at Sea Trials

Rated Speed (rpm)	Expected Engine Speed During Sea Trials (rpm)
2800	2820-2850
2500	2520-2550
2400	2420-2450
2300	2320-2350
2100	2120-2150
1925	1945-1980
1800	1820-1850

Eliminating Engine Overloading on Overwheeled Vessels

When the engine speed (rpm) measured during the sea trial of a vessel fails to attain the required sea trial speed, the reason generally is one of the following:

Excessive hull fouling – Solvable by cleaning the hull and re-running the sea trial.

Low engine power – Resolved by measuring and recording engine performance parameters such as inlet, exhaust and fuel rate.

Incorrect transmission or propeller – A detailed discussion of the resolution of this condition follows: Simply, this discussion will be restricted to fixed pitch propellers.

Engine fuel setting adjustment – Many vessel operators and shipyards want to increase the engine fuel (rack) setting when their engine does not reach rated speed during sea trials. At first glance, this seems to be the easiest and least costly remedy.

However, in such a situation, this solution is incorrect, even if the engine speed (rpm) does increase to the expected rated rpm. Increasing the fuel (rack) setting will result in reduced engine life, increased wear, or in worst case, early engine failure. The vessel operators engine repair and maintenance costs will likely far exceed the cost of replacing or modifying the existing transmission or propeller.

High idle adjustment – Another often considered alternative is increasing *high idle* engine speed to the specified free running speed. This will not provide the desired results since the fuel stop is already at the maximum fuel position, and an increase in high idle will not result in any appreciable speed change.

Properly sized propeller and/or reduction ratio – The correct, but more costly, remedy is to install a properly matched propeller and/or transmission ratio to allow the engine to operate within its rating guidelines.

Avoiding driveline component changes – There is another alternative which we will consider in cases where driveline component changes cannot or will not be considered. This method consists of a reduction of both the engine fuel setting and the high idle speed. Of course, the engine power and rated speed are reduced in the process; however, we are taking advantage of the fact that the propellers power demand drops off much faster than the engine power capability when engine and propeller speed is reduced (refer to Figure 1.2).

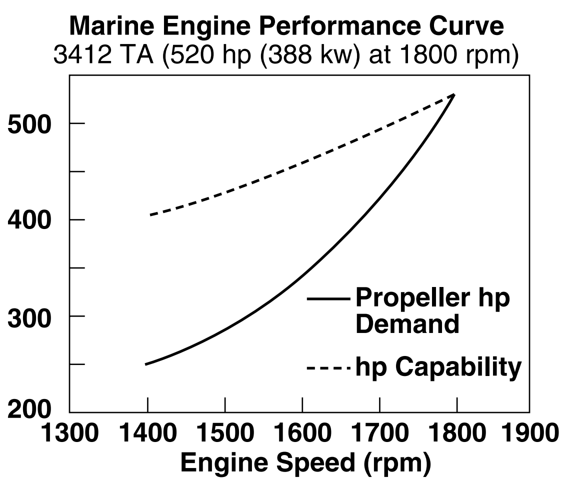


FIGURE 1.2

The net result is that the engine will perform within its application limits and the engine/propeller match have been optimized. The following formula generally applies for a standard fixed pitch propeller:

$$\frac{\mathbf{hp}_1}{\mathbf{hp}_2} = \left[\frac{\mathbf{N}_1}{\mathbf{N}_2}\right]^3$$

or by rewriting the equation

$$\mathbf{hp}_2 = \mathbf{hp}_1 \times \left[\frac{\mathbf{N}_2}{\mathbf{N}_1}\right]^3$$

Where:

$\mathbf{hp}_1$ = Engine power produced at the full throttle speed recorded during the sea trial. This power level is determined by referring to the appropriate marine engine performance curve corresponding to the original engine rating sold by the dealer and reading the power on the curve at the recorded speed.

$\mathbf{hp}_2$ = Calculated propeller power demand at the new reduced engine speed (rpm) proposed for this application.

$\mathbf{N}_1$ = Engine speed (rpm) observed and recorded during the original sea trial – prior to fuel setting and high idle modifications. (This speed should always be measured with a precision tachometer.)

$\mathbf{N}_2$ = New, reduced engine speed (rpm) which must be determined in order to provide an acceptable engine, transmission, and propeller match.

For example: Consider a 3408B DITA engine, sold at a continuous rating of 365 hp at 1800 rpm. During the sea trial, the maximum attainable engine speed was only 1620 rpm. This engine was operating in an unacceptable overload (or *lug*) condition. The Marine Engine Performance Curve (for a continuous rating of 365 hp (272 kw) at 1800 rpm) indicates that the engine was producing (and the propeller was demanding) 344 hp at the limited speed of 1620 rpm. This power requirement exceeds the approved continuous rating of 330 hp at 1620 rpm. The solution is to further reduce the rpm until the approved engine rating, as shown on the 3408B marine engine rating curve, exceeds the propeller demand.

For this example we will calculate the power required if the rated engine rpm was reduced to 1550.

$$\mathbf{hp}_2 = 334 \times \left[\frac{1550}{1620}\right]^3 = 301 \text{ hp}$$

Reducing the engine speed by 70 rpm has resulted in a decrease in propeller demand of 43 hp. The approved engine continuous rating at 1550 rpm is 314 hp and the propeller demand has been reduced to 301 hp.

At the initial trials, the recorded vessel speed was 10.2 knots for this 21 m long seiner. Resetting the engine from 344 hp @ 1620 rpm to 314 hp @ 1550 rpm would decrease the vessel speed to 9.7 knots, a relatively insignificant difference, especially considering the gain in engine life.

Propeller Pitch Correction

An overpitched propeller must have its pitch reduced to allow the engine to reach rated rpm. The pitch must be reduced by an amount proportional to the engine rpm ratio. The following formula defines this relationship:

$$\mathbf{P}\ \text{required} = \mathbf{P}\ \text{present} \times \frac{\textbf{Engine rpm}\ \text{while over loaded}}{\textbf{Desired Engine rpm}}$$

Where:

P required = pitch the propeller must have to allow the engine to run at rated rpm

P present = pitch of the propeller which is preventing the engine from reaching its rated rpm

Engine rpm while overloaded = engine rpm under normal working conditions when equipped with the propeller whose pitch is too great

Desired Engine rpm = desired expected engine speed during Sea Trial (see Table on p. 14)

Propeller Errors and Propeller Measurement

Fast boats need more precise propellers than slow speed workboats.

Propeller pitch errors which would be insignificant on a 10 knot river towboat, will cost a high speed patrolboat or yacht 2 or 3 knots of its top speed.

Propellers on fast boats must be precisely manufactured if design performance is to be attained and they must remain within nearly new specifications to prevent severe performance deterioration. This is particularly true of propellers' leading and trailing edges. Tiny errors in profile, almost too small to be detected by feel, can constitute sites for initiation of cavitation. In severe cases, this can result in blade failure or loss after as little as 24 hours of high speed running.

Most industry professionals can relate instances where new propellers have been found to be several inches out of the specified pitch. When propellers are repaired or repitched, it is even more difficult to restore the necessary precision for highest performance vessels.

The problem usually is the tooling. Most propeller pitch measurement machines can not resolve or detect the small errors which prevent a boat from attaining first-class performance. All other things being equal, the skill of the propeller finishing machinist will make the difference between barely-adequate and first-class boat performance.

Propeller Measurement Tools
There are several basic types of tools commonly used for propeller pitch measurement:

Swing Arm Type
This machine generally consists of: a stand which supports the propeller in a horizontal position, a vertical column which passes through the center of the propeller's hub, a *swing arm* which rotates around the vertical column, and a vertical measuring rod which can slide in and out on the swing arm.

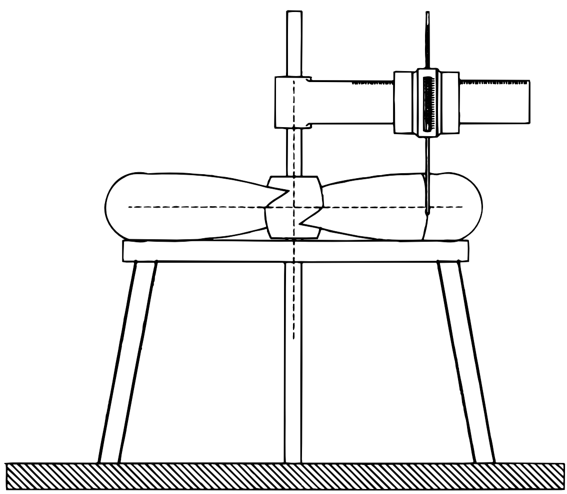


FIGURE 1.3

This machine reaches down from a horizontally mounted swing arm and “touches” the blade at several radial locations, at some standard increments of angle. The difference in elevation, the radial position, and the angular increment between readings allow pitch to be calculated between any two locations. The accuracy of this device is related to the rigidity of the swing arm and the degree of looseness in the required bearings. The potential accuracy of the propellers measured will be directly proportional to the number of measurements on each blade (places at which it touches each blade). For commercial (workboat) propellers, it is common to examine the blade at six (6) to nine (9) places per blade. On high-performance civilian propellers, it is common to examine each blade at twenty-five (25) to fifty (50) places while military propellers may be examined at several hundred places per blade. The skill of the machinist is applied in smoothing or “fairing” the areas between the measurements.

Pitch Blocks
Pitch blocks are precisely shaped anvils, against which individual propeller blades are hammered to repair or correct their shape.

They can be used to measure propellers by comparing the shape of an unknown propeller to a set of incremental pitch blocks until a match is found.

Angle-Measuring Type
Angle-Measuring Devices relate the angle of a circumferential line on the blade to a horizontal reference plane and calculate the pitch from the angle and the radial position.

Caterpillar markets an angle-measuring pitch measuring tool – Part Number 8T5322.

Ducted Propellers (Kort Nozzles)

The Propeller Duct, sometimes called a Kort nozzle is a ring, wrapped around a generally square-tipped, propeller. The ring has an airfoil-shaped cross section.

The ducted propeller is best used on vessels such as trawlers, tugs, and towboats with towing speeds of 3-10 knots. Ducted propellers should not be used on relatively fast vessels.

To aid in selection, perform the following calculation. If the result is less than 30, the use of the ducted propeller should not be considered as it may result in a net loss of vessel performance.

$$\mathbf{B}p = \mathbf{(srpm)}\ \frac{(\sqrt{\mathbf{shp}})}{(\mathbf{V}_a)^{2.5}}$$

Where:

Bp = Basic Propeller Design Variable

srpm = Propeller Shaft Speed (rpm)

shp = Shaft Horsepower (shp)

$\mathbf{V}_a$ = Velocity of Advance of the Propeller (knots) generally equals 0.7 to 0.9 times boat speed

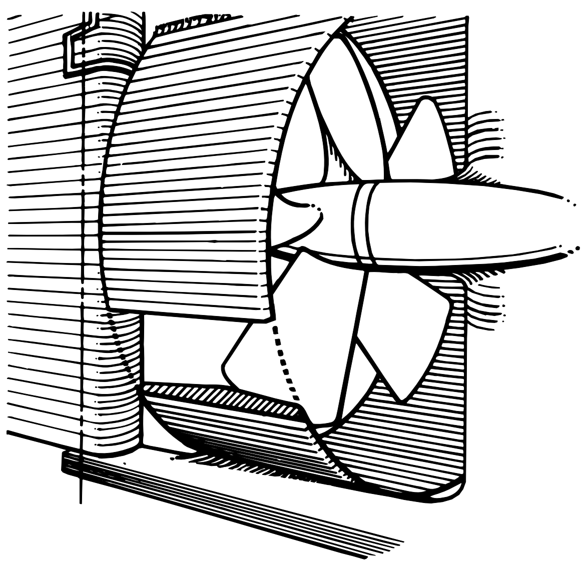


FIGURE 1.4

The nozzle configuration or profile most often used is a No. 19A nozzle although a No. 37 specifically designed for backing is obtainable. Nozzles are made of mild steel with a stainless steel liner to stand up to erosion. They may be mounted to steel, wood or fiberglass hulls.

A comparison of bollard pull ahead and astern for the open water propeller versus the No. 19A (taken as 100% in ahead) and the No. 37 nozzle follows.

	Ahead	**Astern**
Nozzle No. 19A	100%	59%
Nozzle No. 37	99%	82%
Open Propeller (B4.70 Type)	69%	55%

These are actual figures for a 2000 hp (1491 kW) installation with 79 inch (2007 mm) diameter propellers. A larger diameter open propeller would show up somewhat better, though not as good as the nozzles.

More specific information on ducted propeller systems generally can be obtained from propeller manufacturers, many of which also manufacture propeller ducts.

Hull Types

All hull types discussed here refer only to the portion of the hull below the waterline. What is above the waterline concerns seaworthiness, seakindliness, stability, comfort, and eye appeal, but has little impact on the propulsion machinery.

There are two basic types of hulls: Displacement Hulls and Planing Hulls. There are also some special types of hulls. These include the Semi-Displacement Hull, Catamaran, Wave-Piercing Catamaran, Hydrofoil, Surface Effects Ship (with both flexible skirts and rigid side-walls), and the Small-Waterplane-Area-Twin-Hull (SWATH) Ship.

Displacement Hull

A displacement hull can be described in most basic terms as a block, with tapered ends.

Displacement Hull's Most Basic Form
To illustrate the basic shapes this allows, five blocks in what are rearranged to form four simple, but fundamental forms which cover most all displacement hull forms.

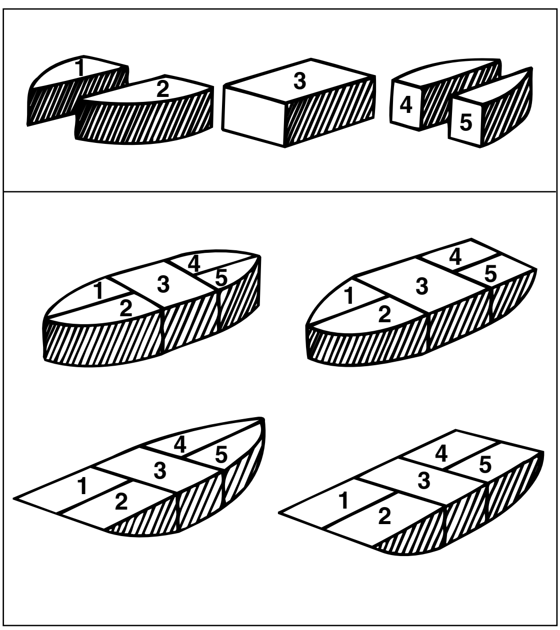


FIGURE 1.5

Keep in mind that this discussion concerns only the portion of the hull below the waterline and that the blocks represent only the submerged part of the hull.

When any one of the hulls shown above moves through the water, waves are formed. The bow pushes the water aside, forming a bow wave. The momentum imparted to the water carries it beyond the boundaries of the hull, leaving a hollow behind it. The wave surges back, into the hollow. At slow speeds, this causes the return surge to bounce off the hull, starting the familiar diverging pattern of troughs and crests originating with the bow wave.

Relation of Hull Length to Boat Speed

The length of a displacement hull determines its eventual top speed. It is literally possible to measure the length of a displacement hull and calculate its highest practical top speed based on this measurement.

This is due to the relationship of boat speed, boat length and wave length.

Boat Length and Wave Length

Wave length and wave speed are directly proportional: the faster a wave, the longer its length.

Since the movement of the hull causes the bow wave, the faster the hull moves, the faster the speed of the bow wave . . . and the longer its length.

As the boat increases its speed, the length of the bow wave will eventually approach the length of the hull.

The speed at which the length of the bow wave equals the hull length is called the Hull Speed Limit.

Further increases in hull speed, beyond the Hull Speed Limit will cause the stern of the hull to drop into the trough of the bow wave.

This has the following bad effects:

- air can enter the displacement hull's propeller/s (reducing propeller thrust)
- the *belly* of the hull is exposed to the oncoming waves (increasing hull resistance)
- the increased incline of the propeller shaft/s reduces the amount of shaft thrust for forward motion (part of the forward component of propeller thrust is wasted in holding up the stern of the boat).

This greatly increases the hull's resistance-to-further-speed-increase. To go faster, the displacement hull must climb the crest of its own bow wave. For example, the last 10% of a displacement hull's top speed costs 27% of its engine power (and fuel consumption).

Mathematical Representation of Hull Speed Ratio
This relationship can be described mathematically. It is called the Hull Speed Ratio.

$$\text{Hull Speed Ratio (SLR)} = \frac{\text{Boat Speed}}{\sqrt{\text{Hull Length}}}$$

When the bow wave length is equal to the hull length, the speed length ratio formula can be expressed as follows:

$$1.34\sqrt{(\text{Hull Length}_{\text{feet}})} = (\text{Boat Speed}_{\text{knots}})$$

or

$$4.5\sqrt{(\text{Hull Length}_{\text{meters}})} = (\text{Boat Speed}_{\text{km/hr}})$$

Planing Hull

The planing hull skims over the surface of the water with relatively little disturbance of the water. The main resistance to planing hull speed is the skin friction. Hulls of this type are very sensitive to the smoothness of the hull, making good hull maintenance essential for top performance. Planing hulls are very sensitive to boat weight.

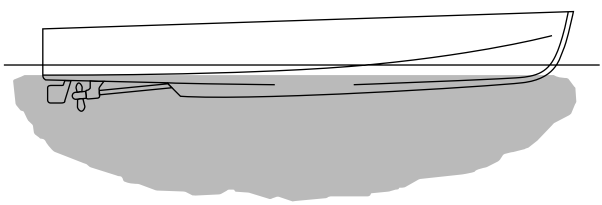


FIGURE 1.6

Semi-Displacement Hull

The semi-displacement hull looks very much like the planing hull and is easily mistaken for the planing hull. Semi-displacement hulls can be described as having characteristics of both planing and displacement hulls, but are not one or the other.

Displacement hulls have trouble with speed length ratios above 1.34 (4.5) due to their hull shape. The planing hulls have difficulties below speed length ratios of approximately 2.5 (8.4) because of their straight fore-and-aft lines.

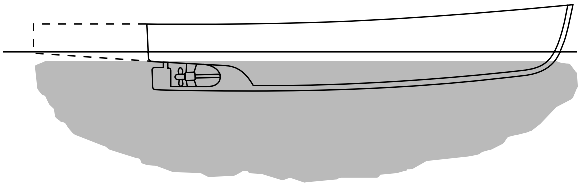


FIGURE 1.7

Semi-displacement hulls are designed to operate well in this speed range.

Semi-displacement hulls are characterized by the angle of the quarter-beam afterbody buttock line. Visualize a pair of vertical, parallel planes intersecting the hull – midway from the longitudinal center of the hull – to the waterline at the side of the boat. The intersection of the planes – with the bottom of the hull near the stern – form the quarter-beam afterbody buttock line (there are two, one on each side, but they have the same shape). The angle of the quarter-beam buttock line is formed between it and a line parallel to the at-rest waterline, Fig. 1.8.

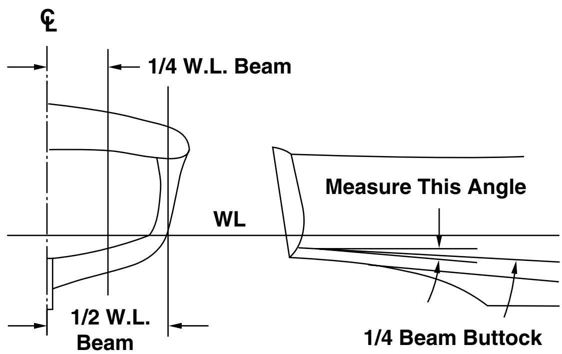


FIGURE 1.8

If the angle of the quarter-beam buttock line is very small (less than 2 degrees), the hull is capable of planing performance. At an angle of 4 degrees, the limiting speed length ratio will be around 2.0. An angle of 7 degrees will limit the speed to speed length ratios of 1.5, or just above displacement hull speeds. These angles should be measured relative to the hull's waterline at rest.

Rules of Thumb

Power to Reach Hull Speed

A useful rule of thumb for vessels below 100 tons displacement is:

Power to Reach Hull Speed horsepower = 5 × [Displacement long tons]

Fuel Consumption

A useful rule of thumb for basic budgetary purposes is:

Fuel Consumption = 1 Liter per hour per 5 horsepower

Formula for Calculating Horsepower

$$\text{Horsepower} = \frac{2\,\pi r \times \text{TORQUE} \times \text{RPM}}{33000}$$

This formula was established by James Watt in the 1800's and requires some known values:

Average horse walks at $2\frac{1}{2}$ MPH

Average horse pulls with a force of 150 pounds

1 mile = 5,280 feet

r = distance from center line of shaft, usually 1 foot

With this background, we will be able to establish the Horsepower formulas used today.

$$5{,}280 \text{ feet} \times 2\tfrac{1}{2} \text{ MPH} = 13{,}200 \text{ FEET per HOUR}$$

$$\frac{13200 \text{ FT/HR}}{60 \text{ Minutes}} = 220 \text{ FEET per MINUTE}$$

$$220 \text{ FT/MIN} \times 150 \text{ POUNDS} = 33{,}000 \text{ FT LBS per MINUTE}$$

$$2\pi r = 6.2831853$$

$$\frac{33000}{6.2831853} = 5252$$

Thus we get the familiar formula used today in calculating Hp.

$$\text{Hp} = \frac{\text{Torque} \times \text{RPM}}{5252} \text{ or expressed another way as}$$

$$\text{Torque} = \frac{\text{Hp} \times 5252}{\text{RPM}}$$

Displacement Hull Calculation

If a vessel's displacement is not known, it can be determined from the dimensions of the vessel, using the following formula.

$$W = \frac{L \times B \times D \times Cb}{M}$$

Where:

W = The vessel's displacement expressed in long tons

L = The length of the vessel, in feet, measured at the actual or designed load waterline (LWL)

B = The extreme width or beam of the vessel, in feet, at the designed load waterline

D = The vessel's molded draft, in feet, measured at its midship section, exclusive of appendages or projections such as the keel

Cb = The block coefficient for the vessel

Light Cargo, Fishing Vessels and Sailing yachts	0.40 – 0.55
Heavy Cargo, Fishing and Tugs	0.50 – 0.65
River Tow Boats	0.55 – 0.70
Self-propelled Barges	0.70 – 0.90
Barges	0.85 – 0.90

M = The volume of water (cubic feet) per long ton

35 for sea water

36 for fresh water

Horsepower Requirements for Displacement Hulls

A displacement hull is define by having a taper at the bow, a taper at the stern, and a $\frac{1}{4}$ beam buttock angle of 8 degrees or greater.

The speed which corresponds to SL = 1.34 is referred to as the displacement hull limiting speed. Attempting to power a displacement hull above this speed will cause the stern of the vessel to “drop” into its own bow wave trough, exposing the oncoming water to the underside of the vessel and entraining air in the propeller. This will effectively cause the vessel to “climb uphill” and reduce the amount of power the propeller is capable of absorbing. This occurs at an SL = 1.34 for a pure displacement vessel, and any attempt to power a displacement vessel in excess of this speed would be considered a waste of fuel and money.

Now that the limiting speed of a displacement hull is defined, we can predict the power requirements to propel displacement hulls at different speeds.

The amount of power required to drive a displacement or a semi-displacement hull of a given weight at a given speed can be approximated by the relationship of the weight to the horsepower (Lbs/Hp). This is expressed as the formula:

$$SL = \frac{10.665}{\sqrt[3]{\frac{Lbs}{Hp}}}$$

SL = Speed – Length Ratio

Hp = Horsepower Delivered to the Propeller

Lbs = Vessel Displacement in Pounds

This formula can be rewritten as:

$$\left(\frac{10.665}{SL}\right)^3 = Lbs/Hp$$

Due to the bow wave limitation discussed earlier, only the portion of the SL versus Lbs/Hp relationship below 1.34 applies to displacement hulls. This implies that it would not be appropriate to power a displacement hull with more than 1 horsepower delivered to the propeller for each 504 pounds of vessel displacement.

An example of how to apply this relationship will help clear this up. Consider a pure displacement hull with the following characteristics:

Waterline length = 200 feet

Vessel displacement = 440,000 pounds loaded

Desired speed = 18 knots

$\frac{1}{4}$ beam buttock angle = 9 degrees

With a $\frac{1}{4}$ beam buttock angle of 9 degrees (greater than 8°), it can be assumed that this vessel will be subject to the speed limit of 1.34.

The next step is to see if the designed SL is within the limits established for a displacement hull, using the formula:

$$SL = \frac{Speed}{\sqrt{WL}} \qquad SL = \frac{18}{\sqrt{200}} \qquad SL = 1.27$$

Since the 1.27 calculated SL is below the limit of 1.34 the speed of 18 knots for this vessel is attainable.

The next step is to determine the Lbs/Hp relationship for this boat using the design SL of 1.27. This is done using the following formula:

$$\left(\frac{10.665}{SL}\right)3 = Lbs/Hp \qquad \left(\frac{10.665}{1.27}\right)3 = 592 \text{ Lbs/Hp}$$

The power required to drive this vessel at 18 knots would then be:

$$Hp = \frac{440000 \text{ Lbs}}{592 \text{ Lbs/Hp}}$$

$$Hp = 743$$

This horsepower requirement seems low, but it must be considered that this is the required horsepower delivered to the propeller, and it does not account for losses in the shafting, marine gear, and engine. It also does not allow for reserve horsepower to allow for added resistance due to wind and waves, towing, dragging nets, power takeoffs, or other load increases, which may occur. In actuality, the installed horsepower of this vessel may be higher than the 743 Hp requirement just calculated.

Horsepower Requirements for Semi-Displacement Hulls

Because of the way these hulls ride in the water, the calculations of required horsepower uses a different formula. A semi-displacement hull is defined as having a point at the bow and tapers to a full beam at the mid-section and then partially tapers to a narrow section at its stern. A semi-displacement hull can be described as a displacement hull with a portion of its after body cut off, or a planing hull with a portion of a tapered after body added on. Semi-displacement hulls can be expected to have a $\frac{1}{4}$ beam buttock angle of between 2° and 8°.

Semi-displacement vessels have displacement hull characteristics in that they are somewhat limited in attainable speed by the bow wave phenomenon. However, semi-displacement hulls also have some planing hull characteristics, which allow them to partially "climb" or plane out of the water at higher speeds. This partial planing characteristic causes the bow wave limitation to occur at higher speed length ratios. In general, speed-length ratios fall between roughly 1.4 and 2.9 for semi-displacement vessels. Effectively, semi-displacement hulls operate at higher speeds than displacement hulls because of their partial planing characteristics, yet are not as sensitive to weight addition as a planing hull, due to their partial displacement hull characteristics. These combined characteristics allow for relatively large cargo or passenger carrying capacity at speeds higher than displacement vessels of similar size.

To determine the power requirements for a semi-displacement hull, the SL versus Lbs/Hp relationship is utilized in the same manner as with displacement hulls. The problem in applying this relationship to semi-displacement hulls, however, lies in the fact that the limiting speed-length ratios can vary between 1.4 and 2.9 for different hulls. Before attempting a power requirement calculation for a semi-displacement hull at a given speed, it is first necessary to determine the SL ratio limit for the vessel to ensure that no attempt is made to power the vessel to speeds higher than this limit.

The limiting SL ratio for a semi-displacement hull is determined by evaluating a factor referred to as the Displacement Length Ratio (DL). The DL ratio can be defined by using the following formula:

$$DL = \frac{\text{disp T}}{(0.01XWL)^3}$$

Where:

DL = Displacement-length ratio

disp T = displacement in long tons (1 long ton = 2240 pounds)

WL = Waterline length in feet

Once the DL ratio has been calculated for a semi-displacement hull, the SL to DL relationship can be applied to determine the limiting SL ratio. This SL ratio will then define the maximum attainable speed of the semi-displacement hull. No attempt should be made to power a vessel over this maximum attainable speed, as this is the point where the bow wave limitation occurs on a semi-displacement hull.

The limiting SL can be defined using the following formula:

$$SL\ ratio = \frac{8.26}{DL^{.311}}$$

Where:

SL ratio = Speed-length ratio

DL ratio = Displacement-length ratio

8.26 = constant used by Caterpillar for this calculation

The following example will help explain how to apply the formulas for calculating the horsepower required for a semi-displacement hull.

Let's use the following for boat characteristics:

WL = 62 feet

$\frac{1}{4}$ beam buttock angle = 3°

Displacement tons = 44 Long tons (98,560 pounds)

Designed speed = 11.5 knots

Beam width = 18 feet at mid-section, tapering to 15 feet at the stern.

Based on this information (3° and slight taper) we can recognize a semi-displacement hull. Since this is a semi-displacement vessel and the DL ratio applies, the DL ratio must first be calculated in order to determine the limiting SL ratio for this vessel. The DL ratio is calculated in the following formula:

$$DL = \frac{44}{(0.01 \times 62)^3}$$

$$DL = 184.6 \approx 185$$

$$SL = \frac{8.26}{(185)^{.311}}$$

$$SL = 1.628 \approx 1.63$$

Any speed used in predicting a power requirement for this vessel must correspond to an SL less than 1.63. 1.63 SL ratio corresponds to the maximum possible speed of this vessel due to bow wave limitation.

Since the maximum SL ratio of 1.63 has been calculated, the next step is to determine the power required to drive the vessel 11.5 knots. As a check before proceeding, the SL ratio corresponding to the design speed of the boat should be calculated to ensure that it is less than the maximum attainable SL of 1.63.

$$SL = \frac{11.5}{\sqrt{62}}$$

$$SL = 1.46$$

Since 1.46 is less than 1.63, it is appropriate to try to power this vessel for 11.5 knots. If the SL had been greater than the 1.63 maximum attainable SL then the design speed of the vessel would have to be reduced before attempting a power prediction.

Now that we have the design SL (1.46), we can go to the formula used in the displacement hull problem. That formula was:

$$LB/Hp = \left(\frac{10.665}{SL}\right)^3$$

$$LB/Hp = \left(\frac{10.665}{1.46}\right)^3$$

$$LB/Hp = 389.8 \approx 390$$

$$HP = \frac{98560 \text{ Lbs for vessel}}{390 \text{ LB/Hp}}$$

$$Hp = 252.7 \approx 253 \text{ Hp}$$

So to power this vessel to the 11.5 knots design speed, it would need 253 Hp to the propeller. This is only for the movement of the vessel through the water and does not take into account auxiliary driven equipment, rough seas, or strong currents. Therefore the actual Hp of the engine in the boat may be larger than this calculation, due to the reserve Hp requirements.

Horsepower Requirements for Planing Hulls

A planing hull is a hull of a form which allows it to climb up on a full plane at high speeds. When up on a full plane, the reduced draft of the vessel causes the bow wave to become very small, and they do not limit the speed of the boat as with displacement and semi-displacement hulls. Because of the reduced draft and lack of a bow wave limitation while up on plane, planing hulls can achieve very high speeds. However, their performance is very sensitive to the addition of weight to the boat.

A planing hull begins with a point at its bow, and tapers to full beam at its midsection, then continues aft with no taper or at most a slight taper. The planing hull also has a $\frac{1}{4}$ beam buttock angle 2° or less.

Very few accurate methods exist for determining power requirements and speed predictions on full planing hulls. Often times, planing hulls are equipped with engines based on past experience and tested during sea trials to determine their level of performance. One simple method in existence for estimating planing hull speed potential is referred to as *Crouch's Planing Speed Formula*. The formula is:

$$\text{Speed} = \frac{C}{\sqrt{\text{Lbs/Hp}}}$$

Speed = Boat speed in knots

C = Coefficient Defining Hull Speed

Lbs = Vessel Weight in Pounds

Hp = Horsepower Delivered to the Propeller

This formula develops a power to speed relationship for planing hulls, and experimentation has determined which coefficients should be utilized to obtain acceptable results. The typical coefficients used at Caterpillar are:

150 = average runabouts, cruisers, passenger vessels

190 = high speed runabouts, light high-speed cruisers

210 = race boats

The following example will help explain how all of this works.

Let's use a boat with a displacement of 14,000 pounds. The boat has a narrow beam, deep vee planing hull powered by two (2) 435 Hp diesels. The boat is equipped with performance propellers and low drag stern drives, so we can consider the boat a race type. It will therefore have a "C" coefficient of 210.

First let's take the Hp of the engines 435 $\times$ 2 = 870. Then we must take into account the reduction gear efficiency, typically 3%. 870 Hp $\times$0.97 = 844 Hp available to the propellers. Then we determine the $\frac{\text{Lbs}}{\text{Hp}}$ by dividing the boat displacement by the horsepower available.

In our case Lbs/Hp = $\frac{14000 \text{ Lbs}}{844 \text{ Hp}}$ or Lbs/Hp = 16.59. Now that we have our Lbs/Hp we can calculate the speed of the boat using Crouch's Planing Speed Formula.

$$\text{Speed} = \frac{210}{\sqrt{16.59}} \quad \text{Speed} = 51.56 \text{ Knots}$$

Let's say this customer wants 60 knots. We can calculate the needed Hp by using the information from the previous formula and working out the answer. The formula for this would be $\frac{C}{\text{Speed}}$ = X. Then Lbs/Hp = X^2

Putting the data in from the previous formula we get the following:

$$\frac{210}{60} = 3.50^2$$

$$\text{Lbs/Hp} = 12.25$$

Since the weight of the boat is 14,000 pounds, we can divide the weight of the boat by the Lbs/Hp ratio of 12.25 to get the Hp needed to operate the vessel at the 60 knot speed.

$$\frac{14000 \text{ Pounds}}{12.25 \text{ Lbs/Hp}} = 1{,}143 \text{ Hp required.}$$

Demand Horsepower, for a hull of the propulsion system on an engine is in a cubic relationship with the speed of the boat.

Example: A vessel is cruising at 20 knots. The demand horsepower on the engine is 500 Hp. The captain now wants to go 25 knots. How much horsepower will it take?

$$\frac{25 \text{ knts}}{20 \text{ knts}} = 1.25 \qquad 1.25^3 = 1.953125$$

$$500 \text{ Hp} \times 1.953125 = \underline{\mathbf{976.5625\ Hp}}$$

$$\text{Boat Speed}^{(1)} = 20 \text{ Knts}$$

$$\text{Act. Hp} = 500 \text{ Hp} \qquad \text{New Hp} = 977 \text{ Hp}$$

What is the new boat speed?

$$\text{Speed}^2 = \sqrt[3]{\left(\frac{\text{New Hp}}{\text{Act Hp}}\right)} \times \text{Boat Speed}^{(1)}$$

$$\text{Speed}^2 = \sqrt[3]{\left(\frac{977 \text{ Hp}}{500 \text{ Hp}}\right)} \times 20 \text{ Knts} = \sqrt[3]{1.954} \times 20$$

$$1.250 \times 20 = 25 \text{ Knts}$$

Hull Speed vs Wave Pattern

Miles per Hour $\times$ 1.15 = Knots

Knots $\times$ 101.3 = Feet per Minute

Miles per Hour $\times$ 88 = Feet per Minute

$$\text{SPEED LENGTH RATIO (SLR)} = \frac{V}{\sqrt{LWL}}$$

Where:

V = Vessel Speed

LWL = Loaded waterline length

The generally accepted SLR limits are as follows:

Displacement type hulls = SLR 1.34

Semi-displacement type hulls = SLR 2.3 – 2.5

Planing hulls = No specific high limit, but not good below an SLR of 2.0

The maximum vessel speed can be calculated using the following formula:

$$V = SLR \times \sqrt{LWL}$$

The maximum vessel speed can also be estimated by watching the wave action along a displacement hull type of the vessel. When the crest to crest distance of the bow wave is equal to the LWL of the vessel, the hull is at its optimum speed. If the bow wave crest to crest distance is equal to $\frac{1}{2}$ the LWL then the vessel is at approximately $\frac{1}{2}$ the optimum hull speed.

Economical speed for displacement type vessels is in the SLR range of 1.0 to 1.2. The crest to crest distance for an SLR of 1.0 is (0.56)(LWL). The crest to crest distance for an SLR of 1.2 is (0.8)(LWL).

Basic Propulsion Theory

The essence of marine propulsion is the conversion of engine power into thrust through some type of propulsion device. Because of its simplicity and efficiency, the screw propeller – basically an axial flow pump – has become the most widely used propulsive device.

Propellers

The ability of a propeller to move a vessel forward, through the water, depends upon several factors:

1. The rotational speed of the propeller, which corresponds to the propeller shaft RPM;
2. The angle or pitch of the propeller blades;
3. The diameter and blade area.

These factors, in combination impose a thrust force on the propeller shaft. This thrust is transmitted through the shaft to the thrust bearing, the principle point where the forces generated by the rotating propeller act upon the hull, and cause forward motion.

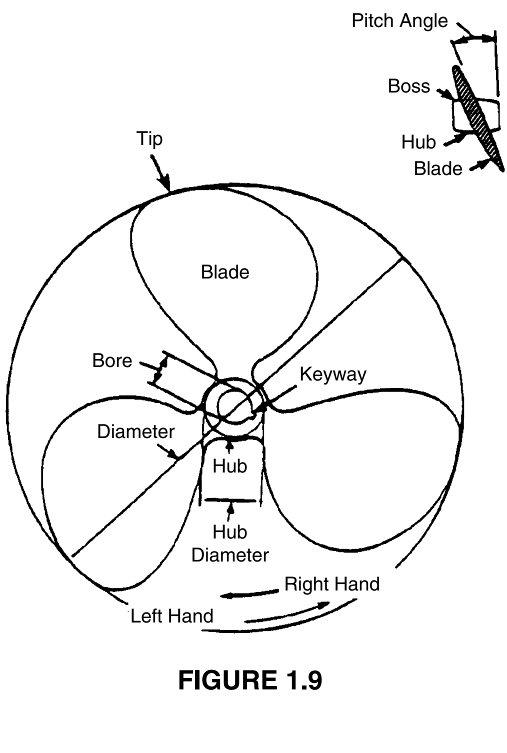


FIGURE 1.9

Figure 1.9 shows a typical 3-bladed propeller. To more intelligently understand the operation of a screw propeller, it is necessary to define the parts of a propeller:

- The *blade* does the work; it pulls water. Naturally, the wider the blade face, the more water it can pull. The more water that can be pulled, the stronger the thrust on the vessel and therefore, a greater amount of work can be done.
- *Propeller diameter* is the diameter of the circle described by the tips of the rotating propeller blades.
- *Blade Angle* is the angle the blade makes in relation to the center line of the hub. It is normally expressed as the distance, in inches. *Pitch* is the distance the blade would advance in one revolution, if it were a screw working in a solid substance.

An important concept in understanding propellers is the pitch ratio. The pitch ratio expresses the relation between the pitch and the diameter of the propeller; often it is referred to as the pitch/diameter ratio. It is obtained by dividing the pitch by the diameter. For example, if a propeller is 60 inches in diameter and has 42 inches of pitch (written as 60" × 42") then the pitch ratio is 42/60 = 0.70.

A general guide for the selection of approximate pitch ratio values is shown, by vessel application, in Figure 1.10.

PITCH RATIO BY VESSEL APPLICATION

Deep water tug boat	0.50 – 0.55
River towboat	0.55 – 0.60
Heavy round bottom work boat	0.60 – 0.70
Medium wt. round bottom work boat	0.80 – 0.90
Planing hull	0.90 – 1.2

FIGURE 1.10

The propeller may be viewed as an axial pump that is delivering a stream of water aft of the vessel. It is this stream of water, equivalent in size to the diameter of the propeller, that is the power that provides thrust to move the vessel through the water. However, to produce thrust, the propeller must accelerate the mass of water it pulls against. In so doing, a portion of the pitch advance is lost to the work of accelerating the water mass. This is known as propeller slip; Figure 1.11 illustrates this concept.

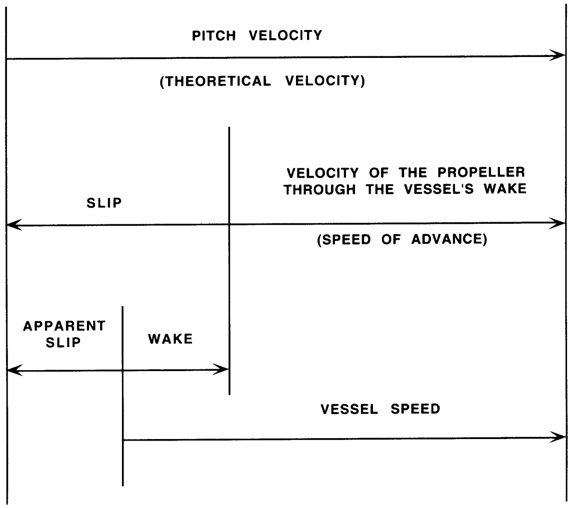


FIGURE 1.11

A propeller with a fixed pitch theoretically has a pitch velocity or linear speed it would travel in the absence of slip. However, because of the work needed to accelerate a mass of water, slip manifests itself as the difference between the pitch velocity and the velocity of the propeller through the vessel's wake or speed of advance.

As a vessel moves through the water, hull resistance, wave formation and converging water at the stern have a tendency to follow the hull. This results in a movement of water under the stern in a forward direction known as wake. The added factor of wake reduces slip to what is known as apparent slip. It also adds to the speed of advance to produce the actual vessel speed. It is obvious from this that propellers function in a very complex manner. There are many factors to be considered when selecting a propeller. The point to realize is that there is no formula that will automatically provide the ideal propeller size for a given vessel and application. This can only be approximated to various degrees of accuracy. The only true test is trial and error under actual operating conditions. Remember, all propellers are a compromise. The general practice is to use the largest diameter propeller turning at the best speed for the vessel's application within practical limits. These limitations are:

1. The size of the aperture in which the propeller is to be installed.
2. The application or type of work the vessel will be doing – towboat, crew boat, pleasure craft, and so forth.
3. Excessive shaft installation angles that may be required when using large diameter propellers.

4. The size of shafting that can be accommodated by the structural members of the hull where the shaft passes through.
5. Comparative weight of propellers, shafts and marine gears with respect to the size of the vessel.
6. The size of marine gears which the hull can accommodate without causing an inordinate degree of shaft angularity.
7. The vessel's inherent ability to absorb the high torque that results from the use of large slow turning propellers.
8. Comparing the cost of using large diameter propellers against any increases in efficiency or performance.

Number Of Propeller Blades

In theory, the propeller with the smallest number of blades (i.e. two) is the most efficient. However, in most cases, diameter and technical limitations necessitate the use of a greater number of blades.

Three-bladed propellers are more efficient over a wider range of applications than any other propeller. Four and sometimes five-bladed propellers are used in cases where objectionable vibrations develop when using a three-bladed propeller.

Four-bladed propellers are often used to increase blade area on tow boats operating with limited draft. They are also used on wooden vessels where deadwood ahead of the propeller restricts water flow. However, two blades passing deadwood at the same time can cause objectionable hull vibration.

All other conditions being equal, the efficiency of a four-blade propeller is approximately 96% that of a three-blade propeller having the same pitch ratio and blades of the same proportion and shape. A "rule of thumb" method for estimating four-blade propeller requirements is to select a proper three-blade propeller from propeller selection charts, then multiply pitch for the three-blade propeller by 0.914. Maximum diameter of a four-blade propeller should not exceed 94% of the recommended three-blade propeller's diameter. Therefore, we multiply diameter by 0.94 to obtain the diameter of a four-blade propeller.

For example, if a three-blade recommendation is:
48 × 34

Multiply pitch (34") by 0.914 = 31"

Multiply diameter (48") by 0.94 = 45"

Four-blade recommendation 45" × 31"

As a word of caution, remember that this is a general rule...for estimating only. Due to the wide variation in blade area and contours from different propeller manufacturers, consult your particular manufacturer before final specifications are decided upon.

A "Rule of the Thumb" for all propeller selection is:

"Towboats – big wheel, small pitch"

"Speedboats – little wheel, big pitch"

All other applications can be shaded between these two statements of extremes.

Propeller Tip Speed

Tip speed, as the name implies, is the speed at which the tips of a rotating propeller travel in miles per hour (MPH). The greater the tip speed, the more power consumed in pure turning. As an example, a 30 inch propeller with a tip speed of 60 MPH absorbs approximately 12 horsepower in pure turning effort. This is a net horsepower loss because it contributes nothing to the forward thrust generated by the propeller.

The following formula can be used to calculate tip speed:

$$T = \frac{D \times \text{SHAFT RPM} \times 60 \times \pi}{12 \times 5280}$$

Where:

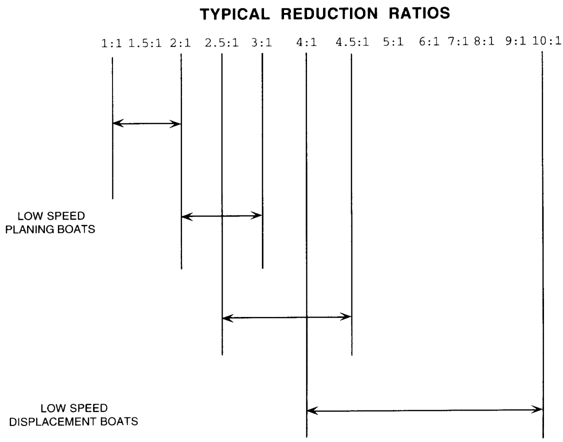
T = Tip speed in MPH

D = Propeller diameter in inches

Cavitation

When propeller RPM is increased to a point where suction ahead of the propeller reduces the water pressure below its vapor pressure, vapor pockets form, interrupting the solid flow of water to the propeller. This condition is known as cavitation.

One of the more common causes of cavitation is excessive tip speed, a propeller turning too fast for water to follow the blade contour. Cavitation can usually be expected to occur at propeller tip speeds exceeding 130 MPH. Cavitation results in a loss of thrust and damaging erosion of the propeller blades.



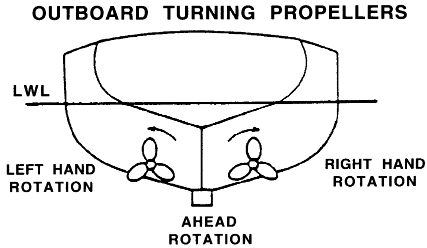
Reduction Gears

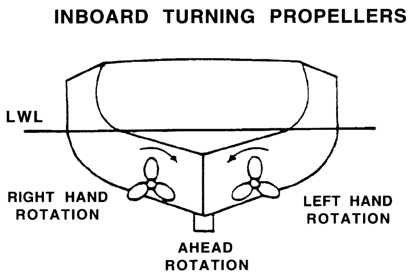
The reduction gear enables the propulsion engine and propeller to be matched so they both operate at their most efficient speeds.

The proper selection of the reduction gear ratio is an important decision in preparing a marine propulsion system. There is a range of commercially available reduction ratios that can help assure optimum vessel performance under a given set of operating conditions.

It is difficult to discuss the selection of reduction gear ratios without mentioning some of the other factors that can influence the selection. The major influencing factors are:

- Expected vessel speed
- Type of vessel
- Vessel duty cycle
- Pitch Ratio
- Propeller tip speed
- Engine horsepower





Propeller Overhang

The maximum distance from the stern bearing to the propeller should be limited to no more than one shaft diameter. Propeller shafts are apt to vibrate and produce a whip action if these limits are exceeded. This condition is greatly accelerated when a propeller is out of balance due to faulty machining or damage.

Propeller Rotation

Propeller rotation is determined from behind the vessel, facing forward. The starboard side is on the right and the port side on the left. Rotation of the propeller is determined by the direction of the wheel when the vessel is in forward motion. Thus, a clockwise rotation would describe a right-hand propeller and a counter-clockwise rotation would be a left-hand propeller.

Right-hand propellers are most frequently used in single screw installations. Twin screw vessels in the U.S. are normally equipped with outboard turning wheels. However, there are some installations where inboard turning wheels will be found. A rotating propeller tends to drift sideways in the direction of the rotation. In a single screw vessel this can be partially offset by the design of the sternpost and the rudder. In a twin screw vessel this can be completely eliminated by using counter-rotating propellers. Although the question of inboard and outboard rotating propellers has been debated many times, authorities on the subject agree that there are no adverse effects on maneuverability with either rotation. In fact, there are those who feel that a gain in maneuverability is obtained with outboard rotating propellers. One point in favor of inboard rotation is a decreased tendency for the propellers to pick-up debris off the bottom in shallow water.

Multiple Propellers

The most efficient method of propelling a vessel is by the use of a single screw. However, there are other factors which, when taken into consideration, make the use of a single propeller impossible. If a vessel has to operate in shallow water, the diameter of the propeller is limited. Therefore, it may be necessary to install two and sometimes three propellers to permit a proper pitch ratio for efficient propulsion.

Another condition requiring multiple propellers is encountered when higher speed yachts need more horsepower than a single engine can develop and still be accommodated in the engine space. As a general rule to follow for calculations in this text, the total SHP of all engines is used when making estimated speed calculations. For calculating propeller size, SHP of each individual engine is used.

Propeller Pitch Correction

An overpitched propeller will overload the engine. To permit the engine to reach its Full power and speed the load must be removed. The load must be reduced by amount proportional to the engine RPM ratio. This can be defined by the following formula:

$$LF = \frac{RPM1}{RPM2}$$

Where:

LF = % of Load

RPM1 = The engine RPM while overloaded “What you have.”

RPM2 = The anticipated engine RPM “What you want to have.”

EXAMPLE FORMULA

The M/V Cat has an engine that produces Full power at 1800 engine RPM. While being tested the engine would only turn to 1750 RPM. Applying the above formula we get the following equation:

$$LF = \frac{1750}{1800}$$

$$LF = 0.97 \times 100$$

$$LF = 97\%$$

This means to get the engine to turn the correct RPM we would have to reduce the load by 3%. If the overload is due to an overpitched propeller then the amount of pitch to be taken out of the current propeller can be determined using the following formula:

$$Pr = Pp \times \frac{RPM1}{RPM2}$$

Where:

Pr = Propeller pitch required

Pp = Present propeller pitch

RPM1 = The engine RPM while overloaded “What you have.”

RPM2 = The anticipated engine RPM “What you want to have.”

Ducted Propellers

Ducted propellers are best used on vessels such as trawlers, tugs, and towboats with towing speeds of 3-10 knots. Ducted propellers should not be used on vessels with relative high speeds.

To help assist in the selection of a ducted propeller, you can perform the following calculation. If the resultant Bp is <(less than) 30, the use of a ducted propeller should not be considered as it may result in a net loss of vessel performance.

$$Bp = SRPM \times \frac{\sqrt{SHP}}{(V_a)^{2.5}}$$

Where:

Bp = Basic Propeller Design Variable

SRPM = Propeller Shaft Speed, RPM

SHP = Shaft Horsepower

V_a = Velocity of Advance of the propeller (knots) generally equals 0.7 to 0.9 times boat speed.

Propeller Formulas and Related Tables

$$\text{Torque} = \frac{(5252 \times \text{Hp})}{\text{Rpm}}$$ Hp = Horsepower
Rpm = Revolutions per minute

Propeller Horsepower Curve Formula

$\text{PHp} = C_{sm} \times \text{Rpm}^n$

C_{sm} = sum matching constant
^{n} = exponent from 2.2 to 3.0, with 2.7 being used for average boats
Rpm = Revolutions per minute

Displacement Speed Formula

$$\text{SL Ratio} = \frac{10.665}{\sqrt[3]{\frac{\text{LB}}{\text{SHP}}}}$$

Where:

SL Ratio = Speed-Length Ratio

and

$$\text{SL Ratio} = \frac{\text{Knts}}{\sqrt{\text{WL}}}$$

Knts = Speed in knots = Boat speed or V
SHP = Shaft Horsepower at propeller
LB = Displacement in pounds
WL = Waterline length in feet

Displacement – Length Ratio Formula

$$\text{DL Ratio} = \frac{\text{disp T}}{(00.01\text{XWL})^3}$$

Where:

disp T = Displacement in long tons of 2,240 pounds, mt = 1.016 long tons
WL = Waterline length in feet

Maximum Speed-Length Ratio vs DL Ratio Formula

$$\text{SL Ratio} = \frac{8.26}{3.215\sqrt{\text{DL Ratio}}}$$

Where:

SL = Speed-length ratio

DL = Displacement-length ratio

Crouch's Planing Speed Formula

$$\text{Knts} = \frac{C}{\sqrt{\text{Lb/SHP}}}$$

Where:

Knts = Speed in knots = Boat Speed = V

C = Constant chosen for the type of vessel being considered

LB = Displacement in pounds

SHP = Horsepower at the propeller shaft

The speed predicted by this formula assumes a propeller has been selected that gives between 50% and 60% efficiency, with 55% a good average.

Analysis Pitch Formula

$$P_0 = \frac{101.33V_a}{N_0}$$

Where:

V_a = Speed in knots through wake at zero thrust

N_0 = Shaft Rpm at zero thrust

Pitch Ratio Formula

$$\text{Pitch Ratio} = P/D$$

Where:

P = Pitch

D = Diameter

Theoretical Thrust Formula

$$\text{Thrust} = \text{Force} = F$$

$$F = MA \text{ or } F = \frac{W}{g} \times (V_0 - V_1)$$

Where:

W = Weight in pounds the column of water accelerated astern by the propeller

g = the acceleration of gravity, 32.2 ft/sec.

V_0 = velocity of water before entering the propeller in feet per second

V_1 = velocity of water after leaving propeller in feet per second

M = Mass in slugs

A = Acceleration in feet per second squared

Developed Area to Projected Area Formula

$$\frac{Ap}{Ad} = 1.0125 - (0.1 \times PR) - (0.0625 \times PR^2)$$

Where:

$\frac{Ap}{Ad}$ = Approximate ratio of projected area to developed area

PR = Pitch ratio of propeller

Mean-Width Ratio Formula

$$\text{Mean-Width Ratio} = \text{MWR}$$

$$\text{MWR} = \frac{\text{Average Blade Width,}}{D} \text{ or}$$

$$\text{MWR} = \frac{\text{Expanded Area of One Blade}}{\text{Blade Height from Root to Tip}} \div D$$

Where:

D = Diameter

Disc-Area Ratio

$$\text{Disc Area} = \frac{\pi D^2}{4} \text{ or } 0.7854D^2$$

$$\text{Disc-Area Ratio} = \text{DAR}$$

$$\text{DAR} = \frac{\text{Expanded Area of all Blades}}{\text{Disc Area}}$$

Where:

D = Diameter

$\pi \approx 3.1412$

Disc-Area Ratio vs Mean-Width Ratio

$$\text{DAR} = \text{Number of Blades} \times 0.51 \times \text{MWR}$$

or

$$\text{MWR} = \frac{\text{DAR}}{\text{Number of Blades} \times 0.51}$$

Where:

DAR = Disc-area ratio

MWR = Mean-width Ratio

Note: These ratios assume a hub that is 20% of overall diameter, which is very close to average. Small propellers for pleasure craft may have slightly smaller hubs, while heavy, workboat propellers, particularly controllable-pitch propellers, may have slightly larger hubs.

Developed Area vs Disc-Area Ratio Formula

$$\text{Ad} = \pi \times \left(\frac{D}{2}\right)^2 \times \text{DAR}$$

Developed Area vs Mean-Width Ratio Formula

$$\text{Ad} = \pi \times \left(\frac{D}{2}\right)^2 \times \text{MWR} \times 0.51 \times \text{Number of Blades}$$

where for both the formulas on page 1-53:

Ad = Developed Area

D = Diameter

DAR = Disc-area ratio

MWR = Mean-width ratio

$\pi \approx 3.1412$

Developed Area for Any Hub Diameter and MWR Formula

$$Ad = MWR \times D \times (1 - Hub\%) \times \frac{D}{2} \times \text{Number of Blades}$$

or

$$Ad = MWR \times \frac{D^2}{2} \times (1 - Hub\%) \times \text{Number of Blades}$$

Where:

Ad = Developed Area

MWR = Mean-width ratio

D = Diameter

Hub% = Maximum hub diameter divided by overall diameter, D

Blade-Thickness Fraction Formula

$$BTF = \frac{t_0}{D}$$

Where:

BTF = Blade-Thickness Fraction

D = Diameter

t_0 = Maximum Blade Thickness as Extended to Shaft Centerline

Rake Ratio Formula

$$\text{Rake Ratio} = \frac{\overline{BO}}{D}$$

Where:

$\overline{BO}$ = Distance between tip of blade projected down to the shaft centerline and face of blade extended down to shaft centerline

D = Diameter

Apparent Slip Formula

$$\text{Slip A} = \frac{\left(\frac{P}{12}\right) \times \text{RPM} - (\text{Knts} \times 101.3)}{\left(\frac{P}{12}\right) \times \text{RPM}}$$

Which can be restated as:

$$P = \frac{\text{Knts} \times 1215.6}{\text{RPM} \times (1 - \text{Slip A})}$$

Where:

Slip A = Apparent Slip

P = Propeller face pitch in inches

Knts = Boat speed through the water or V in Knots

RPM = Revolutions per minute of the propeller

Slip vs Boat Speed Formula

$$\text{Slip} = \frac{1.4}{\text{Knts}^{0.057}}$$

Where:

Knts = Boat speed in knots

DIA-HP-RPM Formula

$$D = \frac{632.7 \times \text{SHP}^{0.2}}{\text{RPM}^{0.6}}$$

Where:

D = Propeller diameter in inches

SHP = Shaft Horsepower at the propeller

RPM = Shaft RPM at the propeller

Optimum Pitch Ratio Formulas

$$\text{Average Pitch Ratio} = 0.46 \times \text{Knts}^{0.26}$$

$$\text{Maximum Pitch Ratio} = 0.52 \times \text{Knts}^{0.28}$$

$$\text{Minimum Pitch Ratio} = 0.39 \times \text{Knts}^{0.23}$$

These formulas have been found to check well with a wide variety of vessels.

Minimum Diameter Formula

$$D_{min} = 4.07 \times (BWL \times H_d)^{0.5}$$

D_{min} = Minimum acceptable propeller diameter in inches

BWL = Beam on the waterline in feet

H_d = Draft of hull from the waterline down (excluding keel,skeg or deadwood) in feet

(Hull draft is the depth of the hull body to the fairbody line, rabbet, or the hull's intersection with the top of the keel. It thus excludes keel and/or skeg.)

$$D_{min} \text{ for twin screws} = 0.8 \times D_{min}$$

$$D_{min} \text{ for triple screws} = 0.65 \times D_{min}$$

Allowable Blade Loading Formula

$$PSI = 1.9 \times V_a^{0.5} \times Ft^{0.08}$$

Where:

PSI = Pressure, in pounds per square inch, at which cavitation is likely to begin

V_a = The speed of the water at the propeller in knots

Ft = The depth of immersion of the propeller shaft centerline, during operation, in feet

Actual Blade Loading Formula

$$PSI = \frac{326 \times SHP \times e}{V_a \times Ad}$$

Where:

PSI = Blade loading in pounds per square inches

SHP = Shaft Horsepower at the propeller

e = Propeller efficiency in open water

V_a = Speed of water at the propeller, in knots

Ad = Developed area of propeller blades, in square inches

Thrust Formula

$$TA = \frac{326 \times SHP \times e}{V_a}$$

Where:

T = Thrust

SHP = Shaft Horsepower at the propeller

e = Propeller efficiency

V_a = Speed of water at the propeller, in knots

Approximate Bollard Pull Formula

$$T_s = 62.72 \times \left(SHP \times \frac{D}{12}\right)^{0.67}$$

T_s = Static thrust or bollard pull, in pounds

SHP = Shaft Horsepower at the propeller

D = Propeller diameter in inches

This formula can also be expressed as:

T_s ton = $0.028 \times (SHP \times D_{ft})^{0.67}$

T_s ton = Thrust in long tons of 2240 pounds

SHP = Shaft Horsepower

D_{ft} = Propeller diameter, in feet

Taylor Wake Fraction Formula

$$Wt = \frac{V - V_a}{V}$$

or

$$V_a = V \times (1 - Wt)$$

Where:

Wt = Taylor wake fraction

V = Boat speed through the water

V_a = Speed of the water at the propeller

Wake Factor Formula

$$Wf = 1 - Wt$$

Speed of Advance Formula

$$V_a = V \times Wf$$

Where:

V = Boat Speed

Wf = Wake Factor

Wt = Taylor Wake Fraction

Wake Factor vs Block Coefficient Formulas for vessels with an SL Ratio of under 2.5

$$\text{Single Screw } Wf = 1.11 - (0.6 \times Cb)$$

$$\text{Twin Screw } Wf = 10.6 - (0.4 \times Cb)$$

Where:

Wf = Wake factor (percent of V “seen” by the propeller)

Cb = Block coefficient of the hull

Block Coefficient Formula

$$Cb = \frac{\text{Displacement}}{WL \times BWL \times H_d \times 64\ \text{Lb/cu.ft.}}$$

Where:

Displacement = Vessel displacement, in pounds

WL = Waterline length, in feet

BWL = Waterline beam, in feet

H_d = Hull draft, excluding keel, skeg or deadwood, in feet

Wake Factor vs Speed Formula

$$Wf = 0.83 \times Knts^{0.047}$$

Where:

Wf = Wake Factor

Knts = Speed in knots

Power Factor Formula

$$Bp = \frac{(SHP)^{0.5} \times N}{V_a^{2.5}}$$

Where:

Bp = Power Factor

SHP = Shaft Horsepower at the propeller

N = Number of shaft revolutions

V_a = Speed of advance of the propeller through the wake

Advance Coefficient Formula

$$\delta = \frac{N \times D_{ft}}{V_a}$$

or

$$\delta = \frac{N \times D}{12 \times V_a}$$

This may also be restated as:

$$D = \frac{\delta = V_a \times 12}{N}$$

Where:

δ = Advance coefficient

N = Shaft RPM

D_{ft} = Propeller diameter in feet

D = Propeller diameter in inches

V_a = Speed of advance of the propeller through the wake

Displacement Speed with Efficiency Formula

$$\text{SL Ratio} = \frac{10.665}{\sqrt[3]{\frac{LB}{SHP}}} \times \sqrt[3]{\frac{\eta}{0.55}}$$

Where:

SL Ratio = Speed-length ratio

LB = Displacement in pounds

SHP = Shaft horsepower at the propeller

η = Propeller efficiency

If the speed in knots is already known, we can multiply the speed directly by

$$\sqrt[3]{\frac{\eta}{0.55}}$$

Planing Speed With Efficiency Formula

$$\text{Knts} = \frac{C}{\sqrt{\frac{LB}{SHP}}} \times \sqrt{\frac{\eta}{0.55}}$$

Where:

Knts = Boat speed in knots

LB = Displacement in pounds

SHP = Shaft horsepower at the propeller

η = Propeller efficiency

If the speed in knots is already known, we can multiply the speed directly by

$$\sqrt[3]{\frac{\eta}{0.55}}$$

Shaft Diameter Formula Solid Tobin Bronze Propeller Shafts

$$Ds = \sqrt[3]{\frac{321000 \times SHP \times SF}{St \times RPM}}$$

Ds = Shaft Diameter, in inches

SHP = Shaft Horsepower

SF = Safety factor (3 for yachts and light commercial craft, 5 to 8 for heavy commercial craft and racing boats)

St = Yield strength in torsional shear, in PSI

RPM = Revolutions per minute of propeller shaft

Shaft Diameter Formula for Monel 400 Propeller Shafts

$$Ds = \sqrt[3]{\frac{321000 \times SHP \times SF}{St \times RPM}} \times 0.80$$

Ds = Shaft Diameter, in inches

SHP = Shaft Horsepower

SF = Safety factor (3 for yachts and light commercial craft, 5 to 8 for heavy commercial craft and racing boats)

St = Yield strength in torsional shear, in PSI

RPM = Revolutions per minute of propeller shaft

Shafts made of Monel 400 should be reduced by 20% the size shaft required for a solid Tobin Bronze shaft.

Shaft-Bearing Spacing Formula

$$Ft = \sqrt{\frac{3.21 \times Ds}{RPM}} \times \sqrt[4]{\frac{E}{Dens}}$$

Where:

Ft = Shaft-bearing spacing, in feet

Ds = Propeller shaft diameter, in inches

RPM = Propeller shaft speed, in revolutions per minute

E = Modulus of elasticity of shaft material, in PSI

Dens = Density of shaft material, in pounds per cubic inch

Propeller Weight Formulas (with 0.33 mean width ratio and a hub diameter of 20%)

Three-Bladed Propeller Weight

$$Wgt = 0.00241 \times D^{3.05}$$

Four-Bladed Propeller Weight

$$Wgt = 0.00323 \times D^{3.05}$$

Where:

Wgt = Weight of propeller in pounds

D = Diameter of propeller in inches

Brake Horsepower vs LOA Formula – Tugs

$$BHP = 100 + \left(\frac{LOA^{4.15}}{111000}\right)$$

Where:

BHP = Maximum brake horsepower of engine

LOA = Length overall of the tug at waterline, in feet

Towing Speed vs Brake Horsepower Formula

$$Knts = 1.43 \times BHP^{0.21}$$

Where:

Knts = Average speed in knots during average tow

BHP = Maximum brake horsepower of engine

D.W.T. of Barges Towed vs BHP Formulas

$$\text{Low D.W.T.} = (1.32 \times \text{BHP}) - 255.25$$

$$\text{Avg D.W.T.} = (3.43 \times \text{BHP}) - 599.18$$

$$\text{High D.W.T.} = (5.57 \times \text{BHP}) - 943.10$$

Where:

DWT = Deadweight tons of barges towed

BHP = Maximum brake horsepower of engine

Rules of Thumb for Propeller Selection

1. ***One inch in diameter absorbs the torque of two to three inches of pitch.*** This is a good rough guide. Both pitch and diameter absorb the torque generated by the engine. Diameter is, by far, the most important factor. Thus, the ratio of 2 to 3 inches of pitch equals 1 inch of diameter is a fair guide. It is no more than that, however. You could not select a suitable propeller based only on this rule.

2. ***The higher the pitch your engine can turn near top horsepower and RPM, the faster your boat can go.*** This is accurate as far as it goes. The greater the pitch, the greater the distance your boat will advance each revolution. Since top engine RPM is constant, increasing the pitch means more speed. Then, why aren't all propellers as small in diameter as possible, with gigantic pitches?

   The answer is simply that when the pitch gets too large, the angle of attack of the propeller blades to the onrushing water becomes too steep and they stall. This is exactly the same as an airplane wing's stalling in too steep a climb. If the pitches and pitch ratios selected are optimum, then within these limits it is worthwhile, on high-speed craft, to use the smallest diameter and greatest pitch possible.

3. ***Too little pitch can ruin an engine.*** This is quite true if the pitch and diameter combined are so low that it allows the engine to run at speeds far over its top rated RPM. Never should the engine be allowed to operate at more than 103% to 105% of rated RPM, while underway and in a "normal" operation. If your engine exceeds that figure, a propeller with increased pitch or diameter is indicated.

4. ***Every two-inch increase in pitch will decrease engine speed by 450 RPM, and vice versa.*** This is a good rough guide for moderate- to high-speed pleasure craft, passenger vessels, and crew boats. Like all rule of thumbs, though, it is no more than a rough guide.

5. ***A "square" wheel (a propeller with exactly the same diameter and pitch)* is the most efficient.** This is not true! There is nothing wrong with a square wheel; on the other hand, there is nothing special about it, either.

6. ***The same propeller can't deliver both high speed and maximum power.*** This is true! A propeller sized for high speed has a small diameter and maximum pitch. A propeller sized for power or thrust has a large diameter. For some boats you can compromise on an in-between propeller, but for either real speed or real thrust there is little common ground.

Related Propeller Tables

Suggested Shaft Speeds

Type of Vessel	SL Ratio	Range of Shaft RPM
Heavy Displacement hulls (Tugs, Push boats, Heavy Fishing Vessels)	Under 1.2	250 – 500
Medium-to-Light Displacement hulls (Fishing vessels, trawlers, workboats, trawler yachts)	Under 1.45	300 – 1,000
Semi-displacement Hulls (Crew boats, Patrol boats, motor yachts)	1.45 – 3.0	800 – 1,800
Planing hulls (Yachts, fast commuters and ferries, high-speed patrol boats)	over 3.0	1,200 – 3,000 +

Minimum Tip Clearance

RPM	SL Ratio	Minimum Tip Clearance
200 – 500	Under 1.2	8%
300 – 1,800	1.2 – 2.5	10%
1,000 and above	over 2.5	15%
High-speed Planing Craft	over 3.0	20%

Shaft Material Characteristics

Shaft Material	Yield Strength in Torsional Shear PSI	Modulus of Elasticity PSI	Density Lb/ Cu. In.
Aquamet 22	70,000	28,000,000	0.285
Aquamet 18	60,000	28,800,000	0.281
Aquamet 17	70,000	28,500,000	0.284
Monel 400	40,000	26,000,000	0.319
Monel K500	67,000	26,000,000	0.306
Tobin Bronze	20,000	16,000,000	0.304
Stainless Steel 304	20,000	28,000,000	0.286

Buttock Angle vs SL Ratio

Buttock Angle	Type Hull	SL Ratio
Less than 2°	Planing	2.5 or Higher
2° – 8°	Semi-displacement	1.4 – 2.9
Greater than 8°	Displacement	1.34 Maximum

Crouch's Formula Constants

C	Type of Boat
150	Average runabouts, cruisers, passenger vessels
190	High-speed runabouts, very light high-speed cruisers
210	Race boat types
220	Three-point hydroplanes, stepped hydroplanes
230	Racing power catamarans and sea sleds

Typical Slip Values

Type of Boat	Speed in Knots	Percent of Slip
Auxiliary sailboat, barges	Under 9	45%
Heavy powerboats, workboats	9 - 15	26%
Lightweight powerboats, cruisers	15 - 30	24%
High-speed planing boats	30 - 45	20%
Planing race boats, vee-bottoms	45 - 90	10%
Stepped hydroplanes, catamarans	over 90	7%

Typical Slip Values – Twin Screw

Type of Boat	Speed in Knots	Percent of Slip
Auxiliary sailboat, barges	Under 9	42%
Heavy powerboats, workboats	9 - 15	24%
Lightweight powerboats, cruisers	15 - 30	22%

Typical Properties of Various Engineering Materials

Material Property	Carbon and Low Alloy Steel	Aluminum Base Alloys	Copper Base Alloys	Magnesium Base Alloys
Utl Tens Str, PSI	60-200,000+	19-53,000	21-125,000	22-45,000
Tens Yield Str, PSI	30-170,000+	8-43,000	11-100,000	11-30,000
Comp Str, PSI	60-200,000	XXXX	XXXX	XXXX
Comp Yield Str, PSI	XXXX	**About** 8-43,000	8-60,000	**About** 11-30,000
Shear Str, PSI	XXXX	14-36,000	XXXX	14-21,000
Ductility **(% Elong in 2 in.)**	35-5	22-0	52-0	12-1
Red of Area, %	65-5	XXXX	40-4	XXXX
Brinell Hardness **(Load)**	130-750 **(3000 kg)**	40-140 **(500 kg)**	47-425 **(500 kg)**	45-84 **(500 kg)**
Stiffness **(Mod of Elasticity, PSI)**	30,000,000	10,300,000	9.1-20,000,000	9,000-13,000
Endurance Limit, PSI	0.4-0.5 × UTS	6,500-23,000	4,000-15,000	9,000-13,000
Impact Resistance **(Charpy, ft-lb)**	3 to 65	0 to 8	0.5 to 40 **(IZOD)**	0.5 to 10 **(IZOD)**
Density @ 68° F **(lb/cu in.)**	0.282-0.284	0.093-0.107	0.264-0.343	0.065-0.067
Coeff of Therm Exp **(10^{-6} in/in° F)**	6.1-7.1 **(32-212° F)**	11.6-15.0 **(68-572° F)**	9.0-12.0 **(68-1652° F)**	14.5 **(68-212° F)**
Melting Range, °F	2600-2775	1000-1220	1675-1930	830-1190
Casting Range, °F	2850-3150	1175-1475	1750-2350	1200-1550

Typical Properties of Various Engineering Materials (continued)

Material Property	Carbon and Low Alloy Steel	Aluminum Base Alloys	Copper Base Alloys	Magnesium Base Alloys
Machinability	< Other Ferrous Alloys	Good to Excellent	Fair to Good Depends on Hardness	Excellent
Damping Capacity	XXXX	XXXX	XXXX	XXXX
Wear Resistance **(Lub. Sliding Friction)**	Good, Improved by Heat Treatment	Poor to Excellent	Good to Excellent	Poor to Excellent
Suitability as a Bearing Material	Inferior to Cast Iron	Poor Except for Special Bearing Alloy	Good to Excellent	Poor
Abrasive Wear	Excellent	Poor	Poor to Good	Poor
Fluidity	Inferior to Cast Iron	Excellent	Fair to Good	Good to Excellent

Typical Properties of Various Engineering Materials (continued)

Material Property	Gray Cast Iron	Ferritic Malleable Iron	Pearlitic Malleable Iron	Ductile Iron
Utl Tens Str, PSI	20-60,000	48-60,000	60-120,000	60-160,000+
Tens Yield Str, PSI	Same as Ten Str	30-40,000	43-95,000	40-135,000
Comp Str, PSI	70-200,000	=UTS	=UTS	1-1.2 × UTS
Comp Yield Str, PSI	XXXX	XXXX	XXXX	XXXX
Shear Str, PSI	1.0-1.6 × UTS	0.9 × UTS	0.9 × UTS	0.9 × UTS
Ductility **(% Elong in 2 in.)**	<1	26-10	12-1	26-1
Red of Area, %	0	23-18	15-0	30-0
Brinell Hardness **(Load)**	135-350 + **(3000 kg)**	110-145 **(3000 kg)**	160-285 + **(3000 kg)**	140-330 + **(3000 kg)**
Stiffness **(Mod of Elasticity, PSI)**	12-18,000,000	25,000,000	28,000,000	23-26,000,000
Endurance Limit, PSI	0.4-0.6 × UTS	0.4-0.6 × UTS	0.4-0.6 × UTS	0.4-0.55 × UTS
Impact Resistance **(Charpy, ft-lb)**	Up to 5	16.5	5-12	16.5
Density @ 68° F **(lb/cu in.)**	0.25-0.266	0.258-0.274	0.258-0.274	0.25-0.28
Coeff of Therm Exp **(10^{-6} in/in° F)**	5.8 **(32-212° F)**	6.6 **(68-750° F)**	Somewhat Higher than Ferritic Malleable	6.4 **(68-212° F)** 7.5 **(68-1112° F)**
Melting Range, °F	2000-2400	2000-2550	2000-2550	2000-2400

Typical Properties of Various Engineering Materials (continued)

Material Property	Gray Cast Iron	Ferritic Malleable Iron	Pearlitic Malleable Iron	Ductile Iron
Casting Range, °F	2200-2850	2550-2850	2550-2850	2200-2700
Machinability	Good	Good	Good	Good
Damping Capacity	About 10 $\times$ Steel	--------------------Between Gray Iron and Mild Steel--------------------		
Wear Resistance **(Lub. Sliding Friction)**	Excellent	Good	Excellent	Good to Excellent
Suitability as a Bearing Material	Poor to Excellent	Good	Poor to Excellent	Poor to Excellent
Abrasive Wear	Poor	Good	Good	Good
Fluidity	Excellent	Good	Good	Excellent

Typical Properties of Various Engineering Materials (continued)

Material Property	Nickel Base Alloys	Titanium Base Alloys	Zinc Base Alloys
Utl Tens Str, PSI	50-145,000		25-52,100
Tens Yield Str, PSI	25-115,000		XXXX
Comp Str, PSI	XXXX		XXXX
Comp Yield Str, PSI	18-80,000		55-93,000
Shear Str, PSI	XXXX		31-46,000
Ductility **(% Elong in 2 in.)**	45-1		10-0.5
Red of Area, %	35-1		XXXX
Brinell Hardness **(Load)**	100-375		75-100 **(500 kg)**
Stiffness **(Mod of Elasticity, PSI)**	21.5-24,000,000	14-16,000,000	
Endurance Limit, PSI	XXXX		6,875-8,500
Impact Resistance **(Charpy, ft-lb)**	4-70 **(Keyhole)**		1-48 **(Unnotched)**
Density @ 68° F **(lb/cu in.)**	0.301-0.312		0.238-0.242
Coeff of Therm Exp **(10^{-6} in/in° F)**	6.8-7.4 **(68-212° F)**		15.1-15.4
Melting Range, °F	2400-2600		727-932
Casting Range, °F	2700-2900		740-800

Typical Properties of Various Engineering Materials (continued)

Material Property	Nickel Base Alloys	Titanium Base Alloys	Zinc Base Alloys
Machinability	Comparable to Steel		Excellent
Damping Capacity	XXXX		XXXX
Wear Resistance **(Lub. Sliding Friction)**	Probably Comparable to Steel		Poor
Suitability as a Bearing Material	Not Normally Used as a Bearing		Poor
Abrasive Wear	Poor to Good		Poor
Fluidity	Comparable to Steel		Excellent

Onset of Shallow Water Effect

As all Marine Analyst know, the desired depth of water to perform a P.A.R. test is $2\frac{1}{2}$ times the draft of the boat. This depth is a “Rule of Thumb” that should keep you out of the shallow water effect. If, as is the case on many river boats, the boat operates in water that is shallower than the desired ($2\frac{1}{2}$), then the test is performed under actual working water depths. The following information will give you some insight into how to determine if you are seeing the effects of shallow water on the load of the engine.

The behavior of a boat in shallow water is amazing. There are two kinds of increases in resistance due to running in shallow water.

1. There is a slight, but measurable, increase beginning when the boat advances into water whose depth is one half to one quarter the length of the boat. At high speeds, it begins when the boat advances into water whose depth is equal to the length of the boat.
2. There is a phenomenal and sudden increase in resistance beginning when the speed of the boat equals 2.3 times the square root of the depth of water in feet, or $V = (2.3)\sqrt{H}$. In which, V = speed in knots and H = depth of water in feet. When $V = (2\frac{1}{2})\sqrt{H}$, we have almost reached the limit at which the boat can be driven in shallow water. When $V = (3.36)\sqrt{H}$, we are at the utmost limit of speed for the boat unless the boat starts to plane, in which case the boat begins to out run the waves that normally would be produced in deep water. As the boat travels faster than its wave train, few waves can be produced; residual resistance decreases, and we have the phenomenon of full planing such as the case of a sport fishing and pleasure craft.

$$V = 2.3 \times \sqrt{H}$$

Where:

V = Vessel speed in knots

H = Water depth in feet

“Critical” Speed at which shallow water effect drops off

$$V = 3.36 \times \sqrt{H}$$

Where:

V = Vessel speed in knots

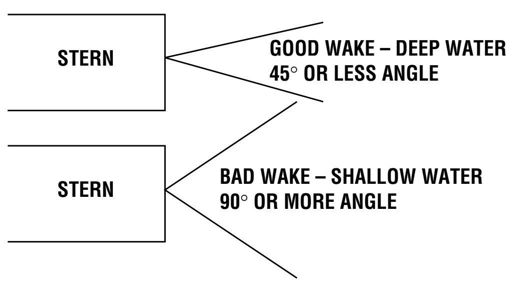
H = Water depth in feet

Let's take an example of a 200 foot boat traveling at 15 knots in deep water. As it is moving, it enters water about 20 feet deep. Since we know the boats speed and the water depth we must solve for the unknown = X. We would use the following formula: $V = (X)\sqrt{H}$ or $15 = (X)\sqrt{20}$ or $X = 3.35$. This means that the boat would slow down appreciably as the speed of the boat equals 3.35 times the square root of the depth of water. For our example then this would be as follows: $V = (3.35)\sqrt{20}$ or $V = 14.98$ knots. In other words, this boat is at the "critical" speed it can operate in the 20 foot water depth. At this point, unless the water depth increases or the boat planes, it will suffer greatly from the effects of shallow water.

The wake that is trailing the boat would be at approximately a 45° angle to the center of the stern, in deep water, will now take a position of 90° to the centerline of the boat as it moves into the shallow water. The engines may begin to lug under the additional load and excessive vibration will become apparent throughout the boat.

Boat owners can watch the angle of their wake from the stern to see when they are getting loading from shallow water effect. The same is true for the Marine Analyst, when conducting a P.A.R. test. If you notice the wake is at a 90° angle from the stern of the boat, while conducting a "Normal Operation" test, then you should operate the boat test in deeper water.

Effects of shallow water on the wake of a boat



Dredge Engines

Basically, dredging is the removal of material from under water, and its disposal elsewhere. It includes two distinct operations: first, excavating the material, and second, transporting it to a disposal area. There are two ways of doing this – mechanically and hydraulically.

Definitions

Mechanical Dredges

Mechanical dredges were the first to be developed. Today three basic types are used:

1. Grapple Dredge
2. Dipper Dredge
3. Bucket Dredge

The Grapple Dredge

The grapple dredge is essentially a derrick mounted on a barge and equipped with a clamshell bucket for dredging. It is most suitable for excavating soft and cohesive materials.

This type of dredge does not give the best results in very soft deposits where the material is likely to be washed out of the bucket or in very hard materials where the penetration is not sufficient to fill the bucket. Grapple dredges have the advantage of being able to work in confined areas near docks and breakwaters.

The Dipper Dredge

The dipper dredge is essentially a barge-mounted power shovel. Its main advantage is in the strong crowding action of the bucket as the dipper stick forces it into the material to be moved. Its best use today is for excavating hard compact materials, rock and other solid formations after blasting. For its size, a dipper dredge can handle larger pieces, thus reducing the amount of blasting. For most other work it has been replaced by more efficient, faster working hydraulic dredges.

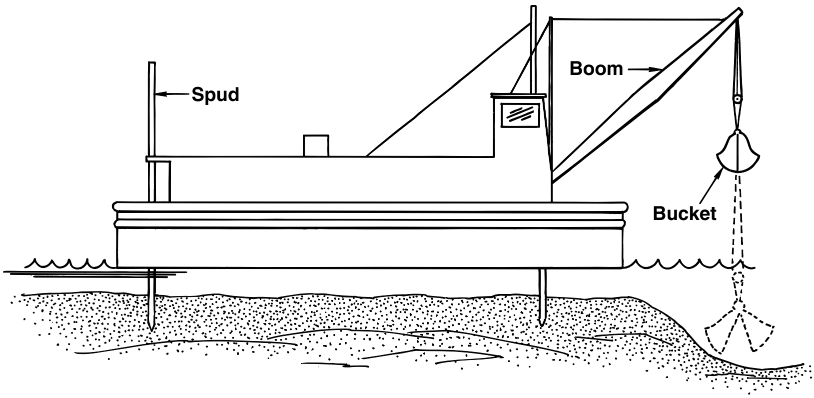


FIGURE 1.12

The Bucket Dredge

The bucket dredge consists of an endless chain of buckets moving from the work face to a point above the surface of the water. Each bucket digs its own load, carries it to the surface and, as it rotates over the top tumbler, dumps its load and goes back for another. Bucket dredges are more efficient than dipper or grapple dredges because the work cycle is continuous. Dredges of this type have found wide use in commercial production of sand and gravel and in the recovery of various ores and precious metals such as tin and gold.

All three types of mechanical dredges have their advantages; however, each fulfills only one part of the two-phase dredging operation of excavation and disposal. Mechanical dredges remove material, but to dispose requires a fleet of barges and tugs to move the material to its disposal point. Hydraulic dredges handle both phases of the dredging process.

Hydraulic Dredges

Unlike the mechanical dredges, hydraulic dredges use the water on which they float to make dredging more efficient. A hydraulic dredge mixes the material to be removed with water and pumps it as a fluid. Hydraulic dredges are usually more versatile, efficient and economical to operate than mechanical dredges because the digging and disposing operation is performed by one self-contained unit.

The Plain Suction Dredge

The plain suction dredge consists of a dredge pump which draws in a mixture of water and excavated material through the suction pipe lowered to the working face of the deposit. The mixture is discharged through a pipeline to the spoil area or into barges or hoppers. The use of units of this type is limited to digging soft and free-flowing materials, such as clay, sand, silt, or gravel.

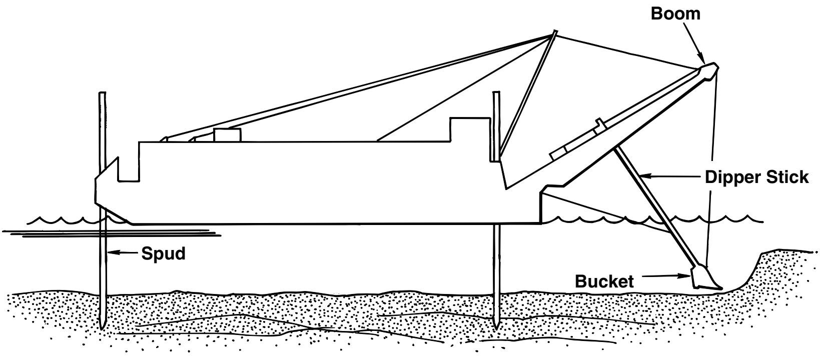


FIGURE 1.13

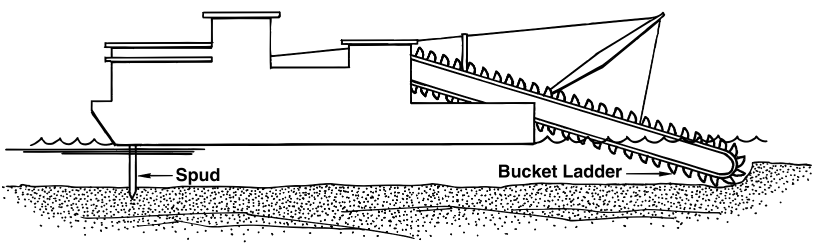


FIGURE 1.14

As a further development, dredges of this type are sometimes equipped with a special suction head, using water jets or other devices to agitate the material. One particular adaptation of this principle is the Dustpan dredge, so named because of the shape of the suction head. Units of this type are used extensively on large rivers where accumulated materials must be rapidly removed from the navigation channel.

The Self-Propelled Hopper Dredge

Resembling an oceangoing ship, the self-propelled hopper dredge functions in a similar manner to the plain suction dredge. In operation, as the suction pipe or pipes are dragged along the bottom while the dredge is moving ahead at a slow speed, a mixture of water material is picked up and conveyed to the pump or pumps installed on the dredge. The discharge pipes are connected to the dredge pump or pumps to carry the materials to the hoppers which are built into the hull. When the hoppers are filled, the dredge proceeds at full speed to the dumping grounds in deep water. Here, the hopper doors built in the bottom of the hull are opened and the material dumped. The dredge then returns to the site of work and repeats the cycle.

Dredges of this type are necessary for maintenance work and improvement in exposed harbor entrances where traffic and operating conditions will not permit use of stationary dredges. These dredges have been built with hopper capacities ranging up to 8,000 yd^3 (6116 m^3).

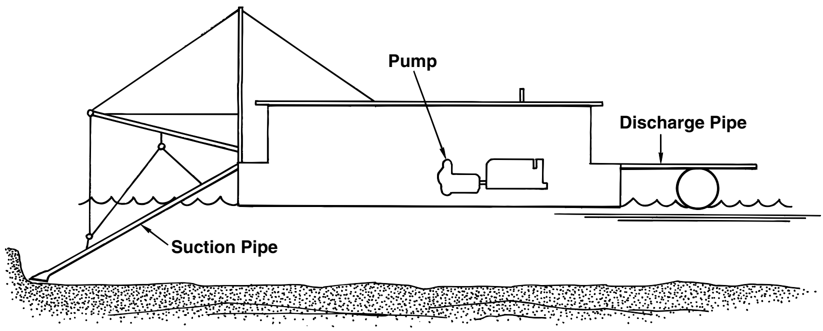


FIGURE 1.15

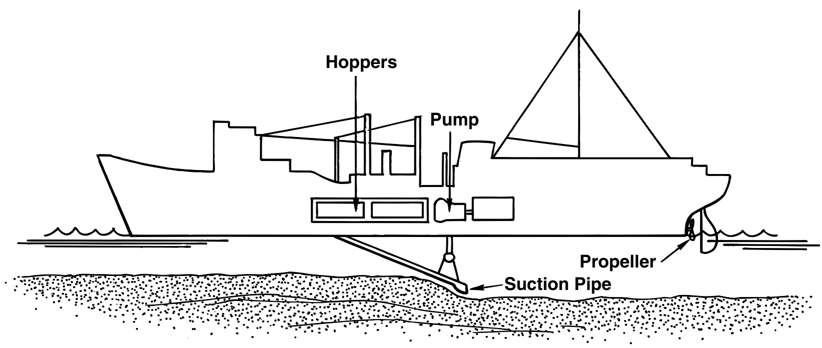


FIGURE 1.16

The Cutterhead Pipeline Dredge

The cutterhead pipeline dredge is the most versatile and widely used marine excavating unit. It is similar to the plain suction dredge, but is equipped with a rotating cutter surrounding the intake end of the suction pipe. This cutter loosens the material which is then sucked in through the dredging pump, delivered to the stern of the dredge and conveyed to the disposal area by means of a pipeline. Hydraulic pipeline dredges can efficiently dig and pump loose materials as well as compacted deposits such as clay and hard pan. The larger and more powerful machines are used to dredge rocklike formations, such as coral and softer types of basalt and limestone, without blasting.

The cutterhead pipeline dredge, like several other types, is held in working position by spuds and advances by walking itself on these spuds. The advantages of the cutterhead pipeline dredge are its versatility and nearly continuous operating cycle, resulting in maximum economy and efficiency.

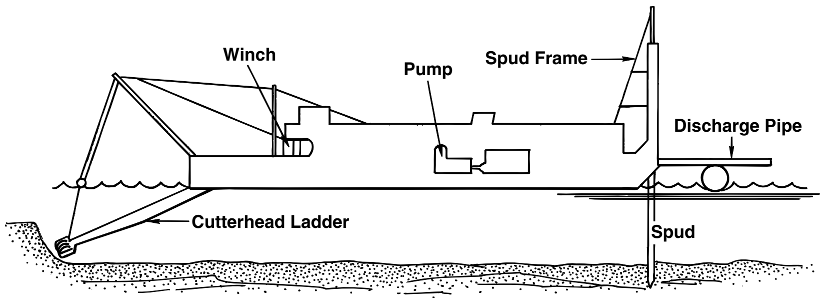


FIGURE 1.17

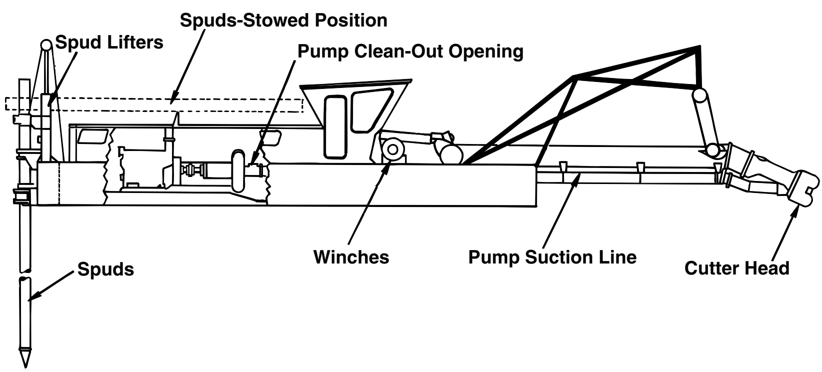


FIGURE 1.18

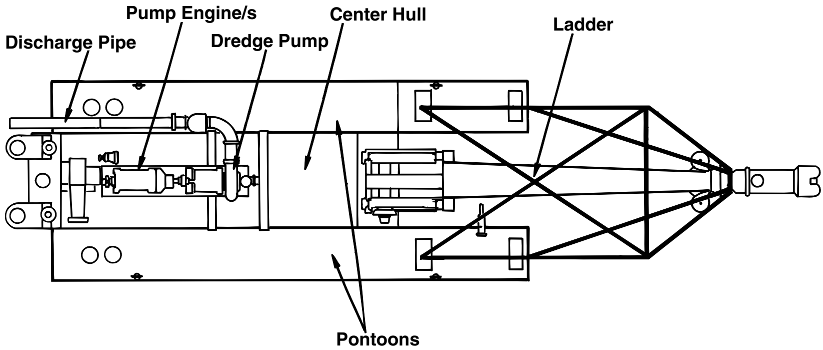


FIGURE 1.19

Dredge Nomenclature

Cutterhead – A rotating toothed auger for dislodging material. The cutterhead contains the pump suction inlet. The cutterhead is usually driven by a separate diesel engine through hydraulic motors, electric motors, or a shafting drive line. Winches and spud lifters may also be driven by this engine.

Ladder – A horizontally hinged boom, rigidly constructed, which provides structural support for the cutterhead, the cutterhead driving mechanism, and the dredge pump suction line. It is hinged to the front of the dredge and may be lifted or lowered to control digging depth.

Main or Center Hull – A rectangular-shaped hull which contains the dredge pump and its associated reduction gearing, clutches, engine(s), and controls. Mounted on the center hull is the control station, swing and ladder winches, spuds, hydraulic drive engine, and the dredge's service power generation machinery.

Spuds – The dredge is equipped with two, long, tubular, sharp pointed poles, vertically mounted on the rear of the dredge. These spuds are raised and alternately lowered into the bottom material. The spuds provide pivot points around which the dredge may swing as the cutterhead advances into the bottom materials.

Pontoons – The pontoons are longer than the center hull and are mounted on either side. They provide flotation stability and fuel and water storage capacity.

Pump Engine Considerations

Horsepower (Engine Load) Versus Discharge Line Length

A common misunderstanding is that more horsepower is required to pump against a long distance line than a short one. The horsepower requirement of a pump is proportional to the gallons per minute (gpm) being pumped. The longer the discharge line, the greater the resistance to flow, therefore, the fewer gpm and a lower horsepower requirement results. Conversely, as the line length is reduced, resistance to flow is reduced, more gpm are being moved and a higher horsepower required.

If a dredge must be operated with a discharge line shorter than its design length, the engine rpm must be reduced. This reduces the pump rpm, causing a decrease of the horsepower requirement. Throttling back will relieve the engine from an overload situation and may even result in an increase in dredge production.

Horsepower Versus Specific Gravity (Percent Solids)

The heavier the material being pumped, the greater the horsepower requirement. It takes less horsepower to pump pure water than it does to move a mixture of solid material and pure water. The pump horsepower requirement is directly proportional to the specific gravity of the pumped fluid.

Example: If a pump engine is called on to produce 100 hp when pumping clear water, the same pump engine must be capable of developing 150 hp while pumping the same flow rate (gpm) of a slurry (water and solid mix) whose specific gravity is 1.5.

Horsepower Versus Pump Speed

The load on the dredge pump engine is proportional to the cube of the pump speed. This means a small increase in pump rpm will result in a much greater horsepower demand on the engine. For example: To double the speed of the pump impeller would require eight times more horsepower. Stated another way, a pump impeller which demands 100 hp to turn at 150 rpm will require 800 hp at 300 rpm.

Engine Operation to Avoid Overload

If dredging conditions are such that the pump engine(s) are not able to reach rated rpm while at full throttle, then throttle position must be reduced to avoid engine overload. Reduce throttle position from full throttle – while digging – until engine speed drops approximately 50 rpm. This will result in approximately the same horsepower output delivered to the pump, but will allow the engine to deliver that horsepower safely, without overfueling.

Engine Installation

Many marine engine installation practices apply equally to dredges. When this is the case, the reader will be referred to the appropriate marine engine section. Only those practices and recommendations that are unique to the dredge application will be discussed in this section.

Mounting and Alignment Mounting Rails

All large bore Vee-type engines should be mounted with angle section, ledge-type marine mounting rails. Engines can be successfully installed using industrial channel section mounting rails, but mounting flexibility is sacrificed. See Marine Mounting Recommendations section for further details on shimming and bolt fit.

Tandem Engine Thermal Growth Considerations

The thermal expansion of engines must not be restrained. The flywheel end of the engine mounting rails should be fixed by a ground body, fitted bolt on either or both sides of the engine. The diameter of the mounting bolts – fixing the engine's rails to the dredge structure – forward of the flywheel must be 0.06 in. (1.6 mm) less than the diameter of the holes in the mounting rails. This clearance will allow the engine and mounting rails to grow without confinement.

When installed properly, there is sufficient axial clearance within the Caterpillar viscous damped engine-to-engine coupling to allow the engine nearest the load to grow without restraint. The axial clearance dimension can be checked on a new installation by measuring from the outer face of the grease retaining plate (of the Caterpillar viscous damped coupling) to the nearest surface of the coupling inner member. This dimension should be 0.34 ± 0.03 in. (8.6 ± 0.76 mm).

Tandem Engine Timing Considerations

Timing Recommendations are contained on Tandem Engine Coupling Arrangement drawings. These directions must be followed to avoid possible torsional vibration problems.

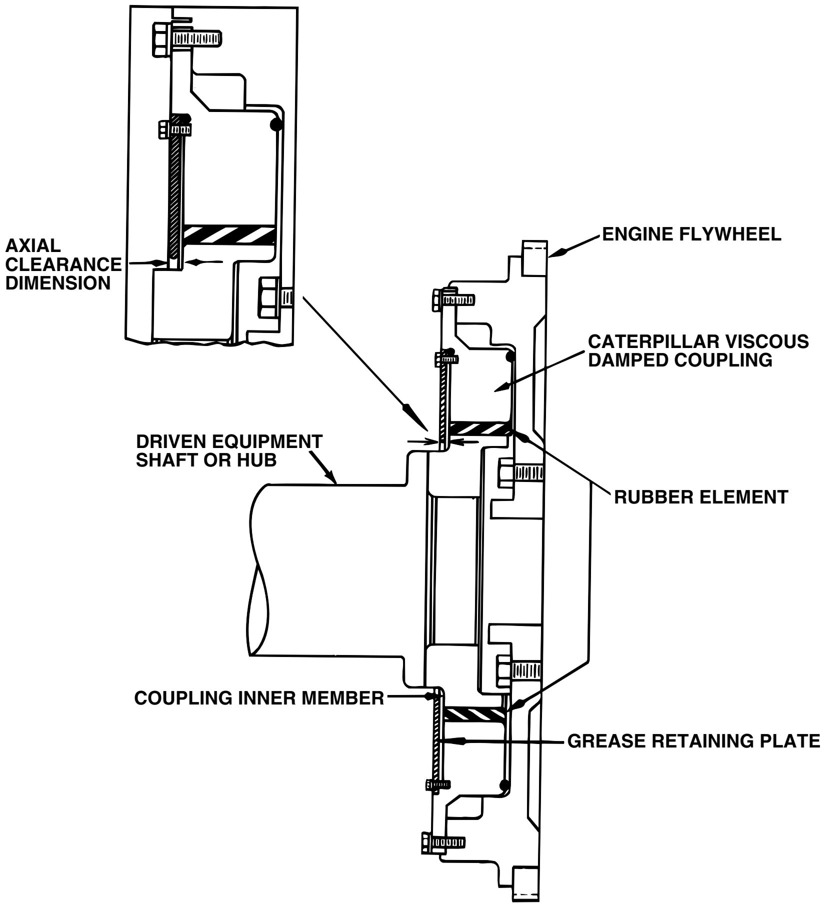


FIGURE 1.20

Tandem Engine Governor Settings (Low Idle rpm)

Some dredge pump drive applications require a special engine low idle setting to avoid torsional resonance. Many Caterpillar engines used in tandem service must have a low idle setting of not less than 600-650 rpm. Always check the engine data plate to determine proper governor settings. Many dredge engine settings are special and not listed in standard Caterpillar Service literature.

Fuel Treatment and Plumbing

Since dredges are normally equipped with very large fuel tanks, condensation, fungus/bacteria growth, and contamination of the fuel may be troublesome. Fuel system maintenance is especially important in dredge applications.

The lowest point within the dredge's fuel tanks should be drained or pumped daily to eliminate condensed moisture and sediment.

Water and sediment traps should be used in fuel supply lines.

Terminate engine fuel supply plumbing at least 12 in. (300 mm) above the lowest point in fuel tanks.

See fuel section for information on detection and prevention of fungus/bacteria growth in fuel tanks.

Exhaust, Ventilation, and Crankcase Vent Systems

All diesel engines require large quantities of clean, cool air for long trouble free life.

Combustion Air

Equip dredge engines with combustion air inlet ducts, located and routed to prevent recirculation of exhaust gases and crankcase fumes. Locate combustion air inlets so they do not ingest heated engine room ventilation air rising through removable roof caps. Exhaust gases must be discharged to atmosphere high enough above the combustion air inlet openings to prevent rebreathing of exhaust gases. Equip exhaust stacks with joints which allow addition of extra sections of exhaust pipe if exhaust recirculation proves to be a problem on operating location. An unrestricted elbow-type exhaust discharge fitting is preferred over the counterbalanced flapper valve because there will be less chance for downward deflection of exhaust gases.

See *Ventilation* and *Exhaust* sections for flow, pressure, and temperature information.

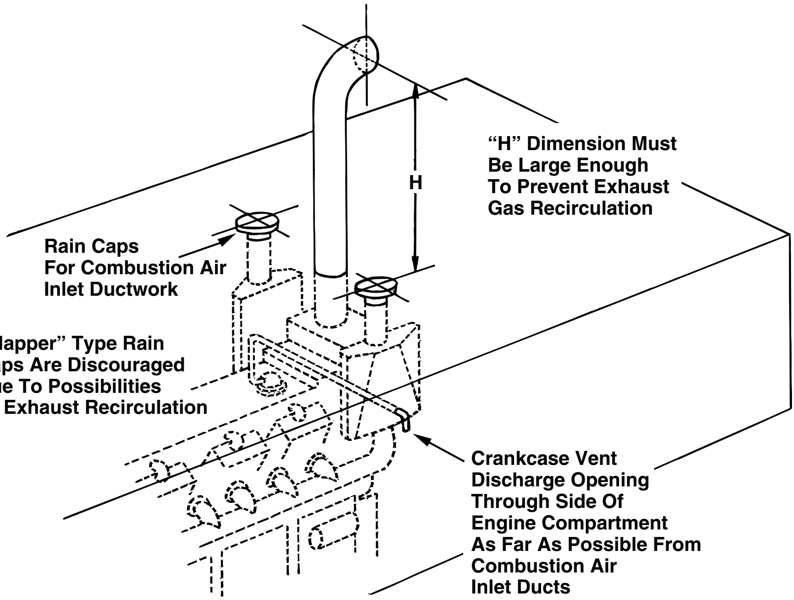


FIGURE 1.21

Ratings

Engines in dredge pump drive service should be applied at the continuous ratings.

Engines driving electric or hydraulic cutterheads and/or winches may carry the intermittent or light duty commercial rating since neither cutterheads nor winches are continuous loads.

Engines driving generators which supply lighting and service pumping power should be rated for prime power due to the continuous nature of lighting and pumping loads.

For additional explanation of Caterpillar engine rating philosophy, see *Ratings* section.

Cooling

The dredging application may place severe demands on the engine cooling system.

Keel Cooling Considerations

The dredge is normally stationary on its digging location with little or no water flowing past the hull. The efficiency of keel coolers is greatly reduced under these conditions. Keel coolers operating in *dead water* conditions require more than twice the surface area that would be required if the cooling surface had a five knot water velocity over the outside of the cooler. See Keel Cooler Area Requirement curves in the Marine Cooling System section for added information.

Heat Exchanger Cooling

Using inboard (shell and tube-type) heat exchangers may be troublesome due to the highly abrasive particles suspended in the water common to dredging operations. Cooling water suction line strainers are a necessity to minimize damage to pumps and heat exchangers tubes. Use Caterpillar engine-mounted sea water pumps (particularly rubber impeller pumps) with the knowledge that their service life, when pumping water containing abrasive particles, will be significantly shortened.

Hydraulic Dredges will have, as one of their normal components, a "service water" pump. This pump is usually designed for abrasive water service. The service water pump provides clean sea water, at higher pressure, for lubrication and flushing of the dredge pump and cutterhead lineshaft bearings. Use of excess flow from the service water pump is a superior alternative to Caterpillar engine mounted sea water pump.

Box Coolers

Box-type coolers offer many of the advantages of keel cooling and shell and tube coolers, particularly in dredging applications.

Aftercooler Cores

Although many dredges operate in freshwater ponds, lakes, and rivers, experience has proven that engine aftercooler cores suitable for sea or salt water are a necessity. The moisture-laden air surrounding any floating equipment will corrode the fins on the air side of nonmarine aftercooler cores severely limiting the heat transfer and possibly even restricting the combustion flow.

Controls

Single Engine Drive

Dredge engine controls are the same as conventional controls for engines in other pumping or electric power generation applications, with the exception of tandem or compound engines driving a single load.

Tandem/Compound Engine Drive

When multiple engines are tandemed (nose-to-nose configuration) or compounded side-by-side configuration with flywheel outputs (combined in gearing or with chains), the capability to share load equally at full load becomes important.

Load Share

Engines must share load equally so one engine, the one taking most of the load, will not wear out prematurely or fail. The precision of the sharing of the load is only important at or near the engines full power capability (large fractions of the engine rating).

Hydra-Mechanical Governors

A way to ensure load share at full load is to adjust the air actuators on Caterpillar standard hydra-mechanical governors so both engines reach the same high idle speed (rpm) with the same air actuator pressure. The adjustment is normally done at the factory when pairs of engines are specified to be used in tandem or compound.

Isochronous Governors

Load sharing is more easily attained if governors capable of isochronous operation are avoided or adjusted to operate in a droop, or non-isochronous mode. Generally 5-10% droop is satisfactory.

Safety System Considerations on Tandem/Compound Engines

Prelubrication System

Wire the oil pressure sensors included with prelubrication systems in series to prevent either tandem/compound engine's cranking motor from engaging before both engines are prelubed.

Shut-down Devices

Sensors connected to automatic shut-down devices must be interconnected on tandem/compound engines to insure both engines shutdown in the event of a malfunction in either engine.

Ventilation

General Information

There are three aspects to ventilation:

Ventilation Air
The flow of air required to carry away the radiated heat of the engine(s) and other engine room machinery.

Combustion Air
The flow of air required to burn the fuel in the engine (propulsion and auxiliaries).

Crankcase Fumes Disposal
The crankcase fumes of the engine must be either ingested by the engine or piped out of the engine room.

Ventilation Air

Engine room ventilation has two basic purposes:

- To provide an environment which permits the machinery and equipment to function dependably.
- To provide a comfortable environment for personnel.

Radiated heat from the engines and other machinery in the engine room is absorbed by engine room surfaces. Some of the heat is transferred to atmosphere or the sea through the hull. The remaining radiated heat must be carried away by the ventilating system.

A system for *discharging* ventilation air from the engine room must be included in the construction of the vessel. Do not expect the engine(s) to carry all the heated ventilation air from the engine room by way of the exhaust piping.

Routing

Correct Ventilation Air Routing is Vital
Comfortable air temperatures in the engine room are impossible without proper routing of the ventilation air.

Fresh air should enter the engine room as far from the sources of heat as practical and *as low as possible.* Since heat causes air to rise, it should be discharged from the highest point in the engine room, preferably directly over the engine. Avoid incoming ventilation air ducts which blow cool air toward hot engine components. This mixes the hottest air in the engine room with incoming cool air, raising the temperature of all the air in the engine room.

Relative Efficiency of Various Routing of Ventilation Air
The sketches below illustrate the relative efficiency of various ventilation routing:

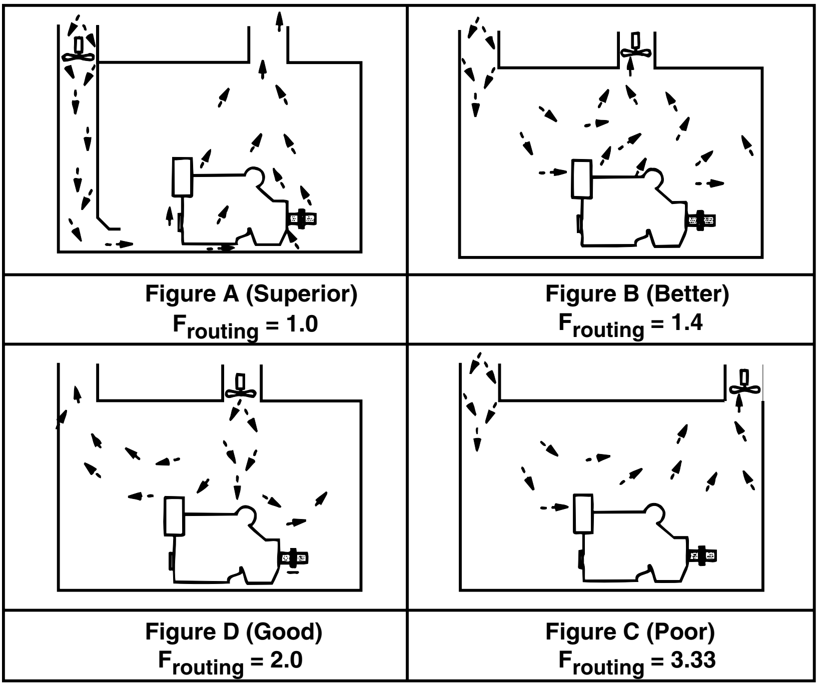


Figure A (Superior) $F_{routing} = 1.0$

Figure B (Better) $F_{routing} = 1.4$

Figure D (Good) $F_{routing} = 2.0$

Figure C (Poor) $F_{routing} = 3.33$

FIGURE 2.1

Where: $F_{routing}$ is a factor which relates the relative efficiency of various ventilation air routing.

Example:

If the routing in Figure A (upper left) is used as a base to which the others are compared:

- 1.4 times more air is required (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure B (upper right).
- It takes twice as much air (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure C (lower right).

- 3.3 times more air is required (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure D (lower left).

Engine Room Temperature

A properly designed engine room ventilation system will maintain engine room air temperatures within 15° F (9° C) above the ambient air temperature (ambient air temperature refers to the air temperature surrounding the vessel). Maximum engine room temperature should not exceed 120° F (49° C).

Quantity Required

In general, changing the air in the engine room every one or two minutes will be adequate, if flow routing is proper.

Provisions should be made by the installer to provide incoming ventilation air of 4-8 cfm (0.1 – 0.2 m^3/min) per installed horsepower (both propulsion and auxiliary engines). This does not include combustion air for the engines. (See following remarks on engine combustion air, page 2-6.)

Engine exhaust ventilation air should be 110 to 120% of the incoming ventilation air. The excess exhaust ventilation air accomplishes two things:

- It compensates for the thermal expansion of incoming air.
- It creates an in draft to confine heat and odor to the engine room.

Operation in extreme cold weather may require reducing ventilation air flow to avoid uncomfortably cold working conditions in the engine room. This is easily done by providing ventilation fans with two speed motors (100% and 50 or 67% speeds).

Through-Hull Opening Design

There must be openings for air to enter the engine room and openings for air to leave the engine room.

There should be an *inlet* for cool air to enter, and a *discharge* for hot air to leave, on each side of the hull. If it is impractical to have two separate openings per side, then avoid having hot discharged air mix with cool air entering the engine room.

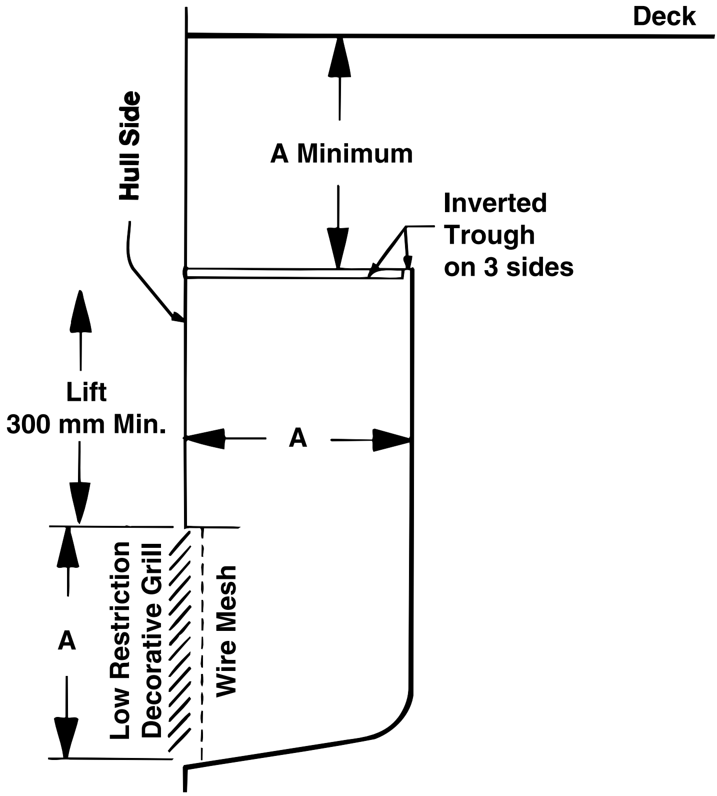
Design Features
Size
Size the openings (A) to keep the air velocity (in the openings) below 2,000 ft/min (610 m/min).

Air Entering the Engine Room

The engine room must have openings for air to enter. The air may also enter from the accommodation spaces (staterooms, galley, salon, companionways, pilot house, etc.)* or directly through the hull or deck. Engine room air inlets through accommodation spaces can be troublesome.

If air is to enter the engine room from the accommodation spaces (staterooms, galley, salon, companionways, pilot house, etc.), good design practice will include sound deadening treatments for the opening(s) which conduct air from the accommodation spaces to the engine room.

*Heating and/or air conditioning of accommodation spaces will be made much more complicated if the engines must rely on that heated/cooled air for combustion. Engine room air inlets through accommodation spaces simplify the task of ensuring the engine room inlet air is kept clean and free from rain or spray.



Features of Through-Hull Ventilation Openings

FIGURE 2.2

Air Leaving the Engine Room

The through-hull or through-deck openings for discharge of heated ventilation air should be located aft of and higher than all intake openings to minimize recirculation.

- The intake air opening should be located forward of – and, if convenient – at a lower elevation, than . . .
- The ventilation air opening, discharging heated ventilation air, which should be located aft of – and at a higher elevation than the intake air opening – to minimize recirculation. Cross- and following-winds make total elimination of ventilation air recirculation impossible.

Fans

In modern installations, natural draft ventilation is too bulky for practical consideration. Adequate quantities of fresh air are best supplied by powered (fan-assisted) systems.

Location
Fans are most effective when they withdraw ventilation air from the engine room (suction fans) and discharge the hot air to the atmosphere.

Type
Ventilating air fans may be of the axial flow type (propeller fans) or the centrifugal type (squirrel cage blowers). When mounting fans in ventilating air discharge ducts (most effective location), the fan motors should be outside the direct flow of hot ventilating air for longest motor life. The design of centrifugal fans (squirrel cage blowers) is ideal.

Sizing
The *name plate* ratings of fans do not necessarily reflect their *as-installed* conditions. Just because a fan's name plate says it will move 1000 cfm of air does not mean it will move 1000 cfm through an engine room which has severely restricted inlet and/or outlet openings. Fans are often rated under conditions which do not reflect *as-installed* flow restrictions. In general, the *as-installed* conditions will be more severe than the fans name plate rating conditions.

Combustion Air

Quantity Required

A diesel engine requires approximately 2.5 ft^3 of air/min/bhp (0.1 m^3 of air/min/brake kW) produced.

Combustion Air Ducts

Design combustion air ducts to have a minimum flow restriction.

Very large amounts of air flow through the combustion air ducts.

Air Cleaners

Engines must be protected from ingesting foreign material. The engine-mounted air filter elements must never be remote-mounted, without factory approval.

If large amounts of sea spray, dust, or insects are expected, external, remote-mounted, precleaners may be installed at the inlet to a duct system to extend the life of the engine-mounted filter elements.

Air Cleaner Service Indicators

Air cleaner service indicators signal the need to change air filter elements when a restriction of 25 in. (6.23 kPa) of water – measured while the engine is producing full rated-power – develops. This allows an acceptable operating period before air filter service or replacement is required.

Duct Restriction

Total duct air flow restriction, including air cleaners, should not exceed 15 in. (3.74 kPa) of water measured while the engine is producing full rated power. It is good design practice to design combustion air ducts to give the lowest practical restriction to air flow, since this will result in longer times between filter element service or replacement.

Velocity of Air in Combustion Air Ducts

Combustion air duct velocity should not exceed 8,000 ft/min (2440 m/min). Higher velocities will cause unacceptable noise levels and excessive flow restriction.

Water Traps

Traps should be included to eliminate any rain or spray from the combustion air. Rain and spray can cause very rapid plugging of the paper air filter elements on some Caterpillar Engines. This will reduce the flow of air through the engine, raising the exhaust temperature with potentially damaging effects.

Temperature

A well designed engine room ventilation system will provide engines with air whose temperature is not higher than 15° F (8.5° C) above the ambient temperature though derating of Caterpillar Marine engines is not required so long as combustion air temperatures remain below 120° F (49° C).

Rain and Spray

The combustion air should be free of liquid water, though water vapor – humidity – is acceptable.

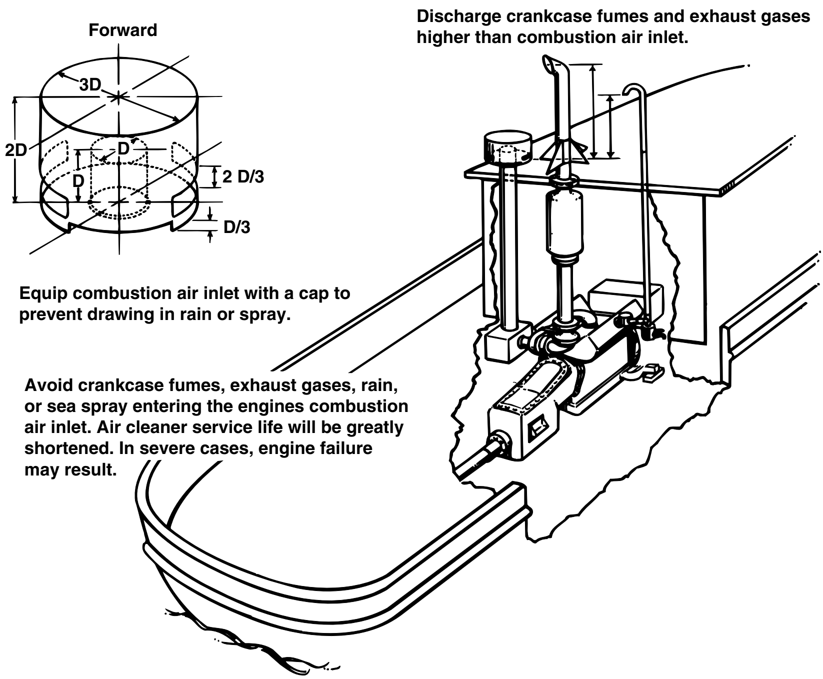


FIGURE 2.3

Sizing of Combined Combustion and Ventilation Air Ducts – Rule of Thumb

Air Must Be Allowed to Enter the Engine Room Freely.

A useful rule of thumb is:

- Use 4-6 sq cm of duct cross-section area per engine kW and no more than three (3) right angle bends. A larger area allows more air flow into the engine room.
- Use 0.5-0.75 sq in. of duct cross-section area per engine horsepower and no more than three (3) right angle bends. A larger area allows more air flow into the engine room.

If more right angle bends are required, increase the pipe diameter by one pipe size.

Crankcase Fumes Disposal

Normal combustion pressures of an internal combustion engine cause a certain amount of blowby past the piston rings into the crankcase. To prevent pressure buildup within the crankcase, vent tubes are provided to allow the gas to escape. 3100 and 3208 and high performance 3176, 3406, 3408, and 3412 marine engines consume their crankcase fumes, by drawing the fumes into the engine's air intake system. Larger Caterpillar marine engines must have their crankcase fumes piped away from the engine to prevent the fumes from plugging their high-efficiency paper air filter elements.

Pipe Sizing

Generally use pipe of the same size as the crankcase fumes vent on the engine. If the pipe run is longer than approximately 10 ft (3 m) or if there are more than three (3) 90° elbows, increase the pipe inside diameter by one pipe size.

Common Crankcase Vent Piping Systems

A separate vent line for each engine is required. Do not combine the piping for multiple engines.

Location of Crankcase Vent Termination

Crankcase fumes must not be discharged into air ventilating ducts or exhaust pipes. They will become coated with oily deposits.

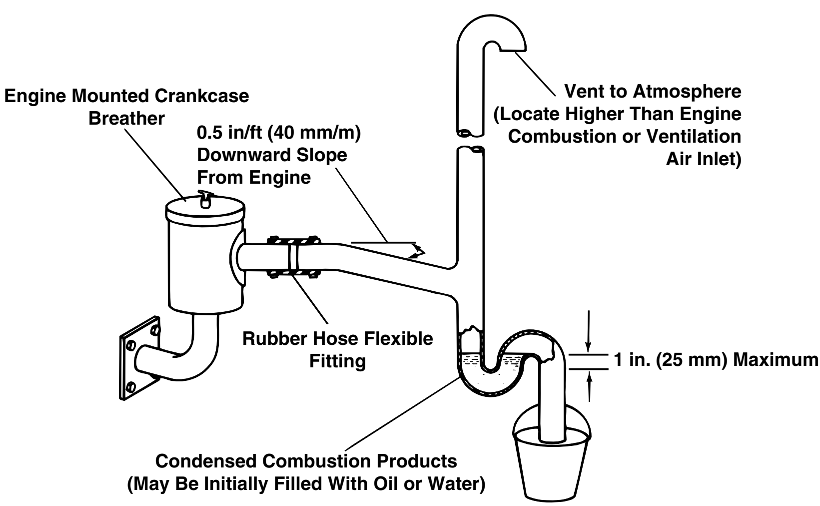


FIGURE 2.4

The crankcase vent pipe may be directed into the exhaust gas flow at the termination of the exhaust pipe.

Preferably, the crankcase vent pipe will vent directly to the atmosphere. The vent pipe termination should be directed to prevent rain/spray entering the engine.

Condensation/Rainwater in Crankcase Fumes Piping

Loops or low spots in a crankcase vent pipe can collect rainwater and/or condensed combustion products. These liquids may be trapped in a drip collector and drained to minimize the amount of oily discharge through the vent pipe and prevent restriction of normal discharge of fumes.

Required Slope of Crankcase Fumes Disposal Piping

Avoid horizontal runs in crankcase vent piping. Install the vent pipe with a minimum slope of 0.5 in/ft (40 mm/m).

Maximum Pressure in the Engine Oil Sump

Under no circumstances should crankcase pressure vary more than 1 in. (25.4 mm) of water from ambient barometric pressure when the engine is new*. Higher crankcase pressures will cause oil leaks. A powered crankcase fumes disposal system should create no more than 1 in. (25.4 mm) of water vacuum in the crankcase.

Crankcase Volumes

The volume of an engine's crankcase is required for the sizing of crankcase pressure relief valves. See the table on the next page.

*As the engine approaches its overhaul interval, blowby (one of the causes of crankcase pressure) will tend to increase. Careful monitoring of crankcase pressure will provide valuable guidance on the condition of an engine's valve guides and piston rings.

Crankcase Volumes

Model	Crankcase Volume	
3116	1.59 ft^3	(0.045 m^3)
3126	1.59 ft^3	(0.045 m^3)
3176	4.9 ft^3	(0.14 m^3)
3304B	1.76 ft^3	(0.05 m^3)
3306B	2.22 ft^3	(0.063 m^3)
3208	0.039 ft^3	(0.0011 m^3)
3406B	8.8 ft^3	(0.25 m^3)
3408B	10.5 ft^3	(0.3 m^3)
3412	14.1 ft^3	(0.4 m^3)
D399	45.2 ft^3	(1.28 m^3)
D398	33.9 ft^3	(0.96 m^3)
D379	22.6 ft^3	(0.64 m^3)
3508	22.9 ft^3	(0.65 m^3)
3512	34.6 ft^3	(0.98 m^3)
3516	49.8 ft^3	(1.41 m^3)
3606	81.2 ft^3	(2.3 m^3)
3608	108 ft^3	(3.06 m^3)
3612	110.2 ft^3	(3.12 m^3)
3616	144 ft^3	(4.08 m^3)

Many marine classification societies (MCS) expect crankcase pressure relief valves to be installed on engines with crankcase volumes more than 21.5 ft^3 (0.61 m^3) or cylinder bores over 7.89 in. (200 mm) in diameter. Caterpillar offers crankcase pressure relief valves on engines larger than the 3408.

Special Ventilation Considerations

Refrigeration Equipment

Prevent refrigerant leakage into the engine's air intake system. Freon or ammonia will cause severe engine damage if drawn into the engine's combustion chambers. The chemicals in refrigerants become highly corrosive acids in the engine's combustion chambers.

If refrigeration equipment is installed within the same compartment as a diesel engine, the diesel engine must take its combustion air from a shipyard-supplied ductwork system which carries air to the engine from an area free of refrigerant fumes.

Exhaust Pipe Insulation Recommended

Long runs of hot, uninsulated exhaust piping will dissipate more heat into the engine room than all the machinery surfaces combined. Completely insulate all exhaust piping within the engine room area. All hot surfaces within the engine room should be insulated if high air temperatures are to be avoided.

Test With Doors and Hatches Closed

Ventilating systems must be designed to provide safe working temperatures and adequate air flow when hatches and doors are secured for bad weather conditions. Test the ventilation system with the vessel fully secured for bad weather. This condition will reflect the most severe test of the ventilation system.

Air Velocity for Personnel Comfort

Maintain air velocity of at least 5 ft/s (1.5 m/s) in working areas adjacent to sources of heat, or where air temperatures exceed 100° F (35° C). This does *not* mean that all the air in the engine room should be agitated so violently. High air velocity around engines and other heat sources is not good ventilation practice. High velocity air aimed at engines will hasten transfer of heat to the air, raising average engine room air temperature.

Exhaust System

General Information

The exhaust system carries the engine's exhaust gases out of the engine room, through piping, to the atmosphere.

A good exhaust system will have minimum back pressure.

Exhaust back pressure is generally detrimental as it tends to reduce the air flow through the engine. Indirectly, exhaust back pressure tends to raise exhaust temperature which will reduce exhaust valve and turbocharger life. There are two general types of exhaust systems seen on boats, wet exhaust systems and dry exhaust systems.

Wet Exhaust System

Wet exhaust systems are characterized by the following:

- Generally the exhaust gases are mixed with the sea water which is discharged from the sea water side of the engine's jacket water heat exchanger.
- Particulate and condensable/soluble gaseous emissions from the exhaust system are effectively scrubbed from the exhaust gases, reducing the possibility of atmospheric pollution. Exhaust piping which is cool enough to be made of uninsulated, fiberglass reinforced plastic (FRP) or rubber.
- The moisture of exhaust gases and sea water is discharged from the boat at or slightly below the vessels waterline.
- With the relatively small elevation difference between the engine's exhaust discharge elbow and the vessels waterline, it is difficult to design a system which will always prevent water from entering the engine through the exhaust system. While a number of proprietary exhaust components are available to help avoid this problem, the most common generic methods are exhaust risers and water lift mufflers.

Exhaust Risers

One way to minimize the possibility of water entering the engine from backflow in the wet exhaust system is to have a steep downward slope on the exhaust piping, downstream of the engine.

Exhaust risers are pipes which elevate the exhaust gases, allowing a steeper slope in the downstream piping.

The risers must be insulated or water-jacketed to protect persons in the engine compartment from the high temperatures of the exhaust gas in the riser. The sea water is not injected into the exhaust gases until downstream of the top of the riser, so the upward-sloping portion of the riser is dangerously hot if not insulated or water-jacketed.

The weight of locally fabricated risers (not provided by Caterpillar) must be supported from the engine and marine transmission. Do not attempt to carry the weight of the risers from the boat's overhead or deck structure. The risers will vibrate with the engine-transmission. The risers must be supported independently from the hull to avoid transmitting those vibrations into the boat's structure and passenger compartments.

Exhaust risers (for other than the smallest Caterpillar Engines) are not available from Caterpillar; the diversity of the various boat builders engine compartments prevents designing a riser with wide usability. See fabricators of custom exhaust components for exhaust risers.

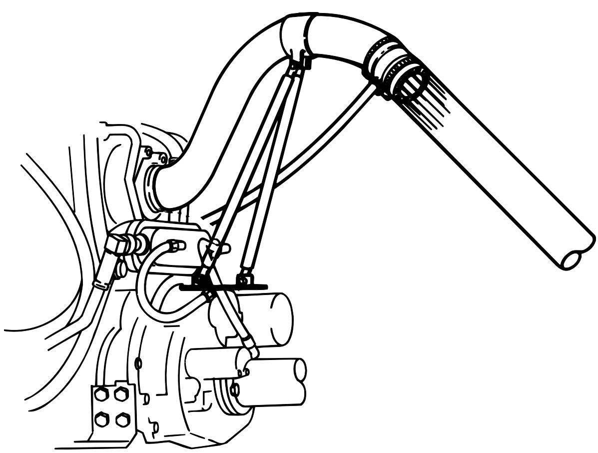
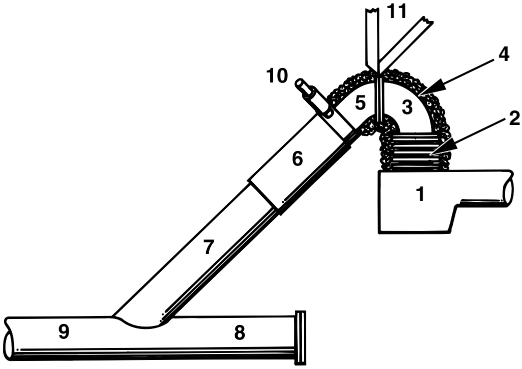


FIGURE 2.5



WET EXHAUST SYSTEM USING DRY EXHAUST ELBOWS
AT ENGINE EXHAUST DISCHARGE

1. **turbocharger heat shield**
2. **flexible pipe connection**
3. **elbow—℄ bend radius $\geq$ diameter of pipe**
4. **insulation, must not restrict flexibility of 2**
5. **elbow (min 15^0) with water discharge ring**
6. **exhaust hose**
7. **connecting exhaust pipe**
8. **surge pipe**
9. **discharge pipe**
10. **raw water discharge connection**
11. **support from overhead structure**

FIGURE 2.6

Water Lift Mufflers

Another way to minimize the possibility of water entering the engine from backflow in the wet exhaust system is by using a water lift muffler.

Water lift mufflers are small, sealed tanks, mounted to the deck in the engine compartment. The tanks have two (2) connections, an inlet connection and an outlet connection. An additional small drain connection in the bottom is often provided. The inlet enters the tank through the top or side.

The tubing of the inlet connection does not extend past the tank walls. The tubing of the outlet connection enters the tank walls, through the top, and extends to the bottom of the tank, where it terminates on an angle.

As the mixture of seawater and exhaust gas enters the tank from the inlet connection, the water level rises in the tank. As the water level rises, the water surface gradually reduces the gas flow area entering the discharge pipe. The reduced area for gas flow causes a great increase in gas velocity. The high speed of the gases, entering the outlet pipe, finely divides the water. The finely divided water is transported to the highest elevation of the exhaust piping as a mist of water droplets.

If good design practice is not followed, the engines exhaust back pressure limit is easily exceeded. The vertical (upward sloping) portion of piping immediately downstream of a water lift muffler must be designed as a pneumatic conveyer, using high exhaust gas velocities to lift finely divided droplets of the sea water to a point from which the gas/water mixture can be safely allowed to drain to the thru-hull fitting.

The designer should size the diameter of the upward sloping portion of the exhaust piping – between the water lift muffler and the highest system elevation – such that the velocity of the exhaust-gas-and-water droplet mixture is not below 5000 ft/min (25.4 m/sec), with the engine running at rated load and speed.

If this velocity is not maintained, the water droplets will not remain in suspension. The water will be forced out of the reservoir of the water lift muffler as a solid *slug* of water. This will cause the exhaust back pressure to be the same as a column of water the height of the upward sloping muffler discharge piping. If the velocity in the upward sloping muffler discharge piping is kept above 5000 ft/min (25.4 m/sec), then the exhaust back pressure will be much lower.

Hose vs Rigid Exhaust Pipe

The weight and heat of the water and exhaust gases can cause nonrigid exhaust piping to sag or deform, leaving low spots between pipe supports.

If the slope of the piping is too shallow, water will collect in the low spots and choke off the flow of exhaust gas. This will lead to excessive exhaust back pressure, smoke, high exhaust temperatures and, in severe cases, premature engine failures.

Hose and other nonrigid piping must be evenly supported over its entire length.

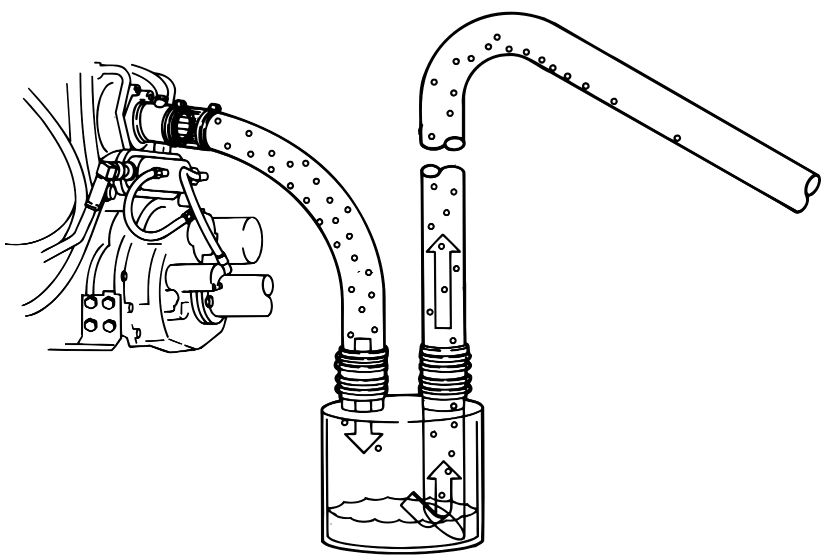


FIGURE 2.7

Preventing Wave Action From Forcing Water Into Wet Exhaust Systems

Waves, striking the hull's exhaust opening, can force water up into the exhaust system. If the waves are severe, or if the exhaust system design allows, the water can reach the engine. Early turbocharger failure or piston seizure may result.

There are a number of ways the kinetic energy of waves entering the engine's exhaust system can be harmlessly dissipated.

The traditional method of preventing water from entering an idle engine is to locate the engine far enough above the water line that breaking waves do not reach the height of the exhaust elbow. While the relative elevation of the engine to the water line is fixed and unchangeable, it is possible to design an exhaust system which protects the engine from ingesting water.

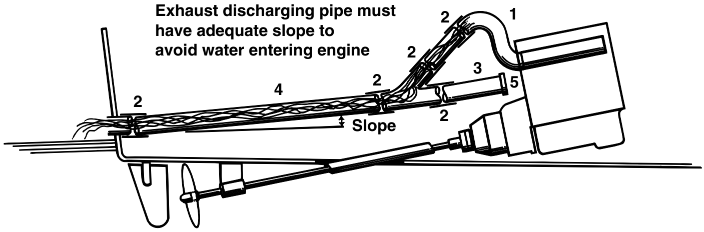
Features of such an exhaust system will include the following:

- Sufficient elevation difference between the water line and the highest point in the exhaust piping to prevent even small amounts of water from reaching the engine.
- Some method of dissipating the kinetic energy of the waves as they enter the exhaust piping. The more effective the method of wave energy dissipation, the lower the elevation difference required.

In no case should the elevation difference between the water line and the highest point in the exhaust piping be less than 22 in. (560 mm).

Surge Chamber

A surge chamber is a branch of the exhaust piping, near the engine, which has one end closed off. When a wave of water enters the exhaust pipe and moves toward the engine, the air trapped in front of the wave will be compressed into the surge chamber. The cushion of compressed air in the surge chamber will force almost all waves back out.



WET EXHAUST SYSTEM
(Engine Mounted Above Water Line)

1. water cooled exhaust elbow on engine - sea water cools elbow, then discharges through peripheral slot at discharge end of elbow into exhaust pipe
2. rubber exhaust hose flexible connection - must be oil and heat resistant
3. backwater surge chamber - prevents sea water surging into engine exhaust when vessel at rest with stern exposed to oncoming waves
4. exhaust pipe - should have slight downward gradient toward discharge end
5. end cover plate - removable for inspection and cleanout purposes

FIGURE 2.8

Valve in Exhaust Discharge

A valve located where the exhaust piping penetrates the hull can keep waves from entering the exhaust piping when the engine is not running. The valve mechanism should not include any components which rely on sliding contact to maintain flexibility. This type of action has proven troublesome in an atmosphere of salt water and exhaust gas. A flexible strip of one of the chemically inert plastics can provide hinge action.

Valves in Exhaust Water Cooling Lines

The cooling water which is injected into the exhaust gas stream must not be interrupted, for any reason, while the engine is running. Without a dependable supply of cooling water, the high temperature of the exhaust gases will cause severe and rapid deterioration of plastic or rubber exhaust pipe, with potentially disastrous consequences.

Therefore, to protect against inadvertent loss of exhaust system cooling, **shut-offs or valves of any kind must never be used in the lines supplying cooling water to water cooled exhaust fittings.**

Location of Exhaust Discharge Opening

All diesel engines will eventually discharge some smoke through their exhaust systems if not when they are new, then certainly near the end of their useful time before overhaul. Locating exhaust discharge openings as far aft as possible will minimize the hull and deck area exposed to the eventual discoloration.

Dry Exhaust System

Dry Exhaust System Warnings Insulation

It is the responsibility of the engine installer to protect combustible parts of the boat and provide personnel protection from the heat of dry exhaust systems piping. **Exposed parts of dry exhaust piping can exceed 1200° F (650° C).**

Rain/Spray
It is the responsibility of the engine installer to provide appropriate drain connections, rain caps or other means to protect the engine from rain-water or sea spray entering the engine through the dry exhaust piping. Long runs of exhaust piping require traps to drain moisture. Traps installed at the lowest point of the line near the exhaust outlet prevent rain water from reaching the engine.

Slope exhaust lines from engine and silencer to the trap so condensation will drain.

Traps may be built by inserting a vertical pipe, with a drain petcock, down from a tee section in the line.

Slope the last few feet of the exhaust pipe discharge to prevent rain water or spray from entering the pipe. Alternatively, fit some form of rain cap to a vertical exhaust pipe section.

Saw cuts in the exhaust pipe to allow rain/spray to drain harmlessly. Deform the edges of all slots. Use a punch on engine side slot edges. Bend inward. Cut through no more than 60° of the pipe circumference.

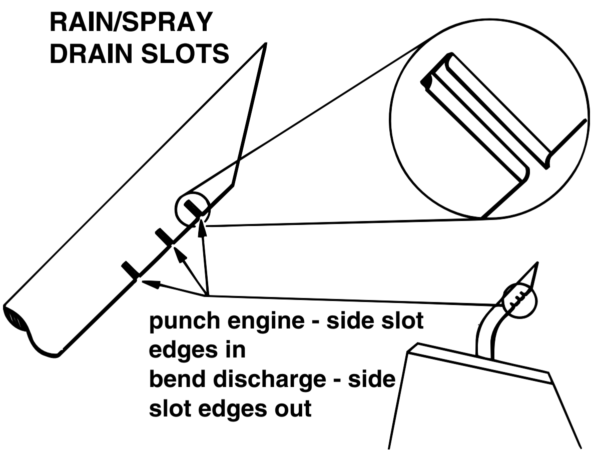


FIGURE 2.9

Exhaust Gas Recirculation

Exhaust stacks must be designed so engine exhaust is discharged high enough, and in a direction to keep it clear of the air turbulence created by wind swirling around the vessel's superstructure. Engine air cleaners, turbochargers and aftercoolers clogged with exhaust products will cause engine failures.

Ventilation

Mufflers and other large dry exhaust system components would be best mounted outside the engine compartment.

This is suggested to minimize the additional and unnecessary load on the machinery compartment's ventilation system.

Flexible Connections

The exhaust pipe must be isolated from the engine with flexible connections. They should be installed as close to the engine's exhaust outlet as possible. A flexible exhaust connection has three primary functions:

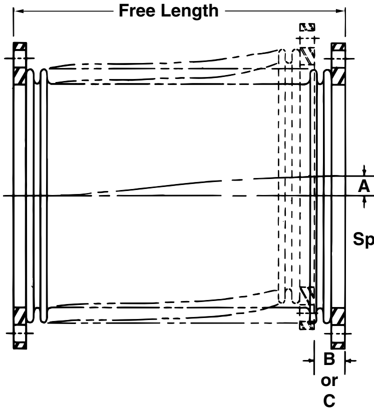
- To isolate the weight of the exhaust piping from the engine. No more than 60 lb (28 kg) of exhaust piping weight should be supported by the engine.
- To relieve exhaust components of excessive vibrational fatigue stresses.
- To allow for relative shifting between reference points on engine exhaust components. This shifting has numerous causes. It may result from expansion and contraction of components due to temperature changes, or by slow but continual creep processes that take place throughout the life of any structure.

Softness or flexibility is very important to prevent excessive vibratory stresses. The flexible connector must have high fatigue life to enable it to survive for indefinite periods. Softness prevents transmission of vibration beyond the connection. Resistance to fatigue keeps it from breaking under vibratory or recycling stresses.

To prevent the exhaust coupling from flexing during exhaust system construction, it is recommended that straps be tack welded between the two flanges to make the coupling rigid. Remove these straps before starting the engines.

The growth and shrinkage of the exhaust pipe must be planned or it will create excessive loads on exhaust piping and supporting structure. Long runs of dry exhaust pipes can be subjected to very severe stresses from expansion and contraction. From its cold state, a steel exhaust pipe will expand about 0.0076 in/ft of pipe for each 100° F (0.11 mm/m for each 100° C). This amounts to about 0.65 in. expansion for each 10 ft. of pipe from 100° F to 950° F (52 mm expansion per m from 35° C to 510° C).

INSTALLATION LIMITATIONS
OF BELLOWS - TYPE FLEXIBLE EXHAUST FITTING



A. max. offset between flanges		B. max. compression from free length		C. max. extension from free length	
in.	mm	in.	mm	in.	mm
0.00	0.00	1.50	38.1	1.00	25.4
0.12	3.05	0.90	22.86	0.50	12.7
0.25	6.35	0.60	15.24	0.28	7.11
0.38	9.65	0.40	10.16	0.20	5.08
0.50	12.7	0.23	5.84	0.00	0.00
0.75	19.05	0.00	0.00	0.00	0.00

Spring Rate of Bellows = 170 lb/in. (19.21 N/m) Approx.

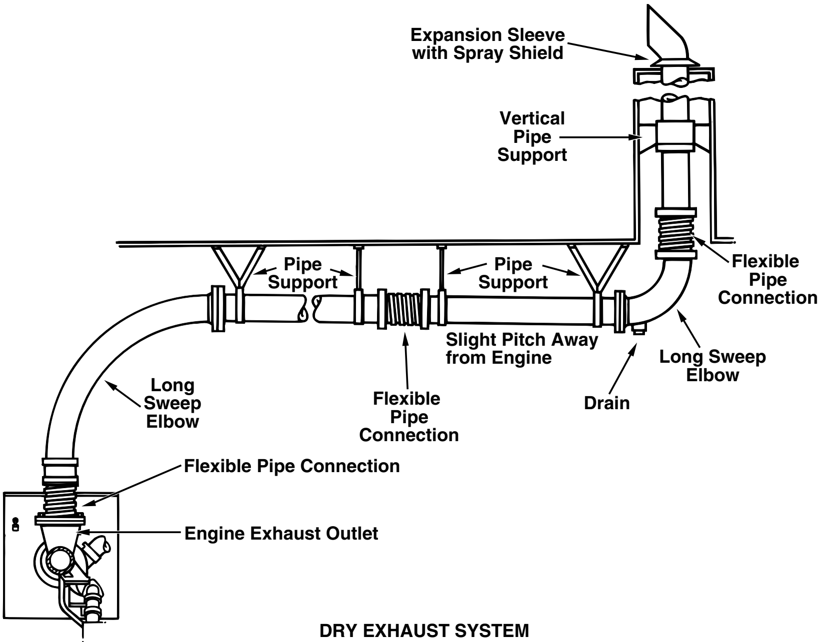
If bellows-type exhaust fittings are distorted beyond limits shown in table while engine is operating at full throttle, service life will be greatly reduced.

"Lagging" or insulation must not restrain flexibility of bellows.

FIGURE 2.10

Divide long runs of exhaust pipe into sections having expansion joints between sections. Each section should be fixed at one end and be allowed to expand at the other.

It is of utmost importance that the flexible pipe connection, when insulated, be insulated in such a way that the flexible pipe connection can expand and contract freely within the insulation. This generally requires either a soft material or an insulated sleeve to encase the flexible pipe connection.



DRY EXHAUST SYSTEM

FIGURE 2.11

Dimension Chart

Flange Type	P/N	Nominal ID	Flange OD	Bolt Circle	# of Bolts	Hole Diameter	Overall Length
		in. (mm)	in. (mm)	in. (mm)		in. (mm)	in. (mm)
Rect.	3N3015	5 (127)	6.42 (163)*	5 (127)**	4	0.657 (16.7)	18 (457)
Rect.	3N3017	6 (152)	8.00 (203)***	6 (152)****	4	0.657 (16.7)	24 (609)
Circ.	5L6297	8 (203)	11 (274)	9.875 (250)	8	0.625 (15.875)	12 (304)
Circ.	5N9505	12 (304)	15.75 (400)	14.75 (375)	12	0.500 (13.8)	12 (304)

*This dimension is the length of each side of a square flange.
**This dimension is from bolt center to bolt center along a side of the rectangular flange.
***This dimension is the length of each side of a square flange.
****This dimension is from bolt center to bolt center along a side of the rectangular flange.

Dry Exhaust System Pipe Supports

The exhaust piping supports/hangers are very important. If the piping is supported with some flexibility between the piping and the structure of the boat, the boat will be much quieter and more comfortable for the occupants.

Exhaust Ejector-Automatic Ventilation

A relatively simple system utilizing an engine's exhaust for ventilating an engine room can be utilized with most dry exhaust systems.

Utilizing the normally wasted kinetic energy of discharging exhaust gases, this system may draw out a quantity of ventilating air approximately equal to the flow of exhaust gas.

Air must be allowed to enter the engine room freely.
A useful rule of thumb is:

- Use 10 cm^2 of duct cross section area per engine kilowatt and not more than three (3) right angle bends.
- Use 1.25 in^2 of duct cross section area per engine horsepower and no more than three (3) right angle bends.

If more right angle bends are required, increase the pipe diameter by one pipe size. For best results, the intake air openings should discharge cool air into the engine room near the floor level. After the intake air has been heated by contact with hot surfaces in the engine room, draw the ventilating air out from a point directly over the engines, near the engine room overhead.

Place the ejector in the exhaust system just prior to the exhaust's discharge to atmosphere to avoid back pressure on the mixture of exhaust gas and hot air through any length of stack. Any bends in the exhaust stack following the mixture can seriously affect the system's performance.

Furthermore, the exhaust stack will remain cooler and cleaner if the engine exhaust is contained within the exhaust piping throughout its run through the stack. The discharged ventilation air will tend to cool the exhaust stack upstream of the point where it is mixed with the exhaust gases.

Exhaust ejectors are most effective on vessels with only one propulsion engine. On multiple engine installations, if one engine is operated at reduced load, the ejector air flow for the engine with reduced load may reverse, pulling exhaust gas from the more heavily loaded engine into the engine room. The following diagrams illustrate methods of laying out the system:

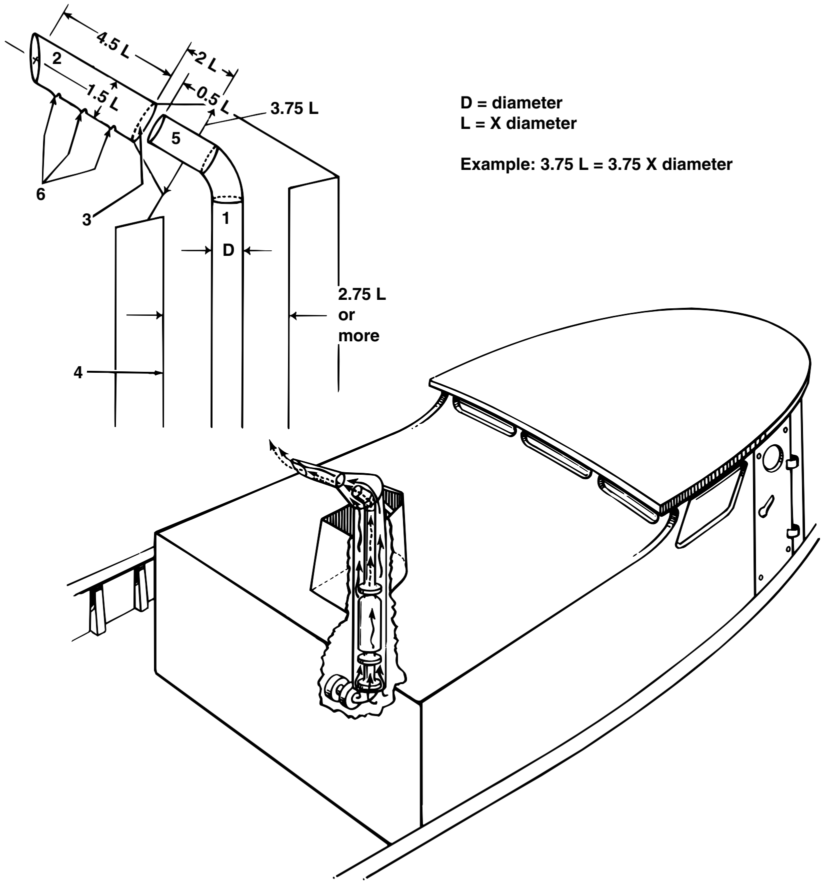

4.5 L
2 L
2
1.5 L
0.5 L
3.75 L
5
6
3
1
D
2.75 L
or
more
4
D = diameter
L = X diameter
Example: 3.75 L = 3.75 X diameter

FIGURE 2.12

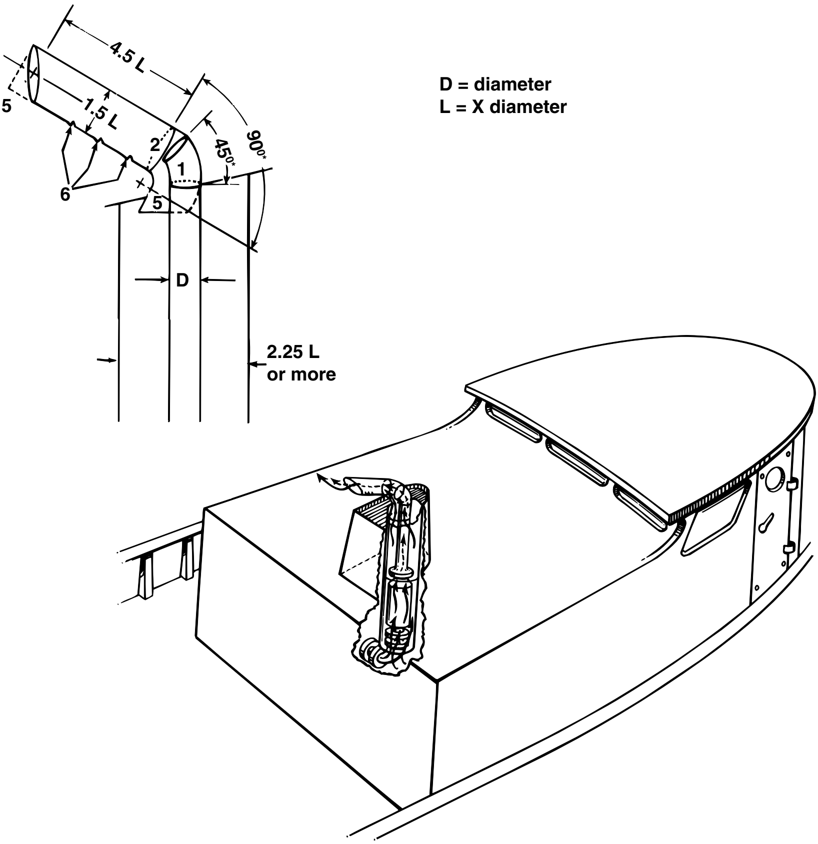


FIGURE 2.13

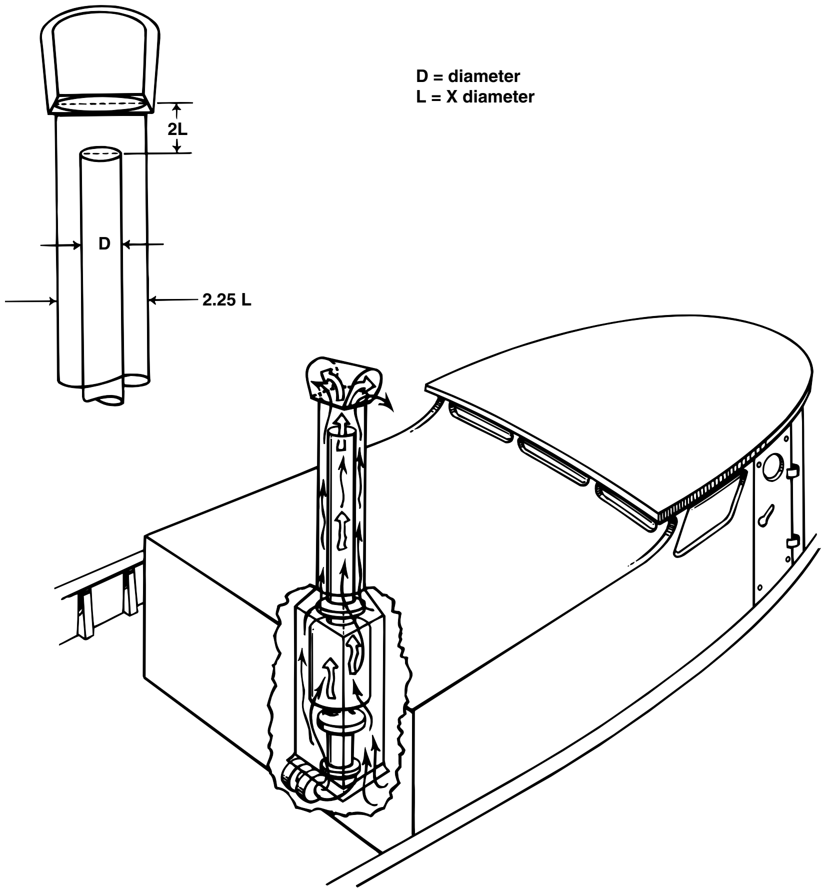


FIGURE 2.14

Formulae for System Diameter to Back Pressure Limits.

These formulae allow the exhaust system designer to calculate a pipe diameter which, when fabricated into an exhaust system, will give exhaust back pressure less than the appropriate limit.

Calculate the pipe diameter according to the formula, then choose the next larger commercially available pipe size.

Exhaust Pipe Diameter to Meet Back Pressure Limits
(Metric Units System)

P = Back pressure limit (kPa) See section on exhaust back pressure limits for specific engine.

$$D = \sqrt[5]{3600000 \frac{LSQ^2}{P}}$$

D = Inside diameter of pipe (mm)

Q = Exhaust gas flow (m^3/min). See engine performance curve.

L = Length of pipe (m). Includes all of the straight pipe and the straight pipe equivalents of all elbows.

$$\textbf{S}\ (kg/m^3) = \frac{352}{\text{Exhaust Temperature} + 273° \text{ F}}$$

S = Specific weight of gas (kg/m^3)

Exhaust Pipe Diameter to Meet Back Pressure Limits
(English Units System)

P = Back pressure limit (inches of water). See section on exhaust back pressure limits for specific engine.

$$\mathbf{D} = \sqrt[5]{\frac{LSQ^2}{187P}}$$

D = Inside diameter of pipe (inches).

Q = Exhaust Gas Flow (ft^3/min). See engine performance curve.

L = Length of pipe (feet). Includes all of the straight pipe and the straight pipe equivalents of all elbows.

S = Specific weight of gas (lb/ft^3).

$$S\ (lb/ft^3) = \frac{39.6}{\text{Exhaust Temperature} + 460° \text{ F}}$$

Formulae for Straight Pipe Equivalent Length of Various Elbows

To obtain straight pipe equivalent length of elbows:

English Units	Metric Units

Standard Elbow (radius of elbow equals the pipe diameter)

$$L = 33 \frac{D}{12} \qquad\qquad L = 33 \frac{D}{1000}$$

Long Radius Elbow radius greater than 1.5 pipe diameters

$$L = 20 \frac{D}{12} \qquad\qquad L = 20 \frac{D}{1000}$$

45° Elbow

$$L = 15 \frac{D}{12} \qquad\qquad L = 15 \frac{D}{1000}$$

Where:

L = Straight Pipe Equivalent Length of Elbows

D = Pipe Diameter

Useful Facts for Exhaust System Designers

Conversion Factors

psi = 0.0361 × in. of water column

psi = 0.00142 × mm of water column

psi = 0.491 × in. of mercury column

kPa = 6.3246 × mm of water column

kPa = 4.0 in. of water column

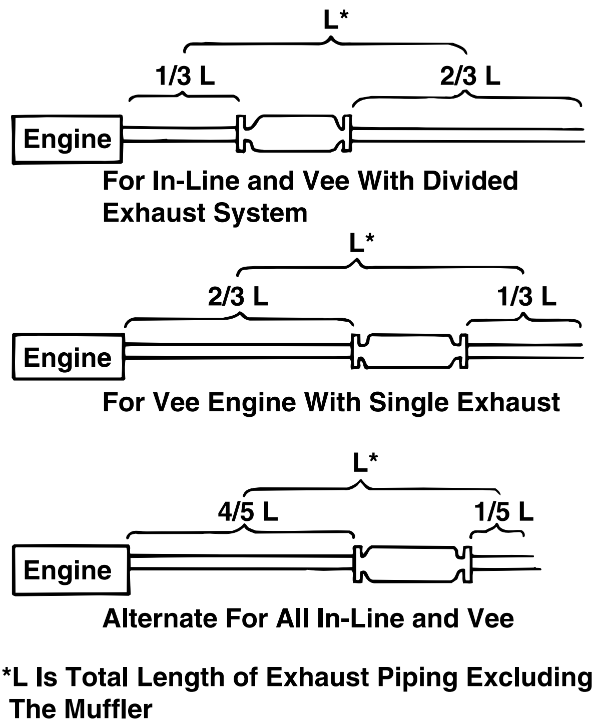
kPa = 0.30 × in. of mercury column

kPa = 0.145 psi

Mufflers

Exhaust noise attenuation is best performed with a quality muffler. However, the attenuation characteristics of a muffler are not the same for all frequencies. The effect of a given muffler could be quite different if the engine runs at two different speeds. The manufacturer must be contacted for any specific muffling characteristics.

The location of the muffler within the exhaust piping, whether close to the engine or nearer the exhaust outlet, and the number of engine cylinders is important. It will affect the efficiency of the muffler. The sketch below offers suggestions for the most efficient muffler location.



MUFFLER LOCATION

FIGURE 2.15

Exhaust Back Pressure Limits

As the exhaust gas moves through the exhaust system, it experiences frictional resistance – causing back pressure on the engine's turbocharger discharge. Exhaust system back pressure has a number of bad effects on the engine.

Excessive back pressure will shorten exhaust valve and turbocharger life due to increased exhaust temperatures. Excessive exhaust back pressure wastes fuel as well.

Maximum Exhaust Back Pressure Limits

	Metric Units	English Units
Naturally Aspirated Engines	8.47 kPa	34 in. H_20
Turbocharged Engines	6.72 kPa	27 in. H_20
Except for those specifically listed below:		
435 hp 3208, 3116, 3126 Propulsion Engines	9.96 kPa	40 in. H_20
3600 Family Engines	The limits on 3600 are competitive with other medium speed diesels. Higher pressure will affect performance and fuel consumption.	

To ensure the above limits are not exceeded during operation, it is recommended the design limit be not more than one-half the specified back pressure limits.

Measuring Back Pressure

Measure exhaust back pressure by a water manometer at the fitting provided in the engines exhaust discharge location. Use a system similar to that shown below.

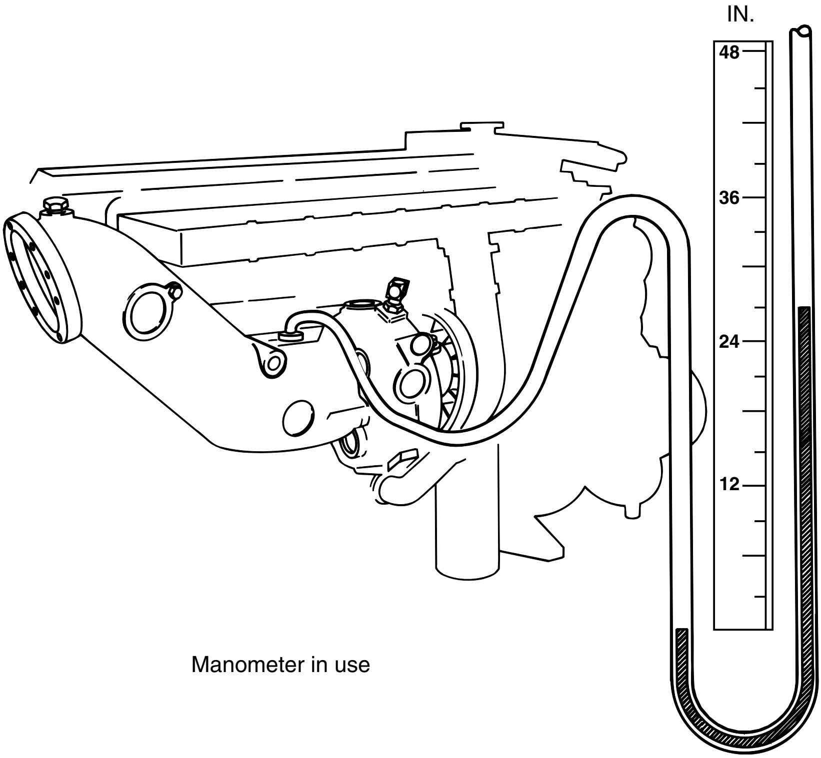


FIGURE 2.16

Warning Against *Common* Exhaust Systems

Although economically tempting, a common exhaust system for multiple engine installations is rarely acceptable. Combined exhaust systems allow operating engines to force exhaust gases into engines not operating. Every gallon of fuel burned provides about one gallon of water in the exhaust. This water vapor condenses in cold engines and quickly causes engine damage. Soot clogs turbochargers, aftercoolers or air cleaner elements. Duct valves separating engine exhausts is also discouraged. High temperature warp valve seats or soot deposits cause leakage.

Slobber (Extended Periods of Insufficient Load)

Extended engine operation at no load or lightly loaded conditions (less than 15% load) may result in exhaust manifold slobber. Exhaust manifold slobber is the black oily fluid that can leak from exhaust system joints. The presence of exhaust manifold slobber does not necessarily indicate an engine problem. Engines are designed to operate at loaded conditions.

At no load or lightly loaded conditions, the sealing capability function of some integral engine components may be adversely affected. Exhaust manifold slobber is not usually harmful to the engine; the results can be unsightly and objectionable in some cases.

Exhaust manifold slobber consists of fuel and/or oil mixed with soot from the inside of the exhaust manifold. Common sources of oil slobber are worn valve guides, worn piston rings and worn turbocharger seals. Fuel slobber usually occurs with combustion problems.

A normally operating engine should be expected to run for at least one hour at light loads without significant slobber. Some engines may run for as long as three, four or more hours before slobbering. However all engines will eventually slobber if run at light loads. External signs of slobber will be evident unless the exhaust system is completely sealed.

If extended idle or slightly loaded periods of engine operation are mandatory, the objectionable effects of the engine slobber can be avoided by loading the engine to at least 30% load for approximately ten minutes every four hours. This will remove any fluids that have accumulated in the exhaust manifold. To minimize exhaust manifold slobber, it is important that the engine is correctly sized for each application.

Ventilation System Formulas

As a rule of thumb, the installer should provide ventilation air flow of about 8 cfm (0.22656 m^3/min) per installed horsepower (both propulsion and auxiliary engines). If combustion air is to be drawn from the engine room increase that figure to $9\frac{1}{4}$ cfm (0.26196 m^3/min).

If you wish to compute more exact engine room air requirements it is necessary to determine the following factors:

H = Heat radiated to the engine room
This data is available from the TMI system for Caterpillar engines. Add in 4 Btu/min per generated 0.07032 kW for the normal maximum auxiliary generator load. Miscellaneous heat loads from other sources (pumps, motors, etc.) can be ignored if they are not exceptional.

Ta = Maximum ambient air temperature the vessel is expected to operate in during its whole life. [Usually assume 105° F (41° C).]

Sa = Density of the air at the maximum ambient air temperature.

Density of Air at Various Temperatures

° F/° C	lbs/cu. ft./kg/m³	° F/° C	lbs/cu. ft./kg/m³
0/–18	0.086/1.38	70/21	0.075/1.20
10/–12	0.084/1.35	80/27	0.074/1.18
20/–7	0.083/1.33	90/32	0.072/1.15
30/–1	0.081/1.30	100/38	0.071/1.14
40/4	0.079/1.27	**110/43**	**0.070/1.12**
50/10	0.078/1.25	120/49	0.068/1.09
60/16	0.076/1.22	130/54	0.067/1.07

dT = Maximum desired air temperature rise in the engine room. (Usually assume 15° F (9° C) rise above ambient if using a 105° F (41° C) ambient)

When these factors have been determined, the ventilation air requirements in cubic feet per minute (cfm) can be calculated by the following formula:

$$Qa = \frac{H}{Sa \times 0.24 \times dT}$$

$$Qa = \frac{H}{Sa \times 0.017 \times dT} = \text{Metric}$$

Qa = Volume of inlet air required in cfm (m^3/min)

H = Radiated heat [btu/min (kW)]

Sa = Inlet air density [lbs/cu. ft. (kg/m^3)]

0.24 = Specific heat of air (btu/lbs/° F)

0.017= Specific heat of air (kW•min/kg•° C)

dT = Temperature rise from ambient air to engine air [° F (°C)]

Ventilation Air Duct Sizing

Before the duct cross-sectional area can be calculated you must determine two elements.

Qcfm = Amount of Ventilation air and Combustion air (combine system) in cfm.

Va = Desired inlet air velocity [Not to exceed 2,000 feet per minute (609.6 m/min)]

Once these two elements have been determined then the following formula can be used to determine the minimum cross-sectional for both intake and exhaust ducts or openings.

$$Av = \frac{144 \times Q_a}{V_a} \qquad Av = \frac{Q_a}{V_a} = \text{Metric}$$

Av = Duct cross sectional area in square inches (m^2)

Q_a = Quantity of air flow in cubic feet per minute (m^3/min)

V_a = Velocity of air in the duct in feet per minute (m/min)

Combustion Air Formulas

If combustion air is to be drawn from the engine room, a slight modification is in order. Since the air used for combustion takes some engine room heat with it, it can be counted partially as ventilation air. This can be added into the calculation by adding about half of the combustion air required ($\frac{1}{2}$ Qc) resulting in the following equation:

$$Qa = \frac{H}{Sa \times 0.24 \times dT} + \frac{1}{2} Qc$$

$$Qa = \frac{H}{Sa \times 0.017 \times dT} + \frac{1}{2} Qc = \text{Metric}$$

Qa = Volume of inlet air required in cfm (m^3/min)

H = Radiated heat [btu/min (kW)]

Sa = Inlet air density [lbs/cu. ft. (kg/m^3)]

0.24 = Specific heat of air (btu/lbs/° F)

0.017 = Specific heat of air (kW•min/kg•° C)

dT = Temperature rise from ambient air to engine air [°F (°C)]

Qc = Combustion air required in cfm (m^3/min)

For combustion air requirement a good rule of thumb is to multiply the horsepower in the engine room by 2.5. Remember to include all engines in the engine room space for this calculation. If you need more exact combustion air figures then you can get that information from the TMI system. However, the 2.5 times rule is usually adequate for sizing purposes.

If the rule of thumb of 8 cfm (0.22656 m^3/min) of air per installed horsepower is applied, the minimum duct cross sectional area (Av) per installed horsepower would be:

Av = 0.6 in^2/Hp (3.87 cm^2/kW) @
Va = 2000 fpm (609.6 m/min)

Av = 0.9 in^2/Hp (5.81 cm^2/kW) @
Va = 1200 fpm (365.8 m/min)

If you included combustion air into the ventilation system [used 9.25 cfm (0.262 m^3/min)]:

$$Av = 0.7\ in^2/Hp\ (4.52\ cm^2/kW) \ @$$
$$Va = 2000\ fpm\ (609.6\ m/min)$$

$$Av = 1.0\ in^2/Hp\ (6.45\ cm^2/kW) \ @$$
$$Va = 1200\ fpm\ (365.8\ m/min)$$

Remember air should enter the engine room freely. It is far better to have extra air than not enough. This installation parameter is second only to sufficient liquid cooling capacity in importance. If the rules of thumb are adhered to they will normally be sufficient, however, they are not overly conservative … Don't Cheat!

Sizing Combustion Air Ducts

Obtain the actual air requirement from the TMI system or use the rule of thumb (2.5 × Hp) to calculate the air required. The formula used to calculate the ventilation cross-sectional area can then be applied by using the appropriate combustion air volume and a velocity. (8000 fpm maximum)

This will most likely yield a cross-sectional area smaller than that of the factory connection to the air cleaner, however, be sure to keep the duct size equal to, or greater than, that of the factory connection.

If the straight length of duct is long, (over 25 × the diameter or diagonal of the factory connection) or includes more than two right angle bends, it would be wise to calculate the pressure drop at full air flow. This can be done using the following formula:

$$dP = \frac{Le \times S \times Q^2}{187 \times d^5} \qquad dP = 3{,}600{,}000 \times \frac{Le \times S \times Q^2}{d^5} = \text{Metric}$$

dP = Pressure loss [inches (kPa) of water]

Q = Air flow [cfm (m^3/min)]

d = Duct diameter [inches (mm)]

Le = Equivalent duct length [ft (m)]

S = Density of combustion air [lbs/cu.ft. (kg/m^3)]

Use the following method to determine Le:

Standard elbow = 2.75 × d

Long Sweep elbow = 1.67 × d

45° elbow = 1.25 × d

d = value must be in inches

Standard elbow = 0.033 × d = meter

Long Sweep elbow = 0.020 × d = meter

45° elbow = 0.015 × d = meter

d = value must be in mm

Exhaust System Formulas

Water Cooled Exhaust

There are two basic types of exhaust systems used in the marine area. The two systems are “wet” (water cooled) and dry exhaust systems. The main consideration is to design the system to remove the exhaust gases from the engine room and limit the backpressure to a minimum.

The limits for a given engines’ exhaust backpressure can be located in the TMI system. In general terms the backpressure limit is 27 inches of water for all Caterpillar turbocharged/turbocharged aftercooled engines. 34 inches of water is the limit for naturally aspirated engines. The 3600 series of engines have a limit of 10 inches of water. Some special rating, such as the 435 Hp 3208 E rating have a limit of 40 inches of water. You need to determine the limit of your engine, rating and then size the exhaust system to be below the limit. Remember that the closer you get to the limit the more affect the exhaust backpressure will have on the performance of the engine.

Many “wet” exhaust systems utilize an exhaust riser to help prevent sea water from entering the engine through the exhaust system when the engine is not operating or when the boat is “backed down” quickly. As a general rule of thumb the riser should be at least 22 inches above the level of the sea water to the lowest portion of the riser.

The minimum water flow requirements to a wet exhaust system can be calculated by using the following formula.

$$\text{Flow} = \frac{Vd \times Ne}{66000} \qquad \text{Flow} = \frac{Vd \times Ne}{285.785} = \text{Metric}$$

Flow = Gallons per minute (L/min)

Vd = Engine displacement [cubic inches (liters)]

Ne = Rated speed (rpm)

66,000 = constant for gallons

285.785= constant for liters

A water lift muffler is also common in some of the smaller pleasure craft. If a water lift muffler is to be used the following are some points to pay close attention to.

1. Size the muffler outlet for a minimum exhaust velocity (gas only) of 5000 ft/min at rated engine power and speed. The following formula will give the maximum pipe diameter, "De" that can be used to insure the 5000 ft/min velocity.

   $De = 0.19 \sqrt{Qe}$ $\qquad$ $De = 28.67 \sqrt{Qe}$ = Metric

   De= The maximum water lift exhaust outlet pipe diameter [inches (mm)]

   Qe= Exhaust flow rate from the muffler [cfm (m^3/min)]

2. The tank itself should be of sufficient size. A rule of thumb would be at least 8 cubic inches per rated horsepower.
3. The inlet pipe to the tank should be truncated near the top of the tank.
4. The outlet pipe should extend to near the bottom of the tank (about 1 inch from the bottom) and should be angle cut (mitered) to increase exit gas velocity at lower loads and flow rates.
5. A siphon break should be installed between the exhaust elbow and the high point of the outlet pipe from the muffler.

Dry Exhaust

The dry exhaust system has some typical points that need to be considered as well.

1. A flexible connection at the engine exhaust outlet. No more than 60 pounds of exhaust piping weight should be supported on the flexible connection.
2. Flexible connection(s) are installed on the horizontal portion and on the vertical stack of the exhaust system.
3. Horizontal portions of the exhaust system are sloped away from the engine.
4. A spray shield/rain trap is used on the exhaust outlet.

The exhaust gas flow rate for a given engine and rating can be obtained from the TMI system. It can be closely estimated by using the following formula.

$$Qe = \frac{(Te + 460) \times Hp}{214} \qquad Qe = \frac{(Te + 273) \times kW}{3126.52} = \text{Metric}$$

Qe = Exhaust gas flow rate [cfm (m^3/min)]

Te = Exhaust gas temperature [°F (°C)]

Hp = Engine rated horsepower (kW)

After you have determined the exhaust gas flow rate the exhaust system backpressure can be calculated using the following formula.

$$dP = \frac{Lte \times Se \times Qe^2}{187 \times d^5} \qquad dP = 3{,}600{,}000 \times \frac{Lte \times S \times Qe^2}{d^5} = Metric$$

dP = Exhaust system backpressure [inches of water] or kPa

Lte = Total length of piping for diameter “d” [ft (m)]

d = Duct diameter [inches (mm)]

Lte is the sum of all the straight lengths of pipe for a given diameter “d”, plus, the sum of equivalent lengths, “Le”, of elbows and bends of diameter “d”. Straight flexible joints should be counted as their actual length if their inner diameter is not less than “d”.

Le = equivalent length of elbows in feet of straight pipe

Standard elbow – Le (ft) = 2.75 × d (inches)

Long elbow – Le (ft) = 1.67 × d (inches)

45 ° elbow – Le (ft) = 1.25 × d (inches)

Note: “Le” results are in feet but “d” must be in inches

Le = equivalent length of elbows in meters of straight pipe

Standard elbow – Le = 0.033 × d = (metric)

Long elbow – Le = 0.020 × d = (metric)

45 ° elbow – Le = 0.015 × d = (metric)

Note: “Le” results are in meters but “d” must be in mm

Qe = Exhaust gas flow [cfm (m^3/min)]

Se = Density of exhaust gas [lbs/cu. ft. (kg/m^3)]

The specific weight of the exhaust gas is calculated using the following formula.

$$Se = \frac{39.6}{(Te + 460)\ °F} \qquad Se = \frac{352}{(Te + 273)\ °C} = \text{Metric}$$

Se = Density [lbs/cu. ft./kg/m^3)]

Te = Exhaust gas temperature [° F (°C)]

d = pipe diameter [inches (mm)]

The values of Lte, Se, Qe, and d must be entered in the units specified above if the formula is to yield valid results for backpressure.

To get the total exhaust pressure you must add to the answer from the above formula the pressure drop of the muffler. The pressure drop for Caterpillar mufflers is available in the TMI system.

Exhaust gas velocity should also be checked. If the velocity is too high, excessive noise or whistle may occur and inner pipe and wall surfaces may erode at an unacceptable rate. As a rule of thumb, the velocity is best kept to 18,000 ft/min or less. The velocity can be calculated using the following formula:

$$Ve = \frac{183 \times Qe}{d^2} \qquad Ve = \frac{1{,}270{,}691.83 \times Qe}{d^2} = \text{Metric}$$

Ve = Exhaust gas velocity [ft/min (m/min)]

Qe = Exhaust gas flow rate [cfm (m^3/min)]

d = Pipe diameter [inches (mm)]

Lubrication Systems

General Information

Bearing failure, piston ring sticking and excessive oil consumption are classic symptoms of oil related engine failure. There are numerous ways to avoid them. Three of the most important are Scheduled Oil Sampling (S•O•S), regular maintenance of the lubrication system, and the use of correct lubricants. Taking these measures can mean the difference between experiencing repeated oil related engine failure and benefiting from a productive and satisfactory engine life. The following information will acquaint the reader with oil; what it is composed of and what its functions are, how to identify its contamination and degradation, typical consequences, and some preventive measures to help you protect your engine against the devastating effects of oil related engine failure.

Function

Engine oil performs several basic functions:

It cleans the engine by carrying dirt and wear particles until the filters can extract and store them.

It cools the engine by carrying heat away from the pistons, cylinder walls, valves, and cylinder heads to be dissipated in the engine oil cooler.

It cushions the engine's bearings from the shocks of cylinder firing.

It lubricates the wear surfaces, reducing friction.

It neutralizes the corrosive combustion products.

It seals the engine's metal surfaces from rust.

Additives

Lubricating oil consists of a mixture of base oil fortified with certain additives. Depending on the type of base, paraffinic, asphaltic, naphthenic or intermediate (which has some of the properties of the former), different additive chemistries are used.

Additive Types

The most common additives are: detergents, oxidation inhibitors, dispersants, alkalinity agents, anti-wear agents, pour-point dispersants and viscosity improvers.

Detergents help keep the engine clean by chemically reacting with oxidation products to stop the formation and deposit of insoluble compounds.

Oxidation inhibitors help prevent increases in viscosity, the development of organic acids and the formation of carbonaceous matter.

Dispersants help prevent sludge formation by dispersing contaminants and keeping them in suspension.

Alkalinity agents help neutralize acids.

Anti-wear agents reduce friction by forming a film on metal surfaces.

Pour-point dispersants keep the oil fluid at low temperatures by preventing the growth and agglomeration of wax crystals.

Viscosity improvers help prevent the oil from becoming too thin at high temperatures.

Total Base Number (TBN)
Understanding TBN requires some knowledge of fuel sulfur content. Most diesel fuel contains some degree of sulfur. One of lubricating oils functions is to neutralize sulfur by-products, retarding corrosive damage to the engine. Additives in the oil contain alkaline compounds which are formulated to neutralize these acids. The measure of this reserve alkalinity in an oil is known as its TBN. Generally, the higher the TBN value, the more reserve alkalinity or acid-neutralizing capacity the oil contains.

Viscosity
Viscosity is the property of oil which defines its thickness or resistance to flow. Viscosity is directly related to how well an oil will lubricate and protect surfaces that contact one another. Oil must provide adequate supply to all moving parts, regardless of the temperature. The more viscous (thicker) an oil is, the stronger the oil film it will provide. The thicker the oil film, the more resistant it will be to being wiped or rubbed from lubricated surfaces. Conversely, oil that is too thick will have excessive resistance to flow at low temperatures and so may not flow quickly enough to those parts requiring lubrication. It is therefore vital that the oil has the correct viscosity at both the highest and the lowest temperatures at which the engine is expected to operate. Oil thins out as temperature increases. The measurement of the rate at which it thins out is called the oil's viscosity *index* (or VI). New refining techniques and the development of special additives which improve the oil's viscosity index help retard the thinning process.

The Society of Automotive Engineers (SAE) standard oil classification system categorizes oils according to their quality.

Cleanliness
Normal engine operation generates a variety of contamination – ranging from microscopic metal particles to corrosive chemicals. If the engine oil is not kept clean through filtration, this contamination would be carried through the engine via the oil.

Oil filters are designed to remove these harmful debris particles from the lubrication system. Use of a filter beyond its intended life can result in a plugged filter.

A plugged filter will cause the bypass valve to open releasing unfiltered oil. Any debris particles in the oil will flow directly to the engine. When a bypass valve remains open, the particles that were previously trapped by the filter may also be flushed from it and then through the open bypass valve. Filter plugging can also cause distortion of the element. This happens when there is an increase in the pressure difference between the outside and inside of the filter element. Distortion can progress to cracks or tears in the paper. This again allows debris to flow into the engine where it can damage components.

Recommended Oils for Various Caterpillar Products

Refer to Operation and Maintenance Manual for lubrication specifications.

Contamination

Contamination refers to the presence of unwanted material or contaminants in the oil. There are seven contaminants commonly found in contaminated oil.

1. Wear Elements
   Wear elements are regarded as those elements whose presence indicates a part or component which is wearing. Wear elements include: copper, iron, chromium, aluminum, lead-tin, molybdenum, silicon, nickel, and magnesium.
2. Dirt and Soot
   Dirt can get into the oil via air blowing down past the rings and by sticking to the oil film and being scraped down from cylinder walls. Soot is unburned fuel. Black smoke and a dirty air filter indicate its presence. It causes oil to turn black.
3. Fuel
4. Water
   Water is a by-product of combustion and usually exits through the exhaust stack. It can condense in the crankcase if the engine operating temperature is insufficient.
5. Ethylene Glycol/Antifreeze
6. Sulfur Products/Acids
7. Oxidation Products
   Oxidation products cause the oil to thicken; oxidation rate is accelerated by high temperature of the inlet air.

Diagnostic Tests

Caterpillar's Scheduled Oil Sampling (S•O•S) program is a series of diagnostic tests designed to identify and measure contamination and degradation in a sample of oil. S•O•S is composed of three basic tests:

1. Wear Analysis
2. Chemical & Physical Tests
3. Oil Condition Analysis

A brief explanation of what each of these tests involves is in order.

Wear Analysis

Wear analysis is performed with an atomic absorption spectrophotometer. Essentially, the test monitors a given component's wear rate by identifying and measuring concentrations of wear elements in oil. Based on known normal concentration data, maximum limits of wear elements are established. After three oil samples are taken, trend lines for the various wear elements can be established for the particular engine. Impending failures can be identified when trend lines deviate from the established norm.

Wear analysis is limited to detecting component wear and gradual dirt contamination. Failures due to component fatigue, sudden loss of lubrication or sudden ingestion of dirt occur too rapidly to be predicted by this type of test.

Chemical & Physical Tests

Chemical and physical tests detect water, fuel and antifreeze in the oil and determine whether or not their concentrations exceed established limits.

The presence and approximate amount of water is detected by a *sputter test*. A drop of oil is placed on a hot plate controlled at 230° F (110° C). The appearance of bubbles is a positive indication (0.1% to 0.5% is the acceptable range).

The presence of fuel is determined with a Setaflash Tester. The tester is calibrated to quantify the percentage of fuel dilution.

The presence of antifreeze can also be determined by a chemical test. (Any indication that is positive is unacceptable.)

Oil Condition Analysis

Oil condition analysis is performed via infrared analysis. This test determines and measures the amount of contaminants such as soot and sulfur, oxidation and nitration products. Although it can also detect water and antifreeze in oil, infrared analysis should always be accompanied by wear analysis and chemical and physical tests to assure accurate diagnosis. Infrared analysis can also be used to customize (reduce, maintain, or extend) oil change intervals for particular conditions and applications.

Recognizing the Causes & Effects of Contamination

S•O•S identifies and measures various contaminants in the oil which cause engine failure. For example, a high concentration of copper indicates thrust washer or bushing wear. A high concentration of chromium indicates piston ring damage (with the exception of plasma coated rings). S•O•S gives you an opportunity to inspect the condition of these parts and, if necessary, take action to prevent further damage. Here are some examples of typical contaminants and what effect they have on the condition of your engine.

Silicon
Above normal readings of silicon can indicate a major problem. Oil loaded with silicon becomes, in effect, a grinding compound which can remove metal from any number of parts during operation.

Sodium
A sudden increase in sodium readings indicates inhibitor leaking from the cooling system. Inhibitor may indicate antifreeze in the system which can cause oil to thicken and become like sludge, leading to piston ring sticking and filter plugging.

Silicon, Chromium, Iron
A combination such as this signals dirt entry through the induction system, possibly causing ring and liner wear.

Silicon, Iron, Lead, Aluminum
This combination indicates dirt in the lower portion of the engine, possibly leading to crankshaft and bearing wear.

Aluminum
This can be critical. Concentrations of aluminum suggest bearing wear. Relatively small increases in the levels of this element should receive immediate attention because once rapid wear begins, the crankshaft may produce large metal particles which will become trapped in the oil filters.

Iron
Iron can come from any number of sources. It can also appear as rust, after engine storage. Frequently, when accompanied by a loss of oil control, increases in iron contamination indicate severe liner wear.

Soot
A high soot content is not usually the direct cause of failure but as solid particles which will not dissolve in the oil, it can plug oil filters and deplete dispersant additives. Soot indicates a dirty air cleaner, engine lug, excessive fuel delivery, or repeated acceleration in the improperly set rack limiter (smoke limiter). It can also indicate a poor quality fuel.

Water
Water combined with oil will create an emulsion which will plug the filter. Water and oil can also form a dangerous metal corroding acid. Most instances of water contamination are the result of condensation within the crankcase. More serious contamination occurs when a leak in the cooling system allows water to enter from outside the engine oil system.

Fuel
Fuel contamination decreases the oil's lubricating properties. The oil no longer has the necessary film strength to prevent metal-to-metal contact. This can lead to bearing failure and piston seizure.

Sulfur
The presence of sulfur signals danger to all engine parts. The type of corrosive wear attributed to high sulfur content can also cause accelerated oil consumption. Also, the more fuel consumed during an oil change interval, the more sulfur oxides are available to form acids. Therefore, an engine working under heavy loads should be checked more often. Also, its TBN should be checked more frequently. Fuel sulfur damage can cause piston ring sticking, and corrosive wear of the metal surfaces of valve guides, piston rings and liners.

Engine operating conditions can also play a major role in the type and degree of oil contamination. A dry environment will for instance affect silicon readings. Another example is engines which stand idle for long periods at a time. The liners in such engines will rust at an unusually rapid rate; oil samples will reveal high iron readings.

Changing Lubrication Oil

Changing lubrication oil can be simplified by using a system as described below: Install a machine thread-to-pipe-thread adapter* in the oil pan drain.

Connect a length of flexible, oil and temperature resistant hose to the adapter. Engine vibration working against a *rigid* pipe can cause drain boss failure in the oil pan in short time.

Connect the other end of the hose to the inlet of a small, electric motor-driven pump. Control the pump motor with a *key-operated switch*. Use a key-operated switch to prevent unauthorized operation of the pump.

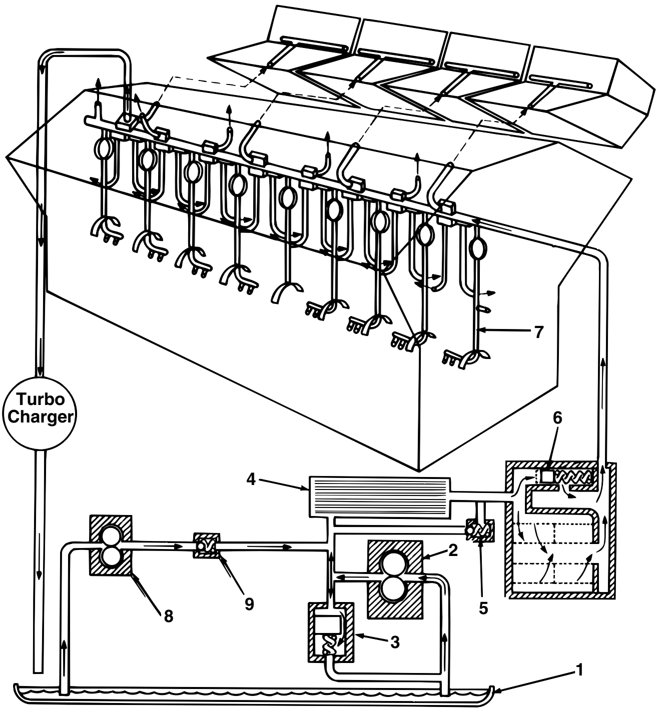
Connect the discharge of the motor-driven pump to a dirty oil tank for storage of the used lube oil until proper disposal is practical.

Keep the Key on the Captain's Key Ring.

Check oil level prior to every engine start.

*Adapter 6L6155 is available to convert the oil pan machine threads to 1/2-14 NPTF female threads for remote oil draining of the 3304B, 3306B, 3406B, and 3408B Marine Engines. Seal 8M4432 and washer 1S3889 are required to prevent leakage between the pan drain boss and the adapter.

Adapter 3N9442 and Gasket 3B1925 are available to convert from machine threads to 1/2-14 NPTF female threads on 3208 Marine Engines.



Engine Lube Oil Flow Schematic

1. **Sump – lube oil is drawn from the sump through a strainer into the inlet of the lube oil pump.**
2. **Lube Oil Pump – the quantity of lube oil delivered by the lube oil pump exceeds the engine's needs when the engine is new. As the engine clearances increase through normal wear, the flow required to properly lubricate the engine will remain adequate.**
3. **Oil Pressure Regulating Valve – this valve regulates oil pressure in the engine and routes excess oil back to the sump.**
4. **Lube Oil Cooler – the oil to the engine is cooled by jacket water in the engine oil cooler.**
5. **Oil Cooler Bypass Valve – when the viscosity of the oil causes a substantial pressure drop in the oil cooler, the bypass valve will open, causing the oil to bypass the cooler until the oil is warm enough to require full oil flow through the cooler.**
6. **Lube Oil Filter – Caterpillar lube oil filters are the full-flow type with a bypass valve to provide adequate lubrication should the filter become plugged. The filter system may have the replaceable element type or the spin-on type. The oil filter bypass valve is a protection against lube oil starvation if the oil filter clogs.**
7. **Engine Oil Passages – the main oil flow is distributed through passages to internal engine components. The oil flow carries away heat and wear particles and returns to the sump by gravity.**
8. **Prelubrication Pump – used only during starting cycle on largest engines.**
9. **Check Valve.**

FIGURE 3.1

Filter Change Technique

Spin-on oil filters are conveniently changed by gripping the loosened used oil filter with a plastic garbage bag. As the used oil filter is then removed, the oil which might have soiled the engine compartment can be caught by the garbage bag.

Lubricating Oil Heaters

Caterpillar does not recommend the use of immersion-type lubrication oil heaters due to their tendency to overheat the oil in contact with the heating element. This overheating causes deterioration and sludging of the lubricating oil and may lead to premature engine failure.

Emergency Systems

Some marine applications require the capability to connect an emergency lubricating oil pump into the engine's lube system.

This is a specific requirement of some marine classification societies for seagoing single propulsion engine applications. The purpose is to ensure lube oil pressure and circulation if the engine lube pump fails.

Requirements for emergency lube system operation:

1. Keep pressure drops to a minimum by using short, low restriction lines.
2. Use a line size at least as large as the engine connection point.
3. Install a low restriction strainer in front of the emergency oil pump.
4. Install a low restriction check valve between the emergency pump discharge and the engine inlet connection.
5. Use a pressure limiting valve in the emergency system set at 125 psi (8.8 kg/cm^2).

Transmissions

Some marine classification societies require emergency lube oil pumps for marine transmissions to meet unrestricted service classification.

Duplex Filters

The optional Caterpillar Duplex Oil Filter System meets the requirements of the standard filter system plus an auxiliary filter system with the necessary valves and piping. The system provides the means for changing either the main or auxiliary filter elements with the engine running at any load to speed. A filter change indicator is included to tell when to change the main filter elements. A vent valve allows purging of air trapped in either the main or auxiliary system when installing new elements. *Air must be purged from the changed section to eliminate possible turbocharger and bearing damage.* **The auxiliary system is capable of providing adequate oil filtration for at least 100 hours under full load and speed operation.**

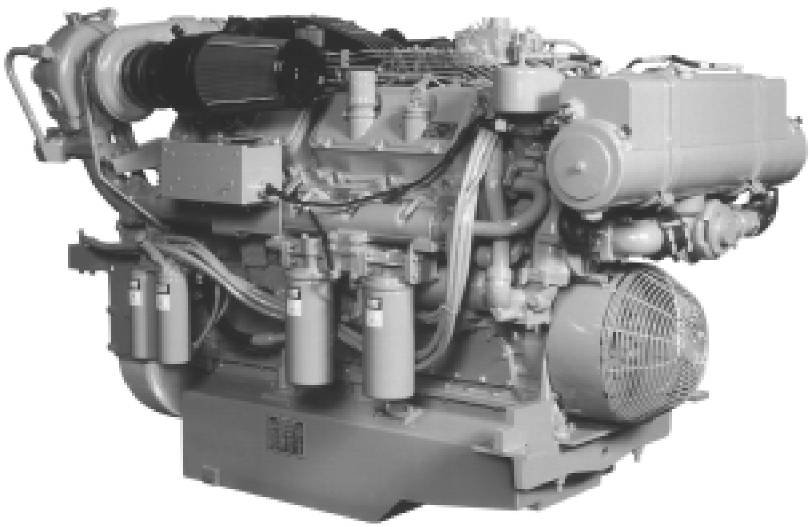


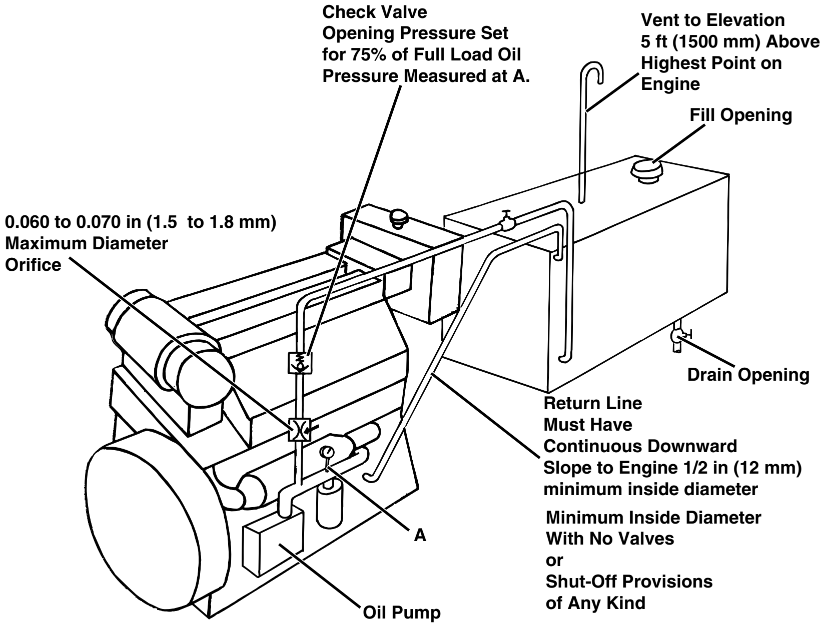
FIGURE 3.2

Auxiliary Oil Sump

If longer oil change periods are desired, consider the auxiliary oil sump. Engine oil change period is directly proportional to total oil quantity, all other factors remaining equal. This is: to double oil change period, add an auxiliary oil sump with a capacity equal to the engine mounted oil sump. This will double the amount of oil available to be contaminated/diluted/neutralized and allow proportionately longer periods between oil changes. Previously mentioned considerations regarding fuel sulfur, oil TBN and oil analysis should be followed. After a basic change period has been confirmed, then an auxiliary oil sump may be used to increase the basic period-based on fuel quality, oil TBN and oil analysis.

Auxiliary Oil Sump System Considerations

1. Connect the oil source line to the auxiliary tank as close to the engine oil pump as possible. **The auxiliary oil sump tank must be full prior to starting the engine**. The auxiliary tank must remain full of oil at all times. As soon as the engine starts, the auxiliary oil sump will overflow, returning the oil to the engine; exactly compensating for the oil removed through the oil source line to the auxiliary tank.
2. Use a 0.060 to 0.070 in. (1.5 to 1.8 mm) orifice in this line to flow approximately 1 Gpm (3.8 L/m).
3. Put a check valve in the oil pump discharge line, set to open at 75% of the measured pressure at the line connection point, when the engine is up to temperature and at maximum operating speed.



AUXILIARY OIL SUMP CONNECTION SCHEMATIC

FIGURE 3.3

Prelubrication

A prelube system provides the capability to prelubricate all critical bearing journals before energizing the starting motors.

The *automatic* system utilizes a small pump which fills the engine oil galleries from the engine oil sump until the presence of oil is sensed at the upper portion of the lubrication system. The starter motors are automatically energized only after the engine has been prelubricated.

The *manual* system uses the engine's manually operated sump pump and allows the engine operator to fill all engine oil passages after oil changes, filter changes, periods of idleness, and before activating the starter motors.

Either prelube system will allow the engine operator to fill all engine oil passages after oil changes, filter changes, and before activating the starter motors. Either system will allow the engine user to minimize the sometimes severe engine wear associated with starting an engine after periods of idleness.

Special Marking of Engine Crankcase Dipstick

Sometimes marine engines are installed and operated in a tilted position. If the tilt angle is significant (5° or more) the amount of oil needed to fill the engine crankcase to the full mark on the dipstick (usually marked for level operation) may be more or less than the correct amount the oil pan was intended to accommodate without uncovering the suction bell or flooding the crankshaft seal.

The maximum safe tilt angle is dependent upon the design of the oil sump as well as the dipstick location – both of which are not necessarily uniform for all engine models. Therefore, where a tilted engine installation is encountered it is wise to check and, if necessary, remark the standard dipstick in order to make certain that the high and low marks will really reflect the proper amount of oil for safe engine operation. Oil pressure may be lost due to an uncovered suction bell, a flooded crankshaft seal may leak excessively, and engine vibration can be caused by crankshaft counterweights dipping into the oil. These are all problems that can be caused by an improper amount of oil in the sump.

Procedure

1. Drain engine crankcase and remove oil filter elements.
2. Install new oil filter elements.
3. Fill crankcase with a given volume of oil (V_f) which can be determined as follows.

(V_f) $=V_r - V_m$

Where:
V_r = Volume of oil required to refill to *Full* mark with filter change.

V_m = Volume of oil between *add* mark and *Full* mark for level operation.

Note: Both Vr and Vm values for a specific engine model are published in the current Technical Marketing Information (TMI) on *Marine Engine Systems and Performance Specification Data* microfiche under subject heading *Pan-Oil Capacity*.

Add to this any additional oil volume required for special filters, oil lines, or coolers which are additions to the standard engine or unique to the installation.

4. Insert the dipstick to make certain that the oil shows on the dipstick. Be certain that the correct dipstick is used and that it does not hit the bottom of the sump or is otherwise improperly installed.

5. Start the engine and operate it at one half rated rpm until the oil has reached normal operating temperature. Reduce engine speed to low idle and mark the level indicated on the dipstick. This is the *add oil* or low mark.

6. Add additional oil equivalent to Vm as shown in the Technical Marketing Information (TMI) and let the engine operate at least another five minutes in order to bring all the oil up to temperature. Mark the new oil level on the dipstick. This is the full oil mark. Refer to Operation and Maintenance manuals for dipstick marking base on installed tilt angles.

Synthetic Lubricants and Special Oil Formulations

Some producers of synthetic lubricants imply their products have properties which allow extended oil life.

Caterpillar Inc. neither endorses nor recommends a brand or type of *extended oil drain interval* crankcase oil for its engines. Caterpillar recommends (S•O•S) Schedules Oil Sampling to determine if extended oil drain periods can be achieved with synthetics. Caterpillar offers both petroleum and synthetic oils which are formulated for maximum wear conditions and long life because the additive package is on the high side of the tolerance range of CG4/CF4 specification.

Crankcase oil is changed because it becomes contaminated with soot (unburned carbon), wear products, partially burned fuel, acids, dirt, and products of combustion. The additive components included in the oil become depleted as they perform their intended functions of dispersing soot, preventing oxidation, wear, foaming, etc. Caterpillar requires petroleum and synthetic engine crankcase lubricants to meet Engine Service Designation CG4/CF4.

Types of Synthetic Oil
Two widely used synthetic oil types use base stocks made of synthetic hydrocarbons or di-basic acid testers. Both types of synthetic base oils have high viscosity indexes which make them advantageous in cold weather operations. Their use in any other application should be treated with caution.

The cost of these synthetic base oils range from three to four times the price of petroleum based lubricants, and makes the economics of their general use questionable.

Another type oil is called a partial synthetic engine oil. This is a petroleum base oil with some synthetic base oil which is blended for good cold weather performance.

Special Oil Formulations
Caterpillar does not recommend the use of additives to extend oil change periods. Oil additives such as graphite, teflon, molybdenum disulfide, etc., which have been properly blended into an oil that meets API CG4/CF4 specification can be used in Caterpillar Diesel Engines. These additives are not necessary to achieve normal life and performance of the engine.

Normal engine life and performance can be achieved by properly applying the engine, by servicing at recommended oil change period, by selecting the correct oil viscosity, by using an API CG4/CF4 oil and performing and maintenance as outlined in the engine operation and maintenance guide.

Caterpillar does not recommend the use of molybdenum dithiophosphate friction modifier additive in the engine oil. This additive causes rapid corrosion of bronze components in Caterpillar Diesel Engines.

Oil Publications Available From Caterpillar

The following publications are available through your local Caterpillar Dealer. Some of the publications may have a nominal charge. Some may be revised or discontinued in the future. These publications should be ordered directly from your dealer. Your dealer can also assist you in answering questions concerning available oils in your operating area.

All Engine Data Sheets are included in the Caterpillar Engine Technical Manual, Volume I, Form No. LEKQ2030.

Synthetic Lubricants and Special Oil Formulations LEKQ2051 (Engine Data Sheet 90.3)

Special Dipstick Marking of Engine Crankcase Dipstick LEKM3272 (Engine Data Sheet 94.0)

Oil Consumption Data LEKQ4028 (Engine Data Sheet 96.2)

Oil and Your Engine SEBD0640

Full Synthetic Diesel Engine Oil PEHP7062

Introduction of New Full Synthetic Cat Diesel Engine Oil SAE 5W-40 PELE0580

Fuel Systems

General Information

Caterpillar Engines have three different types of fuel systems.

The earliest has the high pressure pumps (for all the cylinders) in a single housing. The input shaft for that housing is driven by the engine's gear train. The high pressure fuel pump housing provides the high pressure fuel to the fuel valves at each cylinder, at the proper time, and in precisely metered amounts. The fuel valves at each cylinder are simple and easily replaced.

A later design combines each cylinder's high pressure pump and the fuel valve in a single unit; therefore, the term *unit injector*. The power to generate the high pressures for injection is taken from the engine's camshafts by way of pushrods and rocker arms.

Electronic unit injectors use engine camshaft and push rods to generate injection press but use electronics to time the fuel delivery and the amount.

Caterpillar Diesel Engine fuel delivery systems are designed to deliver more fuel to the engine than is required for combustion.

The excess is returned to the fuel tanks.

Cleanliness

Clean fuel meeting Caterpillar's fuel recommendations provides outstanding engine service life and performance; anything less is a compromise and the risk is the user's responsibility. Dirty fuel and fuels not meeting Caterpillar's minimum specifications will adversely affect:

- The perceived performance of the combustion system and fuel filters.
- The service life of the fuel injection system, valves, pistons, rings, liners and bearings.

Heat in Fuel

Excess fuel (returned to the fuel tanks) picks up engine heat and can raise the temperature of the fuel in the tanks.

To avoid decreased injector life, fuel temperature to the engine must not exceed 150° F (66° C). Heat will also increase the specific volume of the fuel, resulting in a power loss of 1% for each 10° F (6° C) above 85° F (29° C).

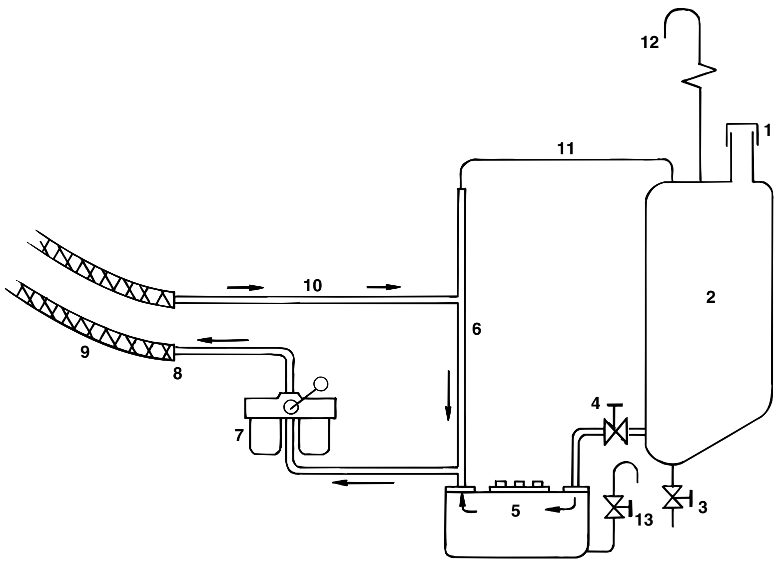
If the tank is so located and is of such size that the accumulated heat will not be objectionable when temperature stabilizes, then nothing more needs to be done. If the stabilized fuel tank temperature is high, the returning fuel should be cooled. See section on Fuel Coolers.

Air in Fuel

Gases entrained in the supplied fuel are discharged from the engine in the returned fuel. The gases (generally, air introduced through leaks in the fuel suction plumbing) must be vented to prevent engine power loss.

Standpipe Systems

The simplest method for eliminating the air problems is to install a standpipe between the fuel tank and the engine. Fuel will flow from the tank to the bottom of the standpipe by gravity. This is the point where the engine picks up fuel. The fuel return line must enter the standpipe at a point a few inches above the higher of either the supply or delivery point. The top of the standpipe can be vented into the top of a fuel tank or to atmosphere. This system works satisfactorily with any number of fuel tanks. There must be no upward loops in piping between the fuel tank and the standpipe, as entrapped air may block fuel flow.



**FUEL SUPPLY SYSTEM-SINGLE TANK
OR DAY TANK**

1. Fuel filler
2. Fuel tank or day tank
3. Drain valve – install at lowest part of tank to enable draining of all water and sediment. Outlet of valve should be plugged when not in use to prevent fuel dripping.
4. Fuel discharge valve
5. Water and sediment trap – must be lowest point of system
6. Fuel return standpipe
7. Primary fuel filter – to be cleanable without shutting down engine
8. Fuel supply line to engine
9. Flexible fuel lines connecting to basic fuel delivery system
10. Return from engine to standpipe
11. Vent from top of standpipe to top of fuel tank
12. Vent from top of fuel tank atmosphere – must be high enough above deck to prevent water washing over deck from entering pipe
13. Cleanout drain for water & sediment-valved and kept below fuel discharge from tank, to allow flushing water & sediment tank by gravity feed from supply

FIGURE 3.4

Fuel Coolers

The excess fuel returned from engines equipped with unit injectors (1.7 liter, 3500 and 3600 Family Engines) can absorb considerable heat from the injectors and the surrounding jacket water. Fuel coolers may be necessary for proper engine performance. The following factors affect the need for fuel cooling equipment:

- **Length of periods of continuous operation** – If the operating periods are short, the amount of heat returned to the fuel tanks will be relatively small. Fuel coolers are not generally required for engines used in high performance applications.

- **Length of time between periods of operation** – If the time between periods of operation is long, the heat will have an opportunity to dissipate.
- **Volume of the fuel tank** – If the volume of the fuel tank is large (larger than 3,000 gal [11 000 L]), it will accept a great deal of heat before the temperature of the fuel leaving the tank increases significantly.
- **Ability of the fuel tanks to dissipate the heat of stored fuel** – If the fuel in the tank is in contact with shell plating*, the fuel heat will be easily dissipated and stored fuel temperature will remain within a few degrees of the ambient water temperature.

Day Tanks (Auxiliary Fuel Tanks)

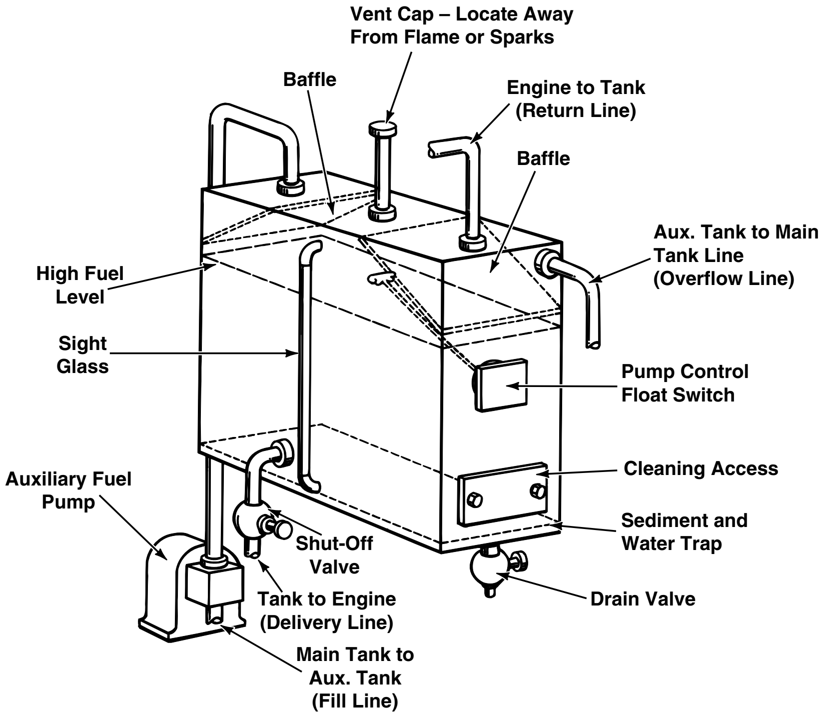
Auxiliary or day tanks are required if the main fuel tanks are located:

- More than 50 ft (15.25 m) from the engine;
- Are located above the engine;
- Or are more than 12 ft (3.65 m) below the engine.

Auxiliary or day tanks also provide a settling reservoir so air, water, and sediment can separate from the fuel.

The auxiliary or day tank should be located so that the level of the fuel is no higher than the fuel injection valves on the engine. If the fuel level is higher, the static pressure may allow fuel to leak into the combustion chambers when the engine is not running. *The presence of liquid fuel in the combustion chamber at the instant of engine starting is very likely to cause engine failure.* The tank should be close enough to the engine so the total suction lift is less than the 12 ft (3.65 m). The smaller this figure, the easier the engine will start.

*The shell plating should be approximately 10% of the inside surface area of the fuel tank.



AUXILIARY FUEL TANK

FIGURE 3.5

Fuel Return Line Pressure Limits

Engine fuel pressure measured in the fuel return line should be kept below 4 psi (27 kPa), except for the 3300 Engine Family, which is 3 psi (20 kPa) and the 3600 Engine Family, which is 51 psi (350 kPa). The fuel return line must be at least the same size as the supply line. A shutoff valve is not recommended.

Cleanliness

All connecting lines, valves, and tanks should be thoroughly cleaned before making final connections to the engine. The entire fuel supply system should be flushed prior to engine start-up.

Tank Design

Material

Fuel tanks are best made from low carbon rolled steel. Zinc, either in the form of plating or as a major alloying component, should not be used with diesel fuels. Zinc is unstable in the presence of sulfur, particularly if moisture is present in the fuel. The sludge formed by chemical action is extremely harmful to the engine's internal components. Zinc should be avoided where continuous contact with diesel fuel is involved.

Sizing

The capacity of a fuel tank or tank system can be estimated by multiplying the average horsepower demand by the hours of operation between refuelings, and divide the result by 16 for U.S. gallons and by 4 for liters.

This calculation does *not* allow for any reserve capacity which should be added to this basic requirement.

Grounding/Bonding (Electrical Connections)

The filler attachment and tank should be connected with a *ground cable* if they are not already connected electrically. The tanks should also be connected to the vessel's bonding system.

This is necessary to reduce the fire hazard of sparks discharged from static electricity buildup during refueling operations.

Drains

All fuel tanks should have easily accessible drain connections. Water and sediment which collects in the bottom of the tank must be eliminated regularly.

Provide clean-out openings for periodical removal of sediment and trash which settles out of fuel tanks.

Well-designed tanks have large enough clean-out openings so the lowest part of the fuel tank can be accessed with cleaning equipment.

Fuel Lines

Material

Black iron pipe is best suited for diesel fuel lines. Copper pipe or tubing may be substituted in sizes of 0.5 in. (13.0 mm) nominal pipe size or less. Valves and fittings may be cast iron or bronze (not brass). Zinc, either in the form of plating or as a major alloying component, should not be used with diesel fuels. Zinc is unstable in the presence of sulfur, particularly if moisture is present in the fuel. The sludge formed by chemical action is extremely harmful to the engine's internal components.

Routing

Whenever possible, route fuel lines under any machinery, so any leakage will be confined to the bilges. Leaks from overhead fuel system components may fall onto hot machinery, increasing the likelihood of fire danger.

Sizing

Determine the fuel line sizing by the supply and return line restriction. The maximum allowable restriction is published in the Engine Performance books (green books). Supply and return lines should be no smaller than the fittings on the engine.

Fuel Specifications

Caterpillar Diesel Engines have the capacity to burn a wide variety of fuels. See your Caterpillar Dealer for current information on fuel recommendations. In general, the engine can use the lowest priced distillate fuel which meets the following requirements:

Properties

Cetane Number or Index
The cetane index is a measure of the ignition quality of fuel which affects engine starting and acceleration.

The fuel supplier should know the cetane number or index of each fuel shipment.

Precombustion chamber fuel systems require a minimum cetane number of 35.

Direct injection engines require a minimum cetane number of 40 for good starting characteristics.

Engine Effects
Fuel with a low cetane number usually causes an ignition delay in the engine. This delay causes starting difficulties and engine knock. Ignition delay also causes poor fuel economy, a loss of power and sometimes engine damage. A low cetane number fuel can also cause white smoke and odor at start-up on colder days. Engines running on fuels with low cetane numbers may need to be started and stopped using a good distillate fuel.

Blended fuels or additives can change the cetane number. The cetane number is difficult and expensive to establish for blended fuels due to the complexity of the required test. White exhaust smoke is made up of fuel vapors and aldehydes created by incomplete engine combustion. Ignition delay during cold weather is often the cause. There is not enough heat in the combustion chamber to ignite the fuel. Therefore, the fuel does not burn completely.

Using a cetane improver additive can often reduce white smoke during engine start-up in cold weather. It increases the cetane number of diesel fuel which improves ignition quality and makes it easier for fuel to ignite and burn. Contact your local fuel supplier for information on where to obtain cetane improvers.

The cetane number sensitivity can also be reduced in an engine by raising the inlet air temperature, if practical.

Cetane number is usually calculated or approximated using a *cetane index* due to the cost of more accurate testing. Be cautious when obtaining cetane numbers from fuel suppliers.

Flash Point
The flash point is the temperature at which fuel vapors can be ignited when exposed to a flame. It is determined by the type of fuel and the air-fuel ratio. It is important for safety reasons, not for engine operating characteristics.

The minimum flash point for most diesel fuels is about 100° F (38° C).

WARNING! For safety, maintain storage, settling and service fuel tanks at least 18° F (10° C) below the flash point of the fuel. Know the flash point of the fuel for safe storage and handling, especially if you are working with heavy fuels that need heating to a higher temperature to flow readily.

Cloud Point
The cloud point of a fuel is that temperature at which a cloud or haze appears in the fuel. This appearance is caused by the temperature falling below the melting point of waxes or paraffins that occur naturally in petroleum products.

Engine Effects
The cloud point of the fuel must be at least 10° F (6° C) below the lowest outside (ambient) temperature to prevent filters from plugging.

The fuel's cloud and pour points are determined by the refiner. Generally, the cloud point is most important to you since it is at this temperature that fuel filter plugging begins to occur and stops fuel flow to the engine.

Steps to Overcome a High Cloud Point Temperature
Three steps can be taken to cope with high cloud point fuels.

1. Use a fuel heater when the outside temperature is below the cloud point of the fuel. Since the cloud point is also the wax melting point, when your fuel temperature is maintained above the cloud point, the wax will remain melted in the fuel. The heater should warm the fuel before it flows through the filter(s). Fuel heaters often use the engine coolant to heat the fuel and prevent wax particles from forming. Make sure the heater is capable of handling the maximum fuel flow of the engine. When the ambient temperature is low enough to require the use of a fuel heater, start and run the engine at low idle until the fuel temperature is high enough to prevent wax formation in the engine fuel filter circuit. Otherwise, high fuel rates with cold fuel will increase the risk of plugging.

Note: Do not allow the fuel to get too warm because fuel above 85° F (29° C) will affect the power output of the engine. Never exceed 150° F (66° C) with straight distillate fuel. The high fuel temperatures also affect the fuel viscosity. When the fuel viscosity falls below 1.4 cSt, pump damage may occur.

2. You can also dilute high cloud point fuels with a low cloud point fuel like kerosene.
3. The fuel manufacturer can also add flow improvers (wax crystal modifiers) to the fuel. These do not change the cloud point of the fuel, but they do keep the wax crystals small enough to pass through the fuel filter.

Caterpillar does not recommend the use of aftermarket fuel flow improvers because of occasional compatibility problems.

Pour Point
The pour point of a fuel is that temperature which is 5° F (3° C) above the temperature at which the fuel just fails to flow or turns solid. Usually the pour point is also determined by the wax or paraffin content of the fuel.

Steps to Overcome a High Pour Point Temperature
The pour point can be improved with flow improvers or the addition of kerosene. Fuel heaters cannot normally solve problems related to a high pour point temperature.

Viscosity
Viscosity is a measure of a liquid's resistance to flow. High viscosity means the fuel is thick and does not flow as easily. Fuel with the wrong viscosity (either too high or too low) can cause engine damage.

When comparing viscosity measurements, be sure they are taken at the same fuel temperature. Caterpillar recommends a viscosity between 1.4 cSt and 20 cSt delivered to the fuel injection pump. Engines with unit injectors can expect a 68° F (20° C) temperature rise between the transfer pump and the injector.

Engine Effects
High viscosity fuel will increase gear train, cam and follower wear on the fuel pump assembly because of the higher injection pressure. Fuel atomizes less efficiently and the engine will be more difficult to start. Low viscosity fuel may not provide adequate lubrication to plungers, barrels, and injectors; its use should be evaluated carefully.

Steps to Correct Viscosity Problems:
The viscosity of fuel will vary with the fuel temperature.

Heating or cooling can be used to adjust viscosity somewhat.

Blending fuels is another way to adjust viscosity.

Viscosity and Heavy Fuel

The Caterpillar 3500 and 3600 Families of Engines can run on a blend of heavy and distillate fuels. Viscosity is a key factor. Heavy fuel must be diluted or heated until it reaches a viscosity of 20 cSt or less before it reaches the fuel system. Unless the engine has extremely low rpm, there is little economic benefit to trying to treat fuel with a higher viscosity than 380 cSt.

Steps to Correct Viscosity Problems

To handle high viscosity fuel, some additional installation requirements may be needed, depending on the exact viscosity. The installation may require:

- Fuel tank and fuel line heating.
- Centrifuging and back flush filtering.
- Externally driven fuel transfer pumps.
- Additional fuel filtering.
- Washing of the turbocharger exhaust turbine. (3600 Family Engines)

Specific Gravity

The specific gravity of diesel fuel is the weight of a fixed volume of fuel compared to the weight of the same volume of water (at the same temperature). The higher the specific gravity, the heavier the fuel. Heavier fuels have more energy or power (per volume) for the engine to use.

Effects on Engine

Light Fuels

When comparing fuel consumption or engine performance, always know the temperature of the fuel measurement for correct gravity and density.

- Lighter fuels like kerosene will not produce rated power.
- Do not adjust engine fuel settings to compensate for a power loss with lighter fuels (with a density number higher than 35 API). There is a likelihood of inaccuracy in the compensation process (if not done by authorized personnel) and the service life of a compensated engine might be seriously reduced if occasionally subjected to denser fuel.
- Fuel system component life can be decreased with very light fuels because lubrication will be less effective (due to low viscosity). Lighter fuels may also be a blend of ethanol or methanol with diesel fuel. Blending of alcohol (ethanol or methanol) or gasoline into a diesel fuel will create an explosive atmosphere in the fuel tank. In addition, water condensation in the tank can cause the alcohol to separate and stratify in the tank. Caterpillar recommends against such blends.

Heavy Fuels

A heavy fuel tends to create more combustion chamber deposit formations which can cause abnormal cylinder liner and ring wear.

Correct Specific Gravity

- Blending is the only way to correct fuel density problems.

Contaminants

Sulfur

Sulfur, in diesel fuel, is converted to sulfur trioxide during combustion. Sulfur trioxide will exhaust from the engine (without causing serious problems for the engine), as long as it does not come in contact with liquid water. If the sulfur trioxide gas does contact liquid water, the result is H_2SO_4 or sulfuric acid; a highly corrosive compound which will cause severe engine damage.

Engines should maintain jacket water temperatures above 165° F (74° C) at all times to minimize internal condensation of water vapor (from combustion).

Fuels containing higher sulfur levels can be utilized in Caterpillar Marine Engines. This does require proper lubrication oil selection. Consult the appropriate lubrication and maintenance manual, published by the Caterpillar Service Department, for specific recommendations.

Maintain the crankcase breather system to prevent condensation in the crankcase oil which will cause rapid TBN depletion.

Maintain a regular Scheduled Oil Sampling (S•O•S) oil analysis program. Infrared (JR) analysis is valuable as well.

Follow standard oil change intervals unless S•O•S or known sulfur content indicates differently.

Caterpillar Fuel Sulfur Analyzer

The Caterpillar 8T0910 Fuel Sulfur Analyzer will allow the vessel operator to immediately analyze fuel containing up to 1.5% sulfur. Caterpillar recommends checking each bulk fuel delivery, especially if fuel quality is questionable.

Vanadium

Vanadium is a metal present in some heavy fuels. It is impractical to remove or reduce this element at the refinery.

Vanadium compounds accelerate deposit formation.

Vanadium is not present in distillate fuels.

Engine Effects

Vanadium in the fuel quickly corrodes hot components. It will often first appear in the form of molten slag on exhaust valve seats.

Vanadium forms highly corrosive compounds during combustion. These compounds attach to hot metal surfaces, like exhaust valve faces, injector tips and turbocharger blades. Vanadium compounds melt and remove the oxide coating. When component temperatures rise, vanadium corrodes even faster. For example, exhaust valves can wear out in a few hundred hours when vanadium content in a fuel is high.

Steps to Help Prevent Vanadium Corrosion Damage
Vanadium compounds must reach their melting point to become active. The best corrosion control is to limit exhaust system component temperatures by controlling the temperature of the exhaust gas. Cooler exhaust gas temperatures can allow an engine to tolerate more vanadium in the fuel.

Some of the measures utilized to deal with high vanadium fuels include:

- Using special heat resistance materials.
- Rotating exhaust valves (standard on Caterpillar Engines).
- Engine derating to lower exhaust temperatures.
- Special cooling of high temperature parts.
- Blending the fuel with low vanadium fuel will reduce effects.

Water
Water can be introduced into the fuel during shipment or as a result of condensation during storage.

Engine Effects
Water (both fresh and salt) can cause:

- Excessive separator sludge after the fuel has been centrifuged.
- Piston ring groove deposits.
- Wear in fuel system plunger and barrel assemblies.
- Power loss from fuel starvation; the water causes fuel filter media to swell, cutting off the engine's fuel supply.

Steps to Overcome Effects of Water
- The effects of water in fuel can be minimized by draining water from the fuel tank daily.
- Obtaining fuel from reliable sources.
- Removal of salt water may require centrifuges.

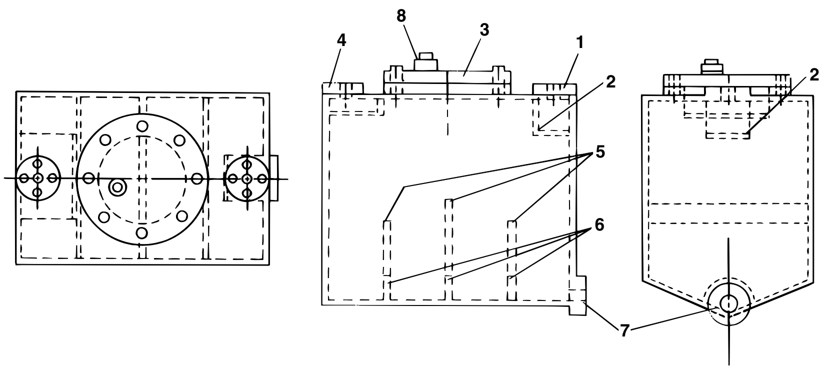
Water Separators
There are two types of water separators.

Sediment-Type Water Separator
The sediment type is installed ahead of the engine's fuel transfer pump. For water and sediment to separate properly, the sediment-type water separator should not be subject to violent motion.

A sediment water separator does not have a filtering media in the element. It does not normally need scheduled element replacement.

The water and sediment trap should be large enough to reduce the fuel flow rate to a velocity less than 2 ft/s (0.61 m/s). The larger particles of sediment and water will settle out at this flow rate.

Locate the water and sediment trap as close to the fuel tank as possible. This is to minimize the length of ship's fuel lines which are subject to water and sediment contamination. It will minimize any problem with water freezing in fuel lines.



SUGGESTED ARRANGEMENT FOR WATER AND SEDIMENT TRAP

1. **Fuel inlet**
2. **Inlet baffle**
3. **Hand hole and cover**
4. **Fuel Outlet**
5. **Baffles**
6. **Openings at bottom of baffles for drainage**
7. **Drain Opening**
8. **Air bleed plug**

$$\textbf{Sediment Trap Capacity} = \frac{\textbf{Fuel Cons.}}{\textbf{25}} + \frac{\textbf{Tank Cap.}}{\textbf{5000}}$$

Note: Suggested minimum size of trap

FIGURE 3.6

Coalescing Water Separator
The coalescing type of separator must be used if the water in the fuel is broken into such small particles that they make the fuel cloudy.

A coalescing-type separator will separate all water from fuel. It can be put anywhere in the fuel line, such as next to the components that need the most protection from water. The elements are composed of two-stage paper media that are replaceable. You can tell the element is plugged when there is a lack of fuel pressure.

Catalytic *Fines*
Catalytic *Fines* are small, hard particles which originate at the refinery. They are usually composed of aluminum and silicon particles and can cause very rapid abrasive wear.

Engine Effects
Catalytic *Fines* will severely damage injection pumps, injectors, piston rings and cylinder liners.

Proper fuel treatment methods (centrifuging and filtration) will remove these particles.

Volatile Fuel Components
Certain liquids are present in fuels in a vapor or gaseous state. This can cause an interruption of fuel supply to the fuel pump.

Lighter fuels and crude oils will have greater tendency to this problem than heavier fuels.

An air eliminator, or vapor trap, can be used to minimize the effect of interrupted fuel supply due to vapor lock.

The vapors and gases, thus separated are combustible and must be disposed of according to safe venting practice.

Simple venting to atmosphere is not adequate, since some of the vapors and gases may be heavier than air and tend to collect or *pool* in low spots, forming a severe safety hazard.

Asphaltenes
Asphaltenes are components of asphalt that are insoluble in petroleum naphtha and hot heptanes but are soluble in carbon disulphide and benzene. They are hard and brittle and are made up of long molecules with high molecular weight. In high concentrations, asphaltenes can cause filter plugging. They often contain heavy metals such as nickel, iron and vanadium. Asphaltenes are not present in distillate fuels.

Microorganisms in Fuel
All water and fuel offer a medium for microorganism growth. These simple life forms live in the water and feed on fuel.

Engine Effects
Microorganisms in fuel cause corrosion and filter plugging. They may be any color but are usually black, green or brown. They grow in long strings and have a slimy appearance. A biocide added to the fuel will kill the microorganisms but will not remove the remains of their bodies.

Extensive filtering of the fuel after using the biocide is required to eliminate engine-mounted filter plugging.

Steps to minimize problems with bacterial growth:

- Avoid long fuel storage periods.
- Drain water from fuel tanks daily.
- Purchase fuel from reliable sources.
- Dose all fuel inventory with biocide at the first sign of microorganism contamination.

Air

Air can be dissolved in fuel, and it can also be pulled into the fuel lines by a leak on the suction side of the fuel transfer pump.

Engine Effects

Air in the fuel will cause starting problems, *missing,* low power and smoke problems. Air can also cause excessive white smoke in some engines.

Reducing the effects of air in the fuel system.

Remove air by bleeding the fuel system. Check for dissolved air in fuel with a 2P8278 Fuel Flow Tube. Correct suction piping leaks.

Filters

Primary Fuel Filter Element Specification

The primary fuel filters elements should have the following properties:

Mesh Size – 70 × 80 strands per in. (32 × 28 strands per cm)

Element – Monel wire cloth material or equivalent

Element Area – 100 in^2 (645 cm^2) or greater

Opening Size – 0.007 in. × 0.0088 in. (0.1778 mm × 0.2235 mm)

Duplex Fuel Filters

Many Caterpillar Engines can be equipped with duplex fuel filters. These filters may be serviced (change elements), without shutting off the engine. There are two types: the *symmetrical* type – which has two identical filter sets and the *main-auxiliary* type – which has a *main* filter set and a smaller capacity *auxiliary* filter set. A special valve connects the two sets of filters in each type. The valve routes the fuel to be filtered through either or both sets of filters.

Both filter sets can be used simultaneously to extend running time in an emergency.

Filter Micron Ratings

Caterpillar does not specify filter or filter paper by micron rating.

Caterpillar specifies actual filter capability, rupture strength, the capacity for holding dirt, flow resistance, filter area, etc.

Micron ratings are easily confused for the following reasons:

- The test for micron ratings is not repeatable at different labs. One manufacturer may give a rating of 0.00039 in. (10 microns), another at 0.000079 in. (2 microns), and a third may rate a particular filter media (paper) at 0.00059 in. (15 microns).
- There is no consistent relationship between micron rating and actual filtration efficiency. The entire filter needs to be tested, not just the media (paper).
- The micron rating does not show what happens to a filter over time. The test provides no information about how a filter will stand up under continual use.

Micron ratings are overemphasized; a 10 micron filter will not always stop a 10 micron particle. Many reputable filter manufacturing firms are drifting away from micron ratings to more conclusive tests.

Smaller micron ratings are not necessarily better.

If all other factors (area) were equal, a smaller micron number media (paper) has a severe drawback: less capacity before plugging, needs to be replaced more often. The size of the pores in the paper needs to be balanced against the costs of the filter replacement.

Common questions are:

- What is the maximum particle size which can pass through Caterpillar filters?
- What is the difference between nominal size and absolute size filters?

For example: A nominal 10 micron filter media (paper) will pass some particles up to about 50 microns in size. Theoretically, an absolute rating of 10 microns will stop all particles larger than 10 microns. In fact, filters with absolute micron ratings of 10 will pass some particles larger than 10 microns due to the irregularity of the paper weave. New filters may pass larger particles than they will after only a few hours of use.

As a general rule, Caterpillar fuel filter media (paper) is about 3 microns nominal, 20 microns absolute. Oil filter media (paper) is about 10 microns nominal, 50 microns absolute. These are approximate values only.

Filters are not effectively compared on the basis of micron rating alone. Evaluate filters on the basis of their ability to collect foreign material as a whole.

Fuel System – Miscellaneous

Disposal of Used Lube Oil

It is necessary to collect, store, and dispose of used crankcase oil from engines correctly. It is not acceptable to dump used crankcase oil into the oceans, rivers and harbors from vessels or offshore drilling and production platform installations. It may be necessary for engine operators to consider burning crankcase oil in their Cat Engines. This can be done, providing the precautions below are carefully followed:

- Only diesel engine crankcase oils can be mixed with the diesel engine fuel supply. The ratio of used oil to fuel must not exceed 5%. Premature filter plugging will occur at higher ratios. *Under no circumstances* should gasoline engine crankcase oil, transmission oils, hydraulic oils, grease, cleaning solvents, etc., be mixed with the diesel fuel. Also, do not use crankcase oils containing water or antifreeze.
- Adequate mixing is essential. Lube oil and fuel oil, once mixed, will combine and not separate. Mix used filtered crankcase oil with an equal amount of fuel, then add the 50-50 blend to the supply tank before new fuel is added (maintaining the 5% used oil to fuel ratio). This procedure should normally provide sufficient mixing. Failure to achieve adequate mixing will result in premature filter plugging by *slugs* of undiluted oil.
- Filter or centrifuge used oil before putting it in the fuel tanks to prevent premature fuel filter plugging, accelerated wear or plugging of fuel system parts. Soot, dirt, metal and residue particles larger than 0.000197 in. (5 microns) should be removed by this process.

  If filtering or centrifuging is not used before adding the oil to the fuel, primary filters with 0.000197 in. (5 microns) capability must be located between the fuel supply and engine. These will require frequent servicing.
- Clean handling techniques of the used crankcase oils are essential to prevent introducing contaminants from outside sources into the diesel fuel supply. Care must be taken in collecting, storing and transporting the used crankcase oil to the diesel fuel tanks.

  Diesel fuel day tank sight glasses may become blackened in time due to the carbon content in the crankcase oil. Ash content of the lube oil added to the fuel may also cause accumulation of turbocharger and valve deposits more rapidly than normal.

Corrosion

Copper Strip Corrosion

Corrosion is commonly tested by examining the discoloration formed on a polished copper strip when immersed in fuel for three hours at

212° F (100° C). Any fuel showing more than slight discoloration should be rejected.

Many types of engine parts are of copper or copper alloys. It is essential that any fuel in contact with these parts be noncorrosive to copper. There are certain sulfur derivatives in the fuel that are likely sources of corrosion.

Sodium or Sodium Chloride (Salt)
Sodium is an alkaline, metallic element. It is very active chemically. Sodium's most common form is table salt.

Sodium is frequently introduced during storage or because of incorrect handling procedures. Sodium can come directly from sea water or salt air condensation in fuel tanks. It can also be present in crude oil in its natural state.

Engine Effects
Sodium acts as a catalyst for vanadium corrosion. When sodium and vanadium combine, they react to form compounds which melt within normal engine operating temperatures.

The sodium/vanadium combination causes high temperature corrosion of exhaust valves. It can also cause turbocharger turbine and nozzle deposits.

Steps to Reduce the Effects of Sodium
Fuel can be blended to reduce the concentration of sodium.

Fuel contaminated with sodium can be *washed* by blending fresh water with the contaminated fuel in one centrifuge and separating the two (with the sodium now dissolved in the added fresh water) in a second centrifuge.

Handle and store fuel in a manner which minimizes the exposure to salt water and salt water laden air.

Crude Oils

Description
Crude oil is used to describe unrefined oils/fuels. Crude oil is basically the same as it was when pumped from the ground. Certain types of crude oils can be burned in Caterpillar Engines. See the Crude Oil Chart (Limits of Acceptability for Use in Caterpillar Engines) in the Fuel Section Appendix.

Heavy/Blended/Residual Fuels

Description

Heavy/Blended/Residual Fuel is composed of the remaining elements from crude oil after the oil has been refined into diesel fuel, gasoline or lubricating oils, etc. After the more desirable products have been refined, the remaining elements (which resemble tar and contain abrasive and corrosive substances) can be combined or diluted with a lighter fuel (*cutter* stock) so they can flow. These are called blended, heavy or residual fuels.

Caterpillar 3500 and 3600 Family Engines can be modified to run on fuels which meet the specifications in the Heavy/Blended/ Residual Fuel Chart in the Fuel Section Appendix.

Caterpillar 3500 and 3600 Diesel Engines can atomize many heavy fuels because of the unit injector fuel system. This system does not have high pressure fuel lines and can withstand higher injection pressures. 3500 Family Engines are capable of operating on blended fuels up to 180 cSt at 50° C at 1800 rpm and lower, usually without changing engine timing. However, engine aerating may be required to keep the exhaust temperature below maximum limits. 3600 Family Engines are capable of operating on blended fuels up to 380 cSt at 50° C.

There are many other considerations to keep in mind when making the decision to switch to heavy fuel. Because heavy fuel is the heavy residue which is left over from the refining process, it has concentrated contaminants. In the best situation, using heavy fuel will increase the workload of the operating personnel. In the worst situation, heavy fuel could cause extremely short engine and component life. For your engine to operate successfully on heavy fuels, you must have a thorough maintenance program and high quality fuel treatment equipment.

It is recommended that you always consult with your local Caterpillar Dealer when considering fuel changes.

The Economics of Using Heavy Fuel

Lower fuel costs make heavy fuel appear to be more economical. Blended fuels can lower costs for some customers, but there are often significant tradeoffs. Fuel price must be compared to fuel contaminants, effects of reduced engine component life, higher maintenance and personnel costs. Conduct a thorough analysis of all the costs involved before you decide to use heavy fuel.

Caterpillar or your Caterpillar Dealer will aid you in this evaluation.

Also, investigate other fuel-saving methods. The following is a list of some fuel-saving alternatives:

- More modern, fuel-efficient engines.
- Lower speed (Engines can operate at 1200 rpm instead of 1800 rpm; 1000 rpm, instead of 1500 rpm; etc.).
- More efficient propeller (larger diameter with reduced pitch) or more efficient generator or other driven unit.
- Waste heat recovery.
- Lighter blends.
- Crude oil instead of diesel fuel.

Installation Costs Associated With Using Heavy Fuel
Installation costs for an engine using heavy fuel may range from 25-85% more than an engine using No. 2 diesel fuel or marine diesel fuel. Other costs result from the need for fuel treatment equipment.

Downtime is also typically increased. Operators must spend more time taking care of engine and fuel handling equipment. They must understand the system and have training on the engine as well as on the actual fuel preparation equipment.

How Your Caterpillar Warranty Applies to Using Heavy Fuel
When you decide to use heavy fuel, you are making an economic trade-off. Though your fuel costs may be 5-40% lower when using blended fuels, this savings does not come free. Because of contaminants, fuel injector, valve and piston ring life could be significantly shorter. These worn components may have to be replaced during the warranty period, but they are not covered by Caterpillar.

Caterpillar does not offer a warranty on replacement of parts which have a shortened service life because of the use of heavy fuel. The Caterpillar warranty which applies to your engine is available from your dealer.

Fuel Blending
Many fuel characteristics can be tailored by blending different fuels. A blended fuel can help improve engine starting and warm-up, reduce deposits and wear, improve emissions and sometimes have an effect on power and economy.

In general, lighter fuels are cleaner and help engine starting. Heavier fuels have higher heating values (per volume), better cetane quality, etc.

The 3600 and 3500 Family Engines can use blended fuel economically as long as the fuel treatment facilities are adequate, and there are trained personnel to run this equipment.

Blended Fuel Should Be Analyzed
Chemical labs can evaluate fuel properties. Some oil companies and regulating agencies also provide fuel analysis services.

Fuel System Maintenance

Filter Maintenance
First clean around the filter housing, then unscrew or otherwise remove the old filter(s) without introducing dirt into the housing.

Lubricate and clean the new filter gasket with *clean* diesel fuel.

Install the new filters *dry*.

Prime the fuel system.

Never pour fuel into the new filter element before you install it. Contaminated fuel will cause fuel system damage.

Always bleed the fuel system to remove air bubbles after changing the fuel filters and before starting the engine.

Check the fuel pressure differential which can indicate a restricted or plugged fuel filter.

Inspect all new filters (especially check the threads on spin-on filters) for debris or metal filings. Any filings already in the filter will go directly to the fuel pumps and injectors.

Use genuine Caterpillar fuel filters to ensure quality, consistency and cleanliness. There are great differences in fuel filters. Even if the filter fits your engine, it might not be the correct filter. There are a lot of important differences between Caterpillar filters and nongenuine filters. For more information on fuel filter differences and considerations, see your Caterpillar Dealer.

Properly store new filters to prevent dust from direct entry into the filter before use.

Cut apart used filters after every filter change. A way to thoroughly inspect filters is to use the 6V7905 Filter Cutting Tool to cut them apart after they have been used (every filter change period). This will allow you to inspect internal filter components, see contaminants, and to also compare brands of filters for quality and filtering effectiveness.

Storage Tank Maintenance
Fill the fuel tank after each day of operation to minimize condensation of water. A full fuel tank helps prevent condensation by driving out moisture laden air. However, don’t fill the tank too full; if the temperature increases, the fuel will expand and may overflow.

Drain water and sediment from the fuel tank at the start of every shift or after the tank has been filled and allowed to stand for 5-10 minutes. Be sure to drain a cupful at the start of every shift for inspection. Drain storage tanks every week.

Install and maintain a water separator before the primary fuel filter.

***As Needed* Periodic Activities**
Test fuel as it is delivered. Identify contaminant levels immediately and notify appropriate operations personnel.

Before storage, test for compatibility between fuel in the tanks and the fuel being purchased. Keep the fuel in separate tanks, if possible.

Use regular S•O•S oil analysis to determine if there are wear particles in the oil and maintain the proper Total Base Number (TBN) level.

Request infrared analysis on used oil to determine the effects of burning heavy fuel on the crankcase oil.

Daily Activities
Maintain and monitor fuel treatment equipment.

Record engine temperatures to assure adequate jacket water temperature, aftercooler temperature and air intake temperature.

Check exhaust thermocouples and record exhaust temperatures. Be alert for worn exhaust valves.

Note: Measure valve stem projection when new; use a stationary point such as the valve cover gasket surface for a reference point. Record the measurements for each valve for later follow-up measurements. If valve *stem* projection moves more than 0.050 in. (1.25 mm), consider disassembly to find the reason. Another way to observe valve face wear is to measure and record changes on valve lash over a period of time.

Fuel Publications Available From Caterpillar

The following publications are available through your local Caterpillar Dealer. Some of the publications may have a nominal charge. Some may be revised or discontinued in the future. These publications should be ordered directly from your dealer. Your dealer can also assist you in answering questions concerning available fuels in your operating area.

All Engine Data Sheets are included in the Caterpillar *Engine Technical Manual*, Volume I, Form No. LEKQ2030.

Mixing Used Crankcase Oil With Diesel Fuel LEKQ6070 (Engine Data Sheet 62.0)

Fuel Recommendations for Caterpillar Diesel Engines LEKQ4219 (Engine Data Sheet 60.1)

Alcohol Fuels for Caterpillar Diesel Engines LEKQ0287 (Engine Data Sheet 61.2)

Fuel Heaters for Cold Weather Operation LEKQ4065 (Engine Data Sheet 64.5 for No. 1 and No. 2 Diesel Fuel Only)

Installation of 8N9754 Fuel Heater Group SEHS7653-02 (Special Instruction)

Fight Fuel Sulfur, Your Diesel's Silent Enemy SEBD0598

Analyzing Fuel Nozzle and Fuel Line Failures SEBD0639

Using Diesel Fuel Thermo-Hydrometers GMGO0977 (Special Instruction)

Using 2P8278 Fuel Flow Tube to Check for Entrained Air in Diesel Fuel GMGO0825 (Special Instruction)

Heavy Fuel Contaminant Levels for 3500 and 3600 Engines LEKQ2314 (Engine Data Sheet 61.1)

Sizing Fuel System Components for Heavy Fuels LEKQ9173 (Engine Data Sheet 61.3)

Heavy Fuel Operating Procedures for 3500 and 3600 Engines LEKQ1177 (Engine Data Sheet 61.4)

Fuel Water Separator for Use With 3208 and 3300 Engines Equipped With Sleeve Metering Fuel System LEKQ3383 (Engine Data Sheet 64.1)

Fuel Conservation Practices LEKQ3106 (Engine Data Sheet 60.2)

Other Publications
ABS Notes on Heavy Fuel Oil (1984)
American Bureau of Shipping
45 Eisenhower Drive Paramus, NJ 07652
U.S.A. Telephone: (201) 368-9100
Attention: Book Order Department

Appendix

Table of Specific Gravity Versus Density

Gravity		Density	
Degrees API @ 15° C (60° F)	Specific Gravity @ 15° C (60° F)	kg/L	lb/gal
25	0.9042	0.902	7.592
26	0.8984	0.897	7.481
27	0.8927	0.891	7.434
28	0.8871	0.886	7.387
29	0.8816	0.880	7.341
30	0.8762	0.874	7.296
31	0.8708	0.869	7.251
32	0.8654	0.864	7.206
33	0.8602	0.858	7.163
34	0.8550	0.853	7.119
35	0.8498	0.848	7.076
36	0.8448	0.843	7.034
37	0.8398	0.838	6.993
38	0.8348	0.833	6.951
39	0.8299	0.828	6.910
40	0.8251	0.823	6.870
41	0.8203	0.819	6.830
42	0.8155	0.814	6.790
43	0.8109	0.809	6.752
44	0.8063	0.804	6.713
45	0.8017	0.800	6.675
46	0.7972	0.795	6.637
47	0.7927	0.791	6.600
48	0.7883	0.787	6.563
49	0.7839	0.782	6.526

Crude Oil Chart

Fuel Properties and Characteristics	Permissible Fuels as Delivered to the Fuel System	
Cetane number or cetane index (ASTM D613 or calculated index) (PC Engines)	Minimum	35
(DI Engines)	Minimum	40
Water and sediment % volume (ASTM D1796)	Maximum	0.5%
Pour Point (ASTM D97)	Minimum	10° F (6° C) below ambient temperature
Cloud point (ASTM D97)		Not higher than ambient temperature
Sulfur (ASTM D2788 or D3605 or D1552)	Maximum	0.5% – Adjust oil TBN for higher sulfur content
Viscosity at 100° F (38° C) (ASTM D445)	Minimum Maximum	1.4 cSt 20 cSt
API gravity (ASTM D287)	Maximum Minimum	45 30
Specific gravity (ASTM D287)	Minimum Maximum	0.8017 0.875
Gasoline and naphtha fraction (fractions boiled off below 200° C)	Maximum	35%
Kerosene and distillate fraction (fractions boiled off between 200° C and cracking point)	Minimum	30%
Carbon residue (ramsbottom) (ASTM D524)	Maximum	3.5%
Distillation – 10% – 90% – cracking % – residue (ASTM D86, D158 or D285)	Maximum Maximum Minimum Maximum	540° F (282° C) 716° F (380° C) 60% 10%
Reid vapor pressure (ASTM D323)	Maximum	20 psi (kPa)
Salt (ASTM D3230)	Maximum	100 lb/1,000 barrels
Gums and Resins (ASTM D381)	Maximum	10 mg/100 mL
Copper strip corrosion 3 hrs @ 100° C (ASTM D130)	Maximum	No. 3
Flashpoint °C °F (ASTM D93)	Maximum	Must be legal limit
Ash % weight (ASTM D482)	Maximum	0.1%
Aromatics % (ASTM D1319)	Maximum	35%
Vanadium PPM (ASTM D2788 or D3605)	Maximum	4 PPM
Sodium PPM (ASTM D2788 or D3605)	Maximum	10 PPM
Nickel PPM (ASTM D2788 or D3605)	Maximum	1 PPM
Aluminum PPM (ASTM D2788 or D3605)	Maximum	1 PPM
Silicon (ASTM D2788 or D3605)	Maximum	1 PPM

PPM = parts per million

Heavy/Blended/Residual Fuel Chart

Fuel Properties and Characteristics	Permissible Fuels as Delivered to the Fuel System		
Water and sediment percent volume (ASTM D1796)	Maximum	3500	3600
		0.5	0.5
Sulfur (ASTM D2788 or D3605 or D1552)	Maximum	4%	5%
Viscosity	Minimum	1.4 cSt	1.4 cSt
(To the Unit Injector) (ASTM D445)	Maximum	180 cSt @ 50° C	380 cSt @ 50° C
Carbon Residue (Conradson Carbon Residue) (ASTM D189)	Maximum	15	18
Vanadium	Maximum (PPM)	250	300
Aluminum (ASTM D2788 or D3605)	Maximum (PPM)	1	2
Silicon (ASTM D2788 or D3605)	Maximum (PPM)	1	2

PPM = parts per million

Heavy/Blended/Residual Fuel Viscosity Chart

Viscosity (cSt @ 50° C)	Viscosity (Redwood Seconds @ 100° F)
30	200
40	278
60	439
80	610
100	780
120	950
150	1250
180	1500
240	2400
280	2500

API° Gravity Correction for Temperature

API = AMERICAN PETROLEUM INSTITUTE
SG = SPECIFIC GRAVITY

$$\text{IF API}^\circ = \frac{141.5}{\text{SG}} - 131.5$$

THEN

$$\text{SG} = \frac{141.5}{(\text{API} + 131.5)}$$

THEN

$$141.5 = \text{SG}(\text{API} + 131.5)$$

The mean coefficients of expansion for different gravity materials up to about 400° F are in a range of 0.00035 – 0.00090. For fuels in the range of 15° API to 34.9° API the mean coefficient of expansion is 0.00040. Fuels in the range of 35° API to 50.9° API have a mean coefficient of expansion equal to 0.00050. Since most of the fuels we deal with at Caterpillar are in these two ranges, the average of the two will be used to perform the calculation. (0.00045 mean coefficient of expansion)*

Let's set up an example problem.

You measure the API gravity of a diesel fuel and find it to be 38° API @ 100° F. You would like to correct this to the standard and determine the weight of the fuel.

***From the Physical Properties of Petroleum Oil**

To solve for this we will use the formula:

$$\text{SG} = \frac{141.5}{(\text{API} + 131.5)}$$

$$\text{Where SG} = \frac{141.5}{(38 + 131.5)}$$

$$\text{SG} = 0.8348$$

0.8348 is the Specific Gravity of the fuel at 100° F. We want it at standard of 60° F. To correct the Specific Gravity we must do the following:

We know that for every 1° F we will have 0.00045 mean coefficient of expansion.

Since we are 40° F above the 60° F standard we will work it out as follows:

(40° F)(0.00045) = 0.018

1.00** – 0.018 = 0.982 Correction Factor

Specific Gravity can now be corrected by the following:

$$\text{CSG} = \frac{0.8348 \text{ SG Measured}}{0.982 \text{ Correction Factor}}$$

CSG = 0.8501

Now that we have the Corrected Specific Gravity (CSG) you can answer the original question by using the following formula:

$$\text{API}^\circ = \frac{141.5}{\text{SG}} - 131.5$$

****1.00 IS THE SPECIFIC GRAVITY OF FRESH WATER**

As follows:

$$\text{Corrected API}^\circ \text{ @ } 60^\circ\text{ F} = \frac{141.5}{0.8501} - 131.5$$

Corrected API° @ 60° F = 34.95 ~ 35

We can also now calculate the weight per gallon of the diesel fuel. First we must realize that the weight of fresh water is 8.328 lbs per gallon. We have said that our Specific Gravity Corrected is 0.8501 that of water. Therefore the weight of our diesel fuel can be calculated by:

(0.8501)(8.328) = 7.076 lbs/gallon.

Fuel System

Fuel Properties

Caterpillar Specifications for Distillate Fuel	
Specification (ASTM Test Procedure)	**Requirement**
Aromatics (D1319)	35 percent maximum
Ash (D482)	0.02 percent maximum
Carbon residue on 10 percent bottoms (D524)	1.05 percent weight maximum
Cetane number (D613)	35 minimum (PC Engines) 40 minimum (DI Engines)
Cloud Point	Maximum not above lowest expected ambient temperature
Copper strip corrosion (D130)	Number 3 maximum
Distillation (D86)	10 percent at 540° F (282° C) Maximum 90 percent at 680° F (360° C) Maximum
Flash point (D93)	Legal limit
API gravity (D287)	30 minimum, 45 maximum
Pour point (D97)	10° F (6° C) minimum below ambient temperature
Sulfur (D3605 or D1552)[1]	3 percent maximum[1]

[1]Caterpillar fuel systems and engine components can operate on high sulfur fuel. However, fuel sulfur levels effect exhaust particulate emissions. High sulfur fuels increase the potential for internal component corrosion. Fuel sulfur levels above 1.0 percent may SIGNIFICANTLY shorten the oil change interval. Refer to the TBN and fuel sulfur topic in the lubricants section for additional information.

Caterpillar Specifications for Distillate Fuel (Continued)

Specification (ASTM Test Procedure)	Requirement
Kinematic viscosity at 104° F (40° C) (D445)[2]	1.4 cSt minimum, 20.0 cSt maximum
Water and sediment (D1796)	0.1 percent maximum
Water	0.1 percent maximum
Sediment (D473)	0.05 percent maximum
Gums and resins (D381)	10 mg per 100 ml maximum 5.8 grains per 1 US gal maximum
Lubricity by Scuffing Load West Test (SBOCLE) or High Frequency Reciprocating Rig (HFRR)[3]	3100 g minimum 0.018 in (0.45 mm) maximum at 140° F (60° C) or 0.015 in (0.38 mm) maximum at 77° F (25° C)

[2]The viscosity limits are for the fuel as delivered to the fuel injection pump. If low viscosity fuels such as JP-8, JP-5, Jet-A-1, or no. 1D diesel are used, fuel cooling may be required to maintain a 1.4 cSt at the fuel injection pump. When using high viscosity fuels or when operating in low temperature conditions, fuel heaters may be required to reduce viscosity to 20 cSt. Refer to SEBD0717, "Diesel Fuel And Your Engine", for additional information.

[3]Lubricity of a fuel is a concern with low sulfur fuel. If the lubricity of a fuel does not meet the minimum requirements, consult your fuel supplier. Do NOT treat the fuel without consulting the fuel supplier. Some additives are not compatible and can cause problems in the fuel system.

Note: There are many after market additives available to treat fuel. Not all additives perform well in all fuel or in all fuel systems. Some lubricity additives may form deposits in the fuel injection system. If lubricity is an issue, consult your fuel supplier for proper recommendations regarding fuel lubricity additives.

Note: Caterpillar has adopted the EMA FQP1 lubricity limit as part of the Caterpillar preferred distillate fuels recommendation. See the above chart.

Blended (Heavy) fuels are usually described by their viscosity, expressed either in "centistokes" (cSt) or "Seconds Redwood". The Redwood scale at 100° F is being phased out and replaced by the centistokes scale at 50° C. The centistoke viscosity may be preceded by the letters IF for "intermediate fuel" or IBF for "intermediate bunker fuel". For example, IF 180 fuel has a viscosity of 180 cSt at 50° C. The following table gives the **approximate** relationship between the two scales.

cSt at 50° C	Seconds Redwood at 100° F
30	200
40	278
60	439
80	610
100	780
120	950
150	1250
180	1500
240	2400
280	2500
380	3500

Fuel API Correction Chart

API Gravity Corrected to 60° F

(Measured Fuel Temperature °F)

Measured ° API Gravity	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°
	° API Gravity At 60° F															
29°	33	32.5	32	31	30	30	29	28	28	27	26.5	26	25	24.5	24	23.5
30°	34	33.5	33	32	31.5	31	30	29	29	28	27.5	27	26	25.5	25	24.5
31°	35	34.5	34	33	32.5	32	31	30	30	29	28.5	28	27	26.5	26	25
32°	36	35.5	35	34	33.5	33	32	31	30.5	30	29	29	28	27.5	27	26
33°	37	36.5	36	35	34.5	34	33	32	31.5	31	30	29.5	29	28.5	28	27
34°	38.5	38	37	36	35.5	35	34	33	32.5	32	31	30.5	30	29	29	28
35°	39.5	39	38	37	36.5	36	35	34	33.5	33	32	31.5	31	30	29.5	29
36°	41	40	39	38	37.5	37	36	35	34.5	34	33	32.5	32	31	30.5	30
37°	42	41	40	39	38.5	38	37	36	35.5	35	34	33.5	33	32	31.5	31
38°	43	42	41	40.5	39.5	39	38	37	36.5	36	35	34.5	34	33	32	32
39°	44	43	42	41.5	40.5	40	39	38	37.5	37	36	35	34.5	34	33	32.5
40°	45	44	43	42.5	41.5	41	40	39	38.5	38	37	36	35.5	35	34	33.5
41°	46	45	44.5	43.5	42.5	42	41	40	39.5	39	38	37	36.5	36	35	34.5
42°	47	46	45.5	44.5	44	43	42	41	40.5	39.5	39	38	37.5	37	36	35
43°	48.5	47.5	46.5	45.5	45	44	43	42	41.5	40.5	40	39	38	37.5	37	36
44°	49.5	48.5	47.5	46.5	46	45	44	43	42	41.5	41	40	39	38.5	38	37
45°	50.5	49.5	49	48	47	46	45	44	43	42.5	42	41	40	39.5	38.5	38
46°	52	51	50	49	48	47	46	45	44	43.5	42.5	42	41	40	39.5	39
47°	53	52	51	50	49	48	47	46	45	44.5	43.5	43	42	41	40.5	40
48°	54	53	52	51	50	49	48	47	46	45	44.5	44	43	42	41	40.5
49°	55	54	53	52	51	50	49	48	47	46	45.5	45	44	43	42	41.5
50°	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44	43	42
51°	57.5	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44	43
52°	58.5	57.5	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44
53°	60	58.5	57	56	55	54	53	52	51	50	49	48	47.5	46.5	46	45

Tooling: Fuel Thermo-hydrometer 1P7408 Test Breaker 1P7438

Distillate Fuel Temperature

Maximum Fuel Supply Temperature:
- — Without Power Reduction: 85° F (29° C)
  Power is reduced 1% for each 10° F (5.6° C) above 100° F (38° C) if engine is running against fuel stop.
- — Without Injector Damage: 150° F (65° C)

Performance Analysis Rules of Thumb

Correction Factors

Fuel Temperature Correction Factors

Fuel Temp °F	Correction Factor
–10	0.905
–5	0.910
0	0.915
5	0.920
10	0.925
15	0.930
20	0.935
25	0.940
30	0.945
35	0.950
40	0.955
45	0.960
50	0.965
55	0.970
60	0.975
65	0.980
70	0.985
75	0.990
80	0.995
85 [1]	1.000
90	1.005
95	1.010
100	1.015
105	1.020
110	1.025
115	1.030
120	1.035
125	1.040
130	1.045
135	1.050
140	1.055
145	1.060
150	1.065
155	1.070
160	1.075

[1] Standard value.

Fuel Density (API) Correction Factors	
Fuel API at 60° F	**Correction Factor**
31.5	0.985
32.0	0.987
32.5	0.989
33.0	0.991
33.5	0.994
34.0	0.996
34.5	0.998
35.0*	**1.000**
35.5	1.002
36.0	1.004
36.5	1.006
37.0	1.009
37.5	1.011
38.0	1.013
38.5	1.015
39.0	1.017
39.5	1.020
40.0	1.022
40.5	1.024
41.0	1.026
41.5	1.028
42.0	1.031
42.5	1.033
43.0	1.035
43.5	1.037
44.0	1.040
44.5	1.042
45.0	1.044
45.5	1.046
46.0	1.049
46.5	1.051
47.0	1.053
47.5	1.055
48.0	1.058

*Standard Value. The measured fuel API and corresponding fuel temperature must be corrected to 60° F before selecting an API correction factor.

Inlet Air Temperature Correction Factors for Turbocharged and JWAC Engines	
Air Temperature °F	**Correction Factor**
–10	0.969
–5	0.971
0	0.972
5	0.974
10	0.976
15	0.978
20	0.980
25	0.982
30	0.984
35	0.985
40	0.987
45	0.989
50	0.991
55	0.992
60	0.994
65	0.996
70	0.998
75	0.999
77*	**1.000**
80	1.001
85	1.003
90	1.004
95	1.006
100	1.008
105	1.009
110	1.011
115	1.012
120	1.014

*Standard Value. Measure between air cleaner and turbo inlet.

Inlet Air Pressure
Correction Factors
for Turbocharged, JWAC and ATAAC Engines

Air Pressure In. Hg	Correction Factor
31.5	0.994
31.0	0.997
30.5*	**1.000**
30.0	1.003
29.5	1.006
29.0	1.010
28.5	1.013
28.0	1.016
27.5	1.020
27.0	1.023
26.5	1.027
26.0	1.030
25.5	1.034
25.0	1.038
24.5	1.042
24.0	1.046
23.5	1.050
23.0	1.055
22.5	1.059
22.0	1.064
21.5	1.068
21.0	1.073
20.5	1.079
20.0	1.083

*30.5 In. Hg is used as the Standard Value to account for air cleaner restriction, vapor pressure (humidity) and exhaust back pressure.

Power Calculation:

$$\text{HP} = \frac{\text{Fuel Rate (GPH)} \times \text{Fuel Density}\left(\frac{\text{LB}}{\text{GAL}}\right)}{\text{BSFC}\left(\frac{\text{LB}}{\text{HP}\bullet\text{HR}}\right)}$$

$$\text{kW} = \frac{\text{Fuel Rate (L/HR)} \times \text{Fuel Density}\left(\frac{\text{GRAM}}{\text{LITER}}\right)}{\text{BSFC}\left(\frac{\text{GRAM}}{\text{kW}\bullet\text{HR}}\right)}$$

BSFC

$$\frac{\text{CSFC (GRAMS/kW HR)}}{454} = \text{LBS/kW HR}$$

$$\frac{\text{LBS/kW HR}}{1.34} = \text{BSFC (LBS/HP HR)}$$

Tolerances

Performance curves represent typical values obtained under normal operating conditions. Ambient air conditions and fuel used will affect these values. Each of the values may vary in accordance with the following tolerances:

Exhaust Stack Temperature	±42 DEG C ±75 DEG F
Intake Manifold Pressure-Gauge	±10 kPa ±3 in Hg
Power	±3 Percent
Fuel Consumption	±6 g/kW-hr ±0.010 lb/hp-hr
Fuel Rate	±5 Percent

Conditions

Ratings are based on SAE J1349 standard conditions of 29.61 in Hg (100 kPa) and 77° F (25° C). These ratings also apply at ISO 3046/1, DIN 6271 and BS 5514 standard conditions of 29.61 in Hg (100 kPa), 81° F (27° C) and 60% relative humidity.

Fuel Rates are based on fuel oil of 35° API [60° F (16° C)] gravity having an LHV of 18,390 Btu/lb (42 780 kJ/kg) when used at 85° F (29° C) and weighing 7.001 lbs/U.S. gal (838.9 g/liter).

Additional Formulas Used to Develop Marine Par Curves

For Torque Check GPH proceed as follows:

Torque Check GPH = TQ COR. Fuel Rate (G/MIN) ÷ 454 × 60 = LBS/HR

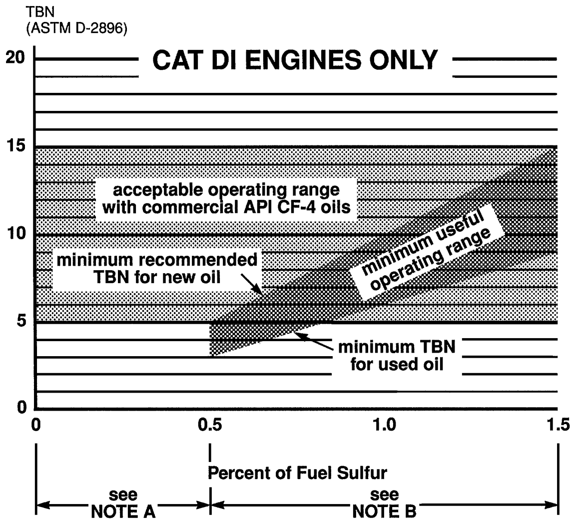
LBS/HR ÷ 7.076 = GPH

For BSFC proceed as follows:

BSFC = Adjusted CSFC (G/kW HR) ÷ 454 = LBS/kW HR

LBS/kW HR ÷ 1.34 = BSFC (LBS/HP HR)

Oil TBN vs. Fuel Sulfur Content



Graph for determination of necessary TBN. Find the fuel sulfur percentage on bottom of the graph. Find point where the new oil TBN line intersects the sulfur content line, and read the required TBN at the left side of the chart.

Rule of Thumb: New oil TBN should be 10 times fuel sulfur content. Change oil when TBN drops to $\frac{1}{2}$ its original value when using API CF-4 or better oil and you are using a DI engine.

Additives

There are chemical substances added to a petroleum product to impart or improve certain properties.

Additives strengthen or modify certain characteristics of the base oil. Ultimately, they enable the oil to meet requirements quite beyond the abilities of the base oil.

The most common additives are: detergents, oxidation inhibitors, dispersants, alkalinity agents, anti-wear agents, pour-point depressants and viscosity improvers.

Here is a brief description of what each additive does and how.

Detergents help keep the engine clean by chemically reacting with oxidation products to stop the formation and deposit of insoluble compounds.

Oxidation inhibitors help prevent increases in viscosity, the development of organic acids and the formation of carbonaceous matter.

Dispersants help prevent sludge formation by dispersing contaminants and keeping them in suspension.

Alkalinity agents help neutralize acids.

Anti-wear agents reduce friction by forming a film on metal surfaces.

A pour-point depressant keeps the oil fluid at low temperatures by preventing the growth and agglomeration (the gathering together into a mass) of wax crystals.

Viscosity improvers help prevent the oil from becoming too thin at high temperatures.

Anti-Wear Additive

This is an additive in a lubricant that reduces friction and excessive wear.

API

This is a trade association of petroleum producers, refiners, marketers, and transporters, organized for the advancement of the petroleum industry by conducting research, gathering and disseminating information, and maintaining cooperation between government and the industry on all matters of mutual interest. One API technical activity has been the establishment of API Engine Service Categories for lubricating oils.

API Engine Service Categories

Gasoline and diesel engine oil performance levels are established jointly by API, SAE, and ASTM called API Engine Service Classifications. API Service Categories are as follows:

Diesel Engines

Category	Status	Service
CI-4	Current	Introduced September 5, 2002. For high-speed, four-stroke engines designed to meet 2004 exhaust emission standards implemented in 2002. CI-4 oils are formulated to sustain engine durability where exhaust gas recirculation (EGR) is used and are intended for use with diesel fuels ranging in sulfur content up to 0.5% weight. Can be used in place of CD, CE, CF-4, CG-4, and CH-4 oils.
CH-4	Current	Introduced in 1998. For high-speed, four-stroke engines designed to meet 1998 exhaust emission standards. CH-4 oils are specifically compounded for use with diesel fuels ranging in sulfur content up to 0.5% weight. Can be used in place of CD, CE, CF-4, and CG-4 oils.
CG-4	Current	Introduced in 1995. For severe duty, high-speed, four-stroke engines using fuel with less than 0.5% weight sulfur. CG-4 oils are required for engines meeting 1994 emission standards. Can be used in place of CD, CE, and CF-4 oils.
CF-4	Current	Introduced in 1990. For high-speed, four-stroke, naturally aspirated and turbocharged engines. Can be used in place of CD and CE oils.
CF-2	Current	Introduced in 1994. For severe duty, two-stroke cycle engines. Can be used in place of CD-II oils.
CF	Current	Introduced in 1994. For off-road, indirect injected and other diesel engines including those using fuel with over 0.5% weight sulfur. Can be used in place of CD oils.
CE	Obsolete	Introduced in 1987. For high-speed, four-stroke, naturally aspirated and turbocharged engines. Can be used in place of CC and CD oils.
CD-II	Obsolete	Introduced in 1987. For two-stroke-cycle engines.
CD	Obsolete	Introduced in 1955. For certain naturally aspirated and turbocharged engines.
CC	Obsolete	For engines introduced in 1961.
CB	Obsolete	For moderate duty engines from 1949 to 1960.
CA	Obsolete	For light duty engines (1940’s and 1950’s).

Gasoline Engines

Category	Status	Service
SL	Current	For all automotive engines presently in use. Introduced July 1, 2001. SL oils are designed to provide better high-temperature deposit control and lower oil consumption. Some of these oils may also meet the latest ILSAC specification and/or qualify as Energy Conserving.
SJ	Current	For 2001 and older automotive engines.
SH	Obsolete	For 1996 and older engines. Valid when preceded by current C categories.
SG	Obsolete	For 1993 and older engines.
SF	Obsolete	For 1988 and older engines.
SE	Obsolete	For 1979 and older engines.
SD	Obsolete	For 1971 and older engines.
SC	Obsolete	For 1967 and older engines.
SB	Obsolete	For older engines. Use only when specifically recommended by the manufacturer.
SA	Obsolete	For older engines; no performance requirement. Use only when specifically recommended by the manufacturer. Gasoline Engines

Note: API intentionally omitted SI and SK from the sequence of categories. For more information about API's Engine Oil Program, call the American Petroleum Institute at 202-682-8516 or visit our website at www.api.org/eolcs. This guide is provided as a service to the motoring public courtesy of the American Petroleum Institute.

Ash Content

This is the noncombustible residue of a lubricating oil or fuel. Lubricating oil detergent additives contain metallic derivatives, such as barium, calcium, and magnesium sulfonates, that are common sources of ash. Ash deposits can impair engine efficiency and power. See detergent.

ASTM (American Society for Testing and Materials)

This organization is devoted to "the promotion of knowledge of the materials of engineering and the standardization of specifications and methods of testing." A preponderance of the data used to describe, identify, or specify petroleum products is determined in accordance with ASTM test methods.

Base Stock

Base stock is a primary refined petroleum fraction, usually a lube oil, into which additives and other oils are blended to produce finished products.

Bid Oil

This is oil produced by an oil company which just meets the minimum of the diesel engine oil performance specifications. These oils are usually the least expensive because they have only the minimum amount of additives to just get by. These oils might be acceptable for lightly loaded applications but could cause problems in more severe machine application.

Blow-By

This comes from an internal combustion engine where seepage of fuel and gases past the piston rings and cylinder wall into the crankcase, results in crankcase oil dilution and sludge formation.

BMEP

Brake mean effective pressure is the theoretical average pressure that would have to be imposed on the pistons of a frictionless engine (of the same dimensions and speed) to produce the same power output as the engine under consideration; a measure of how effectively an engine utilizes its piston displacement to do work.

Borderline Pumping Temperature °C (ASTDM D3829)

This is the temperature at which the oil becomes too viscous (thick) and cannot be moved when force is applied. The oil, however, is not yet a solid (pour point).

Bulk Delivery

This is a large quantity of unpackaged petroleum product delivered directly from a tank truck, tank car, or barge into a consumer's storage tank.

Colloid

A colloid is a suspension of finely divided particles 5 to 5000 angstroms in size in a gas or liquid, that do not settle and are not easily filtered. An Angstrom is a unit of wave length of light equal to one ten billionth of a meter which carries a positive or negative charge.

Colloids are usually ionically stabilized by some form of surface charge on the particles to reduce the tendency to agglomerate (gather into a ball or mass). A lubricating grease is a colloidal system, in which metallic soaps or other thickening agents are dispersed in, and give structure to, the liquid lubricant.

Color Scale

These scales serve primarily as indicators of product uniformity and freedom from contamination. The scale is a standardized range of colors against which the colors of petroleum products may be compared. There are a number of widely used systems of color scales, including: ASTM scale (test method ASTM D 1500), the most common scale, used extensively for industrial and process oils.

Crude Oil

Crude oil is a complex, naturally occurring fluid mixture of petroleum hydrocarbons, yellow to black in color, and also containing small amounts of oxygen, nitrogen, and sulfur derivatives and other impurities. Crude oil was formed by the action of bacteria, heat, and pressure on ancient plant and animal remains, and is usually found in layers of porous rock such as limestone or sandstone, capped by an impervious layer of shale or clay that traps the oil. Crude oil varies in appearance and hydrocarbon composition depending on the locality where it occurs. Crude is refined to yield petroleum products.

Demerit Rating

This is an arbitrary graduated numerical rating sometimes used in evaluating engine deposit levels following testing of an engine oil's detergent-dispersant characteristics. On a scale of 0-10, the higher the number, the heavier the deposits. A more commonly used method of evaluating engine cleanliness is merit rating. See Engine Deposits.

Detergent

This is an important component of engine oils that helps control varnish, ring zone deposits, and rust by keeping insoluble particles in suspension and in some cases, by neutralizing acids. A detergent is usually a metallic compound. Because of its metallic composition, a detergent leaves a slight ash when the oil is burned. A detergent is normally used in conjunction with a dispersant.

Dispersant

A dispersant is an engine oil additive that helps prevent sludge, varnish, and other engine deposits by keeping soot particles suspended in a colloidal state (prevents these particles from gathering into a ball or mass).

Engine Deposits

These are hard or persistent accumulations of sludge, varnish, and carbonaceous residues due to blow-by of unburned and partially burned (partially oxidized) fuel, or from partial breakdown of the crankcase lubricant. Water from condensation of combustion products, carbon, residues from fuel or lubricating oil additives, dust, and metal particles also contribute. Engine deposits can impair engine performance and damage engine components by causing valve and ring sticking, clogging of the oil screen and oil passages, and excessive wear of pistons and cylinders. Hot, glowing deposits in the combustion chamber can also cause pre-ignition of the air-fuel mix. Engine deposits are increased by short trips in cold weather, high temperature operation, heavy loads (such as pulling a trailer), and over-extended oil drain intervals.

EPA (Environmental Protection Agency)

The EPA is an agency of the federal executive branch, established in 1970 to abate and control pollution through monitoring, regulation, and enforcement, and to coordinate and support environmental research.

Fighting Grade Oil

See Bid Oil.

Flashpoint

This is the lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air. Flash point is an important indicator of the fire and explosion hazards associated with a petroleum product.

Lubrication

Lubrication is the control of friction and wear by the introduction of a friction-reducing film between moving surfaces in contact. The lubricant used may be a fluid, solid, or plastic substance.

Merit Rating

This is an arbitrary graduated numerical rating commonly used in evaluating engine deposit levels when testing the detergent-dispersant characteristics of an engine oil. On a scale of 10-0, the lower the number, the heavier the deposits. A less common method of evaluating engine cleanliness is demerit rating. See Engine Deposits.

Mineral Oil

This is any petroleum oil, as contrasted to animal or vegetable oils. Also, a highly refined petroleum distillate, or white oil, used medicinally as a laxative.

OSHA (Occupational Safety and Health Administration)

Oxidation

Oxidation is the chemical combination of a substance with oxygen. All petroleum products are subject to oxidation. This degrades their composition and lowers their performance. The oxidation process is accelerated by heat, light, metal catalysts (agents which bring about a chemical reaction) and the presence of water, acids or solid contaminants.

These substances react with each other to form sludges, vanishes and gums that can impair equipment operation.

To minimize oxidation and its effects, carefully select a good base stock oil, insure an oxidation inhibitor is added to the base stock and maintain equipment and change oil to prevent contamination and excessive heat.

Oxidation Inhibitor

This is any substance added in small quantities to a petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called anti-oxidant. An oxidation inhibitor may work in one of three ways (1) by combining with and modifying peroxides (compounds high in oxygen) to render them harmless, (2) by decomposing the perioxides, or (3) by rendering an oxidation catalyst (metal or metalions) inert; that is, lacking in a chemical reaction. See Oxidation.

Oxidation Stability

This is the resistance of a petroleum product to oxidation; hence, a measure of its potential service or storage life. There are a number of ASTM tests to determine the oxidation stability of a lubricant or fuel, all of which are intended to simulate service conditions on an accelerated basis. In general, the test sample is exposed to oxygen or air at an elevated temperature, and sometimes to water or catalysts (usually iron or copper). Depending on the test, results are expressed in terms of the time required to produce a specified effect (such as pressure drop), the amount of sludge or gum produced, or the amount of oxygen consumed during a specified period.

Pass-Oil

See Bid Oil.

Pour Point

Pour point is the lowest temperature at which an oil or distillate fuel is observed to flow, when cooled under conditions prescribed by test method ASTM D97. The pour point is 5° F (3° C) above the temperature at which the oil in a test vessel shows no movement when the container is held horizontally for five seconds. Pour point is lower than wax appearance point or cloud point. It is an indicator of the ability of an oil or distillate fuel to flow at cold operating temperatures.

Ring Land

This is the area on the surface of the piston that is between either the top of the piston and first ring groove or between two adjacent ring grooves.

Ring Sticking

Ring sticking is freezing of a piston ring in its groove, in a piston engine or reciprocating compressor, due to heavy deposits in the piston ring zone. This prevents proper action of the ring and tends to increase blow-by into the crankcase and to increase oil consumption by permitting oil to flow past the ring zone into the combustion chamber. See Engine Deposits.

SAE (Society of Automotive Engineers)

The Society of Automotive Engineers reviews the total automotive engine and lubricant situation and defines the requirement for new oil specifications.

SAE Oil Viscosity Classification

Because of the important effects of oil viscosity, the Society of Automotive Engineers (SAE) has developed a system for classifying lubricating oils in terms of viscosity only; no other physical or performance characteristics are considered.

The viscosity numbers without the letter W are based upon 210° F viscosities. Viscosity at that temperature correlates with oil consumption and other oil performance characteristics influenced by viscosity at normal engine operating temperatures. The viscosity numbers with the letter W are based on 0° F viscosities.

The 0° F viscosities for W-numbered oils were selected because they correlate with the cranking characteristics of motor oils in the average automobile engine under low-temperature starting conditions.

Viscosity Grades for Engine Oils

SAE Viscosity grade	Viscosity (cP)[a] at temp. (°C) max	Boderline[b] pumping temp. (°C) max	Viscosity[c] at 100° C min	(cSt) max
0W	3250 at –30	–35	3.8	—
5W	3500 at –25	–30	3.8	—
10W	3500 at –20	–25	4.1	—
15W	3500 at –15	–20	5.6	—
20W	4500 at –10	–15	5.6	—
25W	6000 at –5	–10	9.3	—
20	—	—	5.6	< 9.3
30	—	—	9.3	<12.5
40	—	—	12.5	<16.3
50	—	—	16.3	<21.9
60	—	—	21.9	<26.1

Note: 1cP = 1mPa s, 1cSt = 1 mm^2/s

[a]ASTM D 2602 (cold cranking simulator)

[b]ASTM D 4684 (MRV TP-1)

[c]ASTM D 445 (capillary viscometer)

Single-Grade Oil

This is the engine oil that meets the requirements of a single SAE viscosity grade classification. i.e., SAE 10W, 30 and 40.

Scote

Scote stands for single cylinder oil test engine. Cat developed, tested and supports the single cylinder oil test engine for the CF-4 engine oil service category. This test is known as the Cat 1K Scote.

Shear Stability

Shear stability is the ability of a multiviscosity oil to resist shear forces (sudden and abrupt changes in movement) on the oil that would cause it to revert to the base oil and become too thin to provide adequate lubrication.

Sludge

In diesel engines, sludge is a soft, black, mayonnaise-like emulsion of water, other combustion by-products, and oil formed during low-temperature engine operation. Sludge plugs oil lines and screens, and accelerates wear of engine parts. Sludge deposits can be controlled with a dispersant additive that keeps the sludge constituents finely suspended in the oil. See Engine Deposits.

Soot

This is unburned fuel. Black smoke and a dirty air filter indicate its presence. It causes oil to turn black.

Synthetic Lubricant

A synthetic lubricant is a lubricating fluid made by chemically reacting materials of a specific chemical composition to produce a compound with planned and predictable properties. The resulting base stock may be supplemented with additives to improve specific properties. Many synthetic lubricants – also called synlubes – are derived wholly or primarily from petrochemicals; other synlube raw materials are derived from coal and oil shale, or are lipochemicals (from animal and vegetable oils). Synthetic lubricants may be superior to petroleum oils in specific performance areas. Many exhibit higher viscosity index (V.I.) better thermal stability (heat resistance) and oxidation stability, and low volatility (which reduces oil consumption). Because synthetic lubricants are higher in cost than petroleum oils, they are used selectively where performance or safety requirements may exceed the capabilities of a conventional oil.

Total Base Number (TBN)

Understanding TBN requires some knowledge of fuel sulfur content. Most diesel fuel contains some degree of sulfur. How much depends on the amount of sulfur in the crude oil from which it was produced and/or the refiner's ability to remove it. One of the functions of lubricating oil is to neutralize sulfur by-products, namely sulfurous and sulfuric acids and thus retard corrosive damage to the engine. Additives in the oil contain alkaline compounds which are formulated to neutralize these acids. The measure of this reserve alkalinity in an oil is known as its TBN. Generally, the higher the TBN value, the more reserve alkalinity or acid-neutralizing capacity the oil contains. Caterpillar uses ASTM test D2896 to determine TBN.

Toxicology

This is a science that deals with poisons and their affect and with the problems involved (as clinical, industrial or legal).

Viscosity

Viscosity is one of the more critical properties of oil. It refers to an oil's thickness or its resistance to flow. Viscosity is directly related to how well an oil will lubricate and protect surfaces that contact one another. Regardless of the ambient temperature or engine temperature, an oil must flow sufficiently to ensure an adequate supply to all moving parts.

The more viscous (or thicker) an oil is, the thicker the oil film it will provide. The thicker the oil film, the more resistant it will be to being wiped or rubbed from lubricated surfaces. Conversely, oil that is too thick will have excessive resistance to flow at low temperatures and so may not flow quickly enough to those parts requiring lubrication. It is therefore vital that the oil has the correct viscosity at both the highest and the lowest temperatures at which the engine is expected to operate.

Viscosity Index (VI)

Oil thins out as temperature increases. The measurement of the rate at which it thins out is called the oil's viscosity "index" (or VI). New refining techniques and the development of special additives which improve the oil's viscosity index help retard the thinning process.

The Society of Automotive Engineers (SAE) standard oil classification system categorizes oils according to their quality (via an alphabetical designation, like CD) and viscosity (via a number).

Zinc

This is widely used as an anti-wear agent in motor oils to protect heavily loaded parts, particularly the valve-train mechanisms (such as the camshaft and cam followers) from excessive wear. It is also used as an anti-wear agent in hydraulic fluids and certain other products.

Cooling Systems

General Information

A properly controlled cooling system is essential to satisfactory engine life and performance. Defective cooling systems and careless maintenance are the direct cause of most engine failures. The factory-supplied cooling system should not be modified since the various circuits of the engine-mounted cooling system have been sized to provide the proper flows to its components. Changes to these circuits can cause flow balance to be disrupted to the point that various engine components may fail.

Need for Cleanliness

All pipe and water passages external to the engine must be cleaned before initial engine operation to ensure there will be flow and that foreign materials will not be lodged in the engine or cooler.

Flexible Connectors

Customer supplied coolant piping **must be attached to the engine with flexible connectors**. The positions of flexible connections and shut-off valves are important considerations. The shut-off valve should be located so that a broken flexible connection can be isolated without having to shut down the whole system.

Engine Cooling Circuits

Caterpillar marine engines generally use one or two cooling water circuits. A closed treated water cooling circuit is always used for cooling the engine jacket. A second circuit is used on turbocharged aftercooled engine arrangements when colder than jacket water aftercooling is required. Cooling of the marine transmission oil is accomplished using either engine jacket water, aftercooler water, or a separate water cooling circuit depending on the model of marine transmission and/or the engine cooling arrangement.

Jacket Water System

Definition

Caterpillar Marine Engines are designed to operate with a jacket water temperature differential of approximately 15° F (8° C) measured across the engine under full load. Minimum jacket water temperatures are controlled by water temperature regulators (thermostats) to provide efficient engine operation. Maximum jacket water temperature limits are controlled by the size of the coolers and flow of coolant. The closed jacket water system consists of engine water jacket (engine block and cylinder heads), the circulating pump, water temperature regulator, oil cooler, engine-mounted expansion tank and heat exchanger.

Water Temperature Regulators

The water temperature regulator (thermostat) and cooler bypass are used to regulate operating temperature. The regulator directs all or part of the water discharged from the engine jacket to the cooler. The remainder is bypassed to the expansion tank on heat exchanger/keel cooled engines or to the water pump inlet on radiator cooled engines where it mixes with cooled water before returning to the engine jacket.

Depending on the engine and configuration, the thermostats may be in a controlled inlet or controlled outlet configuration. The operating temperature of the jacket water will be about the same for either system if the thermostat settings are the same or similar. In either the outlet or inlet control system, thermostat placement and sensing of jacket water temperature (and therefore bypass control) is always at the jacket water outlet.

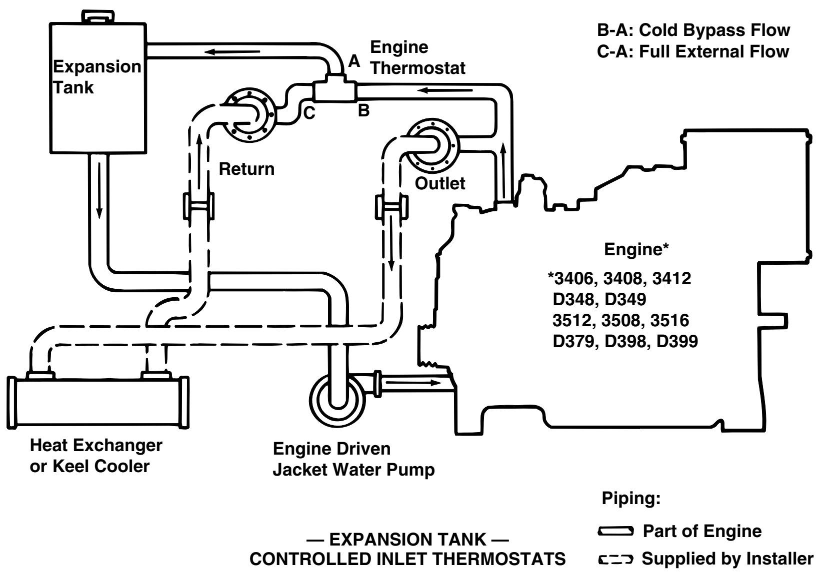


FIGURE 4.1

The expansion tank and cooler perform the same function as the radiator. A radiator fan provides air flow through the cooling fins of the radiator to transfer coolant heat to the air. An external water supply is used to accomplish heat transfer when using a heat exchanger or keel cooler.

The inlet temperature controlled system provides less cycle temperature variation because mixing of the bypass jacket water and the cooled water takes place in the expansion tank before passing to the jacket water pump. The volume of water already in the expansion tank dilutes and smooths the temperature change rate.

With the simpler outlet control system, mixing occurs at the water pump inlet and temperature change (or cycles) may be more sudden and drastic. This can pose serious problems where the sea water is very cold and may require some special trimming or modification of the vessels cooling circuit.

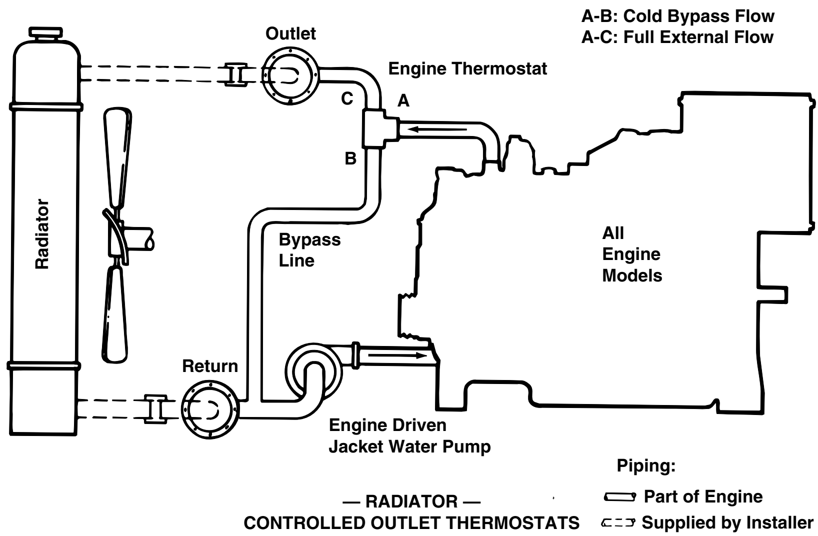
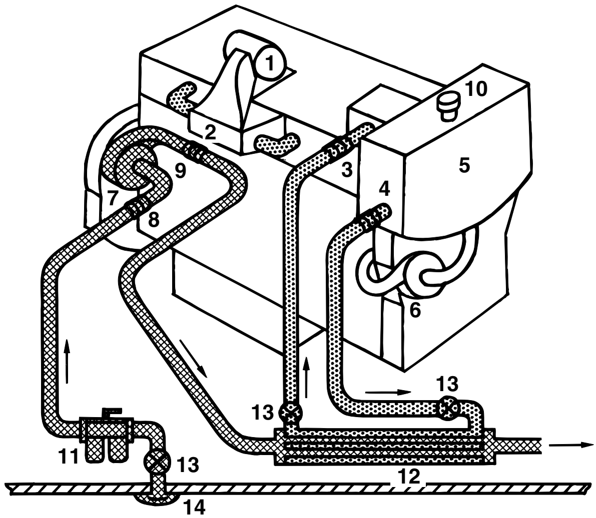


FIGURE 4.2

Heat Exchanger Cooling for Jacket Water

Heat exchangers can be mounted either on the engine or remote from the engine. Engine-mounted heat exchangers require the least amount of pipe fitting since the jacket water connections to the heat exchanger are provided by the factory.

Remote-mounted heat exchangers require connecting the jacket water inlet and outlet at the engine to the shell side of the exchanger. As shown below, an engine driven seawater pump is used to circulate the cooling water through the tubes of the heat exchanger.



JACKET WATER AFTERCOOLED
Heat Exchanger

1. Turbocharger
2. Aftercooler, jacket water cooled
3. Jacket water outlet connection
4. Jacket water inlet connection
5. Expansion tank
6. Jacket water pump
7. Auxiliary pump, seawater
8. Seawater inlet connection
9. Seawater outlet connection
10. Pressure cap
11. Duplex full-flow strainer
12. Heat exchanger
13. Shut-off valve
14. Seawater intake

FIGURE 4.3

Keel Cooling for Jacket Water

A keel or skin cooler is an outboard heat exchanger which is either attached to the submerged part of a vessel's hull or built as a part of it. Jacket water is generally circulated through the cooler by the engine's water pump.

Water Specifications

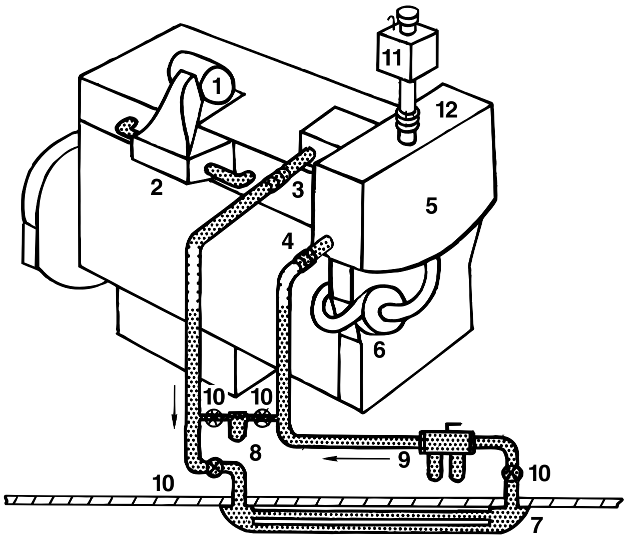
Caterpillar used two water classifications: fresh water and seawater.

Fresh Water

Fresh water refers to drinkable water. Prior to chemical water treatment for engine corrosion inhibiting, it must be in a pH range of 5.5 to 9.0, containing no more than 40 ppm chlorides. Total dissolved solids must be less than 340 ppm. Total sulfates must be no more than 100 ppm. Total hardness must be less than 170 ppm. This is the cooling water that is used within the engine's jacket water system.

Seawater

Seawater refers to salt water, river water, lake water and all waters that do not meet the fresh-water requirement. Heat exchanger components in contact with this water should be copper-nickel construction, or equivalent, highly corrosion resistant material. This is not the water retained within the engine's jacket water system.



JACKET WATER AFTERCOOLED
Keel Cooler

1. **Turbocharger**
2. **Aftercooler, jacket water cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Keel cooler**
8. **Bypass filter**
9. **Duplex full-flow strainer**
10. **Shut-off valve**
11. **Auxiliary expansion tank**
12. **Flexible connection**

FIGURE 4.4

Chemical Water Treatment for Engine Corrosion Inhibiting

All jacket water must be treated with chemicals for satisfactory engine life. Even potable water is not suitable for use by itself, except for short periods of time (during sea trials or during an emergency). It is good practice to chemically protect or drain engine jacket water before storage or extended transportation of the engine. This is necessary to avoid corrosion and scale from forming in the system. The resulting cooling solution (mixture of proper pH water and corrosion inhibitors) should have a pH in the range of 5.5 to 9.

Water Softener-Treated Water
Water that has been softened (chemically treated to lower the mineral content) by the addition of chlorides cannot be used in the cooling system. Water that is softened by the removal of calcium and magnesium can be used.

Chromate Corrosion Inhibitors
Inhibitors containing chromate compounds should not be used in Caterpillar Engine cooling systems. The concentration of chromate solutions is difficult to control and these solutions are extremely toxic. Before dilution, they can damage human skin. State and local regulations severely limit discharge of chromate solutions into inland and coastal waters.

Soluble Oil
Soluble oil is not recommended for cooling system protection.

Antifreeze
The climate where the engine will be used will determine the need for antifreeze. If antifreeze is needed, Caterpillar dealers can recommend specific types. Corrosion inhibitors are required. Some antifreeze products do not contain corrosion inhibitors. If the antifreeze chosen does not contain corrosion inhibitors, corrosion inhibitors must be added separately. Some antifreeze solutions, because of their higher viscosity (thicker than plain water), will reduce the cooling systems heat transfer capacity. Do not use higher than required concentrations of antifreeze. This practice can cause engine overheating. Antifreeze does not lose its ability to give freeze protection, but the additives in the antifreeze wear out with time and the antifreeze will not give certain other protection to the cooling system. Replace antifreeze periodically or add maintenance quantities of the additives, as directed by the antifreeze manufacturer.

Watermakers, Domestic Water Heaters, Cabin Heaters
Watermakers, domestic water heaters and cabin heaters can put normally-wasted jacket water heat to work. This has the potential for recovery of approximately 15% of the fuel input energy.

Certain aspects of the engine cooling system must be thoroughly understood to avoid misapplication. For example, an engine will only produce significant amounts of waste heat if there is a significant load on the engine. Many engines in marine service are lightly loaded for large parts of their life and are poor choices for installation of watermakers, domestic water heaters, and cabin heaters. When an engine is lightly loaded, almost all of the engine's jacket water flow goes through a bypass line, from the thermostat housing to the jacket water pump inlet, to maintain a constant high flow through the engine's cooling passages.

Watermakers, domestic water heaters and cabin heaters can *overcool* an engine.

If the watermaker, domestic water heater, or cabin heater extracts too much heat from the flow of jacket water, the engine's water temperature sensors/thermostats will sense the engine cooling jacket is operating at a dangerously low temperature. It will attempt to correct the condition by reducing the external flow of cooling water. If there are automatic controls on the watermaker, domestic water heater, or cabin heater, it may shut off having sensed insufficient flow for continued operation. This leads to a troublesome condition of repetitive starting and stopping of the watermaker, domestic water heater, or cabin heater. Automatic control of these devices has proven troublesome and is not recommended. Consider the use of auxiliary jacket water heaters so during periods of light engine load, adequate amounts of heat can be sent to the watermaker, domestic water heater, or cabin heater.

Cooling water piping to and from the watermakers, domestic water heaters, and cabin heaters must not allow entrained air/gases to collect. Trapped air/gases will displace the water required to carry engine heat to the watermakers, domestic water heaters, and cabin heaters and interfere with proper operation. Trapped air/gases can be vented by installing small, approximately 0.125 in. (3 mm), inside diameter-vent lines. The vent lines should carry air/gases from the high points in the domestic water heater and its associated piping to a higher point in the engine jacket water cooling circuit – normally an installer-supplied auxiliary expansion tank.

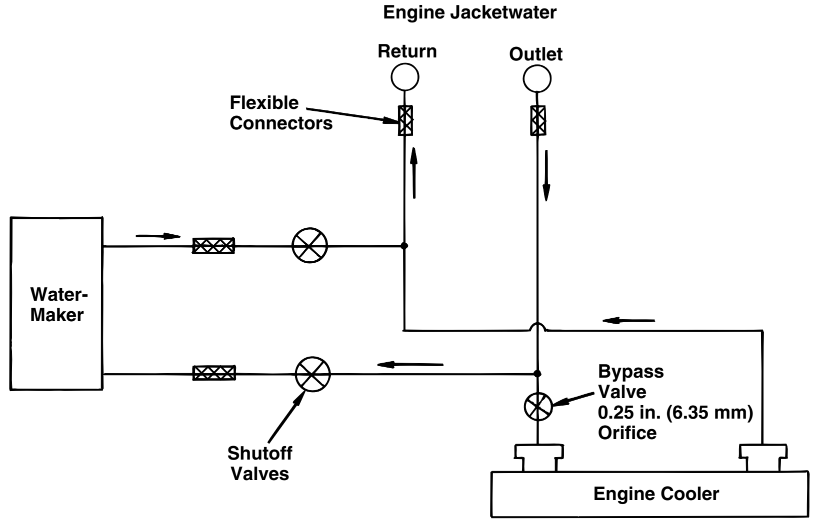
See the engine general dimension drawing for the connection locations of points on the engine where water for this purpose should be extracted and returned.

Watermaker Controls

The watermaker controls may be either manually operated valves or thermostatically controlled valves.

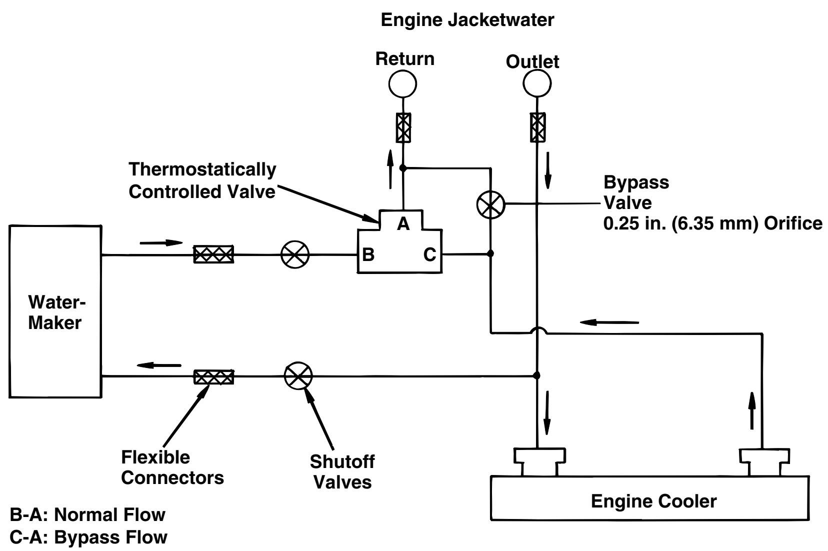
Any failure of the water maker control system (electrical, air, etc.) must shut off jacket water flow to the watermaker and return the flow to the engine heat exchanger.

The thermostat valve, shown in the figure describing automatic control watermaker circuit, would have a temperature setting that will not interfere with the engine thermostats. This valve should begin to divert water flow to the engine heat exchanger at no more than 190° F (88° C) and be fully diverting at 205° F (96° C). For safety, the bypass valve(s) in the engine heat exchanger circuit should contain 0.25 in. (6.35 mm) orifices so there will be a slight water flow in case all valves are inadvertently left closed. This orifice is then required to assure water flow to actuate an alarm system. If the watermaker cannot handle the full heat rejection of the engine and/or cannot handle the full water flow of the engine, the automatic system must be used.



MANUAL CONTROL WATERMAKER CIRCUIT

FIGURE 4.5



AUTOMATIC CONTROL WATERMAKER CIRCUIT

FIGURE 4.6

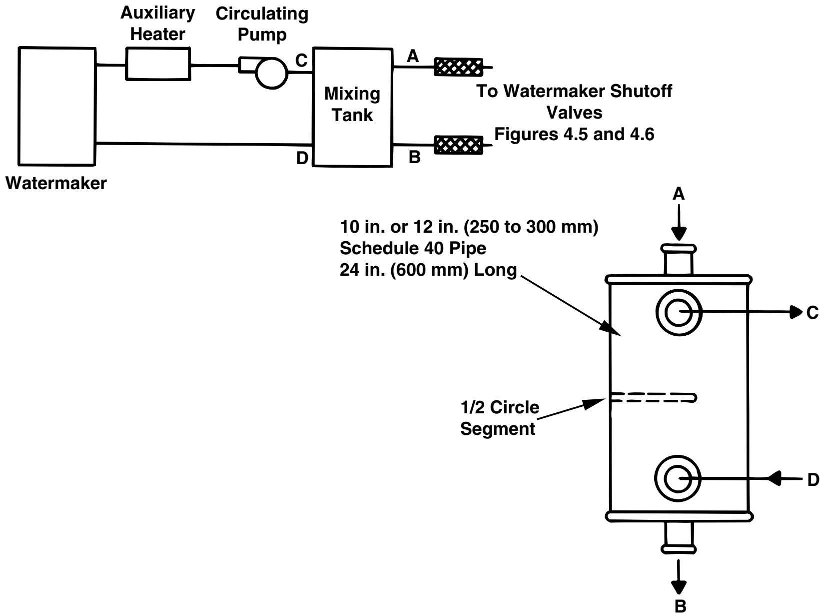


FIGURE 4.7

Interconnecting Engines

Several problems arise from interconnection of several engines: unequal water flow, one failure shuts down all engines, excessive external head pressures, etc. For these reasons, separate connection of one engine per watermaker is recommended. It is the customer's responsibility to provide a system that is compatible with the engine cooling system in all modes of operation.

When the Watermaker is Far from the Engine

When the watermaker is a long distance from the engine or where the watermaker requires a constant water flow, a mixing tank and circulating pump is required. Do not use a circulating pump by itself, because the circulating pump head pressure will damage the engine thermostats in the event they are closed. Although the mixing tank is not Caterpillar supplied, it can be used with either of the suggested circuits. An auxiliary electrical heater may be installed as shown.

Aftercooler Systems

Caterpillar uses two types of cooling circuits for the aftercooler. One type provides engine jacket water for cooling the air in the aftercooler. The other type provides a separate cooling circuit for the aftercooler. *All aftercooled Caterpillar Engines applied in a marine environment should be equipped with a seawater-type aftercooler core to assure satisfactory core life.*

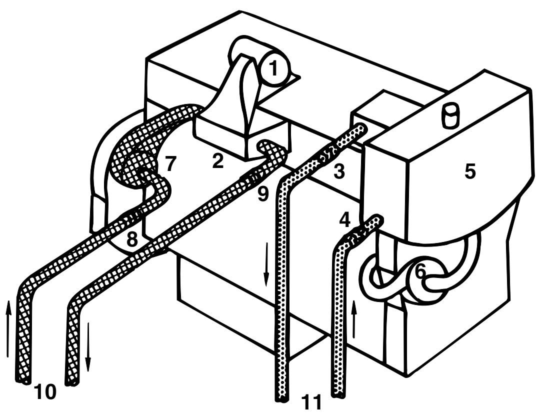
Jacket Water Aftercooling

Jacket water aftercooling uses engine jacket water in the tube side of the aftercooler and results in inlet manifold temperatures lower than those obtained in nonaftercooled turbocharged engines. The lower inlet manifold air temperature allows a jacket water aftercooled engine to achieve a rating higher than either a naturally aspirated or turbocharged-only engine. Jacket water aftercooled circuits are completely installed at the factory.

Separate Circuit Aftercooling

As the name implies, the separate circuit aftercooler circuit, SCAC, provides water to the aftercooler from a source other than engine jacket water. It is used to provide colder water to further reduce inlet manifold air temperatures.

The two arrangements of the separate circuit aftercooled engine configuration provide either an open seawater circuit or a closed freshwater circuit for the aftercooler water.



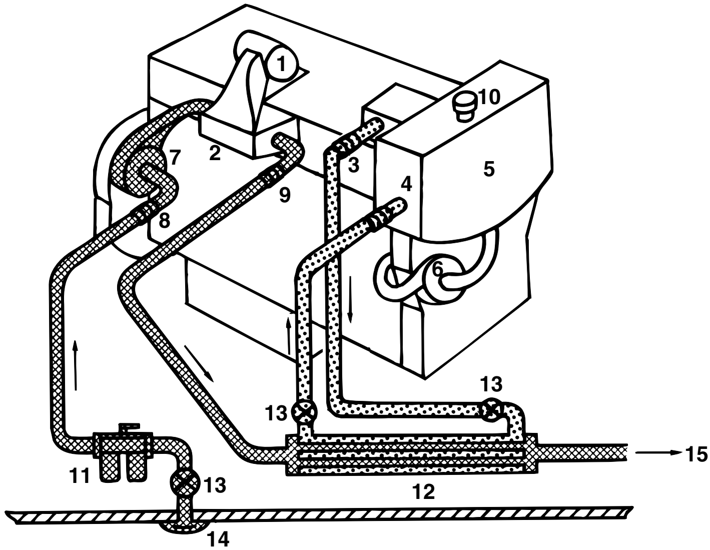
SEPARATE CIRCUIT AFTERCOOLED

1. **Turbocharger**
2. **Aftercooler, auxiliary water cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary water pump**
8. **Auxiliary water inlet connection**
9. **Auxiliary water outlet connection**
10. **Lines to aftercooler cooler**
11. **Lines to jacket watercooler**

FIGURE 4.8

Seawater Aftercooling

Engines equipped with seawater aftercoolers use untreated water in the tube side of the aftercooler. Seawater refers not only to salt water but also includes river water, lake water or any source of untreated water. Use of seawater for aftercooling achieves inlet manifold air temperatures lower than those resulting from jacket water or separate circuit fresh water aftercooling. This lower inlet manifold air temperature permits ratings of seawater aftercooled engines to exceed those for jacket water aftercooled engines.



SEPARATE CIRCUIT AFTERCOOLED
Seawater Aftercooled

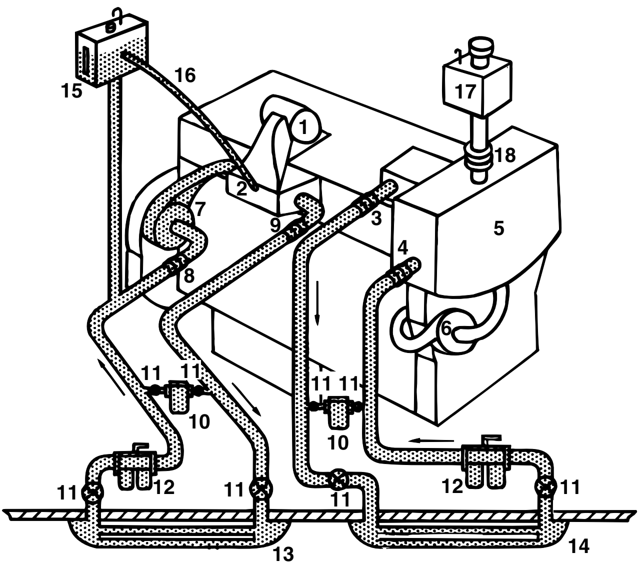
1. **Turbocharger**
2. **Aftercooler, seawater cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary seawater pump**
8. **Auxiliary seawater inlet connection**
9. **Aftercooler outlet connection**
10. **Pressure cap**
11. **Duplex full-flow strainer**
12. **Heat exchanger**
13. **Shut-off valves**
14. **Seawater intake**
15. **Seawater discharge**

FIGURE 4.9

Separate Keel Cooler for Aftercooler

The use of keel or skin coolers in the aftercooler circuit allows a low temperature, fresh water closed circulating system to be used. All closed fresh water aftercooler circuits require the installation of an expansion tank. Refer to the section of auxiliary expansion tanks. The use of an inlet manifold air temperature gauge, or alarm, can provide guidance for required cleaning of the system in order to maintain the desired engine performance. The use of an inlet manifold air temperature sensing device is strongly recommended.

Caution must be used when using the aftercooler keel cooler water circuit to cool an auxiliary piece of equipment (i.e. marine transmission). The auxiliary equipment cooler should be connected to the water circuit after it leaves the engine aftercooler to avoid adding any heat to the water before it enters the aftercooler. The additional resistance of the auxiliary equipment cooling circuit must be held to a minimum to avoid reducing the flow of water to the aftercooler.



SEPARATE CIRCUIT AFTERCOOLED
Keel Coolers

1. **Turbocharger**
2. **Aftercooler, keel cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary fresh water pump**
8. **Auxiliary fresh water inlet connection**
9. **Aftercooler outlet connection**
10. **Bypass filter**
11. **Shut-off valve**
12. **Duplex full-flow strainer**
13. **Keel cooler for aftercooler**
14. **Keel cooler for jacket water**
15. **Expansion tank for aftercooler circuit**
16. **Vent line for aftercooler circuit**
17. **Auxiliary expansion tank**
18. **Flexible connection**

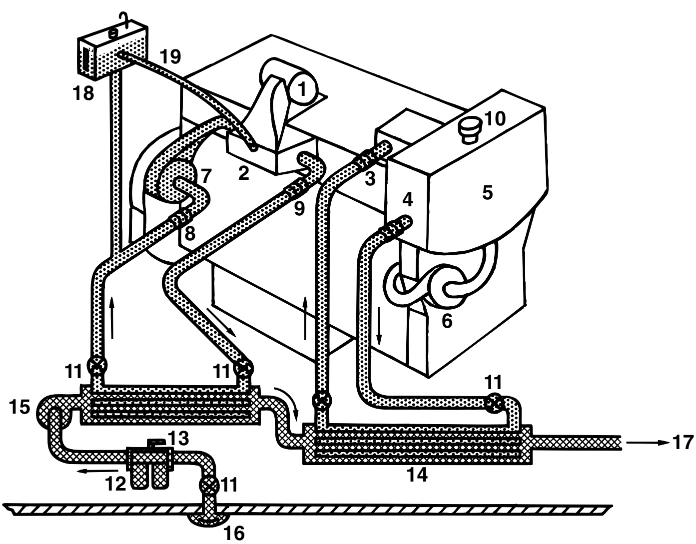
FIGURE 4.10

Heat Exchanger for Aftercooler

A shell and tube type heat exchanger will also provide cooling for fresh aftercooler water if the seawater temperatures are cold enough to provide adequate cooling. The use of an inboard shell and tube type heat exchanger for the aftercooler circuit requires the use of a seawater pump in addition to the freshwater pump used to circulate water through the aftercooler. An expansion tank is also required for the aftercooler circuit.

Overcooling of Aftercooler Air

The separate circuit aftercooler cooling system must be designed with sufficient capacity for the hottest water and the higher ambient air conditions for operation in climates where both air and seawater temperatures run to extremes. This results in a cooler with excess capacity in cold seawater and warm air conditions. This will result in condensation in the engine's intake system, especially during prolonged light engine load. Extremely cold seawater in the aftercooler can also cause condensation when engine inlet air temperatures are relatively warm with high moisture content. To minimize condensation during light engine load in separate circuit aftercooled systems, it is desirable to maintain the inlet manifold temperature between 100° F and 125° F (38° C and 52° C). This may be achieved by recirculating the aftercooler cooling water back to the auxiliary water pump inlet until the desired temperature is reached. Cool water should then be mixed with the recirculated water to maintain the temperature. The temperature of the water to the aftercooler can be controlled by using a thermostatically controlled three-way valve.

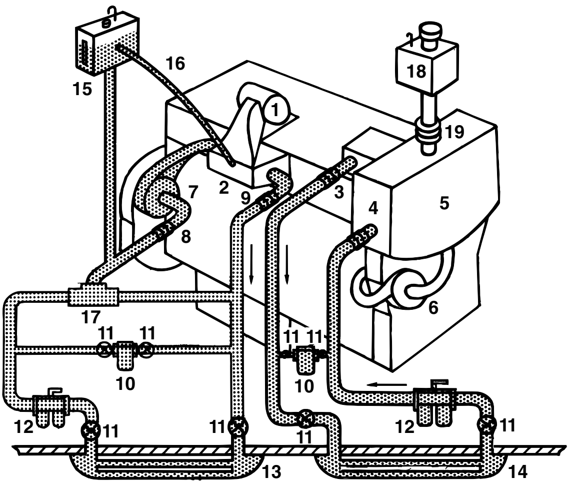


SEPARATE CIRCUIT AFTERCOOLER
Heat Exchangers

1. **Turbocharger**
2. **Aftercooler, heat exchanger cooler**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary fresh water pump**
8. **Auxiliary fresh water inlet connection**
9. **Aftercooler outlet connection**
10. **Pressure cap**
11. **Shut-off valve**
12. **Duplex full-flow strainer**
13. **Heat exchanger for aftercooler**
14. **Heat exchanger for jacket water**
15. **Customer provided seawater pump**
16. **Seawater intake**
17. **Seawater discharge**
18. **Expansion tank for aftercooler circuit**
19. **Vent line for aftercooler circuit**

FIGURE 4.11

On closed circuit keel cooled or heat exchanger systems, the aftercooler water is bypassed around the cooler until it reaches the desired aftercooler inlet temperature. On seawater aftercooled engines, the warmed water from the heat exchanger is recirculated to the aftercooler until the desired aftercooler inlet water temperature is obtained. The thermostat valve used must be capable of being used continuously in seawater and be equipped with electrolytically compatible components.



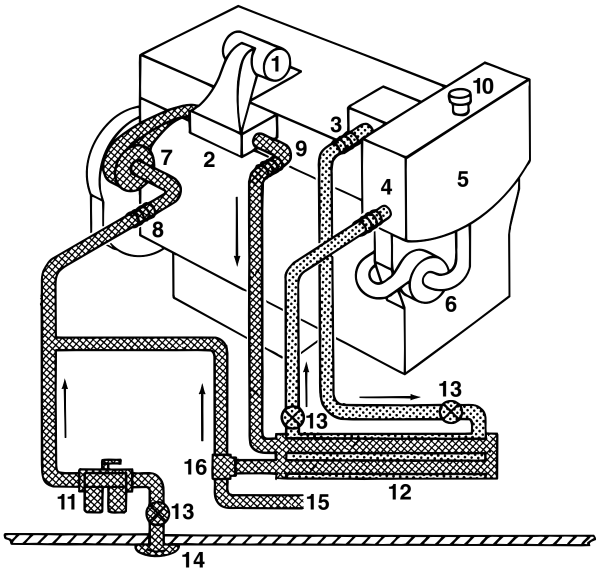
SEPARATE CIRCUIT AFTERCOOLED
Aftercooler Keel Cooler Bypass

1. **Turbocharger**
2. **Aftercooler, keel cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary fresh water pump**
8. **Auxiliary fresh water inlet connection**
9. **Aftercooler outlet connection**
10. **Bypass filter**
11. **Shut-off valve**
12. **Duplex full-flow strainer**
13. **Keel cooler for aftercooler**
14. **Keel cooler for jacket water**
15. **Expansion tank for aftercooler circuit**
16. **Vent line for aftercooler circuit**
17. **Bypass valve – thermostatically controlled**
18. **Auxiliary expansion tank**
19. **Flexible connection**

FIGURE 4.12

The thermostatic valve used should not allow the temperature of the water to the aftercooler to exceed 85° F (30° C). The keel cooler, heat exchanger and marine transmission oil cooler used must be sized for this maximum temperature. A thermostatically controlled 3-way valve that is equipped with a remote sensor to monitor the inlet manifold air temperature can be used. Adjust the remote sensor to insure that the thermostatic valve does not permit recirculation when the inlet manifold temperature reaches 120° F (49° C).

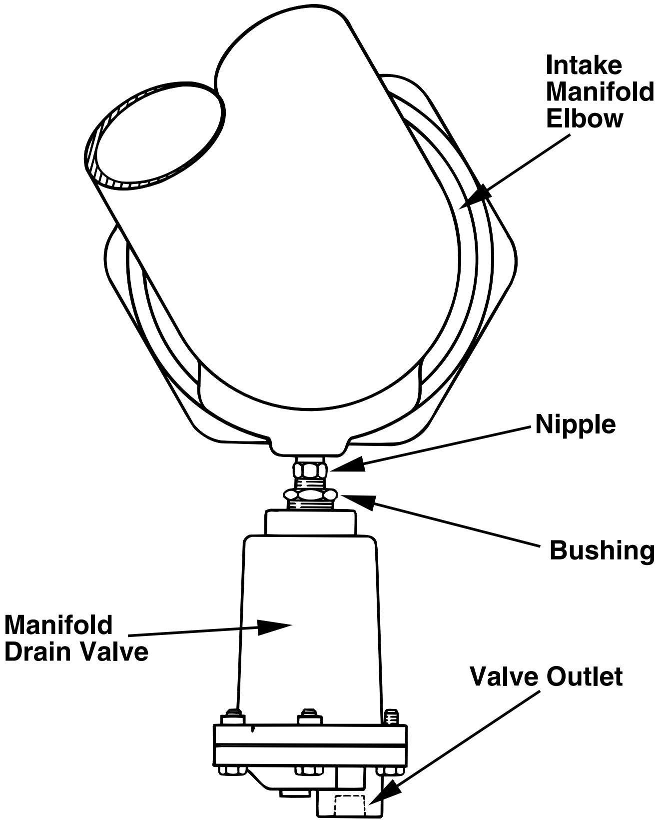
It is important that water be recirculated rather than be throttled to reduce flow. It is essential that unrestricted water flow through the aftercooler be maintained regardless of temperature conditions. Size thermostatic valve plumbing to have internal diameters as large or larger than the inlet connection of the auxiliary pump. Use an air intake manifold temperature alarm set for 125 to 135° F (52 to 57° C) maximum to warn of system malfunction.



SEPARATE CIRCUIT AFTERCOOLED
Aftercooler Seawater Recirculation

1. **Turbocharger**
2. **Aftercooler, seawater cooled**
3. **Jacket water outlet connection**
4. **Jacket water inlet connection**
5. **Expansion tank**
6. **Jacket water pump**
7. **Auxiliary seawater pump**
8. **Auxiliary seawater inlet connection**
9. **Aftercooler outlet connection**
10. **Pressure cap**
11. **Duplex full-flow strainer**
12. **Heat exchanger**
13. **Shut-off valves**
14. **Seawater intake**
15. **Seawater discharge**
16. **Bypass valve – themostatically controlled**

FIGURE 4.13



CONDENSATE VALVE GROUP

FIGURE 4.14

In situations where condensation can be a problem, a corrosion-resistant water trap can be attached to the intake manifold(s) of the engine.

Seawater System

General
The installation, size and material of the seawater suction lines is extremely important.

Size
Flow restriction in the sea water suction piping will result in abnormally high engine temperatures which can lead to unscheduled shutdowns and, in severe cases, reduced engine life. To minimize flow restriction, pipes and hoses should be at least as large as the sea water pump suction opening.

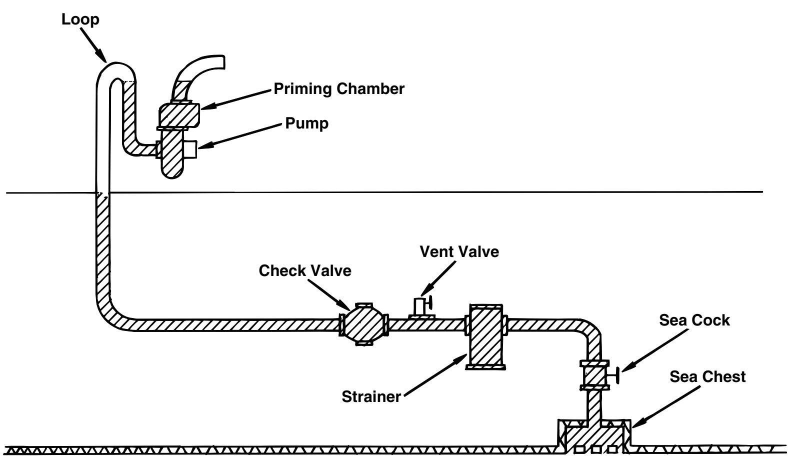
If the distance to the thru-hull fitting or sea chest is large or if many pipe elbows or bends in the hose are used, the pipe or hose size should be one size larger than the sea water pump opening (suction connection). In no case should the sea water pressure, measured at the sea water pump suction, be less than 3.5 psi (24 kPa) vacuum.

Suction Line Design Considerations
On the inlet side of the pump, as much as possible of the seawater piping, should be below the vessel water line without air traps.

Install a water pressure actuated check valve downstream of the strainer and as close to it as possible. The function of the check valve is to prevent water from draining out of the pump inlet while the pump is not operating and during cleaning of the strainer. Install a vent valve between the strainer and the check valve to allow venting of trapped air after cleaning the strainer and opening the sea cock. If the pump is above the vessel water line, install a piping loop above the pump inlet elbow to trap enough water to keep the pump and priming chamber filled.

Sea Water Inlet Design Considerations
The sea water inlet serves the following functions:

- Provides a low restriction connection for the seawater inlet plumbing.
- Provides a connection point for the Sea Cock (seawater shutoff valve – installed between the sea water inlet and the seawater inlet plumbing).
- Provides a way to separate air from the sea water required for cooling. Sea chests must have vent connections to allow air, forced under the hull during maneuvering, to be purged *before* it is able to reach the centrifugal seawater pump.



CENTRIFUGAL SEAWATER PUMP INLET PLUMBING

FIGURE 4.15

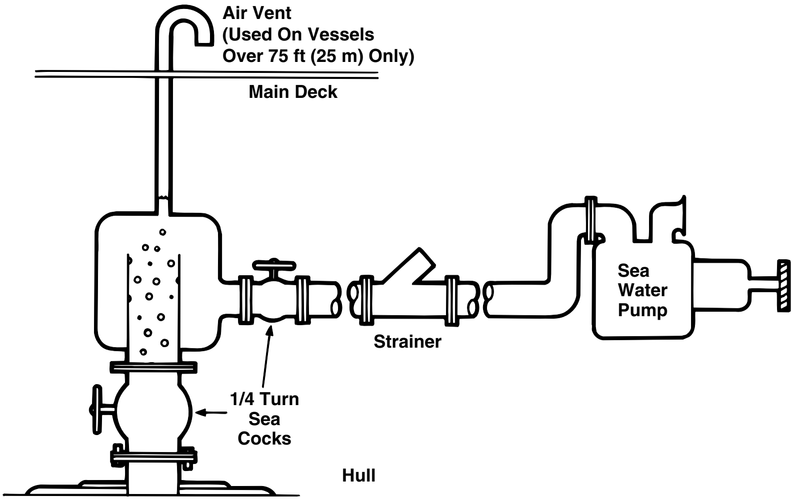


FIGURE 4.16

Seawater Pumps

Caterpillar offers three types of seawater pumps:

- Rubber Impeller
- Water Ring
- Centrifugal

Rubber Impeller Seawater Pumps

Rubber impeller seawater pumps are characterized by excellent priming characteristics, though they often suffer relatively short life in abrasive waters.

Water Ring Seawater Pumps

Their priming characteristics are less than rubber impellers, but can lift up to 5 ft (1.5 m) **Caution:** A goose neck may be necessary with these pumps to keep water in the pump for priming. They are made entirely of corrosion resistant metals, with no elastomeric components.

Centrifugal Seawater Pumps

Centrifugal seawater pumps must be installed with their inlet below the boats *light* waterline. Air allowed to enter centrifugal seawater pumps will likely result in loss of prime and probable engine damage due to loss of cooling. Do not start an engine equipped with a centrifugal pump unless the pump and priming chamber are full of water.

Material

An excellent material for piping carrying seawater is of the copper-nickel alloys. The cost of such piping makes its use unusual for all but the most critical systems.

The material of all the seawater piping should be the same, whenever practical. If parts of the seawater piping, made of different metals, make contact with each other, one of the metals will corrode, sometimes very rapidly.

The materials will corrode according to their position in the electromotive series. See electromotive series chart in section of Useful Tables to Designers of Cooling Systems.

Black iron pipe is often used in seawater service (replacement should be planned every two or three years). If it is necessary to use pipe or other cooling system components of more than one material, avoid letting the dissimilar metals touch, even by mutual contact with an electrically-conductive third material.

Corrosion will be much more severe if a flow of electrons is able to pass freely from one of the metals to the other.

Seawater Strainer

Purpose

Strainers protect the seawater pump, heat exchanger and other cooling system components from foreign material in the seawater. The foreign material can plug or coat heat transfer surfaces, causing overheating of the engine. If abrasive, foreign material will erode pump impellers and soft metal parts, reducing their effectiveness.

Location

Install strainers below the boat's water line and as close to the sea water intake or sea chest as possible (adjacent to the sea cock). The strainer must be installed so it can be easily cleaned, even in the worst weather conditions.

Type

While simplex strainers, which require shutoff of the sea water flow, are adequate to protect the engine, greater safety will result from using duplex strainers, which can be cleaned without interrupting sea water flow or engine power.

Size

Well sized strainers will impose no more than 3 ft (9 kPa) of water restriction to flow at full seawater flow conditions. Suppliers can help in the proper selection of strainer size by providing the flow restriction of each size of strainer at varying water flow conditions.

Mesh Dimensions
Recommended strainer media (screens) should not pass solid objects larger than 1/16 in. (1.6 mm) in diameter. Plate type heat exchangers require a mess less than 3 mm, while the tube type heat exchangers requires a mess less than 5 mm.

Strainer Differential Pressure Sensors
Schools of small fish, floating debris (plastic bags, plant material, etc.) or ice chips can plug a clean strainer in a few seconds. When the differential pressure across the connections of a strainer goes too high, the strainer needs to be cleaned. A differential pressure switch, will provide early warning of strainer plugging and resultant loss of engine cooling. In time, high engine water temperature alarms will also warn of a loss of sea water flow, but the differential pressure sensor will give early warning and the precise location of the problem.

Zinc Plugs
General Information
Zinc plugs are installed in portions of the engine where dissimilar metals must be used in the presence of seawater. Their sacrificial action protects critical cooling system components from corrosion.

Inspection Schedule
Inspect the zinc plugs within 24 hours of filling the piping with sea water. If no significant corrosion is noted, inspect them again after 7 days of sea water submersion. If no significant deterioration is noted, reinspect in 60-90 days. Thereafter, inspect annually and replace if necessary.

Thread Sealant on Zinc Plug Threads
Install zinc plugs with clean threads. Never install zinc plugs using teflon tape or nonelectrically-conductive pipe sealers. The insulating properties of such sealers will stop the protective action of the zinc plugs.

Marine Growth
Marine plants and animals will enter seawater piping and take up residence there. Many forms of sea life are very comfortable within engine cooling system piping and will grow to a size which will threaten adequate flow. The lack of predators, darkness and abundance of suspended food particles combine to create prime growth conditions for sponges, barnacles and like creatures. Strainers are no protection against creatures which are microscopic in size during their infant stages of life. Periodic operation in fresh water will rid boats of salt water life infestation and vice versa. In any case, it will be necessary to remove and clean piping and heat exchanger passages of the corpses. Use of high water temperature alarms, seawater pump pressure switches, and other instrumentation can warn of gradual loss of seawater flow and are recommended. Periodic chemical treatment combats marine growth. Chemical type and concentration must be controlled to prevent deterioration of the seawater cooling system components. Contact

a knowledgeable chemical supplier. Continuous low-concentration chemical treatment via either bulk chemical or self-generating electrical processes are offered by various manufacturers.

Seawater Pump Maintenance

Flexible impeller seawater pumps require periodic service. The impellers must be replaced when worn to maintain adequate seawater flow and avoid engine overheating. It is a good idea to put a little soft soap, like that used by mechanics for hand cleaning, on the new impeller just prior to installing it. The soap will lubricate the new impeller long enough for it to fully achieve prime, protecting it from overheating. A spare impeller, for flexible impeller seawater pumps, should be carried on board at all times.

Stern Tube Lubrication/Cooling

It is good practice to divert a small portion of the engine's seawater, before discharging it overboard, to lubricate/cool the stern tube and stuffing box (sometimes called the *packing gland*). The engine's seawater has been strained and the flow of water from the stuffing box end of the stern tube will tend to keep sand or other abrasive material out of the stern tube. Avoid using excessive quantities of the engine's flow of seawater, as this practice tends to increase the seawater system restriction, making the engine more likely to overheat. Generally 1-3 gal/min (4-12 L/min) are adequate.

Potential Problems

Nonreinforced Seawater Pump Suction Hose

The vacuum inside the seawater pump suction hose can become quite high. If the hose is not internally reinforced, atmospheric pressure will collapse it. That will severely impede the flow of seawater with potentially dangerous results. Use hose which is sufficiently strong to resist collapse due to high suction vacuum.

Internal Hose Deterioration

Some hose will *shred* internally, releasing bits of rubber which can plug cooling passages. It is good practice to use good quality hoses. If users are unsure of their hoses' quality, it is good practice to examine hoses internally at least once during their life. Replace them with good quality hose every three years.

Achieving and Maintaining Seawater Pump Prime

Pump speeds and suction pressures must fall within certain limits for sea water pumps to achieve prime (start pumping water). The priming characteristics of Caterpillar sea water pumps are available from the factory.

Sea Water Discharge through Exhaust System

Wet exhaust systems use sea water, after it has passed through the various heat exchangers and coolers, to cool the hot exhaust gases. After sea water is injected into the hot exhaust gas (generally immediately downstream of the engine's turbocharger), the temperature of the gas is reduced enough to allow use of sections of rubber hose, fiberglass-reinforced plastic pipe or other similar materials to be used as exhaust pipe. **It is critical that nothing interfere with the flow of sea water which cools the exhaust gas. Anytime the engine is operating, the flow of seawater must be present.**

System Coolers

There are two types of heat exchanging systems recommended for use with the Caterpillar Diesel Marine Engines. These involve the use of either inboard mounted heat exchangers or outboard mounted keel coolers.

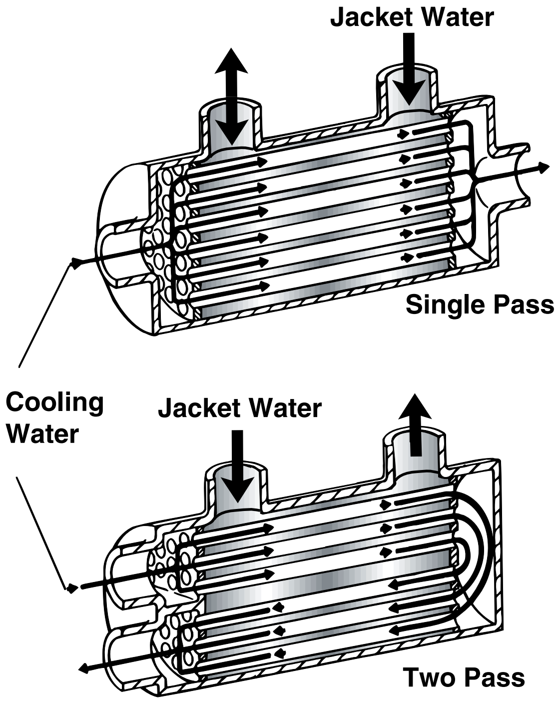
Heat Exchanger Cooling

Caterpillar inboard heat exchangers are shell-and-tube type or plate type. Heat is transferred from the hot, fresh water flowing through the engine to the cold sea water.

Heat exchanger cooled systems require a sea water pump to circulate sea water through the heat exchanger tubes or plates. It is good design practice to "always put the seawater through the tubes". The tubes can be cleaned by pushing a metal rod through them; the shell side requires chemical cleaning which is only available at shore-side facilities.

The fresh water is circulated through the heat exchanger shell, across the tubes, by the engine-driven water pump.

Most shell and tube heat exchangers are of either the single-pass or the two-pass type. This designation refers to the flow in the cold water circuit of the exchanger. In the two-pass type, the cold water flows twice through the compartment where jacket water is circulated; in the single-pass type only once. When using a single-pass exchanger, the cold water should flow through the exchanger in a direction *opposite* to the flow of jacket coolant to provide maximum differential temperature and heat transfer. This results in improved heat exchanger performance. In a two-pass exchanger, cooling will be equally effective using either of the jacket water connection points for the input and the other for return.



HEAT EXCHANGER TYPES

FIGURE 4.17

Heat exchangers should always be located at a lower level (elevation) than the coolant level in the expansion tank.

Heat Exchanger Sizing

Occasionally, special applications exist which require an inboard heat exchanger size not available as a Caterpillar unit. When these conditions exist, it is necessary to obtain a heat exchanger from a supplier other than Caterpillar. In order to expedite the selection of a nonstandard heat exchanger, a Heat Exchanger Selection Worksheet is included. Heat exchanger suppliers will provide information and aid in selecting the proper size and material for the application.

For a given jacket water flow rate, the performance of a heat exchanger depends on both the cold water flow rate and differential temperature. To reduce tube erosion, the flow velocity of the cold water through the tubes should not exceed 6 fps (183 cm/s).

At the same seater flow rate, the flow resistance and the flow velocity will be greater through a two-pass heat exchanger than through a single-pass heat exchanger. The heat exchanger should be selected to accommodate the cold water temperature and flow rate needed to keep the temperature differential of the jacket water below about 15° F (8.3° C) at maximum engine heat rejection. Thermostats must be retained in the jacket system to assure that the temperature of the jacket water coolant returned to the engine is approximately 175° F (79° C).

Size heat exchangers to accommodate a heat rejection rate approximately 10% greater than the tabulated engine heat rejection. The additional capacity is intended to compensate for possible variations from published or calculated heat rejection rates, overloads or engine malfunctions which might increase the heat rejection rate momentarily. It is not intended to replace all factors which affect heat transfer, such as fouling factor, shell velocity, etc.

Pay particular attention to the shell side pressure drop to ensure that the entire cooling system flow resistance does not exceed the limitations on the engine freshwater pump.

Heat Exchanger Sizing Worksheet

Heat Exchanger Sizing Data

Required by Heat Exchanger Supplier

Engine Jacket Water Circuit:

1. Jacket water heat rejection*	________	Btu/min (kW)
2. Jacket water flow*	________	Gpm (L/sec)
3. Anticipated seawater maximum temperature	________	F° (C°)
4. Seawater flow	________	Gpm (L/sec)
5. Allowable jacket water pressure drop	________	ft (m) water
6. Allowable seawater pressure drop	________	ft (m) water
7. Auxiliary water source (sea water or fresh water)	☐ ☐	seawater fresh water
8. Heat exchanger material (admiralty or copper-nickel)	☐ ☐	adm. metal cu-ni
9. Shell connection size**	________	
10. Tube side fouling factor***	________	

Aftercooler Water Circuit:

1. Aftercooler circuit water heat rejection*	____________	Btu/min (kW)
2. Aftercooler circuit water flow*	____________	Gpm (L/s)
3. Anticipated seawater maximum temperature	____________	F° (C°)
4. Seawater flow*	____________	Gpm (L/s)
5. Allowable Aftercooler Circuit Water Pressure Drop*	____________	ft (m) water
6. Allowable seawater pressure drop*	____________	ft (m) water
7. Auxiliary water source (sea water or fresh water)*	☐ ☐	seawater fresh water
8. Heat exchanger material (admiralty or copper-nickel)	☐ ☐	adm. metal cu-ni
9. Shell connection size**	____________	
10. Tube side fouling factor***	____________	

*Refer to TMI (Technical Marketing Information)

**Refer to engine general dimension drawing

***Fouling Factor, a descriptive quantity often found on heat exchanger specifications, refers to the heat exchangers ability to resist fouling. As defined in Caterpillar literature, fouling factor is the percentage of the heat transfer surface which can be fouled without losing the heat exchanger's ability to dissipate the engine's full heat load.

Maximum Seawater Temperature

Size heat exchangers such that the seawater is not heated above approximately 130° F (54° C). Higher seawater temperatures will result in fouling of the heat transfer surfaces with chalk-like compounds.

Keel Coolers

A keel cooler is an outboard heat exchanger which is either attached to, or built as part of, the submerged part of a ship's hull. The heated water from the engine(s) circuit(s) is circulated through the cooler by the engine-driven water pump(s).

Keel Cooler Types

Fabricated Keel Coolers

Fabricated keel coolers may be made of pipe, tubing, channel, I-beams, angle or other available shapes. The choice of materials used is dependent on the waters in which the vessel will operate. These materials must be compatible with materials used in the vessel's hull in order to prevent galvanic corrosion.

Sizing of Fabricated Keel Coolers

Engine water temperature maximum limits are controlled by size of the keel cooler. Heat transfer rates through any cooler depend mainly on cooling water temperature, cooling water flow and heat transfer surface area. A cooler may have to operate at its maximum capacity at zero hull speed, as in the case of an auxiliary generating set, operating while the vessel is in port. The minimum area calculated includes a fouling factor. Materials used in cooler construction, condition of waters in which the vessel will operate and service life expectancy will influence the size selection of a new cooler.

Keel cooler area recommendations contained in the graphs below *apply only to keel coolers made of structural steel (channel, angle, half pipe, etc.) welded to the ship's shell plating*. These recommendations take into account the thermal resistance to heat transfer of the steel plate, the internal and external water films, and the internal and external surface corrosion factors. The coefficient of heat transfer of the fresh water film flowing inside the cooler is based upon a flow velocity of 3 ft/sec (0.9 m/sec). The coefficient of heat transfer for the raw water film varies with the velocity of water flow past the cooler due to vessel speed. Surface corrosion factors are based on treated fresh water and polluted river water. Miscellaneous factors become so predominant in the resultant heat transfer rate that the type of material used and thickness of metal become minor considerations.

Normal deterioration of the cooler's inner and outer surfaces in the form of rust, scale and pitting progressively reduce a keel cooler's effectiveness over a period of years. Protective coatings and marine growths will also reduce the rate of heat transfer. It can take 4-5 years before deterioration stabilizes in keel coolers. *It must be designed considerably oversize when new.*

Because of the severe deterioration of heat transfer characteristics associated with structural steel coolers, adequate cooler size sometimes becomes impractical. This is particularly true in regions of high seawater temperature (over 85° F [30° C]). *In these regions, the use of "packaged" keel coolers, or box coolers, made of corrosion-resistant materials is suggested.* These coolers can provide more heat exchange surface area in a given volume on, or within the hull, than the coolers made of structural steel.

Keel Cooler Sizing Worksheet

Engine Jacket Water Circuit:

1. Jacket water heat rejection* ______________ Btu/min (kW)
2. Jacket water flow* ______________ Gpm (L/sec)
3. Vessel speed classification
   - ☐ 8 knots & above
   - ☐ 3 knots
   - ☐ 1 knot
   - ☐ still water
4. Anticipated seawater maximum temperature ______________ F° (C°)
5. Minimum cooler area required (per unit) ______________ ft^2/Btu/min ______________ (m^2/kW)
6. Minimum area required (Line 1 times Line 5) ______________ ft^2 (m^2)

Aftercooler Water Circuit:

1. Aftercooler circuit heat rejection* ______________ Btu/min (kW)
2. Aftercooler circuit water flow* ______________ Gpm (L/sec)
3. Vessel speed classification
   - ☐ 8 knots & above
   - ☐ 3 knots
   - ☐ 1 knot
   - ☐ still water
4. Anticipated seawater maximum temperature ______________ F° (C°)
5. Minimum cooler area required (per unit) ______________ ft^2/Btu/min ______________ (m^2/kW)
6. Minimum area required (Line 1 times Line 5) ______________ ft^2 (m^2)

Marine Gear Oil Cooling Circuit:

1. Marine gear heat rejection** ______________ Btu/min (kW)
2. Vessel speed classification
   - ☐ 8 knots & above
   - ☐ 3 knots
   - ☐ 1 knot
   - ☐ still water
3. Anticipated seawater maximum temperature ______________ F° (C°)

4. Minimum cooler area required (per unit) ________________ ft^2/Btu/min ________________ (m^2/kW)

5. Minimum Area Required (Line 1 times Line 5) ________________ ft^2 (m^2)

*Refer to TMI (Technical Marketing Information)

**See section on Marine Gear Heat Rejection

Marine Gear Heat Rejection

The Twin Disc marine gears offered by Caterpillar are 95% to 97% efficient, depending on the service factor.

Service Factor	Marine Gear Efficiency	Marine Gear Power Loss Factor
I	97%	3%
II	97%	3%
III	96%	4%
IV	95%	5%

Maximum heat rejection to the marine gear cooling system is equal to the transmitted power from the engine multiplied by the power loss factor.

$H_{(\text{marine gear})} = P_{(\text{engine})} \times F_{(\text{power loss})}$

Where:

$H_{\text{marine gear}}$ = Heat rejection of the marine gear oil

P_{engine} = Power generated in the engine and transmitted through the marine gear

$F_{\text{power loss}}$ = A factor relating the heat generated in the marine gear oil to the marine gear efficiency

The following conversion factors are tabulated below.

42.41 x hp = Btu/min

31.63 x kW = Btu/min

Aftercooler Circuit Keel Cooler Area Graph

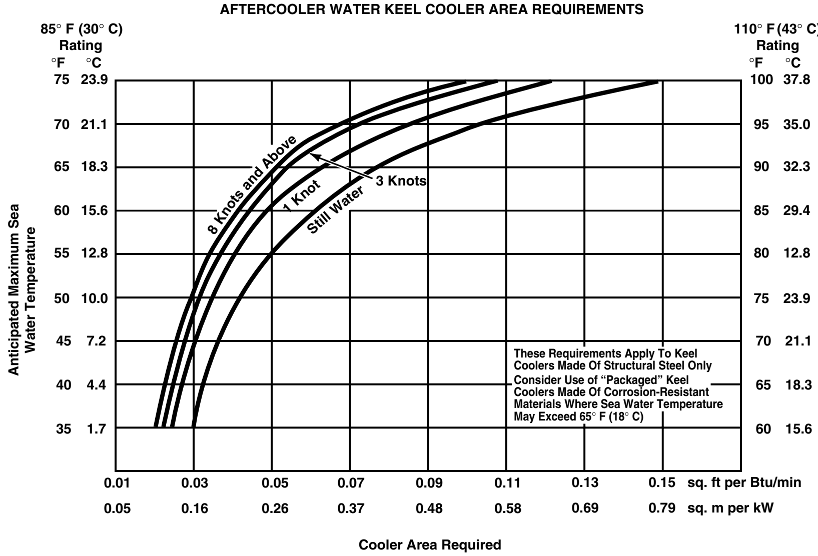


FIGURE 4.18

Jacket Water Circuit Keel Cooler Area Graph

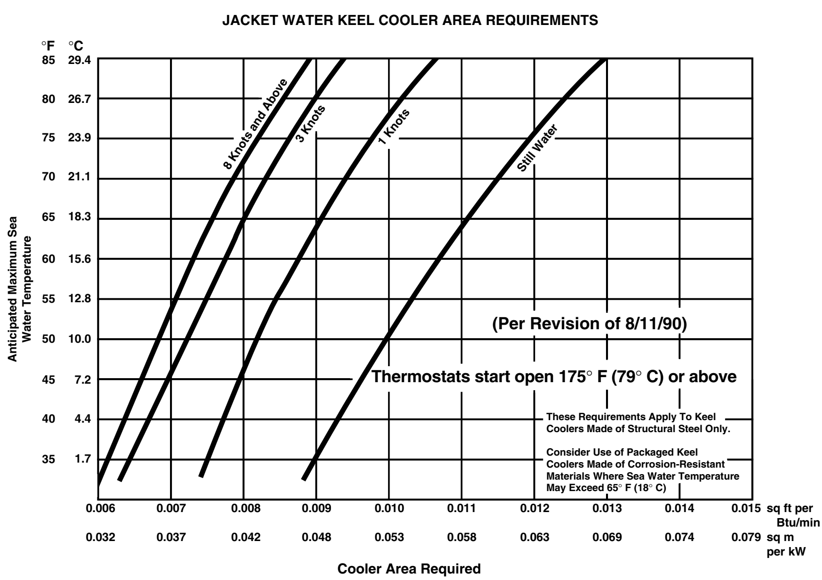


FIGURE 4.19

Marine Gear Oil Cooling Circuit Keel Cooler Area Graph

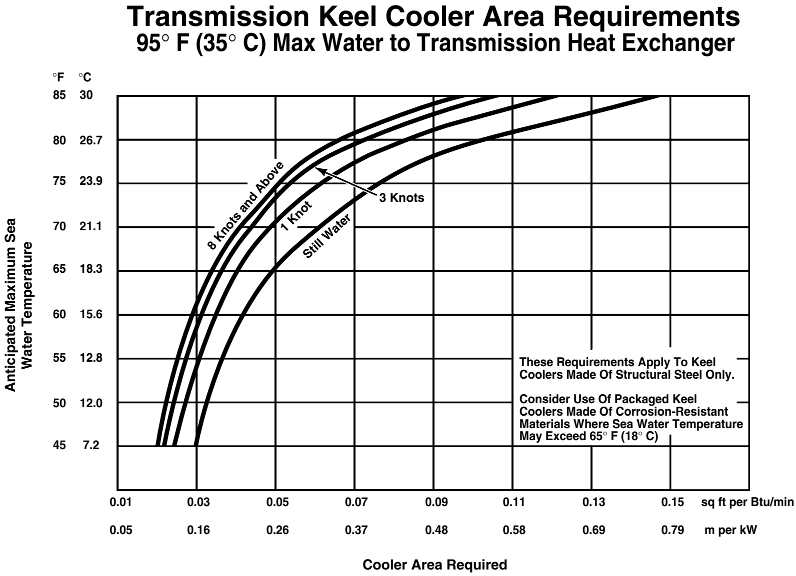


FIGURE 4.20

Design/Installation Considerations

Water Velocity Inside the Cooler

If the water flows through the keel coolers passages too fast (more than 8 ft/sec [2.5 m/sec]), the internal components will deteriorate (be eroded away), particularly near manifold entrances and exits, elbows and other discontinuities in the water flow. If the water flows through the keel coolers' passages too slowly (less than 2 ft/sec [0.6 m/sec]) rust particles, sand, or other particulate matter in the water will settle out, tend to choke off the flow, and degrade the transfer of heat. Use the following procedure to determine the proper flow pattern through the keel cooler:

- Determine the maximum and minimum expected water flow through the keel cooler. This can be determined from the engines water pump performance data.
- Subtract the minimum expected water flow from the maximum expected water flow.
- Multiply the resultant difference (between the min and max flow) by 2/3. Add 2/3 the resultant difference (from the prior step) to the minimum flow*. This is the *most likely water flow*. Use this figure to determine how to distribute the water flow through the keel cooler passages.

*For design purposes, this is the most likely water flow through the keel cooler. This is dependent on the use of good practice in sizing the connecting piping.

- Determine the cross-sectional area of one keel cooler passage. This is best done by consulting the manufacturer or an engineering reference on shapes of structural channel, pipes, angles, etc.
- Use a good conversion factor table to convert: the *most likely water flow* to units of ft^3/min (m^3/min), and cross-sectional area of one keel cooler passage to units of ft^2 (m^2).
- Divide the most likely water flow by the cross-sectional area of one keel cooler passage.
- The result will be the average velocity through the keel cooler flow passages. If the average velocity through the keel cooler flow passages is greater than 8 ft/sec (2.5 m/sec), arrange the water flow in parallel, so it passes through two or more of the keel cooler passages per pass through the keel cooler. If the average velocity through the keel cooler flow passages is less than 2 ft/sec (0.6 m/sec), use a keel cooler passage with a smaller cross section.

Use of Keel Inserts to Improve Local Flow Velocity

It is economically desirable to use steel channels for keel cooler passages which are so large in the cross-sectional area that water flow is too slow for effective heat transfer. It is useful in this situation to install keel cooler inserts. Keel cooler inserts are devices which cause localized high water velocity or turbulence within the keel cooler passage. An effective design for keel cooler inserts is a *ladder-like* device, inserted into the full length of the keel cooler passages.

Using the same metal alloy as the hull and keel cooler*, fabricate a crude ladder of rod** and flat bar***.

The flat bar cross pieces must not restrict flow through the keel cooler flow passages, but simply redirect the flow to avoid laminar flow due to too slow an average velocity.

Insert the ladder into the keel cooler flow passages and weld on the end fittings (inlet and outlet manifolds).

Direction of Flow Through Keel Coolers

Engine coolant should flow through the keel cooler from the rear to the fore end. This is *counter-flow* to the seawater and will significantly increase the effectiveness of the heat transfer. This is rarely practical to implement completely since the flow must be divided through the various flow passages in the keel cooler. If the flow is divided through too many passages, the velocity becomes too slow to maintain turbulent flow conditions.

*For protection against galvanic corrosion.

**Approximately 1/4 in (6 mm) Diameter.

***Approximately same shape, but 70% of, the cross sectional area of the keel cooler flow passages.

This will reduce heat transfer. The best compromise is to manifold the coolant in such a way that the flow, in the largest practical number of flow passages, is from rear to the fore end of the vessel.

Bypass Filters

Welded structural steel keel or skin cooler systems require the installation of strainers between the cooler and the pump inlet. Material, such as weld slag and corrosion products, must be removed from the system to prevent wear and plugging of cooling system components. Use a continuous bypass filter to remove smaller particles and sediment. The element size of the continuous bypass filter should be 0.000787 to 0.000197 inches (20 to 50 microns). Do not exceed 5 gal/min (19 L/min) water flow through the bypass and filter.

Strainers

Full-flow strainers are desirable. The strainer screens should be sized no larger than 0.063 in. (1.6 mm) mesh for use in closed freshwater circuits. The strainer connections should be no smaller than the recommended line size. The use of a differential pressure gauge across the duplex strainers will indicate the pressure drop, and enables the operator to determine when the strainers need servicing.

The pressure drop across a strainer at the maximum water flow must be considered part of the system's external resistance. Suppliers can help in the proper selection of strainers and furnish the values of pressure drop versus flow rate. The strainer should be selected to impose no more than 3 ft (1 m) water restriction to flow under clean strainer conditions.

Packaged Keel Coolers

Packaged keel coolers are purchased and bolted to the outside of a ship's hull.

Manufacturers offer keel coolers in many configurations. They are generally made of copper-nickel alloys and are initially toxic to marine growth. This is one of their more important advantages. Another important advantage of packaged keel coolers is their compactness and light weight when compared to fabricated keel coolers. It is not uncommon to find packaged keel coolers that are able to cool an engine with less than 20% of the heat transfer surface of an analogous fabricated keel cooler.

Sizing of Packaged Keel Coolers

Manufacturers of packaged keel coolers publish sizing guides which will allow the user to determine the proper size of unit for specific conditions. Caterpillar does not offer guidance outside of manufacturers guidelines.

Packaged Keel Cooler Sizing Worksheet

Collect the information described on the following worksheet. The information thereon is required to accurately size a packaged keel cooler.

Packaged Keel Cooler Sizing Worksheet

Engine Jacket Water Circuit:

1. Jacket water heat rejection* ______________ Btu/min (kW)
2. Jacket water flow* ______________ Gpm (L/s)
3. Vessel speed classification
   - ☐ 8 knots & above
   - ☐ 3 knots
   - ☐ 1 knot
   - ☐ still water
4. Anticipated seawater maximum temperature ______________ °F (°C)

Aftercooler Water Circuit:

1. Aftercooler circuit heat rejection* ______________ Btu/min (kW)
2. Aftercooler circuit water flow* ______________ Gpm (L/s)
3. Vessel speed classification
   - ☐ 8 knots & above
   - ☐ 3 knots
   - ☐ 1 knot
   - ☐ still water
4. Anticipated seawater maximum temperature ______________ °F (°C)

*Refer to TMI (Technical Marketing Information)

Restoration of Toxicity-to-Marine Growth of Copper-Nickel Keel Coolers

The toxicity will decline in time. It can be at least partially restored by a thorough cleaning of the cooler and wiping its heat transfer surfaces with a solution of vinegar saturated with salt (sodium chloride).

Paint and Packaged Keel Coolers

Paint will *greatly* reduce the heat transfer capability of packaged keel coolers. ***Never paint them.***

Packaged Keel Coolers and Galvanic Corrosion

Packaged keel coolers are almost never made of the same metal alloy as the rest of the hull*. If the piping is not the same metal alloy as the keel cooler, it is necessary to electronically isolate the packaged keel cooler from the hull metal and the ship's piping.

*There is a manufacturer making packaged keel coolers of aluminum alloy. This will significantly reduce the galvanic corrosion problems associated with such dissimilar metals as aluminum and copper-nickel submerged in salt water.

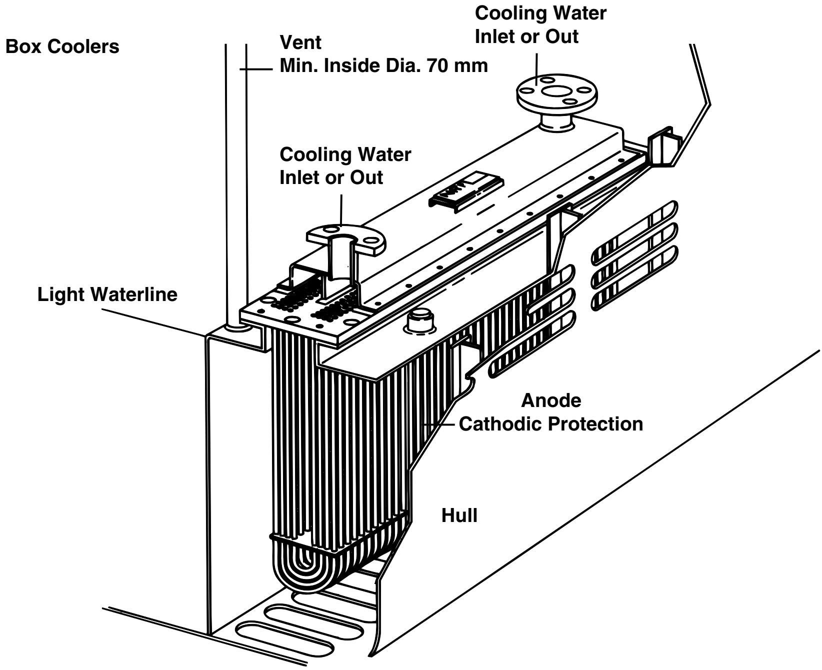


FIGURE 4.21

See the installation instructions of the packaged keel cooler manufacturer.

Location of Keel Coolers on the Hull

Locate the keel cooler in a well protected area on the hull. This is particularly true of packaged keel coolers which are manufactured of lighter gauge material than fabricated keel coolers.

To achieve the greatest possible heat transfer, locate the separate keel cooler for the aftercooler low on the hull, forward of the keel coolers, for the main and electric set engine jacket water. Heated water from the aftercooler should enter the keel cooler at the rear-most end and be discharged from the cooler for return to the engine at the cooler's forward end. This arrangement assures maximum heat transfer with the vessel either dead in the water or moving ahead.

While the area immediately forward of the propeller(s) is a region of high water velocity and high enough on the hull to be protected from grounding damage, one must consider the effects on the keel cooler from sandblasting (from the propeller(s) during backing maneuvers).

Pumps for Keel Cooler Circuits

Ordinarily, the engine water pump will satisfactorily circulate the engine jacket water through the keel cooler, if the water lines to and from the cooler are relatively short, of adequate size, with minimum bends and if the keel cooler restriction is low. If the total external flow resistance cannot be held within the jacket water pump's capacity, an auxiliary boost pump will be required.

Need for Corrosion Inhibitor
A suitable corrosion inhibitor, carefully maintained, will minimize internal corrosive effects. See the section on cooling system protection.

Venting and Piping of Keel Coolers
Locate the cooler and its through-hull connections so the length of water piping will be kept to a minimum and the cooler will be well vented. Extend water piping downward from the engine to the keel cooler, without high points.

It is very difficult to purge trapped air from the high points of some keel coolers. The air must be bled off during initial fill and whenever the system is completely drained. Vent plugs must be designed into the keel coolers where they rise toward the bow and stern, and any other high points where air may be trapped.

Radiator Cooling

With radiator cooling, the hot water from the engine jacket flows to the radiator core where it is cooled by air being pushed or pulled over the core fins by a fan. The cooled water is then pumped back through the engine; circulation is maintained by a gear- or belt-driven jacket water pump.

When Used
Radiator cooling is used to cool engines that must be located well above the vessel water line or for emergency generator sets that require completely independent support systems.

Radiator Sizing
As with all cooling systems, radiators are usually sized for a heat rejection load a minimum of 10% greater than the maximum full load heat rejection rate of the engine. This allows for overload conditions and system deterioration. This 10% should be added after a careful calculation has been made of the radiator size required to accommodate the maximum heat rejection rate (under normal full load operating conditions) at maximum ambient air temperature.

Keep in mind that radiators lose capacity when operated at altitude or when filled with antifreeze. These conditions should be compensated for and added to the 10% compensation discussed above.

Radiators With Engine-Driven Fans
Some Caterpillar Engines may be ordered with engine-driven fans and close-coupled radiators. They are generally available in two sizes for

each engine. The smaller designed for 110° F (43° C) maximum ambient and the larger for 125° F (52° C) maximum ambient temperature.

Caterpillar fan drives are designed to prevent excessive crankshaft loading and to resist vibrations.

Fan Drive Outboard Bearings
Fan drives sometimes require an outboard bearing on the crankshaft pulley. These drives must have a flexible coupling between the pulley and the engine crankshaft. This coupling must not interfere with the longitudinal thermal growth of the crankshaft.

Fan Power Demand
The fan included in Caterpillar radiator systems represents a parasitic load of about 4-8% of the gross power output of the engine.

Radiator System Pressure
Caterpillar radiator cooling systems are designed to work under a pressure of 4-7 psi (27.6-48.3 kPa) to avoid boiling of coolant and allow for best heat transfer.

Remote-Mounted Radiators
On installations where it is desirable to locate the radiator at some distance from the engine – on an upper deck, outdoors or in another room, a remote radiator can be used. Remote-mounted radiator systems require special attention due to the added restriction imposed on the cooling water flow by additional piping. Careful calculations should be made to determine whether a higher output pump is necessary.

Height of Remote Radiators Above Engine
Never remote-mount radiators more than 33 ft (10 m) above the engine. At greater heights, the static head may cause leakage at the engine water pump seals. Consider use of Hotwells in case of need for mounting radiators higher than these guidelines.

Radiators Mounted Below Engines
The radiator top tank loses its air venting capability if it's located below the level of the engine regulator (thermostat) housing.

When a radiator must be mounted lower than the engine, the factory-supplied expansion tank must be used.

Connection Size
Coolant connections must be as large as (or larger than) the applicable engine coolant connections.

Fan Noise
When selecting radiator location, consider fan noise. Noise may be transmitted through the air inlet as well as outlet. As further precaution against noise and vibration, do not rigidly attach ducting to the radiator.

Direction of Prevailing Winds
Also consider the direction of the prevailing winds so the wind does not act against the fan. Another method is to install an air duct outside the wall to direct the air outlet (or inlet). Use a large radius bend and turning vanes to prevent turbulence and air flow restriction.

Hotwell
Hotwell systems are used when static head exceeds 33 ft (10 m) or a boost pump imposes excessive dynamic head.

A mixing tank accommodates total drainback of the remote cooling device and connecting piping. A baffle divides the tank into a hot and cold side but is open sufficiently to assure full engine flow. Baffles are also used where water enters the tank to minimize aeration.

If the Hotwell does not have sufficient volume, the pumps will draw in air during operation. The Hotwell tank must be large enough to accept the full volume of the remote radiator and the interconnecting piping, plus some reasonable amount to prevent air ingestion by the pumps. Generally, 110% of the radiator and piping volume is adequate.

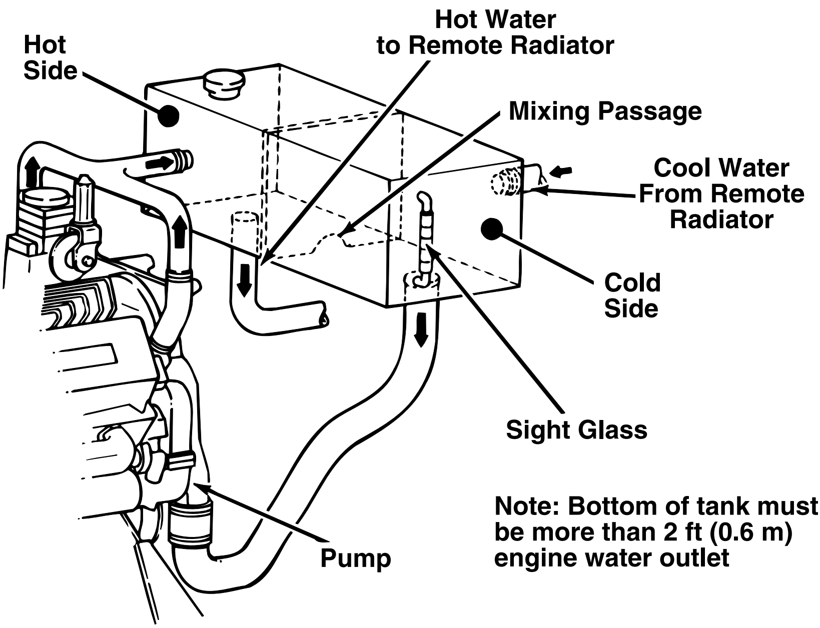


FIGURE 4.22

Piping Slope for Effective Venting
Piping carrying coolant from the engine to the radiator must have a continual upward slope. This is to allow any gases in the coolant to be separated from the coolant and vented in the radiator top tank.

Recirculation

Care must be taken to ensure engine exhaust gases are not drawing into the radiator. Additionally, the radiators must be arranged so the hot air discharge of one radiator does not recirculate to the inlet of another radiator. Also, for maximum efficiency, the direction of radiator air flow should not be against the direction of strong prevailing winds.

When an engine-mounted radiator is used and the generator set is installed in the center of the room, a blower fan can be used and a duct provided to the outside.

This prevents recirculation and high equipment room temperatures. Some radiator packages have, as standard, a radiator duct flange for ease of installation. The duct is as short and direct as possible; its cross-section area should be as large or larger than the radiator core to minimize backpressure. The anticipated backpressure for a proposed duct design should be less than 0.5 in (12.7 mm) of water.

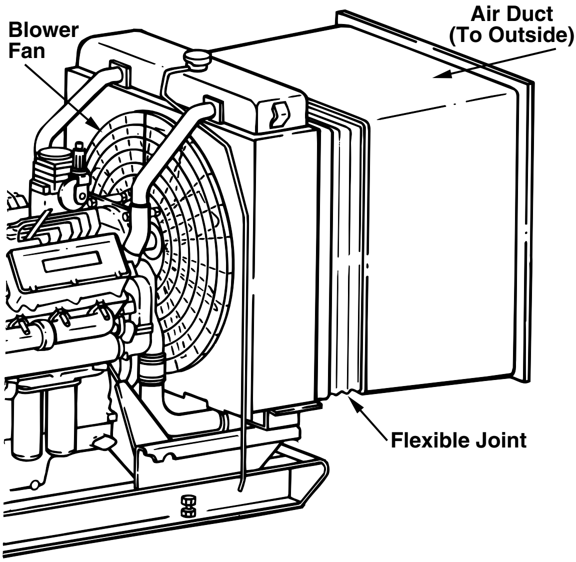


FIGURE 4.23

Duct Work

Duct work and adjustable shutters can be used to direct some or all of the warmed radiator air for heating purposes. Support duct work independently of the engine or radiator.

Static pressure imposed by the duct work must be determined for each installation. Consult the radiator manufacturer to determine the permissible static pressure.

The fan shroud must be properly positioned for optimum air flow. With a blower fan, two-thirds of the fan width should be outside the shroud. With a suction fan, two-thirds of the fan width should be inside the shroud.

Radiator Air Flow
Backpressure or air flow restriction reduces radiator performance. If radiator air flow is to be ducted, consult the radiator manufacturer regarding the allowable backpressure. An engine installation in an enclosed space requires that the inlet air volume includes the combustion air requirements of the engine unless the air for the engine is ducted directly to the engine from the outside.

Expansion Tanks

Functions

Expansion tanks perform the following functions:

- Vent gases in the coolant
  - — to reduce corrosion.
  - — to prevent loss of coolant due to displacement by gases.
- Provide a positive head on the system pump.
  - — to prevent cavitation.
- Provide expansion volume.
  - — to prevent coolant loss when the coolant expands due to temperature change.
- Provide a place to fill the system, monitor its level, and maintain its corrosion inhibiting chemical additives.
- Provide a place to monitor the system coolant level.
  - — an alarm switch located in the expansion tank will give early warning of coolant loss.*

Fill Rate

The Caterpillar engine-mounted cooling circuits are designed to completely vent during the initial fill for fill rates up to 5 gpm (19.0 L/min). Vent lines are located such that the external cooling circuit will also be vented if the customer piping is installed level with, or below, the proper engine connecting points, and if no air traps are designed in the piping.

Type of Expansion Tank

Engine-Mounted Expansion Tank (Manufactured by Caterpillar)

The engine-mounted expansion tank provides all of the above functions for the engine's jacket water circuit. Caterpillar does not provide expansion tanks for the engines auxiliary water circuit (the aftercooler circuit). It can provide adequate expansion volume for only a modest amount of jacket water. Table 4.1 describes the allowable external volume using only the engine-mounted expansion tank. Consult TMI for engine coolant capacity.

*In case of a system leak, the water in the auxiliary expansion tank must be completely drained before the engine is in danger from coolant loss. Therefore, a water level switch and sight glass will give early warning of coolant loss and significantly protect an engine from this problem.

Table of Cooling System Volumetric Data

Cooling System Volumetric Data

Engine Model	Allowable External Volume With Engine Mounted Tank	
	U.S. Gal	Liters
3116	0.0	0.0
3126	0.0	0.0
3208NA	2.0	7.5
3208T&TA	2.0	7.5
3304B	2.0	7.5
3306B	2.0	7.5
3176/96	0.0	0.0
3406C	10.0	38.0
3406E	0.0	0.0
3408C	14.0	53.0
3412C	14.0	53.0
3412E	0.0	0.0
3508	64.0	243.0
3512	48.0	182.0
3516	32.0	122.0

TABLE 4.1

Deaerator

All the functions of engine mounted expansion tanks may be fulfilled by a simple volume chamber, a few feet higher than, and connected to the jacket water pump, by a continuously upward-sloping standpipe – all *except* for the need to continuously vent combustion gas bubbles.

A deaerator is a device to separate gas bubbles from engine coolant in the absence of a factory-designed, engine-mounted expansion tank.

It is mounted, in series, in the main flow of jacket water between the engine and its heat exchanger.

A simple volume chamber is still required to handle coolant expansion and for venting the separated bubbles to atmosphere.

Engines installed with a simple, volume tank and a deaerator can avoid the use of the engine-mounted expansion tank.

Jacket Water Circuit Auxiliary Expansion Tank (Fabricated by the Engine Installer)
An auxiliary expansion tank is needed when additional expansion volume is required in the cooling system. This generally occurs when keel coolers are used and may occur when remote-mounted heat exchangers are used.

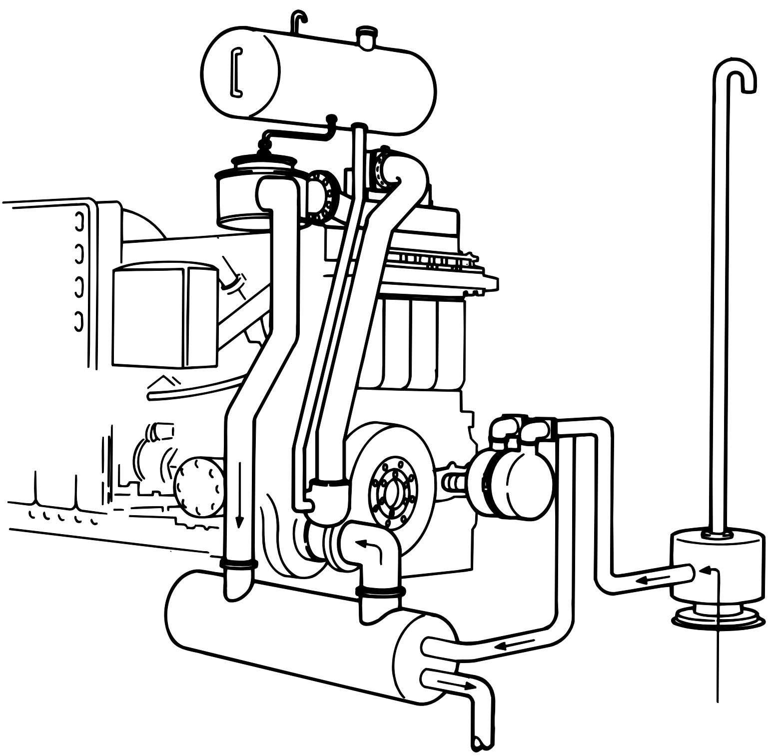
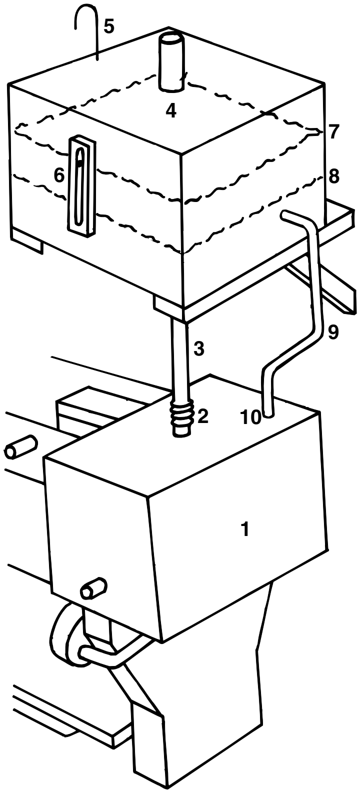


FIGURE 4.24

The auxiliary tank can consist of a simple tank. Internal baffles are not required.

The engine-mounted components of the cooling system will adequately separate gases from the coolant. However, the gases, once separated, must be allowed to rise by a continuous upward sloped standpipe to the auxiliary expansion tank. Additional air vent piping may be required if the auxiliary expansion tank is not located directly above the engine-mounted expansion tank.



AUXILIARY EXPANSION TANK
Engine Jacket Water

1. **Engine mounted expansion tank**
2. **Flexible connection**
3. **Connecting pipe**
4. **Auxiliary expansion tank**
5. **Tank vent**
6. **Level gauge**
7. **Engine mounted expansion tank**
8. **Flexible connection**
9. **Connecting pipe**
10. **Connect lower end of fill vent to vent piping entering rear side of engine mounted expansion tank**

Note: Do not drill engine mounted expansion tank

FIGURE 4.25

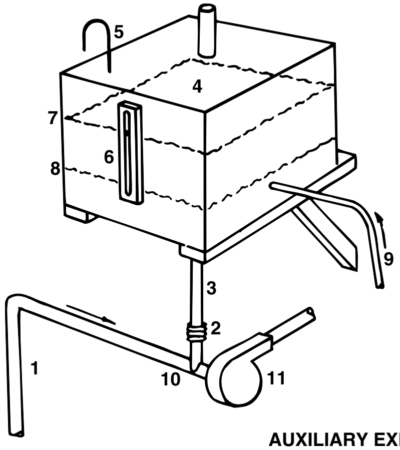
Aftercooler Circuit Auxiliary Expansion Tank (Fabricated by the Engine Installer)
All closed fresh water aftercooler circuits require an expansion tank. The tank provides coolant expansion volume, allows system venting and provides a positive pressure on the inlet side of the circulating pump. The expansion tank must be the highest point in the aftercooler water circuit.

This tank is a simple reservoir with the connecting pipe placed as close to the pump inlet as possible. See Auxiliary Expansion Tank Sizing Worksheet to determine the minimum volume required.

Separately support and isolate the auxiliary tank from the pump inlet and cooler by flexible connections. Install a vent line from the high point on the engine aftercooler circuit to a point in the tank below the tank's low water level. This line must be sloped upwards from the engine to the tank.

All closed separate circuit aftercooler circuits require installation of a vent line. A tapped hole is provided at the high point in the engine-mounted aftercooler circuit. Install a vent line from that point to the aftercooler circuit expansion tank. Vent line size of 0.25 in. (6.3 mm) is adequate. The vent line should enter the tank below the low water level. If possible, water lines connecting to the aftercooler circuit should be level with or below the connecting points on the engine. If the water lines must run above the connection points on the engine, it will be necessary to vent the high points in the external system. Air traps in the external system piping should be avoided.

Sizing the Volume of Auxiliary Expansion Tanks
The minimum volume of the auxiliary tank should include the total jacket water system expansion volume required, plus the volume for the water to the low water level in the tank. The worksheet on pages 44 and 45, *Auxiliary Expansion Tank Sizing*, can be used to determine the minimum volume required.



1. Return line from cooler
2. Flexible connection
3. Connecting pipe
4. Auxiliary expansion tank
5. Tank vent
6. Level gauge
7. Operating level
8. Cold fill level
9. Vent line from aftercooler
10. Connecting line to auxiliary pump inlet
11. Auxiliary fresh water pump

AUXILIARY EXPANSION TANK
Separate Circuit Aftercooler—Fresh Water

FIGURE 4.26

Auxiliary Expansion Tank Sizing

Engine Model _____________ Rating ________ hp at ________ rpm

For Engine Jacket Water, Figure 4.25:

Auxiliary jacket water expansion tanks are not always required.

1. Allowable external volume _________ gal/L, with engine mounted tank. (This value shown in Table 4.1, on page 4-40.)
2. Total volume of jacket water contained in external cooling circuit (not furnished as part of engine) _________ gal/L. See Table 4.2, page 4-54, for volume per length of standard iron pipe.
3. Line 2 minus Line 1 _________ gal/L.
   If this value is zero or less, additional tank is not required.
   If this value is greater than zero, an auxiliary tank is required.
4. If required, the *minimum* volume of the auxiliary expansion tank can be determined by:
   a. Engine volume (TMI) ____________________
   b. External volume Line 2 ____________________
   c. Total volume –
      sum of line a and line b ____________________
   d. Multiply line a by 0.06 ____________________
   e. Multiply line b by 0.04 ____________________
   f. Multiply line c by 0.01 ____________________
   g. Total of lines d, e and f ____________________

   (This is the minimum volume of the jacket water auxiliary expansion tank.)

For Separate Circuit Aftercooler, Figure 4.26:

1. Total volume of aftercooler external water __________ gal/L.
2. Multiply Line 1 by 0.02 __________ gal/L.
3. Add the cold fill volume desired in auxiliary expansion tank to Line 2. Total of Line 2 and cold fill volume __________ gal/L.

   (This is the minimum volume of the aftercooler circuit auxiliary expansion tank.)

Mounting of Auxiliary Expansion Tank

Separately support and isolate the auxiliary tank against vibration from the engine-mounted tank with a flexible connector.

Pressurization of Systems Containing Auxiliary Expansion Tanks – Afterboil

Generally, pressure caps are not required or desirable on auxiliary expansion tanks. This is to allow free venting and refilling, when required.

An exception exists in the situation of high performance craft, such as fast ferrys, yachts and patrol craft: vessels of this type are prone to have their engines stopped immediately after periods of hard use. In this circumstance, a phenomenon known as *afterboil* can occur.

Afterboil is the boiling (change of liquid to vapor) of the coolant, caused by hot engine components which have lost coolant flow and pressure when the engine is hastily shut off. This can result in sudden loss of coolant out the vents and fill openings of the expansion tank. This can be dangerous to personnel in the area if they are not expecting it.

Afterboil Hazard – How to Avoid It

System pressurization with pressure caps on the auxiliary expansion tanks will minimize afterboil but cannot completely avoid it. It is strongly recommended that auxiliary expansion tank vents and fill openings be arranged so any hot coolant being discharged during afterboil will not present danger to personnel. Vents should carry the vented hot water directly into the bilge.

Use of the *Burp Bottle*

This is just like the overflow bottle system found on most modern automobiles and for the same reasons.

After each occurrence of afterboil, the system will need to be refilled. This can be avoided by using a *burp bottle*. The burp bottle is a reservoir for temporary storage of the discharged coolant. The jacket water circuit auxiliary expansion tank vent leads to the bottom of the burp bottle. As soon as the steam bubbles condense within the engine, the displaced coolant will be drawn back into the system by the resultant vacuum. Use of the burp bottle requires the jacket water circuit auxiliary expansion tank be fitted with a double-acting pressure cap*.

Filling of Auxiliary Expansion Tanks

Auxiliary expansion tanks in vessels operated so their engines are not subjected to afterboil should have permanently installed provisions to add water from the ship's portable water supply plumbing. It should be possible for the operator to add water to the system by opening and shutting a valve. This is to minimize danger to the operator when adding system water during severe sea conditions.

Care should be taken to ensure that the coolant full level in the tank is above all piping in order to fill the system.

If it is necessary to design a cooling system that will not purge itself of air when being filled, provide vent lines from high points to the expansion tank. These vents should enter the tank below the normal low water level to prevent aeration of the water which will circulate through these lines when the engine is running. Slope the vent line upwards with no air traps. The vent line should be 0.25 in. (6.3 mm) tubing. Use of a smaller size will clog and may not provide adequate venting ability. Too large a vent tube may introduce a circuit that could contribute either to subcooling or overheating, depending on the location.

If at all possible, avoid external piping designs that require additional vent lines.

Cooling System Protective Devices

A most common problem associated with properly installed cooling systems is loss of coolant, generally due to breaking a water hose and overheating, which can have many causes. As with many engine safety devices, the decision to automatically shut down the engine without warning, or to continue operation risking total engine destruction, is for the careful consideration of the owner. In conditions where the entire boat and the lives of those on board are at stake, it may be appropriate to use a safety system which does not have automatic shutdown capability. The boat's pilot has the option to continue operation of a distressed engine to provide a few more minutes of engine power to escape a more present danger.

*A double-acting pressure cap is one which will hold a certain pressure or vacuum.

Coolant Level Switches

Coolant level switches are devices which can give early warning of coolant loss. They generally consist of a sealed single pole-double throw switch, actuated by a float which rides on the surface of the coolant in the expansion tank. It is good design practice to locate the coolant level switch in the highest part of the cooling system – to give earliest warning of a drop in coolant level. High water temperature switches will not give warning of coolant loss; their temperature sensing portion works best when surrounded by liquid water rather than steam.

High Water Temperature Switches

High water temperature switches are devices which continuously monitor the temperature of some fluid, generally coolant, and actuate switch contacts when the fluid temperature goes above some preset limit. In the case of jacket water coolant, the set point is usually between 205° and 215° F (96° and 102° C), depending on the engine, cooling system type, and whether alarm of *impending problems* or *actuation of engine shutdown systems* is desired. Switches can be set for either condition.

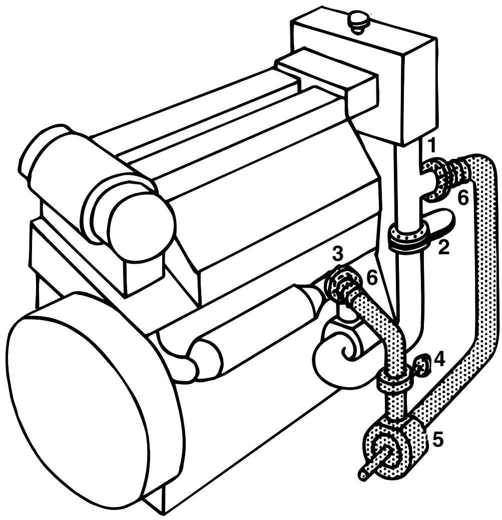
Emergency Systems

The worldwide marine classification societies require in certain applications that, for unrestricted seagoing service, engines be equipped with a separate emergency supply of cooling water flow. The requirement applies to both the engine jacket water and auxiliary (sea or fresh) water systems. The purpose of the emergency systems is to ensure cooling if either the jacket water or auxiliary (sea or fresh) water pump should fail. The customer-supplied emergency pumps should provide flow equal to the failed pump to permit operation at full, continuous power with the emergency systems. For pump flow requirements of engine-mounted pumps, refer to Technical Marketing Information (TMI) or consult the Caterpillar Dealer. If reduced power operation is acceptable, reduced flows can be utilized. Use flexible connectors at the engine to protect the piping and engine.

Jacket Water Pump Connections

The optional Caterpillar emergency jacket water connections (available for the large Vee engines) meet the requirements of the engine and the marine classification societies. Use of these connections permits the emergency system to utilize the normal jacket water as the coolant and to bypass the engine-mounted jacket water pump. The system includes a blanking plate or valve to direct jacket water to the emergency system and flanged connection points on the engine for the emergency system piping. Figure 4.27 is a schematic diagram of the system properly connected. The customer-supplied emergency water pump should provide flow equal to the failed pump.

The use of seawater in the engine jacket water system is not recommended. If seawater must be used in the jacket water system to ensure the safety of the ship in an emergency situation, use the lowest engine power level commensurate with the sea state. On reaching port, the jacket water system must be thoroughly flushed and cleaned.



EMERGENCY JACKET WATER PUMP CONNECTIONS
(Location of Jacket Water Pump May Vary)

1. **Flanged tee connection — to emergency pump**
2. **Blanking plate — closed for emergency pump operation**
3. **Flanged tee connection — from emergency pump**
4. **Valve — customer supplied (open for emergency pump operation)**
5. **Emergency pump — customer supplied**
6. **Flexible connector — customer supplied**

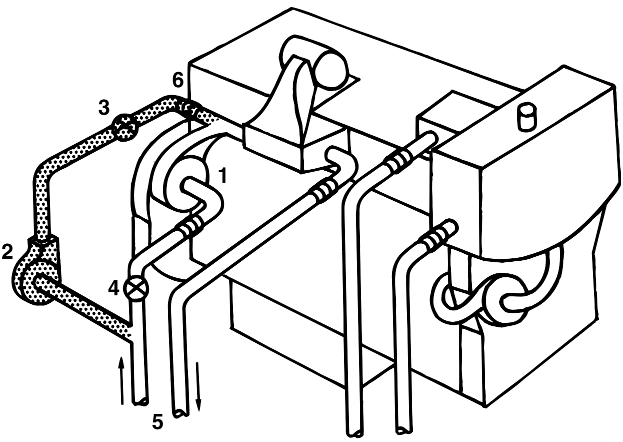
FIGURE 4.27

Auxiliary Seawater Pump Connections

All emergency seawater cooling connections are to be provided by the installer and connected as indicated in the figure illustrating emergency auxiliary pump connections. The emergency seawater pump should provide flow equal to the failed pump.

Auxiliary Freshwater Pump Connections

All emergency connections for separate keel cooled aftercooler circuits are to be provided by the installer, and connected as indicated in the figure illustrating emergency auxiliary pump connections. The flow required for the emergency separate keel cooled aftercooler pump should equal the failed pump. The use of seawater in the separate keel cooled aftercooler circuit is not recommended. The engine-mounted pump and lines are of ferrous material and have low corrosion resistance in seawater. If seawater must be used in an emergency to ensure the safety of the ship, thoroughly flush the system as mentioned in the jacket water section, and inspect the parts for corrosion damage and deposits.



EMERGENCY AUXILIARY PUMP CONNECTIONS

1. **Engine mounted auxiliary pump**
2. **Customer provided emergency auxiliary pump**
3. **Customer provided valve (normally closed)**
4. **Customer provided valve (normally open)**
5. **Auxiliary cooling circuit**
6. **Flexible connection**

FIGURE 4.28

Central Cooling Systems

A central cooling system is defined as one which cools multiple engines and which combines many individual system components (heat exchangers and pumps) into large *central* ones. There are economic advantages to such systems.

Advantages of a Central Cooling System

There are fewer lines to install, significantly reducing the amount of shipyard labor required to install such a system.

The smaller number of components cost less to procure, inventory, and support with repair units.

Larger components are generally more robust and can be expected to last longer.

Disadvantages of a Central Cooling System

It is very difficult to diagnose problems in such a system because there are so many modes of operation possible:

For example: with a system containing three engines, one heat exchanger, and two pumps, there will be 162 possible combinations or modes of operation.

Following is a list of common errors in designing such systems:

Running	Engine Load	Maintenance Condition	Redundancy Required for Reliability
Yes	High	Operational shutdown for maintenance but still connected to the system	In the heat exchanger
No	Intermediate		In the interconnecting plumbing*
	Low	Overhaul in process, disconnected from the system	In the pump(s) and their controls/switchgear

*In areas of severe marine growth problems, it is a good idea to have two parallel sets of plumbing so that one set can be in process of being cleaned at any given time.

Flow Control

There are upper and lower limits to the allowable flow through an engine. The system must be able to throttle the flow through each engine independently.

Temperature Control

The heat exchanger must be capable of delivering the proper amount of cooling, proportional to engine load.

Load Control

The amount of *external* water flow through a Caterpillar Engine is directly proportional to the engine's load. The greater the load, the greater the amount of cooling required and the more water the engine's internal cooling circuitry will discharge for cooling. At light loads, the engine's temperature controls will bypass the external portion of the engine cooling system, recirculating virtually all of the coolant. If the water pressure presented to an engine by a central cooling system is too high, the proper operation of the engine's temperature controls may be overridden, and the engine will suffer over or under cooling problems. It is very difficult to adequately balance and control the flow through several engines, all of which might be operating at widely varying loads.

The water pressure on an engine jacket water inlet cannot be allowed to exceed 25 psi (172 kPa). Economic factors encourage many designers to use higher pressures. Do not use higher pressures. Higher pressures will significantly reduce water pump seal life.

Suggestions for Design of a Successful Central Cooling System
Keep each engine's jacket water system independent of all others. The load control problems are not economically solvable.

Use a separate heat exchanger at each engine for cooling of the engine jacket water.

Provide a *ring main* of freshwater, circulated by at least two, parallel water pumps. A third water pump should be kept in reserve to maintain operation when either of the other pumps require maintenance. Each pump should be identical for ease of parts inventory and maintenance. The ring main is the water source for each engine's independent cooling system. The temperature and pressure of the water in the ring main do not need precise control. Each engine should have an engine-driven, auxiliary (not jacket water) water pump. This pump will draw water from the ring main and return it back to the ring main, downstream.

System Pressure Drop

The total external system resistance to flow must be limited in order to ensure adequate flow. The resistance to flow is determined by the size and quantity of pipe, fittings and other components in the portion of the cooling system which is external to the engine. As the resistance (pressure drop) increases, the engine-driven water pump flow decreases.

The external resistance imposed on the pump (also called external head) includes both the resistance ahead of the pump inlet and the resistance downstream of the engine. The resistance to flow in the external circuit of a closed circulating system consists only of the frictional pressure drop. The resistance to flow in an external open cooling circuit consists of not only the frictional pressure drop but also the height of suction lift on the pump inlet and the heights of the lift on the engine outlet.

Curves showing water flow versus total external system head for engine-driven pumps are available. The value for the maximum external resistance must not be exceeded in the cooling circuit added by the customer in order to maintain minimum water flow. Flows lower than the minimums will certainly shorten the life of the engine.

When designing the engine cooling systems, pressure drop (resistance) in the external cooling system can be calculated by totaling the pressure drop in each of the system's components. The section of useful tables to designers of cooling systems can be used to determine the pressure drop through pipe, fittings and valves. Suppliers of other components, such as strainers and sea cocks, can provide the data required for their product.

It is always necessary to evaluate the design and installation of the cooling circuits by testing the operation and effectiveness of the completed system to ensure proper performance and life.

Corrosion

Galvanic Corrosion in Seawater

When two dissimilar metals are electrically connected and both submerged in saltwater, they form a battery and an electrochemical reaction takes place. In this process, one metal is eaten away. The rate of deterioration is proportional to a number of factors:

- The differential potential between the two metals on the electrochemical series (see Useful Tables to Designers of Cooling Systems).
- The relative areas of the two metals: If there is a small area of the more noble metal relative to the less noble metal, the deterioration will be slow and relatively minor. If there is a large area of the more noble metal such as copper sheathing on a wooden hull, and a much smaller area of the less noble metal, such as iron nails holding the copper sheathing to the wood, the wasting away of the iron nails will be violent and rapid.

Dissimilar Metal Combinations to Avoid

- Bronze Propeller on Steel Shaft
- Mill Scale on Hull Plate (Internal or External)
- Aluminum Fairwaters Fastened to a Steel Hull
- Steel Bolts in Bronze Plates
- Bronze Unions and Elbows Used With Galvanized Pipe
- Bronze Sea Cocks on Iron Drain Pipes
- Brass Bilge Pumps on Boats With Steel Frames
- Brass, Bronze, or Copper Fasteners in Steel Frames
- Stainless Steel Pennants on Steel Mooring Chains

- Bronze or Brass Rudder Posts With Steel Rudders
- Bronze Rudders With Steel Stopper-Chains
- Steel Skegs (Rudder Shoes) Fastened With Bronze or Brass Leg Screws
- Steel and Brass Parts in the Same Pump

Rule of Thumb:
Do not put iron or steel close to or connected with alloys of copper under salt water.

The Protective Role of Zinc

If alloys of copper (bronze, brass), iron (steel), and zinc are all connected together and submerged in salt water, the zinc will be eaten away, protecting the iron (steel). It is necessary to have a metallic electrical connection to the metals to be protected. This is usually easy to accomplish on a steel hull. It is more difficult on a fiberglass hull, since special electrical connection may be required unless the zincs are connected directly to one of the metals, preferably the copper alloy.

The Zinc Must Never Be Painted! When electrical contact is made through the fastening studs, it's desirable to put galvanized or brass bushings in the holes in the zincs so that contact will be maintained as the zincs corrode.

Zincs should be periodically inspected. As they work, a white, crust-like deposit of zinc oxides and salts form on the surface. This is normal. If it does not form and the zincs remain clean and like new, they are not protecting the structure.

If the zincs are not working, look for the following conditions:

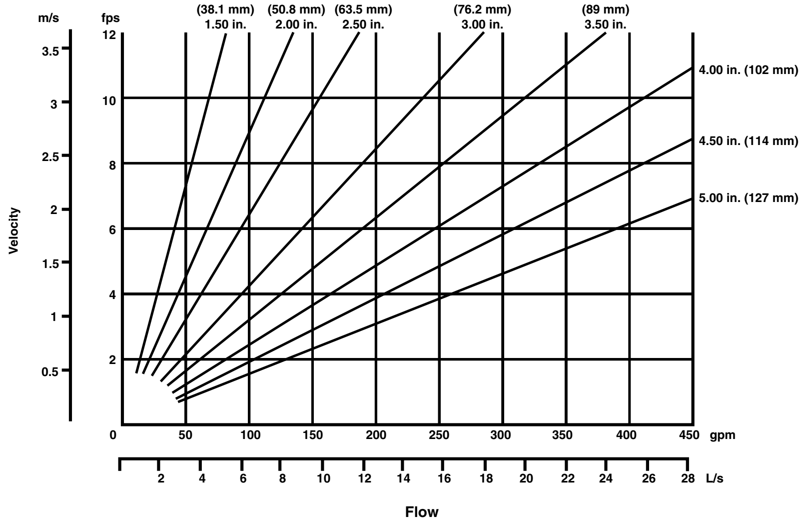
- The anode is not electrically bonded to the structure.
- The paint on the structure is still in near perfect condition.

Pipe Dimensions

Standard Iron Pipe

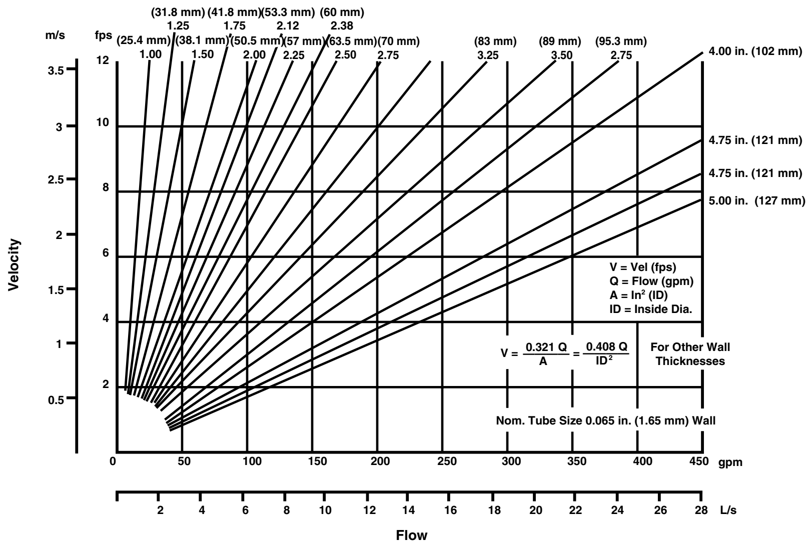
Nominal Size		Actual I.D.		Actual O.D.		ft. per	m per	ft. per	m per
in.	(mm)	in.	(mm)	in.	(mm)	gal.	Liter	cu. ft.	m^3
⅛	3.18	0.270	6.86	0.405	10.29	336	27.0	2513	27,049
¼	6.35	0.364	9.25	0.540	13.72	185	16.1	1383	14,886
⅜	9.53	0.494	12.55	0.675	17.15	100.4	8.3	751	8,083
½	12.7	0.623	15.82	0.840	21.34	63.1	5	472	5,080
¾	19.05	0.824	20.93	1.050	26.68	36.1	2.9	271	2,917
1	25.4	1.048	26.62	1.315	33.4	22.3	1.9	166.8	1,795
1¼	31.75	1.380	35.05	1.660	42.16	12.85	1.03	96.1	1,034
1½	38.1	1.610	40.89	1.900	48.26	9.44	0.76	70.6	760
2	50.8	2.067	52.25	2.375	60.33	5.73	0.46	42.9	462
2½	63.5	2.468	62.69	2.875	73.02	4.02	0.32	30.1	324
3	76.2	3.067	77.9	3.500	88.9	2.60	0.21	19.5	210
3½	88.9	3.548	90.12	4.000	101.6	1.94	0.16	14.51	156
4	101.6	4.026	102.26	4.500	114.3	1.51	0.12	11.30	122
4½	114.3	4.508	114.5	5.000	127	1.205	0.097	9.01	97
5	127	5.045	128.14	5.563	141.3	0.961	0.077	7.19	77
6	152.4	6.065	154	6.625	168.28	0.666	0.054	4.98	54
7	177.8	7.023	178.38	7.625	193.66	0.496	0.04	3.71	40
8	203.2	7.982	202.74	8.625	219.08	0.384	0.031	2.87	31
9	228.6	8.937	227	9.625	244.48	0.307	0.025	2.30	25
10	254	10.019	254.5	10.750	273.05	0.244	0.02	1.825	19.6
12	304.8	12.000	304.8	12.750	323.85	0.204	0.016	1.526	16.4

Velocity Versus Flow (Standard Pipe Sizes)



VELOCITY vs FLOW
Standard Pipe Sizes 1.5 to 5 in.
(38.1 to 127 mm)

FIGURE 4.29



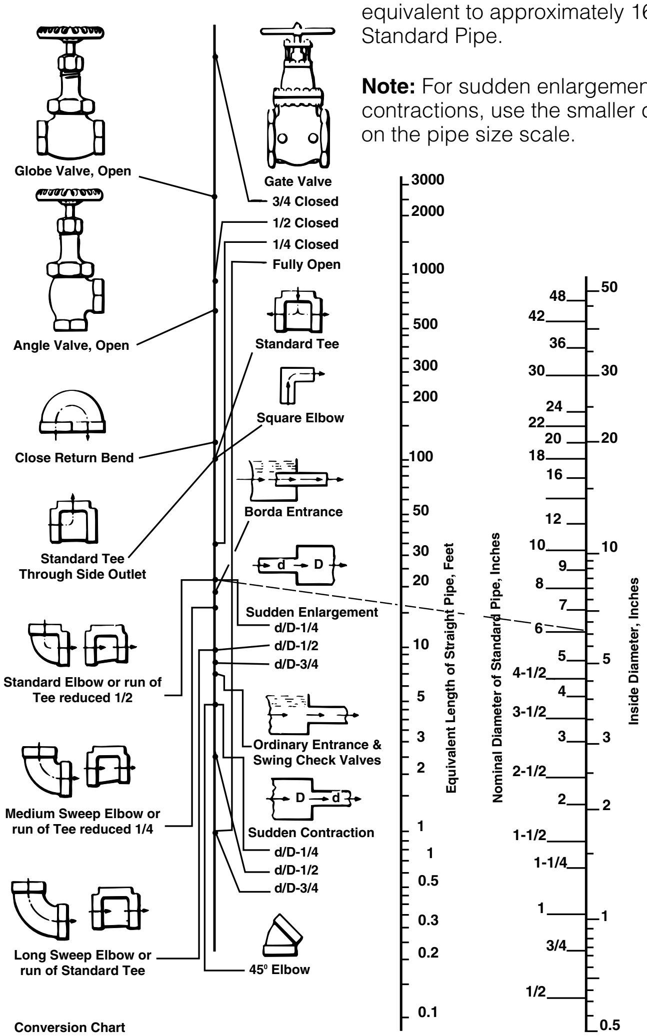
VELOCITY vs FLOW
Tube Sizes From 1 in. to 5 in. O.D. (25.4 mm to 127 mm)
(Common Usage Wall Thickness)

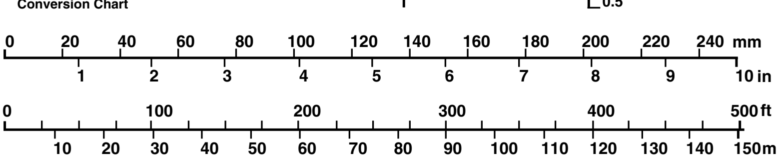
FIGURE 4.30

Resistance of Valves and Fittings to Flow of Fluids

Example: The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note: For sudden enlargements or sudden contractions, use the smaller diameter, **d**, on the pipe size scale.





This chart is for illustrative purposes only. Do not attempt to use this for measurement.

Electrochemical Series

Corroded End – Least Noble
Magnesium
Magnesium Alloys
Zinc
Beryllium
Aluminum Alloys
Cadmium
Mild Steel or Iron
Cast Iron
Low Alloy Steel
Austanitic Cast Iron
Aluminum Bronze
Naval Brass
Yellow Brass
Red Brass
18-8 Stainless Steel (Active)
18-8-3 Stainless Steel (Active)
Lead-Tin Solders
Lead
70-30 Copper-Nickel
Tin
Brasses
Copper
Bronzes
Copper-Nickel Alloys
Monel
Admiralty Brass, Aluminum Brass
Manganese Bronze
Silicon Bronze
Tin Bronze
Silver Solder
Nickel (Passive)
Chromium-Iron (Passive)
18-8 Stainless Steel (Passive)
18-8-3 Stainless Steel (Passive)
Silver
Ni-Cr-Mo Alloy 8
Titanium
Ni-Cr-Mo Alloy C
Gold
Platinum
Graphite
Protected End – Most Noble

Corrosion Rates of Various Metals in Seawater

Representative Corrosion Rates in Seawater

Metal	Corrosion Rate in Quiet Seawater* mm/yr
Aluminum	0.02 to 1.20
Zinc	0.02 to 0.25
Lead	> 0.02 to 0.38
Iron (Steel)	0.10 to 0.25
Silicon Iron	0.00 to 0.07
Stainless Steel**	0.00 to 0.12
Copper Alloys	0.01 to 0.38
Nickel Alloys	0.00 to 0.02
Titanium	Nil
Silver	Nil
Platinum	Nil

*Rates are ranges for general loss in seawater at ambient temperatures and velocities no greater than 3 ft (1 m) per second. Pitting penetration is not considered.

**Many stainless steels exhibit high rates of pitting in stagnant seawater.

Δ T-Flow Relationship

$$\Delta T\,(^\circ F) = \frac{\text{Heat Rejection (BTU/MIN.)}}{\text{Flow (GPM)} \times \text{Density (LB/GAL.)} \times \text{Spec. Heat (BTU/LB}\bullet{}^\circ\text{F)}}$$

	Pure Water	Sea Water	50/50 Water – Glycol	Diesel Fuel
Density (LB/GAL.)	8.1	8.5	8.6	7.1
Specific Heat (BTU/LB•°F)	1.0	0.94	0.85	0.45

$$\Delta T\,(^\circ C) = \frac{\text{Heat Rejection (kW)}}{\text{Flow (L/MIN.)} \times \text{Density (KG/L)} \times \text{Spec. Heat} \left(\frac{\text{kW}\bullet\text{MIN.}}{\text{KG}\bullet{}^\circ\text{C}}\right)}$$

	Pure Water	Sea Water	50/50 Water – Glycol	Diesel Fuel
Density (KG/L)	0.98	1.02	1.03	0.85
Specific Heat $\left(\frac{\text{kW}\bullet\text{MIN.}}{\text{KG}\bullet{}^\circ\text{C}}\right)$	0.071	0.066	0.06	0.032

Piping Design – Flow Relationships

Recommended Coolant Velocities
- Jacket Water: 2-8 FT./SEC. (0.6-2.5 M/SEC.)
- Sea Water: 2-6 FT./SEC. (0.6-1.9 M/SEC.)

Maximum Fresh Water Velocities for 3600 Engines
- Pressurized Lines: 14.8 FT./SEC. (4.5 M/SEC.) Max.
- Suction Lines: 4.9 FT./SEC. (1.5 M/SEC.) Max.

Flow Restriction of Fittings Expressed as Equivalent Feet of Straight Pipe

Size of Fitting	2"	2½"	3"	4"	5"	6"	8"	10"	12"	14"	16"
90 Ell	5.5	6.5	8	11	14	16	21	26	32	37	42
45 Ell	2.5	3	3.8	5	6.3	7.5	10	13	15	17	19
Long Sweep Ell	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Close Return Bend	13	15	18	24	31	37	51	61	74	85	100
Tee – Straight Run	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Tee – Side Inlet or Outlet	12	14	17	22	27	33	43	53	68	78	88
Globe Valve Open	55	67	82	110	140						
Angle Valve Open	27	33	41	53	70						
Gate Valve Fully Open	1.2	1.4	1.7	2.3	2.9	3.5	4.5	5.8	6.8	8	9
Gate Valve Half Open	27	33	41	53	70	100	130	160	200	230	260
Check Valve	19	23	32	43	53						

Strainers:

As a general rule of thumb, strainers should be of adequate capacity to create no more than 1.5-2.0 psi (10-14 kPa) of pressure drop under clean strainer conditions at maximum flow. Recommended strainer media (screens) should not pass solid objects larger than 1/16 in. (1.6 mm) in diameter. It is strongly recommended to have a serviceable strainer.

Typical Friction Losses of Water in Pipe

(Old Pipe)
(Nominal Pipe Diameter)

Gallons per Minute		Head Loss in Feet of Water per 100 ft. of Pipe (m per 100 m)							Gallons per Minute	
gpm	(l/s)	¾" (19.05 mm)	1" (25.4 mm)	1¼" (31.75 mm)	1½" (38.1 mm)	2" (50.8 mm)	2½" (63.5 mm)		gpm	(l/s)
5	.34	10.5	3.25	0.84	0.40	0.16	0.05	3" (76.2 mm)	5	.34
10	.63	38.0	11.7	3.05	1.43	0.50	0.17	0.07	10	.63
15	.95	80.0	25.0	6.50	3.05	1.07	0.37	0.15	15	.95
20	1.26	136.0	42.0	11.1	5.20	1.82	0.61	0.25	20	1.26
25	1.58	4" (101.6 mm)	64.0	16.6	7.85	2.73	0.92	0.38	25	1.58
30	1.9	0.13	89.0	23.0	11.0	3.84	1.29	0.54	30	1.9
35	2.21	0.17	119.0	31.2	14.7	5.10	1.72	0.71	35	2.21
40	2.52	0.22	152.0	40.0	18.8	6.60	2.20	0.91	40	2.52
45	2.84	0.28	5" (127 mm)	50.0	23.2	8.20	2.76	1.16	45	2.84
50	3.15	0.34	0.11	60.0	28.4	9.90	3.32	1.38	50	3.15
60	3.79	0.47	0.16	85.0	39.6	13.9	4.65	1.92	60	3.79
70	4.42	0.63	0.21	113.0	53.0	18.4	6.20	2.57	70	4.42
75	4.73	0.72	0.24	129.0	60.0	20.9	7.05	2.93	75	4.73
80	5.05	0.81	0.27	145.0	68.0	23.7	7.90	3.28	80	5.05
90	5.68	1.00	0.34	6" (152.4 mm)	84.0	29.4	9.80	4.08	90	5.68
100	6.31	1.22	0.41	0.17	102.0	35.8	12.0	4.96	100	6.31
125	7.89	1.85	0.63	0.26	7" (177.8 mm)	54.0	17.6	7.55	125	7.89
150	9.46	2.60	0.87	0.36	0.17	76.0	25.7	10.5	150	9.46

Typical Friction Losses of Water in Pipe (cont.)

gpm	(l/s)	4" (101.6 mm)	5" (127 mm)	6" (152.4 mm)	7" (177.8 mm)	8" (203.2 mm)	2½" (63.5 mm)	3" (76.2 mm)	gpm	(l/s)
175	11.05	3.44	1.16	0.48	0.22		34.0	14.1	175	11.05
200	12.62	4.40	1.48	0.61	0.28	0.15	43.1	17.8	200	12.62
225	14.20	5.45	1.85	0.77	0.35	0.19	54.3	22.3	225	14.20
250	15.77	6.70	2.25	0.94	0.43	0.24	65.5	27.1	250	15.77
275	17.35	7.95	2.70	1.10	0.51	0.27	**9" (228.6 mm)**	32.3	275	17.35
300	18.93	9.30	3.14	1.30	0.60	0.32	0.18	38.0	300	18.93
325	20.5	10.8	3.65	1.51	0.68	0.37	0.21	44.1	325	20.5
350	22.08	12.4	4.19	1.70	0.77	0.43	0.24	50.5	350	22.08
375	23.66	14.2	4.80	1.95	0.89	0.48	0.28	**10" (254 mm)**	375	23.66
400	25.24	16.0	5.40	2.20	1.01	0.55	0.31	0.19	400	25.24
425	26.81	17.9	6.10	2.47	1.14	0.61	0.35	0.21	425	26.81
450	28.39	19.8	6.70	2.74	1.26	0.68	0.38	0.23	450	28.39
475	29.97		7.40	2.82	1.46	0.75	0.42	0.26	475	29.97
500	31.55		8.10	2.90	1.54	0.82	0.46	0.28	500	31.55
750	47.32			7.09	3.23	1.76	0.98	0.59	750	47.32
1000	63.09			12.0	5.59	2.97	1.67	1.23	1000	63.09
1250	78.86				8.39	4.48	2.55	1.51	1250	78.86
1500	94.64				11.7	6.24	3.52	2.13	1500	94.64
1750	110.41					7.45	4.70	2.80	1750	110.41
2000	126.18					10.71	6.02	3.59	2000	126.18

Helpful Formula's for the Marine Analyst

The outside surface area of a pipe can be determined using the following formula:

Outside surface area in Square Feet per Foot = 0.2618 × Pipe Diameter

The velocity of water in a pipe can be calculated using the following formula:

$$\mathbf{V = \frac{GPM \times 0.408}{D^2}}$$

V = Velocity in Feet per Second
GPM = Gallons per minute of water flow
D = Pipe diameter nominal – Inches (ID)

The velocity of water in a tube can be calculated using the following formula:

$$\mathbf{V = \frac{GPM \times 0.427}{D^2}}$$

V = Velocity in Feet per Second
GPM = Gallons per minute of water flow
D = Pipe diameter nominal – Inches (OD)

The multiplier for determining the length in feet of **channel** to get a certain amount of surface area, can be determined by using the following formula:

$$\mathbf{L = \frac{12}{\text{web height} + (2 \times \text{flange width})}}$$

Length of Channel to achieve surface area require = L × Square foot area requirement.

The multiplier for determining the length in feet of **pipe** to get a certain amount of surface area, can be determined by using the following formula:

$$\mathbf{L = \frac{12}{\text{Pi} \times \text{outside diameter}}}$$

Length of pipe to achieve surface area require = L $\times$ Square foot area requirement.

$$\frac{\text{GPM}}{60} = \text{Gals. second}$$

Gals. second $\times$ 0.1337 = cubic feet/second

$$\frac{\text{Cubic feet/second}}{\text{square foot cross sectional area}} = \text{Velocity in feet/second}$$

Coolant Chemical and Physical Properties

Minimum Acceptable Water Characteristics for Use in Engine Cooling Systems

Properties	Limits	ASTM[1] Test Methods
Chloride (Cl), gr/gal (ppm)	2.4 (40) max.	D512b, D512d, D4327
Sulfate (SO4), gr/gal (ppm)	5.9 (100) max.	D516b, D516d, D4327
Total Hardness, gr/gal (ppm)	10 (170) max.	D1126b
Total Solids, gr/gal (ppm)	20 (340) max.	D1886a
pH	5.5 – 9.0	D1293

[1]American Society for Testing and Materials

Boiling Point of Coolant at Varying Antifreeze Concentrations

% Concentration	Temperature at Which Coolant with Ethylene Glycol Will Boil[1]
20	217° F (103° C)
30	219° F (104° C)
40	222° F (106° C)
50	226° F (108° C)
60	231° F (111° C)
70	238° F (114° C)

[1]At sea level.

Protection Temperatures for Antifreeze Concentrations[1]

Protection to:	Concentration
5° F (–15° C)	30% antifreeze, 70% water
–12° F (–24° C)	40% antifreeze, 60% water
–34° F (–37° C)	50% antifreeze, 50% water
–62° F (–52° C)	60% antifreeze, 40% water

[1]Ethylene glycol-based antifreeze.

Barometric Pressures and Boiling Points of Water at Various Altitudes

Barometric Pressure

Altitude	Inches Mercury	Lb. per Square Inch	Feet Water	Point Water Boiling
Sea Level	29.92 In.	14.69 P.S.I.	33.95 Ft.	212.0° F
1000 Ft.	28.86 In.	14.16 P.S.I.	32.60 Ft.	210.1° F
2000 Ft.	27.82 In.	13.66 P.S.I.	31.42 Ft.	208.3° F
3000 Ft.	26.81 In.	13.16 P.S.I.	30.28 Ft.	206.5° F
4000 Ft.	25.84 In.	12.68 P.S.I.	29.20 Ft.	204.6° F
5000 Ft.	24.89 In.	12.22 P.S.I.	28.10 Ft.	202.8° F
6000 Ft.	23.98 In.	11.77 P.S.I.	27.08 Ft.	201.0° F
7000 Ft.	23.09 In.	11.33 P.S.I.	26.08 Ft.	199.3° F
8000 Ft.	22.22 In.	10.91 P.S.I.	25.10 Ft.	197.4° F
9000 Ft.	21.38 In.	10.50 P.S.I.	24.15 Ft.	195.7° F
10000 Ft.	20.58 In.	10.10 P.S.I.	23.25 Ft.	194.0° F
11000 Ft.	19.75 In.	9.71 P.S.I.	22.30 Ft.	192.0° F
12000 Ft.	19.03 In.	9.34 P.S.I.	21.48 Ft.	190.5° F
13000 Ft.	18.29 In.	8.97 P.S.I.	20.65 Ft.	188.8° F
14000 Ft.	17.57 In.	8.62 P.S.I.	19.84 Ft.	187.1° F
15000 Ft.	16.88 In.	8.28 P.S.I.	18.07 Ft.	185.4° F

Caterpillar Diesel Engine[1]
Antifreeze Protection Chart
(Fahrenheit)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	5	-34																
7		-18	-54															
8		-7	-34															
9		0	-20	-47														
10		5	-12	-34	-62													
11			-5	-22	-44													
12			0	-16	-34	-56												
13			3	-8	-24	-44												
14				-5	-18	-34	-53											
15				0	-13	-26	-42	-62										
16				3	-7	-20	-34	-50										
17					-3	-14	-26	-42	-59									
18					0	-10	-20	-34	-47									
19					3	-7	-16	-26	-39	-56								
20					5	-3	-12	-22	-34	-47	-62							
21						0	-8	-18	-26	-39	-53							
22						2	-5	-14	-22	-34	-44	-59						
23						5	-3	-10	-18	-28	-39	-50						
24							0	-17	-16	-24	-34	-44	-56					
25							2	-5	-12	-20	-28	-39	-50	-62				
26							3	-1	-8	-16	-24	-34	-44	-56				
27								0	-7	-14	-20	-28	-39	-47	-59			
28								2	-5	-10	-18	-24	-34	-42	-53			
29								3	-1	-8	-14	-22	-28	-39	-47	-59		
30								5	0	-7	-12	-18	-26	-34	-42	-53	-62	
31									2	-3	-10	-16	-22	-28	-39	-47	-56	
32									3	-1	-7	-14	-20	-26	-34	-42	-50	-59

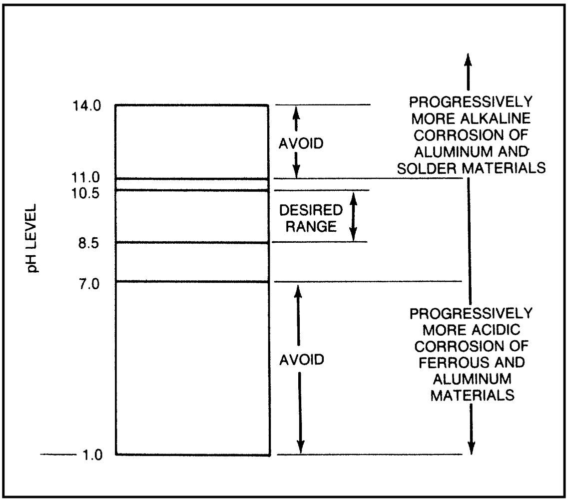
Caterpillar Diesel Engine[1]
Antifreeze Protection Chart
(Celsius)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	-15	-37																
7		-28	-48															
8		-22	-37															
9		-18	-29	-44														
10		-15	-24	-37	-52													
11			-21	-30	-42													
12			-18	-27	-37	-49												
13			-16	-22	-31	-42												
14				-21	-28	-37	-47											
15				-18	-25	-32	-41	-52										
16				-16	-22	-29	-37	-46										
17					-19	-26	-32	-41	-51									
18					-18	-23	-29	-37	-44									
19					-16	-22	-27	-32	-39	-49								
20					-15	-19	-24	-30	-37	-44	-52							
21						-18	-22	-28	-32	-39	-47							
22						-17	-21	-26	-30	-37	-42	-51						
23						-15	-19	-23	-28	-33	-39	-46						
24							-18	-22	-27	-31	-37	-42	-49					
25							-17	-21	-24	-29	-33	-39	-46	-52				
26							-16	-18	-22	-27	-31	-37	-42	-49				
27								-18	-22	-26	-29	-33	-39	-44	-51			
28								-17	-21	-23	-28	-31	-37	-41	-47			
29								-16	-18	-22	-26	-30	-33	-39	-44	-51		
30								-15	-18	-22	-24	-28	-32	-37	-41	-47	-52	
31									-17	-19	-23	-27	-30	-33	-39	-44	-49	
32									-16	-18	-22	-26	-29	-32	-37	-41	-46	-51

[1]Also for use in natural gas engines

pH Scale for Coolant Mixture



Temperature Regulators

CAT Part No.	Opening Temperature*	Fully Open Temperature
4W0018	81° F (27° C)	99° F (37° C)
7C0311	113° F (45° C)	131° F (55° C)
7E1237	154° F (68° C)	178° F (81° C)
4P0301	154° F (68° C)	178° F (81° C)
4W4011	170° F (77° C)	192° F (89° C)
7E6210	171° F (77° C)	192° F (89° C)
7N0208	175° F (79° C)	196° F (91° C)
9N2894	175° F (79° C)	197° F (92° C)
7E7933	181° F (83° C)	198° F (92° C)
4W4794	183° F (84° C)	198° F (92° C)
7N8469	190° F (88° C)	205° F (96° C)
7C3095	190° F (88° C)	208° F (98° C)
4W4842	190° F (88° C)	208° F (98° C)
7W0371	203° F (95° C)	219° F (104° C)
9Y7022	212° F (100° C)	230° F (110° C)
9Y8966	230° F (110° C)	265° F (129° C)

*Normally stamped on regulator

New Temperature Regulators

1330, 1355

3606 (8RB), 3608 (6MC), 3612 (9RC), 3616 (1PD) Industrial Engines

The 3600 Family of Engines has three sets of temperature regulators. The regulators are the jacket water (JW) inlet control, the oil cooler and aftercooler (O/C and A/C) inlet control, and the oil cooler oil temperature control. The chart identifies the new and former regulators. The recommended service hours of temperature regulators is every **6000 service meter hours** or annually, whichever occurs first.

Temperature Regulators

Application	New Regulator Part No.	Former Regulator Part No.	Nominal Temperature °F (°C)	Temperature Range °F (°C)
JW Inlet Control Distillate Fuel	6I4957[2]	4W4794	194 (90)[1]	185-203 (85-95)
JW Inlet Control Distillate Fuel	6I4950[3]	4W4794	189.5 (87.5)[1]	179.8-197.6 (82-92)
JW Inlet Control Residual Fuel	6I4956	7C3095	199.4 (93)[1]	190.4-208.4 (88-98)
O/C-A/C Inlet Control Distillate Fuel	6I4952	7C0311	118 (46)	118.4-122 (48-50)
O/C-A/C Inlet Control Residual Fuel (Two Step)	6I4963[2] 6I4951	4W0018 7E1237	89.6 (32) 167 (75)	80.8-98.6 (27-37) 154.4-177.8 (68-81)
Oil Cooler	6I4954[2]	7E6210	181.4 (83)	168.8-192.2 (76-89)
Oil Cooler	6I4955	4P0301	167 (75)	154.4-177.8 (68-81)

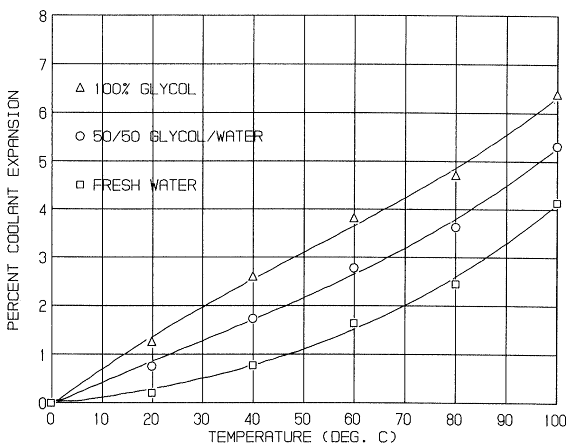
NOTES:
1. Jacket water thermostats control jacket water inlet temperature, while water temperature gauge reads **outlet** temperature. If the external cooling system has the proper restriction and the engine is operating at full load, the **outlet** temperature will be approx. 9° F above inlet temperature.
2. These part numbers are recommended for inland tow boat applications.
3. Alternate thermostats used if application has an outlet temperature of 210° F.

Diagnostic Tooling

Self-Sealing Probe Adapters:

Size	CAT Part No.
⅛" NPT	5P2720
¼" NPT	5P2725
½" O-ring	4C4547
9⁄16" O-ring	5P3591
¾" O-ring	4C4545
Pressure Probe	164-2192

Coolant Expansion Rates



As a rule of thumb, expansion tanks should have a capacity of 16% of the total system coolant volume for expansion plus reserve.

Densities of Liquids [at 60° F (16° C)]

Liquid	lb/U.S. gal	lb/cu ft	kg/cu meter	Specific Gravity
Water, Fresh	8.3	62.1	994.6	1.00
Water, Sea	8.5	63.6	1018.3	1.02
Water/Glycol	8.55	64.0	1024.4	1.03
Diesel Fuel	7.1	53.1	850.7	0.855
Lube Oil	7.6	56.8	909.7	0.916
Kerosene	6.7	50.1	802.7	0.807

Supplemental Coolant Additive (Conditioner or Inhibitor)

SCA %

30% – 60% Antifreeze solution . . . . 3% to 6%

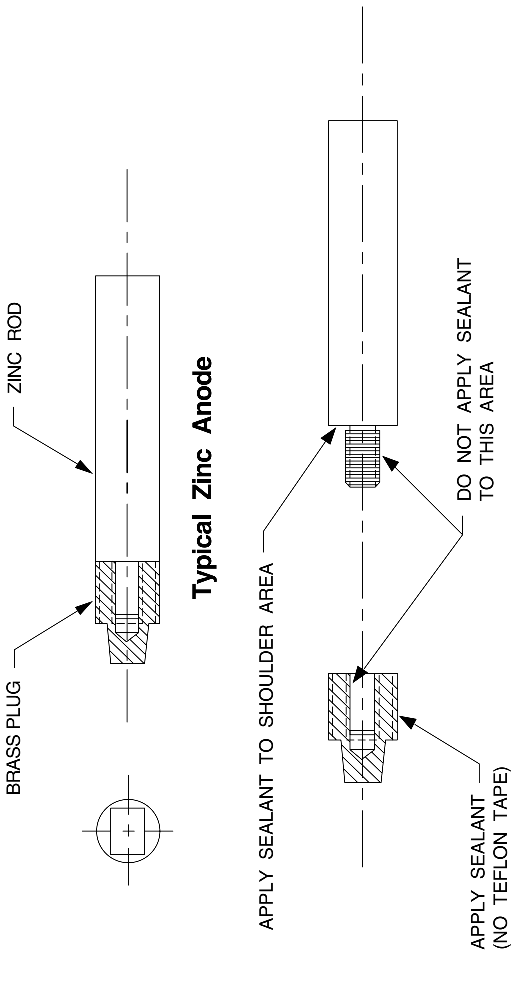
Water-only coolant. . . . . 6% to 8%

Caterpillar recommends using antifreeze in the coolant mixture to get maximum life from cooling system components. 30% is minimum recommendation.

Zinc Anode Summary

Zinc Rod	Straight Thread Size	Rod Length From Shoulder (mm)	Rod Length From Shoulder (in)	Zinc Rod Diameter (mm)	Zinc Rod Diameter (in)
6L3104	1/4 - 20	38.1	1.50	9.5	0.38
6L2283	1/4 - 20	57.0	2.25	10.0	0.39
6L2287	3/8 - 16	22.4	0.88	12.7	0.50
6L2281	3/8 - 16	30.2	1.19	12.7	0.50
6L2280	3/8 - 16	41.0	1.62	13.0	0.51
5B9651	3/8 - 16	50.8	2.00	16.0	0.63
6L2288	3/8 - 16	63.5	2.50	16.0	0.63
6L2289	3/8 - 16	76.0	3.00	16.0	0.63
7F9314	3/8 - 16	114.3	4.50	16.0	0.63
6L2016	5/8 - 18	20.5	0.81	22.0	0.87
6L2284	3/4 - 10	53.8	2.12	31.8	1.25
6L2285	3/4 - 10	63.5	2.50	31.8	1.25

Apply sealant only to the shoulder of the zinc rod before assembling to the brass plug. Sealant is *not* to be applied to the straight threaded joint between the rod and plug. Apply thread sealant to the external pipe thread of the plug following normal procedures and specifications as illustrated below.



Typical Zinc Anode

Sealant Application - Zinc Anode

Brass plugs currently available through the Caterpillar Parts System for use with Caterpillar zinc rods are shown below. Check status and availability prior to final selection. Sacrificial anodes are not provided with the factory supplied heat exchangers. They can be ordered through the Caterpillar parts distribution system.

Brass Plug Summary

Rod Thrd.	Brass Plug	External Plug Thread	Drill Dia. (mm)	Boss Min. Dia. (mm)	Boss Min. Thk. (mm)
1/4 - 20	6L2282	1/4 - 18	11.2	28	6
3/8 - 16	6L2279	3/8 - 18	14.5	30	7
3/8 - 16	5B9169	1/2 - 14	18.0	35	8
5/8 - 18	6L2020	3/4 - 14	23.2	40	9
3/4 - 10	6L2286	1-1/4 -11-1/2	38.0	55	11

Similar to galvanic corrosion, electrolytic corrosion occurs with an external source of current flow through the coolant. Despite sea water or engine coolant mixture quality, presence of an electrical potential can cause electrolytic corrosion damage to the cooling system materials. Aluminum materials are attacked very rapidly by this type of corrosion. Most materials common to cooling systems, such as copper, brass, bronze, copper-nickel, steel, and cast iron, are susceptible to electrolytic corrosion.

Electrical systems must be designed to eliminate continuous electrical potential on any cooling system component. Electrolytic corrosion is extremely difficult to troubleshoot, since the source of electrical current must be located. A common cause is improper grounding or corroded ground connections. Care must be taken during design, installation, and maintenance phases to assure all grounds are tight and corrosion free.

Marine Growth

Over a period of time, marine growth will adversely impact the efficient operation of heat exchangers. It is necessary to periodically *disassemble* heat exchangers to clean heads and tubes. The use of local thermometers, high temperature alarms, and other instrumentation can warn of gradual loss of sea water flow, and are highly recommended. Periodic chemical treatment will also combat marine growth in sea water systems. The chemical type and concentration must be controlled to prevent deterioration of components in the sea water circulating system, and to minimize environmental impact. Contact a knowledgeable supplier if a chemical treatment system is to be installed. Continuous low concentration chemical treatment via either bulk or self-generating electrical processes are available from various manufacturers.

Electro-chemical Series

Corroded End – Least Noble
Magnesium
Zinc
Cadmium
Mild Steel or Iron
Low Alloy Steel
Aluminum Bronze
Naval Brass
Yellow Brass
18-8 Stainless Steel (Active)
18-8-3 Stainless Steel (Active)
Lead
Tin
Brasses
Copper
Bronzes
Copper-Nickel Alloys
Monel
Silicon Bronze
Tin Bronze
Silver
Titanium
Gold
Platinum
Protected End-Most Noble

The further metals are apart on the list, the greater the activity. For example, zinc connected to graphite would deteriorate faster than zinc connected to say mild steel.

Metals freely erode at approximately the following voltages depending on their composition:

	Erode
Bronze	300 millivolts
Steel	500 millivolts
Aluminum	650 millivolts
	Protect
Bronze	600 ± 100 millivolts
Steel	850 ± 100 millivolts
Aluminum	800 to 1050 millivolts

The voltages of metals can be estimated by measuring the voltages between sea water and the metal. The following scale is what you can expect to see in sea water @ 75° F.

Metal or Alloy	Millivolts
Magnesium	1580
Zinc	1050
Cadmium	860
Mild Steel or Iron	790
Low Alloy Steel	740
Aluminum Bronze	625
Naval Brass	450
Yellow Brass	450
18-8 Stainless Steel (Active)	*
18-8-3 Stainless Steel (Active)	*
Lead	420
Tin	500
Brass (60/40)	330
Copper	340
Copper-Nickel Alloys	200
Monel	110
Silicon Bronze	260
Tin Bronze	260
Silver	80
Titanium	100
Gold	< 0
Platinum	< 0

*Stainless Steel could read from 0 to 575 depending on composition and oxygen content of the sea water.

Rule of Thumb: Select metals to be connected, or close in wet wood, that are within 200 millivolts of each other to reduce galvanic corrosion.

Corrosion Rates of Various Metals in Sea Water

Representative Corrosion Rates in Sea Water (Mils per year)

Aluminum	1 to 3
Zinc	1
Lead	0.5
Iron (Steel)	5
Copper	1 to 2
Stainless Steel**	0
Copper-Nickel Alloys	0
Nickel Alloys	0
Titanium	0
Silicon Bronze	1 to 2
Austenitic Cast Iron	2

*Rates are ranges for general loss in sea water at ambient temperatures and velocities no greater than 3 ft (1 m) per second. Pitting penetration is not considered.
**Many stainless steels exhibit high rates of pitting in stagnant sea water.

Multiply mils by 25 for um/year

Electrolysis

The results of electrolysis appear to be the same as galvanic action. However, electrolysis is caused by an external current rather than a current developed by the different metals in contact with an electrolyte.

When electrical current passes through impure water the water will decompose; impurities present in the water will help the decomposition. Also, when the current passes from a positive source to a negative source through the water, the positive source disintegrates. The decomposition of the positive source is commonly termed electrolysis.

The greatest cause of electrolysis is improper grounding of electrical equipment.

Rule of Thumb: All electrical grounds should be grounded back to the negative on the battery. ***Never use the hull as a ground.***

The following list are common sources for stray currents:

A.C. polarity reversals
Improperly installed polarity alarms **(low resistance polarity indicator circuits should include a normally off, momentary test switch)**
A.C. shorts from hot to case
Frayed, cut or waterlogged insulation
Wire in bilge water
Salt bridges on terminal strips or junction blocks
Staples, nails or screws through wires
Improperly grounded equipment
D.C. equipment using bonding system of the hull for return wire negative
Loose connections.

Procedure to troubleshoot an electrolysis problem:

1) **Start by turning on and off all A.C. & D.C. circuit breakers and master switches** including the boat shore power transfer switch. Unplug shore power to the boat.

2) **Measure the hull potential (Hull to sea water)**

3) **Plug in the shore power cable**

   Measure the hull potential. If there is a sustained voltage reading, as opposed to a “spike” or no reading, it is indicating a stray current down the ground wire or between the power inlet and the master switch or breaker. **Find and fix the problem!**

If there is no difference in hull potential proceed to step 4.

4) **Turn on first circuit breaker,** usually ship-shore or shore power breaker.

   If hull potential changes find and correct the problem.

   If no change was noted in the hull potential then move on to the next switch or breaker in line. Correcting any problem encountered.

Each problem circuit must be checked by tracing the wire from the output side of the breaker, to the electrical equipment on that circuit, and back to the neutral bus.

Every time there is a branch in the circuit, you must check each branch out separately to determine which branch contains the problem.

It is important that as each circuit is turned on the equipment actually controlled by that circuit should actually be turned on.

KEEL COOLER SIZING WORKSHEET

GENERAL INFORMATION:

Project ______________________________ Engine ____________

Application ______________________________

Fuel Type ______________________________

Rated Power ____________________ bkW Rated Speed __________ rpm

Cooling System Type (Combined or Separate) ______________________________

DESIGN-POINT CONDITIONS:

Engine Power	____________	bkW
Engine Speed	____________	rpm
Heat Rejection Data (from TMI):		
Jacket Water	____________	kW
Oil Cooler	____________	kW
Aftercooler	____________	kW
Vessel Speed	____________	knots
Maximum Expected Raw Water Temperature	____________	°C
Raw Water Type / Description	____________________	

CIRCUIT ANALYSIS INFORMATION:

Circuit Being Analyzed	____________________	
Total Circuit Heat Rejection	____________	kW
Max Allowable Coolant-to-Engine Temp	____________	°C
Regulator (Thermostat) Part Number	____________________	
Start-to-Open Temperature	____________	°C
Full-Open Temperature	____________	°C
Total Circuit Flow	____________	L/min
Coolant Velocity thru Keel Cooler	____________	m/sec
Max Allowable Circuit Resistance	____________	kPa
Coolant Water Type	____________________	
Antifreeze Content (glycol)	____________	%
Steel Thickness of Heat Transfer Surface	____________	mm

CIRCUIT ANALYSIS INFORMATION:

Baseline Unit Heat Rejection Capacity (Figure 17) = ____________ $\frac{(\text{kW/sq m})}{°\text{C}}$

Total Correction Factor (see Figures 18 and 19):

Water Factor (______) x Glycol Factor (______) x Raw-Water Factor (______) x Thickness Factor (______) = ____________

Corrected Unit Heat Rejection Capacity:

Baseline Capacity (________) x Total Correction Factor (________) = ____________ $\frac{(\text{kW/sq m})}{°\text{C}}$

Temperature Difference Calculation:

Coolant-to-Engine Temperature (________) °C - Raw Water Temperature (________) °C = ____________ °C

Unit Heat Rejection Capacity @ Design Temperatures:

Corrected Unit Capacity (________) x Temperature Difference (________) = ____________ kW/sq m

Total Surface Area Required:

Total Circuit Heat Rejection (________) / Unit Capacity @ Design Temps (________) = ____________ sq m

Baseline Performance Conditions

The baseline performance curves in Figure 4.17 are for the following conditions:

Engine coolant: Treated fresh water (no glycol)

Engine coolant fouling factor: 0.0010 (no excessive hardness)

Raw water fouling factor: 0.0030 (typical river water)

Steel thickness: 6.35 mm (0.25 in)

Correction Factors

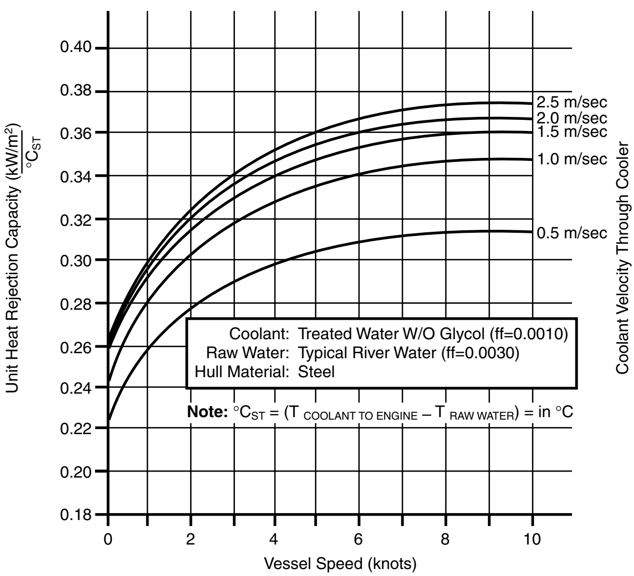
The *baseline* keel cooler performance (unit heat rejection capacity) obtained from Figure 17 must be adjusted to account for actual conditions. Correction factors (multipliers) required are shown in Figures 4.18 and 4.19.

Use of extremely hard water: Figure 4.18

Use of antifreeze (glycol): Figure 4.18

Raw water fouling factors: Figure 4.18

Steel thickness (heat transfer surface): Figure 4.19



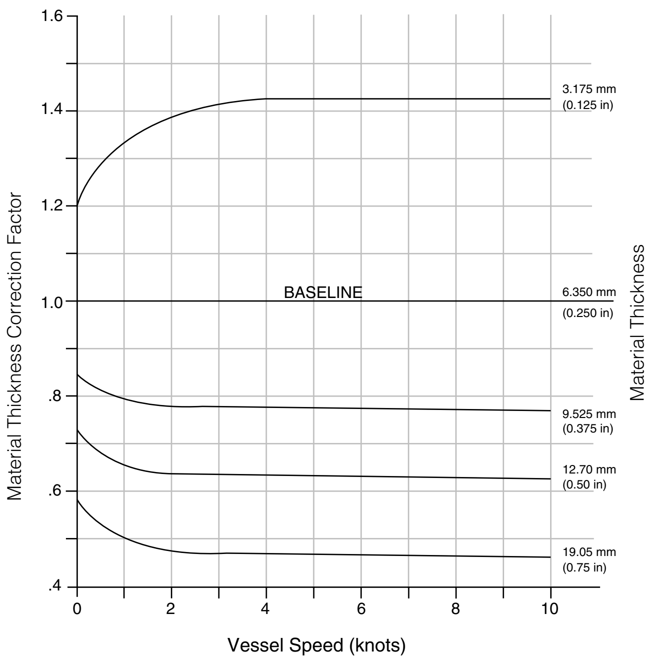
Keel Cooler Performance & Sizing
Baseline Heat Rejection Capacity

FIGURE 4.17

Keel Cooler Performance Correction Factors			
Correction Factors for Cooling System Water:			
Water meets Caterpillar specifications			(baseline)1.00
Extremely hard water (>15 grains/gal)			0.90
Correction Factors for Antifreeze:			
0% glycol			(baseline)1.00
10% glycol			0.97
20% glycol			0.94
30% glycol			0.91
40% glycol			0.88
50% glycol			0.85
Correction Factors for Raw-Water Type			
		Correction Factors @ Vessel Speed	
Raw-Water Description	***Fouling Factor**	**<2 knots**	**>2 knots**
River water (baseline)	0.0030	1.00	1.00
Open sea (ocean water)	0.0007	1.11	1.16
Great Lakes	0.0010	1.10	1.13
Chicago Canal	0.0060	0.88	0.85

* Fouling factor is shown here for reference only and is used to calculate the vessel speed correction factor.

FIGURE 4.18



Keel Cooler Performance & Sizing
Capacity Corrections for Material Thickness
(Structural Steel)

FIGURE 4.19

Piping Symbol

Symbol	Description	Symbol	Description	Symbol	Description
	Gate Valve		Un-Insulated Pipe		Tank Heating Coil
R	Gate Valve with Remote Operating Gear Attached		Insulated Pipe		Gauge Glass (Automatic Closure)
LO	Locked "Open" Valve		Air Vent with Flame Screen		Plate Heat Exchange
LC	Locked "Closed" Valve		Air Vent w/Flame Screen & Closure		Shell and Tube Heat Exchanger
	Globe Valve		Air Vent w/Flame Screen, Check Valve & Closure		Centrifugal Pump
T	Screw Down Non-Return Valve		Drip Pan		Positive Displacement Pump
LS	Lock Shut Valve	T	Thermometer		Manhole in Tank
	Swing Check Valve		Thermometer	FM	Flow Meter
	Three -way Cock	HTA	High Temperature Alarm		Pipe Return to Tank
	Air Operated Three-Way Cock (or Valve)	LTA	Low Temperature Alarm		Pump Suction Bell
	Relief Valve	HLA	High Level Alarm	F	Filter
	Angle Valve	LLA	Low Level Alarm	ΔP	Differential Pressure Indicator
	Pressure Control Valve	PSH	Pump Start	PS	Pressure Switch
	Self-Contained Temperature Control Valve w/ Manual Override	PSL	Pump Stop	A	Alarm
	Butterfly Valve		Pressure Switch	M	Motor
	Ball Valve		Steam Blow-Out		
	In-Line Relief Valve		Sounding Valve with Lever		
	Diverting Valve with Manual Lever	S	Simplex Strainer		
	Temperature Control Valve	S S	Duplex Strainer		
	Air Operated Butterfly Valve		Orifice Plate		
	Flexible Connector	P	Pressure Gauge		
	Flexible Connector	L	Level Indicator		

Schedule of Piping

SYSTEM		PIPING		TAKE DOWN JOINTS		BOLTS	NUTS	GASKETS	VALVES				FITTINGS		GENERAL NOTES
##	SERVICE	SIZE	TYPE	SIZE	TYPE				SIZE	PRESS	MATERIAL	TRIM	SIZE	TYPE	
1	Cooling Fresh Water	Above 0.5 in. (10 mm)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 0.5 in. (10 mm)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Grade B	ASTM A307 Grade B	Inserted Rubber Sheet	2 in. (50 mm) and above	125#	Cast Iron or Forged Steel Flanged	Brass	2 in. (50 mm) and Above	Forged Steel Std. Wt., Butt Welded ends, ASTM A-234	
		0.5 in. (10 mm) and Below	Seamless Copper, ASTM B88, Type K or L	Below 0.5 in. (10 mm)	Brass Unions, Bite Joint or Sleeve				1.5 in. (40 mm) and below	200#	Bronze	Brass	1.5 in. (40 mm) and Below	Ductile Iron, Forged Steel, or Brz., Screwed	
2	Cooling Sea Water	Above 0.5 in. (10 mm)	90 / 10 CuNi Pipe	Above 0.5 in. (10 mm)	Bronze Flanges, Brazed.	ASTM A307 Galv.	ASTM A307 Galv.	Inserted Rubber Sheet	2 in. (50 mm) and above	125# 150#	Cast Iron, Flanged Cast Steel, Flanged	Brass or Monel	Above 0.5 in. (10 mm)	Bronze, Brazed; or Built-up Cu, Flanged	Or use ## 3 which is acceptable substitute
		0.5 in. (10 mm) and Below	Seamless Copper, ASTM B88, Type K or L	Below 0.5 in. (10 mm)	Brass Unions, Bite Joint or Sleeve				1.5 in. (40 mm) and below	200#	Bronze, Flanged or Screwed	Brass or Monel	0.5 in. (10 mm) and Below	Brass Joints	
3	Sea Chest, Overboard, Air Vent, and Blow-Out Conn.	All	Seamless, ASTM A106, Sch. 80 Grade A or B, Galvanized	Above 0.5 ft. (10 mm)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Inserted Rubber Sheet	2 in. (50 mm) and above	150#	Cast Steel, Flanged	Brass or Monel	2 in. (50 mm) and Above	Butt Welded Galvanized	
				Below 0.5 ft. (10 mm)	Brass Unions, Bite Joint or Sleeve				1.5 in. (40 mm) and below	200#	Bronze, Flanged	Brass or Monel	1.5 in. (40 mm) and Below	Ductile Iron or Forged Steel, Galv. Screwed	
4	Oil & Fuel-Filling, Transfer, and Service	Above 0.5 in. (10 mm)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 0.5 in. (10 mm)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Nitrile	2 in. (50 mm) and above	125# 150# *	Cast Iron or Forged Steel, Flanged Cast Steel, Flanged	Brass	2 in. (50 mm) and Above	Forged Steel Std. Wt., Butt Welded ends, ASTM A-234	*Valves on Oil & Fuel tanks will be Cast Steel Flanged
		0.5 in. (10 mm) and Below	Seamless Copper, ASTM B88, Type K or L	Below 0.5 in. (10 mm)	Brass Unions, Bite Joint or Sleeve				1.5 in. (40 mm) and below	200#	Bronze, Flanged or Screwed	Brass	1.5 in. (40 mm) and Below	Ductile Iron or Forged Steel Screwed or Socket Weld	
5	Exhaust Gas	All	Steel Resistance Welded, ASTM A53*	All	Steel Plate Flanges	ASTM A307 Galv.	ASTM A307 Galv.	Hi-Temp., Asbestos Free					All	Forged Steel, Butt Welded Flngd. (Flex conns. to be Stainless Steel)	*Pipe to be at least 0.25 in. (7 mm) thick
6	Exhaust Gas - Open Drains	All	Steel Resistance Welded, ASTM A53 Sch. 40						2 in. (50 mm) and above	200#	Bronze, Flanged or Screwed	Brass	All	Forged Steel, Butt Welded	
									1.5 in. (40 mm) and below	200#	Bronze, Flanged or Screwed	Brass	All	Forged Steel, Butt Welded	
7	Starting Air and Control Air	Above 0.5 in. (10 mm)	Seamless, ASTM A106, Sch. 40 Grade A or B	Above 0.5 in. (10 mm)	Steel Slip-on Welded Flanges, Butt Welded or Sleeve	ASTM A307 Galv.	ASTM A307 Galv.	Nitrile	2 in. (50 mm) and above	150#	Cast Iron or Forged Steel, Flanged	Brass	2 in. (50 mm) and Above	Forged Steel, Flanged or Butt Welded	
		0.5 in. (10 mm) and Below	Seamless Copper, ASTM B88, Type K or L	Below 0.5 in. (10 mm)	Brass Unions, Bite Joint or Sleeve				1.5 in. (40 mm) and below	200#	Bronze, Flanged or Screwed	Brass	1.5 in. (40 mm) and Below	Forged Steel, Screwed or socket weld	

Driveline

Drivelines can be subdivided into two groups, depending on how the thrust forces driving the hull are created.

Screw propeller drivelines have a propeller converting engine power to thrust outside the hull. The thrust forces are generated on the propeller and transmitted to the hull through the propeller shafting and marine transmission.*

Jet drives have engine driven water pumps, either within the hull or bolted rigidly to it, which accelerate large flows of water. The thrust of the water leaving the pump propels the hull. The thrust forces are applied to the hull through the pump housing.

Screw Propeller Drivelines

There are several ways screw propeller drivelines connect the engine to the propeller.

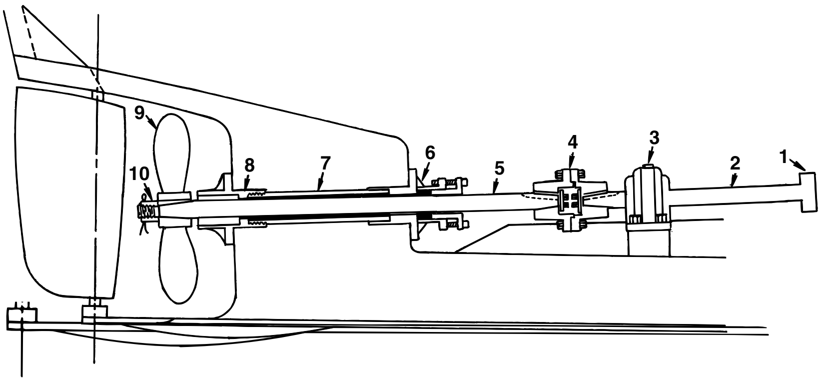
Conventional In-Line Propeller Systems

In conventional in-line propeller systems, the propeller shafting is straight, rigid and transmits the propeller thrust in a direct line from the marine gear output flange to the propeller. The engine(s) is/are located low, near the longitudinal center of the hull, and the marine gear(s) generally accepts the full propeller thrust.

Shaft Diameter and Bearing Spacing Selection

To prevent premature damage to shaft bearings, the shaft bearings should be close enough to prevent shaft whip, but far enough apart to permit the shaft to conform to the hull's flexing. For this reason, shafting should be designed for the thrust and torque forces applied. Since the tail shaft is more subject to damage from a propeller's contact with submerged objects, it should be strengthened for this purpose. The following nomograms will serve as a guide for shaft sizes and bearing spacing for commonly used shaft materials consistent with good marine practice.

*Boats with ducted propellers (Kort nozzles) receive a portion of their thrust directly from the hydrodynamic forces on the ducts. Ducted propellers are not common on fast boats due to the high drag of propeller ducts at high boat speeds.



DRIVELINE COMPONENTS –CENTERLINE MOUNTED THROUGH STERN POST

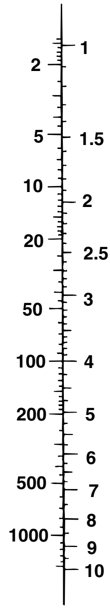
1. Shaft companion flange
2. Intermediate shaft
3. Shaft bearing –pillow block, expansion type
4. Flange type shaft coupling
5. Tail shaft
6. Stuffing box –may or may not contain bearing
7. Stern tube –one end threaded, the other slip fit
8. Stern bearing
9. Propeller
10. Retaining nut

FIGURE 5.1

SHAFT DIAMETER SELECTION NOMOGRAPH

Horsepower per 100 rpm Propeller Speed

Shaft Diameter (inches)



Tailshafts for heavy duty service should be increased by adding 1% of the propeller diameter to the basic shaft diameter.

Intermediate shafts may be reduced to 0.95 of the resultant shaft sizes.

Mild steel, read directly.
Tobin bronze, multiply by 1.05.
Monel, multiply by 0.88.

Example 1

Condition
Select bronze propeller shaft for engine with Intermittent rating of 315 hp @ 2000. Reduction ratio, 2:1. Propeller diameter, 32 inches. Light duty operation.

Solution
Intermittent hp = 315

Propeller rpm = $\frac{2000}{2}$ = 1000

hp per 100 rpm = $\frac{315}{10.00}$ = 31.5

Basic shaft diameter = 2.75 in.

Bronze shaft diameter = 2.75 x 1.05 = 2.88 in.

NOTE: Round off shaft diameter to nearest larger standard size.

Example 2

Condition
Select steel intermediate shaft and bronze tailshaft for heavy duty service. Engine develops 300 continuous hp @ 1800 rpm. Reduction ratio, 4.5:1. Propeller diameter, 54 inches.

Solution
Continuous hp = 300

Propeller rpm = $\frac{1800}{4.5}$ = 400

hp per 100 rpm = $\frac{300}{4.00}$ = 75

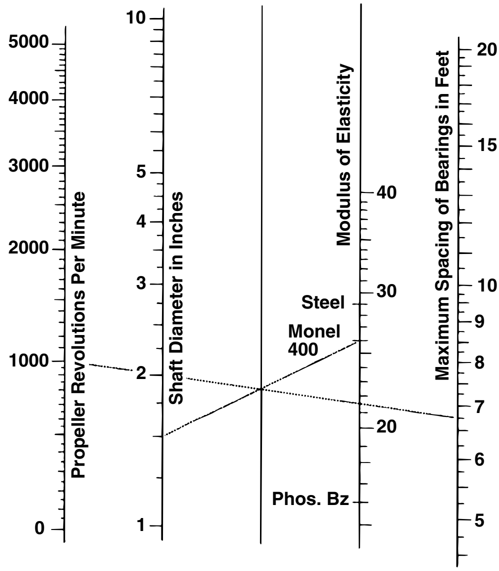
Basic shaft diameter = 3.64 in.

Steel intermediate shaft = 3.64 x 0.95 = 3.46 in.

Bronze tailshaft = (3.64 x 1.05) + (54 x 0.01)
= 3.82 + 0.54 = 4.36 in.

FIGURE 5.2

BEARING SPACING



Space bearings — rule a line from shaft in second line scale to modulus in fourth scale (26 for Monel). Then rule a line from point of intersection on center scale to connect propeller rpm on left scale and extend the line to right scale.

"Monel" is a registered trademark of International Nickel Corp.

Chart published courtesy of Paul G. Tomalin

FIGURE 5.3

Location of first shaft bearing aft of the marine transmission

The location of the first line shaft bearing from the marine transmission flange is extremely important.

To avoid inducing unwanted forces on the marine transmission thrust bearing, the line shaft bearing should be located at least 12, and preferably 20, or more shaft diameters from the marine transmission output flange. If the bearing must be located closer than 12 diameters, the alignment tolerances must be reduced substantially and the use of a flexible coupling considered.

Vee Drives

In Vee Drives, the propeller shafting is in two sections. The first section of shafting is from the propeller to a *Vee drive unit*.

The Vee drive unit is a bevel-gear box which allows the shafting to change directions. The Vee drive unit accepts full propeller thrust, transmitting the thrust to the hull through its mounting feet.

The second section of shafting turns sharply backward from the Vee drive unit to the engine. The engine is generally mounted as far to the rear of the boat as possible, with its flywheel end facing toward the bow of the boat.

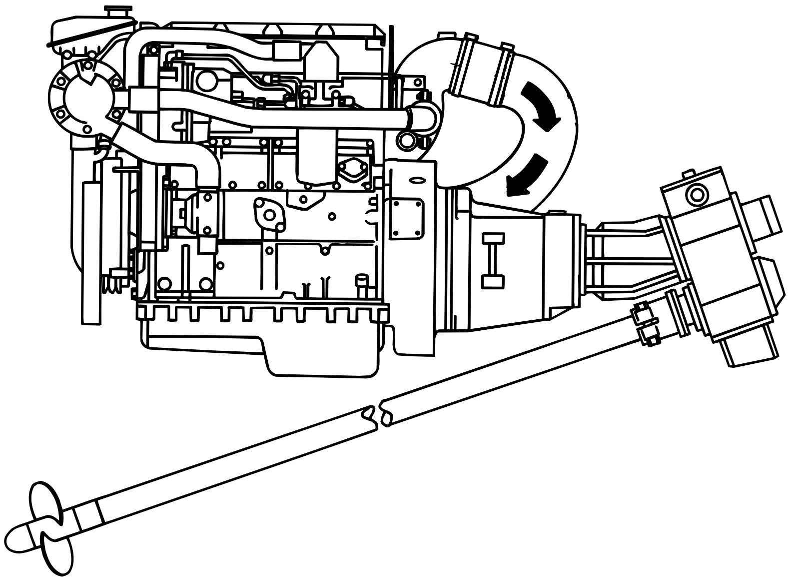


FIGURE 5.4 VEE DRIVE

There are a number of advantages of the Vee drive layout:

The engine is located at the extreme rear of the boat, taking minimal usable space within the hull.

Because the shafting between the engine and the Vee drive unit is not loaded with propeller thrust forces, that section of shaft can include universal joints or other soft couplings. The driveline softness allows use of soft engine mounts, resulting in a very quiet installation.

Disadvantage of the Vee drive arrangement:

The engine center of gravity is relatively high. It is further aft than conventional inline drivelines. This reduces stability and adversely affects hull balance.

Z Drive

The Z drive is a drive arrangement where the engine is connected to a right angle gear unit. A vertical drive shaft leads down through the hull to a submerged, second right angle gear unit. The lower right angle gear drives the propeller through a short length of horizontal drive shaft.

The engine may face either fore or aft. Transverse engine orientations are not recommended.*

*The rolling of the boat can shorten the life of the crankshaft thrust bearings. When the boat rolls, the crankshaft will slide back and forth, hammering on its thrust bearings. If the engine is running, the motion will be dampened by the engine's oil film. If the engine is not running, the oil film is not present to protect the thrust bearing.

Stern Drives

The stern drive is a drive arrangement wherein the engine is connected to a reverse-reduction unit (to provide the reversing capability) which drives two right angle gear sets (through a double universal joining shaft) and a propeller. The engine flywheel faces aft.

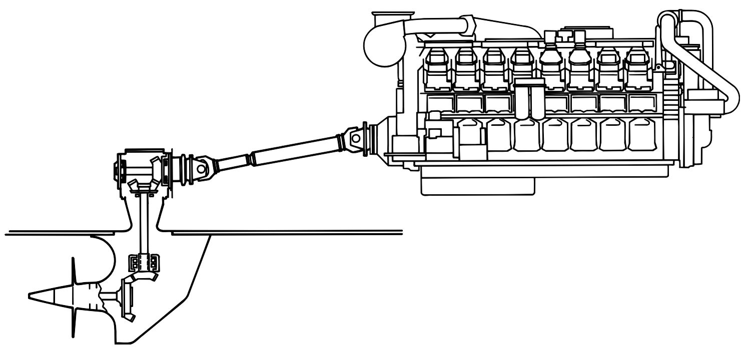


FIGURE 5.5 STERN DRIVE

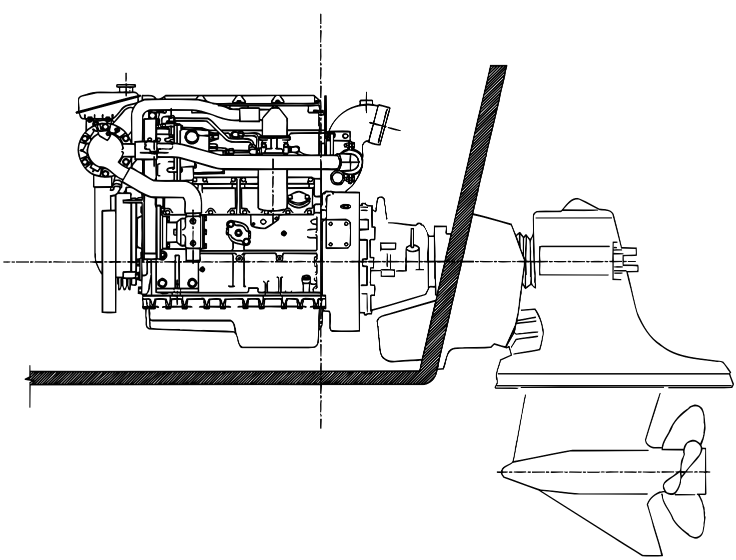


FIGURE 5.6

Jet Drive

Definition of Jet Drive

The boat is propelled by the acceleration of a flow of water, picked up from the bottom of the hull through an inlet grill and forced out through a nozzle mounted in the stern of the boat. The water flow is powered by an engine driven pump. The pump impeller is driven through a clutched reduction unit or direct from the engine flywheel to a universal joint shaft.

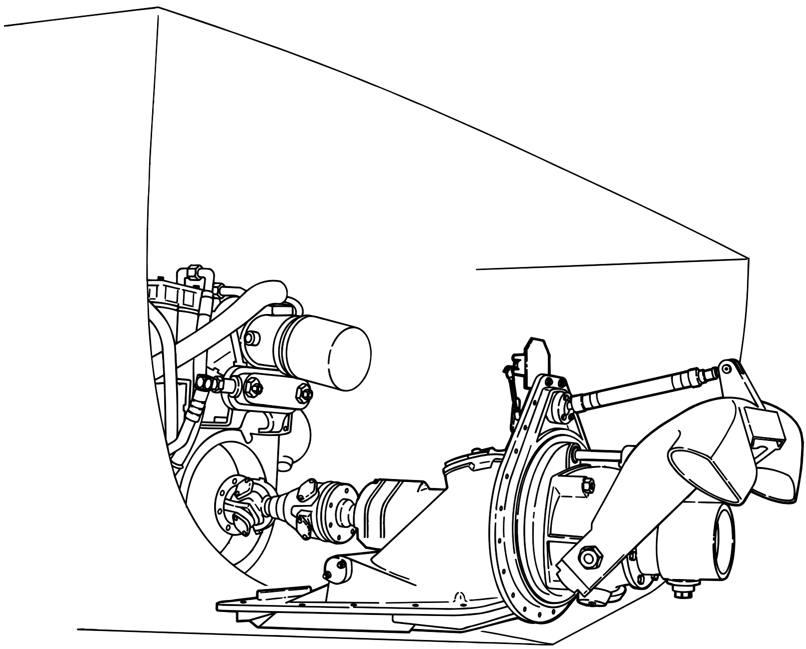


FIGURE 5.7 JET DRIVE

Advantages of Jet Drive

- There is no need for a *reverse* gear. Reverse mode of operation can be accomplished by means of *buckets* or vanes on the discharge nozzle, which redirect the jet's discharge stream forward instead of aft.
- Operation in water too shallow for conventional propeller systems is possible.

Engine load with jet drives normally follow a cubic demand. Jet drive systems are significantly less prone to overload, since jet power demand is not very sensitive to vessel speed. Jet Drive units are less prone to damage from floating debris.

Disadvantages of Jet Drives

Disadvantages of the Jet Drive arrangement include:

- Block loading of the engine if the boat comes off the water ingesting air and loss of load. When the boat comes back in the water, block loading can occur if the engine speed is not matched to the load.
- A tendency to plug the inlet grill with debris. Some jet propulsion units are equipped with built-in cleaning mechanisms.

Torsional Vibration

Definition

Torsional vibration is cyclic irregularity of rotation in a shafting system. It is caused by engine combustion pulses, reciprocating motion and the propeller. As shafts in the system rotate, both the input torque (as each cylinder fires) and the resistance to rotation (caused by the propeller) varies. The torque variation is natural and unavoidable. It is only dangerous when uncontrolled.

Any shaft rotating with a mass attached to each end is capable of torsional vibration if there is any irregularity in the rotation of either mass. Rotation originates with the power stroke of the piston.

The simplified drivetrain below illustrates the relationship of shaft diameter, length and inertia of the natural frequency of the system.

Sources of Torsional Vibration

Many components in the driveline can cause or contribute to torsional vibration:

- Irregularity in the flow of water to a propeller caused by struts, appendages, hull clearance
- Propeller blade-to-blade pitch inaccuracies
- The intermeshing of gear teeth in the marine transmission
- Misaligned flexible couplings
- Universal joints (except for constant velocity types)
- Firing of individual cylinders of the engine
- Auxiliary loads driven from any of the engine's power takeoffs

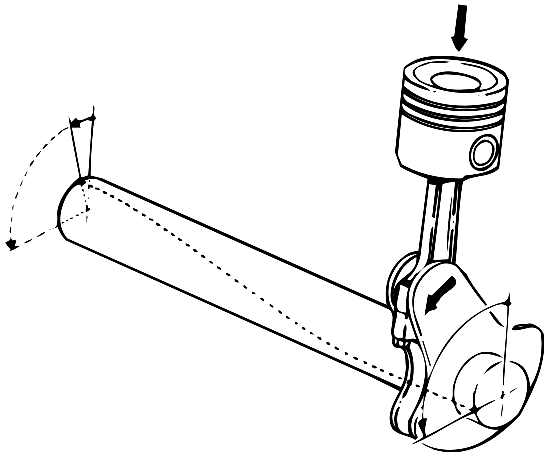


FIGURE 5.8

Mathematical Torsional Vibration Analysis

To ensure the compatibility of an engine and the drive equipment, a theoretical Torsional Vibration Analysis (TVA) is necessary. Disregarding the torsional compatibility of the engine and driven equipment, can result in extensive and costly damage to components in the drive train or engine failure. The torsional report will show the natural frequencies, the significant resonant speeds, and either the relative amplitudes or a theoretical determination of whether the maximum permissible stress level is exceeded. Also shown are the approximate nodal locations in the shafting system for each significant natural frequency.

Conducted at the design stage of a project, the mathematical torsional analysis may reveal torsional vibration problems which can be avoided by modification of driven equipment, shafts, masses or couplings.

Data Required to Perform Mathematical Torsional Analysis

The following technical data is required to perform a torsional analysis:

1. Operating speed ranges – lowest speed to highest speed, and whether it is variable or constant speed operation.
2. Load curve on some types of installations for application with a load dependent variable stiffness coupling.
3. With driven equipment on both ends of the engine, the horsepower requirement of each set of equipment is required and whether operation at the same time will occur.
4. A general sketch of the complete system showing the relative location of each piece of equipment and type of connection.

5. Identification of all couplings by make and model, along with WR^2* and torsional rigidity.
6. WR^2 or principal dimensions of each rotating mass and location of mass on attached shaft.
7. Torsional rigidity and minimum shaft diameter, or detailed dimensions of all shafting in the driven system, whether separately mounted or installed in a housing.
8. If a reciprocating compressor is utilized, a harmonic analysis of the compressor torque curve under various load conditions is required. If this is not available, then a torque curve of the compressor under each load condition is required. The WR^2 of the available flywheels for the compressor should be submitted.
9. The ratio of the speed reducer or increaser is required. The WR^2 and rigidity that is submitted for a speed reducer or increaser should state whether or not they have been adjusted by the speed ratio squared.
10. The WR^2 and number of blades on the propeller.

*WR^2 is a Polar Moment of inertia. It is the way we quantify the tendency of an object to resist changing its rotational speed. A flywheel is an object specifically designed to have a high polar moment of inertia. If its metal were concentrated near its hub, it would have a much lower polar moment of inertia, yet would have the same weight.

Availability of Torsion Characteristics of Caterpillar-Furnished Equipment

Upon request, mass elastic systems of items furnished by Caterpillar will be supplied to the customer without charge so that he can calculate the theoretical Torsional Vibration Analysis.

Mass elastic data for Caterpillar Diesel Engines, marine gears and generators is covered in the Technical Information System (TIS) and in Technical Marketing Information (TMI). If desired, Caterpillar will perform torsional vibration analyses. The data required prior to the analysis is described above. There is a nominal charge when this service is provided by Caterpillar.

Timing of Mathematical Torsional Vibration Analysis

The best time to perform a Mathematical Torsional Vibration Analysis is during the design phase of a project; before the driveline components are purchased and while the design can be easily changed if the TVA shows problems are likely to exist.

Responsibility for Torsional Compatibility

Since compatibility of the installation is the system designer's responsibility; it is also his responsibility to obtain the torsional vibration analysis.

Driveline Couplings

There are two types of driveline couplings: Rigid and soft couplings.

Rigid Couplings

Rigid shaft couplings may be classified by the method of attaching the shaft to the coupling.

Society of Automotive Engineers (SAE) Standards – SAE J755
Use of SAE standard shaft ends and couplings is recommended. They represent the highest standards of rigidity and reliability.

Other Rigid Couplings
The couplings using SAE standard shaft ends and hubs are cumbersome to remove and must be machined very carefully, to ensure concentricity and perpendicularity tolerances are met. The following couplings are easier to install and remove. They are also simpler to manufacture.

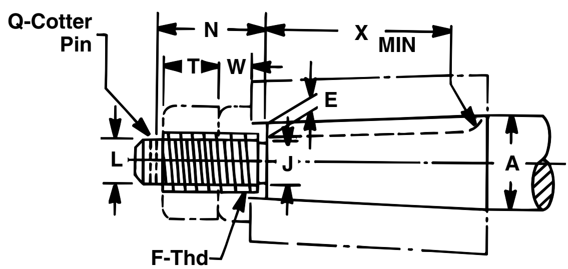


FIGURE 5.9

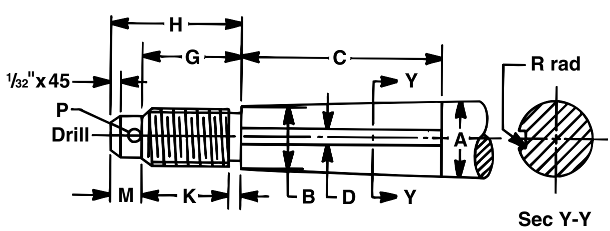


FIGURE 5.10

Dimensions for Shafts $\frac{3}{4}$ to 6 inch in Diameter

Non Shaft Diameter "A"	Small End Diameter "B"		Taper Length Diameter "C"	Keyway Width Diameter "D"			Keyway Side Diameter "E"			Keyway Fillet Radius "R"	Thread "F"		Taper End to Thread "G" End
	Min	Max		Nom	Min	Max	Nom	Min	Max		Dia	TPI	
0.75	0.624	0.626	2.00	0.19	0.1865	0.1875	0.10	0.095	0.097	0.031	0.50	13.0	1.063
0.88	0.726	0.728	2.38	0.25	0.249	0.250	0.13	0.125	0.127	0.031	0.63	11.0	1.250
1.00	0.827	0.829	3.75	0.25	0.249	0.250	0.13	0.125	0.127	0.031	0.75	10.0	1.438
1.13	0.929	0.931	3.13	0.25	0.249	0.250	0.13	0.125	0.127	0.031	0.75	10.0	1.438
1.25	1.030	1.032	3.50	0.31	0.3115	0.3125	0.16	0.157	0.160	0.063	0.88	9.0	1.625
1.38	1.132	1.134	3.88	0.31	0.3115	0.3125	0.16	0.157	0.160	0.063	1.00	8.0	1.813
1.50	1.233	1.235	4.25	0.38	0.374	0.375	0.19	0.189	0.192	0.063	1.13	7.0	2.000
1.75	1.437	1.439	5.00	0.44	0.4365	0.4375	0.22	0.219	0.222	0.063	1.25	7.0	2.250
2.00	1.640	1.642	5.75	0.50	0.499	0.500	0.25	0.251	0.254	0.063	1.50	6.0	2.625
2.25	1.843	1.845	6.50	0.56	0.561	0.5625	0.28	0.281	0.284	0.094	1.75	5.0	3.000
2.50	2.046	2.048	7.25	0.63	0.6235	0.625	0.31	0.312	0.315	0.094	1.75	5.0	3.000
2.75	2.257	2.259	7.88	0.63	0.6235	0.625	0.31	0.313	0.316	0.094	2.00	4.5	3.500
3.00	2.460	2.462	8.63	0.75	0.7485	0.750	0.31	0.311	0.314	0.094	2.33	4.5	3.875
3.25	2.663	2.665	9.38	0.75	0.7485	0.750	0.31	0.311	0.314	0.125	2.50	4.0	4.375
3.50	2.866	2.868	10.25	0.88	0.8735	0.875	0.31	0.310	0.313	0.125	2.50	4.0	4.375
3.75	3.069	3.071	10.88	0.88	0.8735	0.875	0.31	0.310	0.313	0.125	2.75	4.0	4.750
4.00	3.272	3.274	11.63	1.00	0.9985	1.000	0.31	0.309	0.312	0.125	3.00	4.0	5.125
4.50	3.827	3.829	10.75	1.13	1.123	1.125	0.38	0.373	0.376	0.156	3.25	4.0	5.625

Dimensions for Shafts $\frac{3}{4}$ to 6 inch in Diameter (cont.)

Non Shaft Diameter "A"	Small End Diameter "B"		Taper Length Diameter "C"	Keyway Width Diameter "D"			Keyway Side Diameter "E"			Keyway Fillet Radius "R"	Thread "F"		Taper End to Thread "G" End
	Min	Max		Nom	Min	Max	Nom	Min	Max		Dia	TPI	
5.00	4.249	4.251	12.00	1.25	1.248	1.250	0.44	0.434	0.437	0.188	3.75	4.0	6.375
5.50	4.671	4.673	13.25	1.25	1.248	1.250	0.44	0.435	0.438	0.188	4.00	4.0	6.750
*6.00	4.791	4.793	14.50	1.38	1.373	1.375	0.50	0.493	0.496	0.219	4.25	4.0	7.500
*6.50	5.187	5.189	15.75	1.38	1.373	1.375	0.50	0.494	0.497	0.219	4.50	4.0	8.250
*7.00	5.582	5.584	17.00	1.50	1.498	0.500	0.56	0.555	0.558	0.250	5.00	4.0	9.000
*7.50	5.978	5.980	18.25	1.50	1.498	1.500	0.56	0.556	0.559	0.250	5.25	4.0	9.375
*8.00	6.374	6.376	19.50	1.75	1.748	1.750	0.56	0.553	0.556	0.250	5.75	4.0	9.750

*6 in. through 8 in. bore uses 1 in./ft taper. 1/12 in. per taper. Angle with centerline 2° 23 ft 9 in.

Dimensions for Shafts $\frac{3}{4}$ to 6 inch in Diameter

Non Shaft Diameter "A"	Extension Beyond Taper "H"	Undercut		Diameter of Pin End "L"	Length of Pin End "M"	Cotter Pin Hole		Cotter Pin "Q"		Nuts			Keyway Length "X"
		"J"	"K"			"N"	"P" Drill	Nom Dia	Length	Size	Plain Thick "T"	Jamb Thick "W"	
0.75	1.313	0.391	0.125	0.375	0.250	1.141	0.141	0.125	0.75	0.500 – 13	0.500	0.313	1.500
0.88	1.500	0.484	0.125	0.438	0.250	1.328	0.141	0.125	0.75	0.625 – 11	0.625	0.375	1.781
1.00	1.750	0.594	0.125	0.500	0.313	1.516	0.141	0.125	1.00	0.750 – 10	0.750	0.438	2.125
1.13	1.750	0.594	0.125	0.500	0.313	1.516	0.141	0.125	1.00	0.750 – 10	0.750	0.438	2.125
1.25	2.719	0.125	0.625	0.375	1.000	0.719	0.172	0.156	1.25	0.875 – 9	0.875	0.500	2.813
1.38	2.250	0.813	0.125	0.750	0.875	1.906	0.172	0.156	1.50	1.000 – 8	1.000	0.563	3.188
1.50	2.438	0.906	0.188	0.875	0.875	2.094	0.172	0.156	1.50	1.125 – 7	1.125	0.625	3.500
1.75	2.750	1.031	0.188	1.000	0.500	2.359	0.203	0.188	1.75	1.250 – 7	1.250	0.750	4.219
2.00	3.125	1.250	0.188	1.250	0.500	2.734	0.203	0.188	2.00	1.500 – 6	1.500	0.875	4.938
2.25	3.500	1.375	0.188	1.375	0.500	3.141	0.266	0.250	2.25	1.750 – 5	1.750	1.000	5.625
2.50	3.500	1.438	0.188	1.438	0.500	3.141	0.266	0.250	2.25	1.750 – 5	1.750	1.000	6.094
2.75	4.000	1.688	0.250	1.688	0.500	3.641	0.266	0.250	2.50	2.000 – 4.5	2.000	1.125	6.656
3.00	4.375	1.938	0.250	1.938	0.500	4.016	0.266	0.250	3.00	2.250 – 4.5	2.250	1.250	7.344
3.25	5.125	2.125	0.375	2.125	0.750	4.578	0.375	0.375	3.00	2.500 – 4	2.500	1.500	8.500
3.50	5.125	2.125	0.375	2.125	0.750	4.578	0.375	0.375	3.00	2.500 – 4	2.500	1.500	9.250
3.75	5.500	2.375	0.375	2.375	0.750	4.953	0.375	0.375	3.50	2.750 – 4	2.750	1.625	10.000

Dimensions for Shafts $\frac{3}{4}$ to 6 inch in Diameter (cont.)

Non Shaft Diameter "A"	Extension Beyond Taper "H"	Undercut		Diameter of Pin End "L"	Length of Pin End "M"	Cotter Pin Hole		Cotter Pin "Q"		Nuts			Keyway Length "X"
		"J"	"K"			"N"	"P" Drill	Nom Dia	Length	Size	Plain Thick "T"	Jamb Thick "W"	
4.00	5.875	2.500	0.375	2.500	0.750	5.328	0.375	0.375	3.50	3.000 – 4	3.000	1.750	10.500
4.50	6.375	2.750	0.375	2.750	0.750	—	—	—	—	3.250 – 4	3.250	1.875	9.625
5.00	7.125	3.250	0.375	3.250	0.750	—	—	—	—	3.750 – 4	3.750	2.125	10.875
5.50	7.750	3.500	0.500	3.500	1.000	—	—	—	—	4.000 – 4	4.000	2.250	12.125
*6.00	8.500	3.875	0.500	3.875	1.000	—	—	—	—	4.250 – 4	4.250	2.250	13.250
*6.50	9.250	4.375	0.500	4.375	1.000	—	—	—	—	4.500 – 4	9.500	2.500	14.375
*7.00	10.000	4.875	0.500	4.375	1.000	—	—	—	—	5.000 – 4	5.000	2.750	15.625
*7.50	10.375	5.125	0.500	5.125	1.000	—	—	—	—	5.500 – 4	5.500	3.000	16.875
*8.00	10.750	5.375	0.500	5.375	1.000	—	—	—	—	5.750 – 4	5.750	3.125	18.125

*6 in. through 8 in. bore uses 1 in./ft taper.1/12 in. per taper. Angle with centerline 2° 23 ft 9 in.

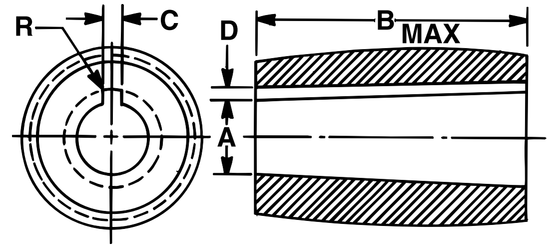


FIGURE 5.11

Marine Propeller Hub Bore Dimensions

Nom Bore Diameter	Diameter Small End "A"		Maximum Length "B"	Keyway Width "C"			Keyway Side Depth "D"		
	Min	Max		Nom	Min	Max	Nom	Min	Max
0.75	0.608	0.610	2.250	0.188	0.1865	0.1875	0.094	0.098	0.100
0.88	0.710	0.712	2.625	0.250	0.249	0.250	0.125	0.129	0.131
1.00	0.811	0.813	3.000	0.250	0.249	0.250	0.125	0.129	0.131
1.13	0.913	0.915	3.375	0.250	0.249	0.250	0.125	0.129	0.131
1.25	1.015	1.017	3.750	0.313	0.3115	0.3125	0.156	0.162	0.165
1.38	1.116	1.118	4.125	0.313	0.3115	0.3125	0.156	0.161	0.164
1.50	1.218	1.220	4.500	0.375	0.374	0.375	0.188	0.195	0.198
1.75	1.421	1.423	5.250	0.438	0.4365	0.4375	0.219	0.226	0.229
2.00	1.624	1.626	6.000	0.500	0.499	0.500	0.250	0.259	0.262

Marine Propeller Hub Bore Dimensions (cont.)

Nom Bore Diameter	Diameter Small End "A"		Maximum Length "B"	Keyway Width "C"			Keyway Side Depth "D"		
	Min	Max		Nom	Min	Max	Nom	Min	Max
2.25	1.827	1.829	6.750	0.563	0.561	0.5625	0.281	0.291	0.294
2.50	2.030	2.032	7.500	0.625	0.6235	0.625	0.313	0.322	0.325
2.75	2.233	2.235	8.250	0.625	0.6235	0.625	0.313	0.322	0.325
3.00	2.437	2.439	9.000	0.750	0.7485	0.750	0.313	0.323	0.326
3.25	2.640	2.642	9.750	0.750	0.7485	0.750	0.313	0.323	0.326
3.50	2.843	2.845	10.500	0.875	0.8735	0.875	0.313	0.324	0.327
3.75	3.046	3.048	11.250	0.875	0.8735	0.875	0.313	0.324	0.327
4.00	3.249	3.251	12.000	1.000	0.9985	1.000	0.313	0.326	0.329
4.50	3.796	3.798	11.250	1.125	1.123	1.125	0.375	0.388	0.391
5.00	4.218	4.220	12.500	1.250	1.248	1.250	0.438	0.450	0.453
5.50	4.640	4.642	13.750	1.250	1.248	1.250	0.438	0.450	0.453
6.00	4.749	4.751	15.000	1.375	1.373	1.375	0.500	0.517	0.520
6.50	5.145	5.147	16.250	1.375	1.373	1.375	0.500	0.516	0.519
7.00	5.541	5.543	17.500	1.500	1.498	1.500	0.563	0.579	0.582
7.50	5.937	5.939	18.750	1.500	1.498	1.500	0.563	0.579	0.582
8.00	6.332	6.334	20.000	1.750	1.748	1.750	0.563	0.582	0.585

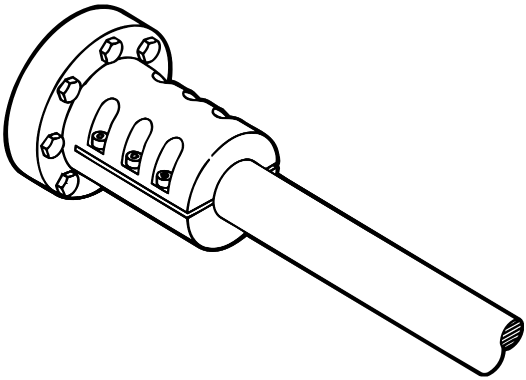


FIGURE 5.12 SPLIT COUPLING

Advantages of the Split Coupling
Split couplings can use shaft ends which require no additional machining after receipt from the shafting supplier. Good quality shafting is generally received with a ground or ground/polished finish. The shaft can generally be removed from a split coupling without use of heat or a press.

The ability to retain the shaft is excellent in a well machined split coupling.

Disadvantages of the Split Coupling
Split couplings use only friction to keep the shaft in the coupling. There is no positive mechanical stop preventing the shaft from pulling out of the coupling.

The inside diameter of the coupling bore should be within 0.001-0.002 in. (0.025-0.050 mm) of the outside diameter of the shaft end to prevent vibration from concentricity error unbalance.

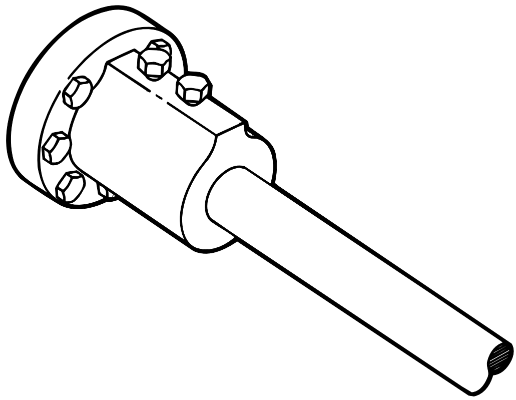


FIGURE 5.13 SET SCREW COUPLING

Advantages of the Set Screw Coupling
The set screw coupling allows very easy shaft removal and reinstallation.

Set screw couplings can use shaft ends which require no additional machining after receipt from the shafting supplier; good quality shafting is generally received with a ground/polished finish.

The set screw coupling requires the least work to manufacture. It is the least expensive of all the rigid couplings.

Disadvantages of the Set Screw Coupling
If the fit between the coupling bore and shaft is loose enough to permit convenient installation/removal, it is generally loose enough to allow at least some vibration due to concentricity error.

Set screws in set screw couplings will cause some marring of the propeller shaft.

The heads of the set screws protrude from the outside surface of the set screw coupling. Good safety practice dictates using guards/shields for personnel protection against accidentally contacting the rotating set screw heads.

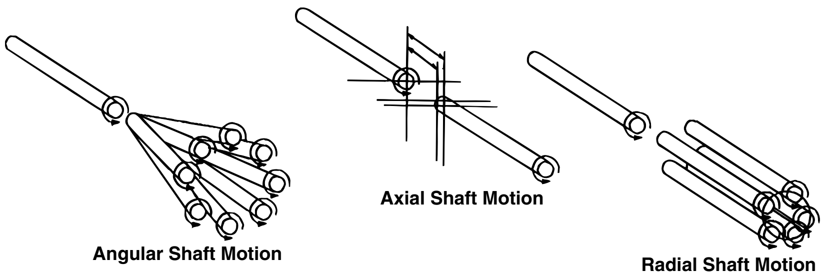


FIGURE 5.14

Soft Couplings

Soft couplings will accept relative motions between their *driving* and *driven* sides without damage. These relative motions can take the following forms.

Types of Softness

Rotating shafts which will move relative to each other need couplings which permit misalignment without damage. The ability to accept misalignment without damage is often called *softness*.

Radial Softness

Couplings which are radially soft will allow the driving or driven shafts some freedom of motion, so long as their centerlines remain parallel.

Axial Softness

Couplings which are axially soft will allow the driving or driven shafts to vary in their end-to-end spacing. The sliding spline joints in the middle of an automotive universal joint shaft, to allow the effective shaft length to vary are shaft couplings with axial softness.

Angular Softness

Angularly soft couplings allow shaft angle to vary. *Universal Joints* are examples of angularly soft couplings.

Combinations of Softness

Most commercially available shaft couplings are able to accommodate combinations of the above types of relative motion or misalignment. They vary in their tolerance for different types of motion. Good design practice will investigate the potential for the various types of shaft motion/ misalignment and confirm the shaft couplings are capable of accommodating the expected shaft motion.

Torsional Vibration Isolation

Torsional vibration is cyclic irregularity of rotation in a shafting system. It is caused by engine combustion pulses, reciprocating motion, and the propeller. As shafts in the system rotate, both the input torque (as each cylinder fires) and the resistance to rotation (caused by irregularities in the velocity of water entering the propeller) vary. The torque variation is natural and unavoidable. It is only dangerous when uncontrolled. Torsionally soft couplings are a way to control torsional vibration.

Protection from Misalignment

Propeller shafts, marine transmissions and engines are mounted to the hull. The hull is not perfectly rigid. Storm waves, temperature changes, propeller thrust, engine torque reaction, vessel loading and other factors result in forces which deform the hull causing misalignment in the shafting. The misalignment is unavoidable. Soft couplings allow the system to accept the misalignment without damage.

Sound Isolation

The driveline of the vessel is a source of noise. One of the methods of reducing shipboard noise is to interrupt the noise path. One path for noise is from the engine down the propeller shaft to the hull via the stuffing box.* A soft coupling in the propeller shaft is an excellent means of introducing resilience into the path between the source of the noise (the engine and transmission) and the receiver of the noise (the ears of the personnel on board).

*There are other equally important noise paths. Another is from the engine to the hull via the exhaust piping. See the Exhaust Section for guidance on use of resilience in supporting exhaust piping.

Another noise path from the engine to the hull is via the engine mounting feet. See the Mounting Section for guidance on use of resilient engine mounts. Cooling lines can transmit engine vibration to the hull where it will be perceived as noise by the crews. Cooling water connections must include flexibility.

Mounting and Alignment

Marine Gear Installation – Propeller Shaft Droop

Introduction

This procedure outlines the first of three basic steps involved in the installation, alignment, and mounting of marine gears. It applies to both free standing gears and gears that are fixed directly to the engine. It has limited application to units which are soft mounted or do not have a shaft support bearing between the gear and stern bushing.

The second and third basic steps concerning:

- Marine gear to propeller shaft alignment.
- Marine gear (and engine) mounting, will be covered in later sections of the application and installation procedures.

Propeller Shaft Droop

Before commencing alignment of the marine gear to the propeller shaft, the shaft *droop*, or *deflection* due to the unsupported shaft and companion flange weight must be compensated for (Figure 5.15). This is an important part of the installation and alignment procedure for marine gears. Otherwise, exceptional loading to the marine gear lower shaft bearings or the first propeller shaft line bearing may result with consequent increased noise or vibration and decreased service life of affected bearings.

Two methods are presented here for eliminating shaft droop as part of the alignment process:

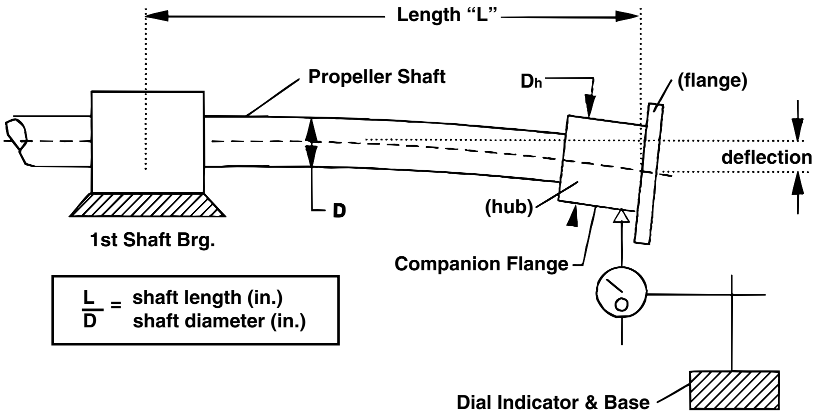
- The *estimated droop* method, whereby droop at the companion flange is estimated from droop tables and directly compensated for.
- The *scaled hoist* method, whereby unsupported shaft weight is directly compensated for.

Both methods give reasonably close approximations of the shafts true center if done correctly.

Note: For both procedures prior connection and alignment of propeller shafting from the first line bearing aft is required. Also, the shaft should be positioned about 0.5 in. (13 mm) aft of its final position when attached to the marine gear.

Estimated Droop Method

This method involves the use of tables which contain calculated deflection or *droop* values for overhung steel shafting with small, medium, or large flanges mounted on the free end (Figures 5.20, 5.21, 5.22; appendix A). Refer to Figure 5.15 for illustration of this deflection or droop and the dimensions that apply in using the droop tables.



SHAFT DROOP DIAGRAM

FIGURE 5.15

Three sets of values, as illustrated in Figure 5.15, are used in determining droop (deflection) at the shaft free end (flange end).

They are:

1. Flange hub dia. "Dh";
2. Propeller shaft dia. "D", and;
3. Shaft overhang length "L".

Dh/D determines which set of droop tables apply (see Appendix A).

Dh/D = 1.40 to 1.74 use Figure 5.20.
Dh/D = 1.75 to 1.99 use Figure 5.21.
Dh/D = 2.00 to 2.25 use Figure 5.22.

The "D" and "L/D" intersection in the appropriate table determines the estimated droop value.

To obtain shaft droop, first determine the values "L/D", and "Dh/D".

Then, go to the proper droop table for the "Dh/D" value and at the intersection of "D" and "L/D" read droop directly in inches.

For example: If Dh = 9.0 in. and D = 6.0 in. then Dh/D = 1.5 and Figure 5.20 should be referred to. If overhung length is 120 in. then L/D = $\frac{120}{6}$ = 20.0. The droop is read directly from Figure 5.20 at the intersection of D = 6.0, and L/D = 20 as droop = 0.148 in.

In many cases the actual D and L/D values will fall between those listed in the tables. In those cases droop can be found by interpolation of the data in the tables. An example of this follows:

D = 6.3 in.
L/D = 20.4
Dh/D = 1.5

Since Dh/D is between 1.4 and 1.74 we will use Figure 5.20.

The actual droop is shown as Ya, see Figure 5.16.

Shaft		**Shaft Diameter**	
L/D	**6.0**	**6.3**	**6.5**
20.0	**0.148**	**(a)**	**0.174**
20.4		**Ya**	
21.0	**0.178**	**(b)**	**0.208**
22.0	**0.211**		**0.248**

FIGURE 5.16

To obtain Ya proceed as follows:

Let D_a = Actual diameter of the shaft
D_1 = Next lower diameter on droop table
L/D_a = Actual length to Diameter ratio
L/D_1 = Next lower L/D ratio on droop table
L/D_2 = Next higher L/D ratio on droop table

Then Y_1 = Droop at L/D_1 and D_1
Y_2 = Droop at L/D_2 and D_2
Y_a = Actual Droop
$Y_a = R\,(b - a) + a$

Where $R = (L/D_a - L/D_1)/(L/D_2 - L/D_1)$
$a = (Da/D_1)^2 \times Y_1$
$b = (Da/D_1)^2 \times Y_2$

In this example

$$R = (20.4 - 20)/(21 - 20) = 0.4$$
$$a = (6.3/6.0)^2 \times 0.148 = 0.163$$
$$b = (6.3/6.0)^2 \times 0.178 = 0.196$$
$$Ya = 0.4\,(0.196 - 0.163) + 0.176$$
$$= 0.189 \text{ in.}$$

Scaled Hoist Method

This method involves lifting, with the use of a scale, a weight equal to one half the overhung shaft weight, plus all the companion flange weight with the lifting applied to the companion flange as shown in the illustration (Figure 5.17).

Weights for steel shafts or circular sections can be calculated using the following formula:

$$\text{WEIGHT (lb)} = 0.22 \times D^2 \times L$$

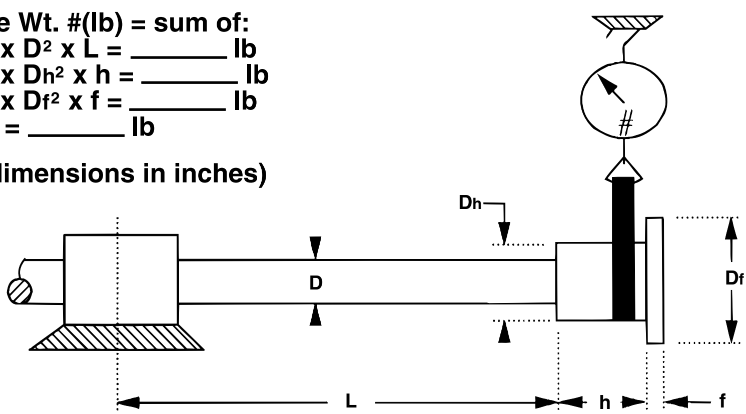
Where:

D = diameter of shaft or circular section in inches
L = length of shaft or circular section in inches

Alternatively, the weights of the shaft and flange sections can be determined by use of Figure 5.18 by simply multiplying the length, in inches, of any cylindrical section by the *lb/in.* value listed for the diameter of that section.

Scale Wt. #(lb) = sum of:
$0.11 \times D^2 \times L$ = ________ lb
$0.22 \times D_h^2 \times h$ = ________ lb
$0.22 \times D_f^2 \times f$ = ________ lb
Wt.# = ________ lb

(all dimensions in inches)



SCALED CORRECTION FOR SHAFT DROOP

FIGURE 5.17

Weights of Circular Steel Sections Per Inch of Length

Section Diameter			**2.00**	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.50**	**3.75**
lb/in. Length			0.88	1.11	1.38	1.66	1.98	2.32	2.70	3.09
4.00	**4.25**	**4.50**	**4.75**	**5.00**	**5.25**	**5.50**	**5.75**	**6.00**	**6.25**	**6.50**
3.52	3.97	4.46	4.96	5.50	6.06	6.66	7.27	7.92	8.59	9.30
6.75	**7.00**	**7.25**	**7.50**	**7.75**	**8.00**	**8.25**	**8.50**	**8.75**	**9.00**	**9.25**
10.0	10.8	11.6	12.4	13.2	14.1	15.0	15.9	16.8	17.8	18.8
9.50	**9.75**	**10.0**	**10.5**	**11.0**	**11.5**	**12.0**	**12.5**	**13.0**	**13.5**	**14.0**
19.9	20.9	22.0	24.3	26.6	29.1	31.7	34.4	37.2	40.1	43.1
14.5	**15.0**	**15.5**	**16.0**	**16.5**	**17.0**	**17.5**	**18.0**	**18.5**	**19.0**	**19.5**
46.3	49.5	52.9	56.3	59.9	63.6	67.4	71.3	75.3	79.4	83.7

FIGURE 5.18

Since half the shaft weight plus all of the companion flange weight is to be compensated for at the scale, total scale weight can be calculated by the work sheet included in Figure 5.17 (example Figure 5.19).

Example Problem:
(ref. Figures 5.17 & 5.19) If in our illustration Figure 5.17, the following dimensions apply:

Shaft diameter **D = 4.0 in.;** and, shaft length **L = 60.0 in.;**

Companion flange hub diameter **D_h = 6.0 in.;** hub length **h = 6.5 in.;**

Flange section diameter **D_f = 9.0 in.;** flange thickness **f = 0.75 in.**

Proceed in calculating hoist pull "P" (lb) as follows: Note: In this example both methods of obtaining weights will be shown.

First, overhung shaft weight is calculated as: (per formula-1)
Wt. = 0.22 $\times$ (4.0)^2 $\times$ 60 = 211.2 lb

(per Figure 5.18)
Wt. = 60 in $\times$ 3.52 lb/in = 211.2 lb

Half of overhung shaft wt. = **105.6 lb**

Then, companion flange weight, including shaft material inserted into the flange, is calculated:

(per formula-1):
Hub section
wt. = 0.22 $\times$ (6.0)^2 $\times$ 6.5 = 51.5 lb

Flange section
wt. = 0.22 × (9.0)² × 0.75 = 13.4 lb

(per Figure 5.18)
Hub section
wt. = 6.5 in × 7.92 lb/in = 51.5 lb

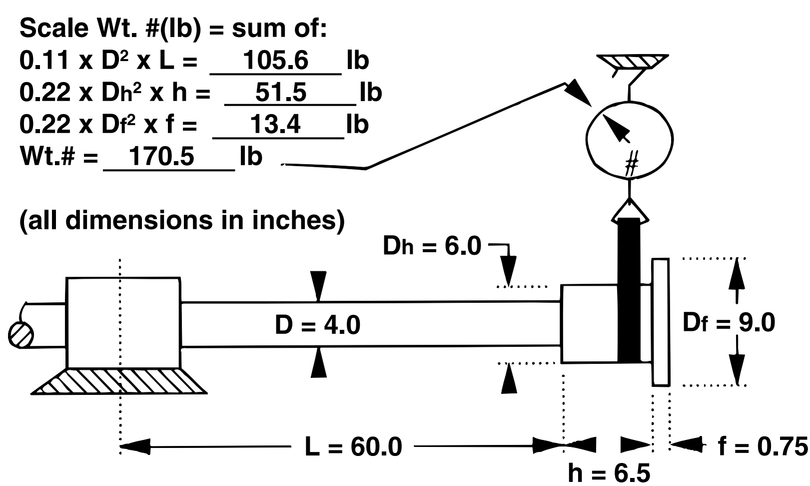
Flange section
wt. = 0.75 in × 17.8 lb/in = 13.4 lb

Total companion flange wt. = **64.9 lb**

Finally, the scale reading at the hoist should be the sum of the total companion flange wt. and half the overhung shaft wt.:
"P" = 105.6 + 64.9 = 170.5 lb

Caution: The hoisting mechanism must be set up in such a manner that the direction of pull or lift is straight up, i.e., no force is to be exerted sideways in order to avoid side to side misalignment of the marine gear to the propeller shaft. This can be checked with a plumb line suspended from the overhead connection for the hoisting mechanism.

Also, if the hoist is to be removed and the shaft supported by other means prior to final connection to the marine gear, dial indicators at vertical and side locations should be employed to insure the shaft remains at its proper position.



SCALED CORRECTION FOR SHAFT DROOP

FIGURE 5.19

Shaft Diameter (inches) for Hub Diameter = 1.40 to 1.74 times Shaft Diameter

Shaft L/d	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
8	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.004	0.005	0.006	0.007	0.008	0.009
9	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.013	0.014
10	0.001	0.002	0.003	0.004	0.005	0.007	0.008	0.010	0.012	0.014	0.016	0.018	0.021
11	0.002	0.003	0.004	0.006	0.007	0.009	0.012	0.014	0.017	0.019	0.023	0.026	0.029
12	0.003	0.004	0.006	0.008	0.010	0.013	0.016	0.019	0.023	0.027	0.031	0.035	0.040
13	0.003	0.005	0.008	0.010	0.013	0.017	0.021	0.025	0.030	0.036	0.041	0.047	0.054
14	0.004	0.007	0.010	0.014	0.018	0.022	0.028	0.033	0.040	0.047	0.054	0.062	0.071
15	0.006	0.009	0.013	0.017	0.023	0.029	0.035	0.043	0.051	0.060	0.070	0.080	0.091
16	0.007	0.011	0.016	0.022	0.029	0.036	0.045	0.054	0.065	0.076	0.088	0.101	0.115
17	0.009	0.014	0.020	0.028	0.036	0.046	0.056	0.068	0.081	0.095	0.110	0.127	0.144
18	0.011	0.017	0.025	0.034	0.044	0.056	0.069	0.084	0.100	0.117	0.136	0.156	0.178
19	0.014	0.021	0.031	0.042	0.054	0.069	0.085	0.103	0.122	0.144	0.166	0.191	0.217
20	0.016	0.026	0.037	0.050	0.066	0.083	0.103	0.124	0.148	0.174	0.201	0.231	0.263
21	0.020	0.031	0.044	0.060	0.079	0.100	0.123	0.149	0.178	0.208	0.242	0.278	0.316
22	0.023	0.037	0.053	0.072	0.094	0.119	0.147	0.178	0.211	0.248	0.288	0.330	0.376
23	0.028	0.043	0.062	0.085	0.111	0.140	0.173	0.210	0.250	0.293	0.340	0.390	0.444
24	0.033	0.051	0.073	0.100	0.130	0.165	0.203	0.246	0.293	0.344	0.399	0.458	0.521
25	0.038	0.059	0.085	0.116	0.152	0.192	0.237	0.287	0.342	0.401	0.465	0.534	0.608
26	0.044	0.069	0.099	0.135	0.176	0.223	0.275	0.333	0.396	0.465	0.539	0.619	0.704
27	0.051	0.079	0.114	0.155	0.203	0.257	0.317	0.384	0.457	0.536	0.622	0.714	0.812
28	0.058	0.091	0.131	0.178	0.233	0.295	0.364	0.441	0.524	0.615	0.714	0.819	0.932
29	0.067	0.104	0.150	0.204	0.266	0.337	0.416	0.503	0.599	0.703	0.815	0.936	1.065
30	0.076	0.118	0.170	0.232	0.303	0.383	0.473	0.573	0.681	0.800	0.927	1.065	1.211

FIGURE 5.20

Shaft Diameter (inches) for Hub Diameter = 1.75 to 1.99 times Shaft Diameter

Shaft L/d	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
8	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.013	0.014
9	0.001	0.002	0.003	0.004	0.005	0.007	0.008	0.010	0.012	0.014	0.016	0.019	0.021
10	0.002	0.003	0.004	0.006	0.008	0.010	0.012	0.014	0.017	0.020	0.023	0.027	0.030
11	0.003	0.004	0.006	0.008	0.010	0.013	0.016	0.020	0.024	0.028	0.032	0.037	0.042
12	0.004	0.006	0.008	0.011	0.014	0.018	0.022	0.027	0.032	0.037	0.043	0.050	0.056
13	0.005	0.007	0.010	0.014	0.019	0.024	0.029	0.035	0.042	0.049	0.057	0.065	0.074
14	0.006	0.009	0.014	0.018	0.024	0.030	0.038	0.045	0.054	0.064	0.074	0.085	0.096
15	0.008	0.012	0.017	0.023	0.031	0.039	0.048	0.058	0.069	0.081	0.094	0.108	0.122
16	0.010	0.015	0.022	0.029	0.038	0.049	0.060	0.073	0.086	0.101	0.117	0.135	0.153
17	0.012	0.019	0.027	0.036	0.047	0.060	0.074	0.090	0.107	0.125	0.145	0.167	0.190
18	0.015	0.023	0.033	0.044	0.058	0.074	0.091	0.110	0.131	0.153	0.178	0.204	0.232
19	0.018	0.027	0.040	0.054	0.070	0.089	0.110	0.133	0.158	0.186	0.216	0.247	0.282
20	0.021	0.033	0.048	0.065	0.084	0.107	0.132	0.160	0.190	0.223	0.259	0.297	0.338
21	0.025	0.039	0.057	0.077	0.101	0.127	0.157	0.190	0.226	0.266	0.308	0.354	0.402
22	0.030	0.046	0.067	0.091	0.119	0.150	0.186	0.225	0.267	0.314	0.364	0.418	0.475
23	0.035	0.054	0.078	0.107	0.139	0.176	0.218	0.264	0.314	0.368	0.427	0.490	0.558
24	0.041	0.063	0.091	0.124	0.163	0.206	0.254	0.307	0.366	0.429	0.498	0.571	0.650
25	0.047	0.074	0.106	0.144	0.188	0.238	0.294	0.356	0.424	0.497	0.577	0.662	0.754
26	0.054	0.085	0.122	0.166	0.217	0.275	0.339	0.411	0.489	0.573	0.665	0.763	0.869
27	0.062	0.097	0.140	0.191	0.249	0.315	0.389	0.471	0.560	0.658	0.763	0.876	0.996
28	0.071	0.111	0.160	0.218	0.284	0.360	0.444	0.538	0.640	0.751	0.871	1.000	1.137
29	0.081	0.126	0.182	0.247	0.323	0.409	0.505	0.611	0.727	0.854	0.990	1.136	1.293
30	0.091	0.143	0.206	0.280	0.366	0.463	0.572	0.692	0.823	0.966	1.121	1.286	1.464

FIGURE 5.21

Shaft Diameter (inches) for Hub Diameter = 2.00 to 2.25 times Shaft Diameter

Shaft L/d	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
8	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.015	0.018	0.020
9	0.002	0.003	0.004	0.006	0.007	0.009	0.011	0.014	0.016	0.019	0.022	0.026	0.029
10	0.003	0.004	0.006	0.008	0.010	0.013	0.016	0.020	0.023	0.027	0.032	0.036	0.041
11	0.004	0.006	0.008	0.011	0.014	0.018	0.022	0.027	0.032	0.037	0.043	0.050	0.057
12	0.005	0.007	0.011	0.014	0.019	0.024	0.030	0.036	0.043	0.050	0.058	0.067	0.076
13	0.006	0.010	0.014	0.019	0.025	0.031	0.039	0.047	0.056	0.065	0.076	0.087	0.099
14	0.008	0.012	0.018	0.024	0.032	0.040	0.050	0.060	0.071	0.084	0.097	0.111	0.127
15	0.010	0.016	0.022	0.031	0.040	0.051	0.062	0.076	0.090	0.106	0.122	0.141	0.160
16	0.012	0.019	0.028	0.038	0.050	0.063	0.078	0.094	0.112	0.131	0.152	0.175	0.199
17	0.015	0.024	0.034	0.047	0.061	0.077	0.096	0.116	0.138	0.161	0.187	0.215	0.245
18	0.019	0.029	0.042	0.057	0.074	0.094	0.116	0.141	0.167	0.196	0.228	0.261	0.297
19	0.022	0.035	0.050	0.069	0.089	0.113	0.140	0.169	0.201	0.236	0.274	0.315	0.358
20	0.027	0.042	0.060	0.082	0.107	0.135	0.167	0.202	0.240	0.282	0.327	0.375	0.427
21	0.032	0.049	0.071	0.097	0.126	0.160	0.197	0.239	0.284	0.334	0.387	0.444	0.505
22	0.037	0.058	0.084	0.114	0.148	0.188	0.232	0.281	0.334	0.392	0.455	0.522	0.594
23	0.043	0.068	0.097	0.133	0.173	0.219	0.271	0.328	0.390	0.458	0.531	0.609	0.693
24	0.050	0.079	0.113	0.154	0.201	0.254	0.314	0.380	0.452	0.531	0.616	0.707	0.804
25	0.058	0.091	0.130	0.178	0.232	0.293	0.362	0.438	0.522	0.612	0.710	0.815	0.928
26	0.067	0.104	0.150	0.204	0.266	0.337	0.416	0.503	0.599	0.703	0.815	0.935	1.064
27	0.076	0.119	0.171	0.233	0.304	0.385	0.475	0.575	0.684	0.802	0.931	1.068	1.215
28	0.086	0.135	0.194	0.265	0.345	0.437	0.540	0.653	0.777	0.912	1.058	1.215	1.382
29	0.098	0.153	0.220	0.299	0.391	0.495	0.611	0.739	0.880	1.033	1.198	1.375	1.564
30	0.110	0.172	0.248	0.338	0.441	0.558	0.689	0.834	0.992	1.165	1.351	1.551	1.764

FIGURE 5.22

Marine Gear Installation

General Information

Alignment of the marine gear to propeller shafting in the vessel warrants close attention. The alignment must be within specified tolerances for satisfactory transmission service life. This discussion outlines the steps in accomplishing such alignment. It applies to both free standing (island mounted) marine gears and those bolted directly to the propulsion engine at the flywheel.

Alignment must be accomplished while the shafting is at, or very near, its true centerline position (ref. discussion in preceding section regarding shaft droop).

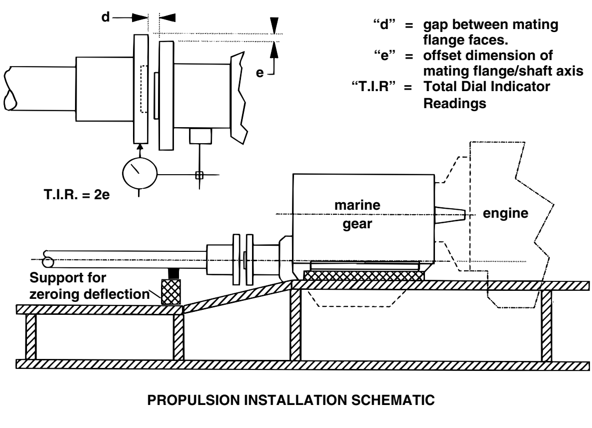
After the propeller shaft droop has been compensated for, and the shaft properly supported at the free end as shown in Figure 5.23, the marine gear or gear and engine combination may then be aligned to the propeller shaft.

Alignment Terms and Parameters

The objective of the alignment process outlined herein is good axial alignment of the marine gear to the shafting. Axial alignment is the relationship of the axis of rotation of the members to be coupled, in this case, the propeller shaft and gear output flanges.

There are two basic alignment parameters involved in this process. They are:

1. Parallel or *bore* alignment.
2. Angular or *face* alignment.



PROPULSION INSTALLATION SCHEMATIC

FIGURE 5.23

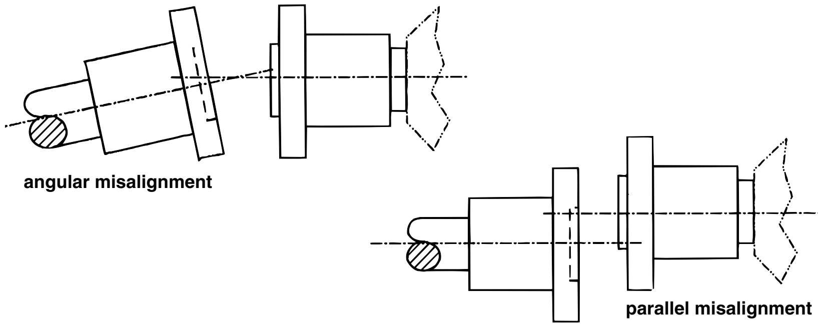


FIGURE 5.24

Angular misalignment occurs when the centerlines (axis) of the marine gear output shaft and the propeller shaft are not parallel. The limits for parallel and angular misalignment are given in the Alignment Procedure section.

Parallel misalignment occurs when the centerlines, or axis, of the marine gear output shaft and propeller shaft are parallel but not in line.

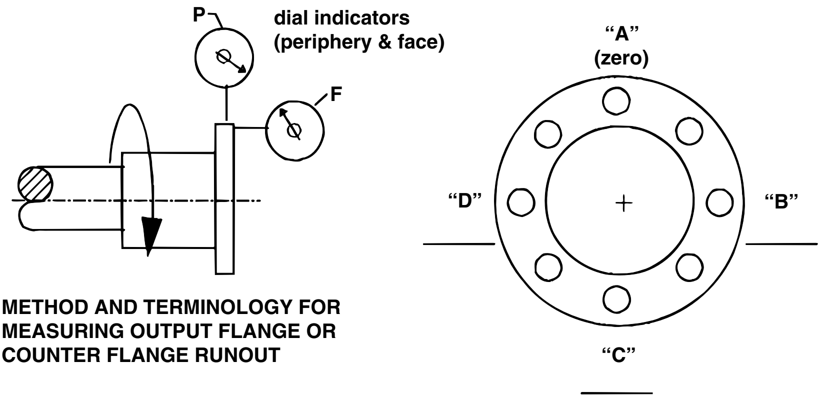
Conditions Required for Alignment

Precision machinery deserves every effort to assure its proper alignment, but it cannot be assumed the machinery bed is a level, stationary, non-deflecting surface. The hull is constantly deflecting, due to daily and seasonal temperature variation, various load and ballast conditions, and sea conditions.

Do not attempt final alignment of propulsion machinery unless the following conditions are met:

- The vessel is in the water.
- All permanent ballast is in place.
- Fuel, Water, and Temporary Ballast Tanks are filled to normal, average, operating levels, generally $\frac{1}{2}$ to $\frac{3}{4}$ filled. It is not necessary to fill fuel tanks with fuel, since it is only the weight of the fluid in the tanks that is important to load the hull to representative displacement. Water is a suitable alternative to fuel for this purpose.
- All major machinery – weighing over 500 lb (225 kg) – is either installed or simulated by equivalent weights appropriately located.

Note: Where prior experience has shown good results, the alignment process can be substantially completed prior to launch. Make final alignment check immediately prior to sea trials.



METHOD AND TERMINOLOGY FOR MEASURING OUTPUT FLANGE OR COUNTER FLANGE RUNOUT

FIGURE 5.25

Alignment Procedure

Marine gears and engines with flywheel housing mounted marine gears:

1. With the propeller shaft set on roller block or oiled “V” block sweep the flange face with a dial indicator (Figure 5.25). While watching the indicator, rotate the shaft and note the point of *minimum* indicator reading. Make a reference mark (with paint, center punch,…) on the flange rim at the bolt hole nearest the point of *minimum* indicator reading. For all future readings on this flange this will be the “ZERO” reference location “A”.
2. With the dial indicator set at the “A” zero reference location, set the dial to zero. Rotate the shaft and measure and record indicator readings at the 3:00, 6:00, and 9:00 positions (facing the flange). These positions correspond to positions “B”, “C”, and “D” respectively. Continue the rotation to one complete turn, rechecking at the “A”, or 12:00 position for zero indicator reading.
3. Using the same zero “A” reference point set the dial indicator to measure and runout of the flange rim (periphery). Repeat the procedure outlined in step 2 to accomplish this.
4. Repeat steps 1 to 3 to measure and record marine gear output flange face and peripheral runout *with the following exception:* Use bolt hole location nearest point of “maximum” indicator reading for zero “A” reference.

Any runout errors must be accounted for in the alignment process. The maximum allowable runout, for most Twin Disc marine gears offered by Caterpillar, is:

Maximum Face Runout = 0.004 in. (0.10 mm)
Maximum Bore Runout = 0.004 in. (0.10 mm)
Runouts shown are total dial indicator readings (T.I.R.).

Note: If face (or bore) runout is excessive on the marine gear flange, some correction may be obtained by removing and reinstalling the flange at a different position (if the type of connection permits).

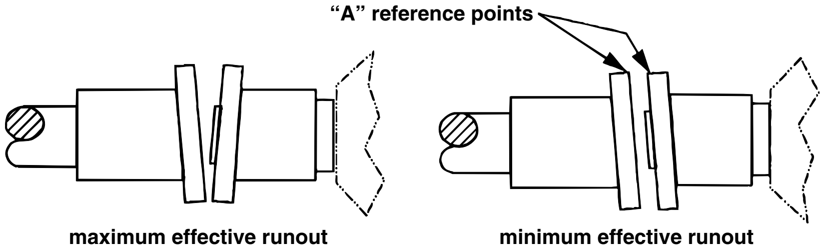
Compensation may also be obtained by selective match of the mating flanges providing flanges have not already been reamed and matched for fitted bolts connection. For example, if the "A" reference points of both flanges, as determined in steps 1 and 4 are mated then face runout compensation will be realized (Figure 5.26).

Carrying this example further, if maximum T.I.R. of the shaft flange is +0.008 in. and that of the marine gear flange is –0.005 in. they are individually out of tolerance, however, their effective runout is their sum which is 0.008 + (–0.005) = 0.003 in. This would be acceptable since it is within the 0.004 in. limit.

5. Position the propeller shaft about 0.3 inches (8 mm) aft of its planned final position.

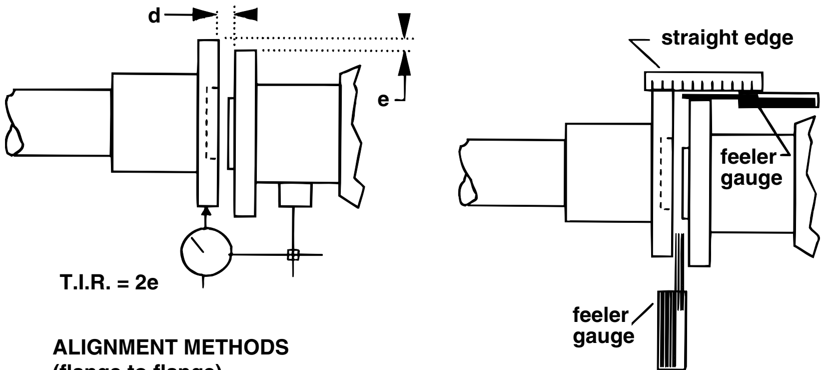
Note: At this point scantlings or supports for the gear engine mounting should be in place with sufficient gap for poured or metal shims. If not, install these supports now.

6. Now move the marine gear (or gear engine package) to its approximate final position so that mating flange gap is about 0.3 in. (8 mm), per step 5, without engaging the flange pilot.
7. **Bore alignment:** Take measurements of the diameter gap at four equally spaced points on the flanges' diameters. A straight edge with a feeler gauge, or a dial indicator may be used as shown in Figure 5.27 to accomplish this. If the dial indicator is used, mount it on the gear output flange as shown and sweep the companion flange for T.I.R. Make appropriate position adjustments with wedges or jacking screws to locate the marine gear output flange within 0.005 in. (0.127 mm) of bore alignment (dimension e, Figure 5.27). Maximum T.I.R. would be 0.010 in. (0.254 mm). A slip fit of mating flange pilots on transmissions so equipped – ensures adequate bore alignment.



COMPENSATION FOR MATING FLANGE FACE RUNOUT

FIGURE 5.26



ALIGNMENT METHODS (flange to flange)

FIGURE 5.27

8. When this condition is met, engage the flanges' pilot surfaces by bringing the propeller shaft and companion flange forward to within 0.180 in. (4.5 mm) at all points about the diameter of the flanges.

9. **Angular Alignment:** Position adjustments of the engine and transmission may now be made to align the marine transmission output flange to a proper angular or face alignment position. Using a feeler gauge, or small hole gauge, take measurements of face gap at four equally spaced positions; A, B, C, and D. (Figure 5.27) Then, proceed as follows:

   a. Tabulate the readings of face gap.

   b. Compare diametrically opposite face gap readings (compare readings at A to readings at C; and readings at B to readings at D).

   c. Subtract the smaller of diametrically opposite readings from the larger for both A to C, and B to D.

   Example: if the reading at A is 0.175 in. and the reading at C is 0.165 in., then subtract 0.165 from 0.175 giving a result of 0.010 in.

d. The resulting differences are proportional to the amount of angular or face misalignment. The face gap difference reading must not exceed 0.005 in. (A to C, or B to D). If the gap difference reading exceeds this value, the engine and marine gear must be moved until the required tolerance is reached.

e. As the engine is moved for angular alignment, ensure the bore alignment is not altered.

10. Recheck all alignment readings, insert the bolts into the flanges, and prepare the marine gear/engine supports for final securing to the boat's engine foundation.

Except for final alignment checks, after securing the unit to the foundation and prior to sea trial of the vessel, this completes the alignment process.

Installation/Alignment Instructions

Caterpillar Engines and other Free Standing Marine Gears and Vulkan Rato Flexible Couplings

Introduction

The purpose of this instruction sheet is to outline a proven and effective procedure for accurate alignment of Caterpillar Marine Engines to free standing reduction gears, most specifically, where Vulkan Rato flexible couplings are used. The procedure can be adapted to most other coupling types if care is taken to allow relative radial and angular movement between engine and marine gear coupling interface during the alignment process.

Preliminary

The following preliminary steps should already have been done or in place before starting engine to gear alignment:

1. Propeller shafting *in place*. Marine gear aligned to shaft and *secured to foundation* with fitted bolts and thrust stops as required.
2. Flexible coupling inner member mounted to marine gear and outer member mounted to engine flywheel per Figure 5.28.
3. Engine positioned in close proximity (by sight) to the final alignment, but with coupling outer and inner members not touching.
4. Jacking screws are for engine side to side and fore and aft positioning movement in place (provided and installed by shipyard or installer). Jacking screws provided with engine for vertical positioning should be clean and well oiled.

5. Necessary tools and instrumentation at hand, such as: dial indicators with bracketry; yoke for mounting instruments to marine gear hub (ref part numbers 6V2042 & 6V2043); pry bar for moving crankshaft fore/aft and flywheel up/down; turning tool for rotating engine at flywheel; and miscellaneous hand tools.

Step 1

a. Clean periphery of flywheel and face of coupling/flywheel adapter plate so dial indicators can sweep face and circular runout at flywheel through one complete rotation. Remove any nicks or burrs that interfere with dial indicator readings. A light cleaning with oil may also be beneficial.

b. Mount dial indicators from flywheel housing as shown in Figure 5.28.

c. Rotate engine through one complete revolution and note total dial indicator readings for both face and periphery of flywheel. Record these readings. (Omit this step if coupling has torsional stop.)

d. Remove an engine block side cover and, with the pry bar between the crankshaft web and the main bearing saddle, move the crankshaft fore and aft. Record total indicator movement on data sheet. Leave crankshaft in full forward position.

e. With pry bar, move flywheel up (full travel) and record half of the total movement. This is the flywheel *droop.*

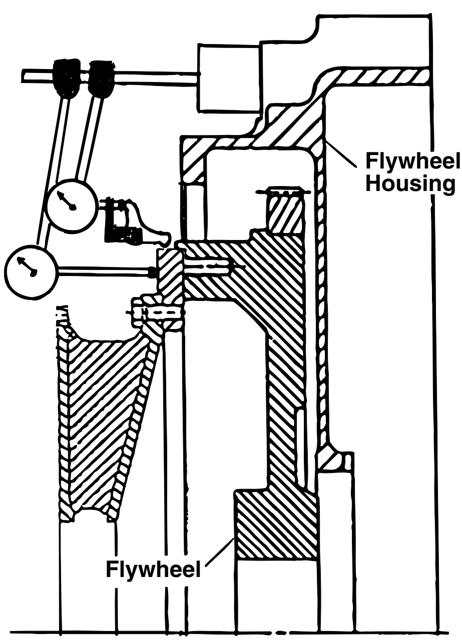


FIGURE 5.28

f. Determine offset dimension “Y”. This is the amount the marine gear should be set higher than the engine and is equal to flywheel droop, (as found in step “e”), plus the difference in thermal growth of the engine and gear input centers “Xt”.

“Y” = [F. W. droop + Xt]
“Xt” is approximated by the formula:
Xt = [0.009 – (0.0004 $\times$ d)] in.
(Where d = gear input to mounting ledge distance in inches.)

Note: For WAF gear models 540 & 560; Xt = + 0.003 in. may be used. For WAF models 860 & 1160; use Xt = –0.002 (negative). Xt for WAF models 640, 660, 740, 760, 840, and 1140 is small and can be ignored.

g. Compute “Y” = F.W. droop + Xt = ______ + ______ = ______ Record “Y” on data sheet, see Figure 5.29.

Step 2

a. Remove dial indicators from flywheel housing.

b. With the crankshaft still fully forward, position the engine to the marine gear so that the flexible coupling outer member is aligned with the inner member (by sight) and the gap between the inner and outer members, measured with a feeler gauge, is equal to half the total fore/aft crankshaft movement, measured in step 1d, ±0.002 in. The gap should be measured at the connection points for the bolts marked “X” in Figure 5.30.

Note: Do not install these bolts at this time.

c. Turn the marine gear input shaft and check for freedom of movement. It should turn without much difficulty but may have a slight drag against the coupling outer or engine side member. If it turns with difficulty, or not at all, repeat part “a” of this step.

Step 3

a. Install necessary yoke, brackets, etc., and mount dial indicators as shown in Figure 5.30.

Note: For the procedure outlined here it will be assumed that movement of the indicator tip into the dial case results in a *positive* reading. Also, all dimensions are in inches unless indicated.

Note: If coupling is equipped with torsional stops (come home feature) proceed directly to sub step "e"; If coupling is not equipped with torsional stops (come home feature) proceed as follows:

b. Swing marine gear input shaft through one revolution while making sure no obstructions or protrusions hinder smooth movement of the indicator tips over the surfaces.

c. Set dial indicators at "A" position and set dials to zero readings. Rotate the marine gear input member (or engine and gear together if equipped with torsional stops) and record T.I.R. readings, for both face and periphery, at locations B, C, and D per diagram in Figure 5.29. Recheck for zero at location A.

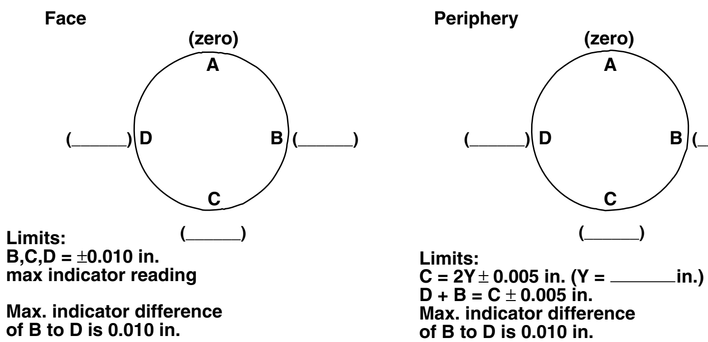


FIGURE 5.29

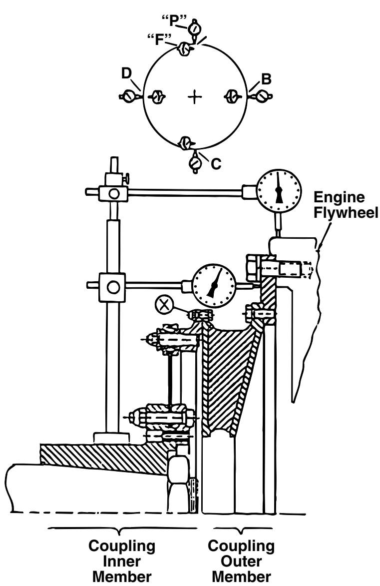


FIGURE 5.30

d. Using the limits outlined in Figure 5.29, for face and peripheral dial indicator readings, adjust engine position as required to obtain readings within those limits. This will probably require several attempts to achieve the desired readings. *For couplings without torsional stop feature,* refer back to runout readings recorded at step 1c. If those readings are not more than 0.005 in. (0.127 mm). face and 0.008 in. (0.203 mm) peripheral proceed directly to step 4, otherwise, continue at “e”.

e. Install several clearance bolts at location “X” so that engine and gear can be rotated together without unduly constraining relative radial movement of the mating coupling members.

f. Repeat sub steps “c” and “d” except rotate engine and gear together by barring or turning the engine flywheel. When readings within the desired range, per Figure 5.29, are obtained remove the clearance bolts at “X” and proceed to step 4.

Step 4

Check axial clearance between coupling members. With crankshaft full forward there should be some clearance between members or, if they are touching, inner member should be rotatable against outer member without excessive drag. (One man should be able to turn gear input shaft by hand or with a 2 ft (0.610 mm) long bar.) With crankshaft all the way to the rear, coupling members should be touching or gap should not exceed 0.020 in. (0.508 mm). Make sure these conditions are met before proceeding to step 5.

Step 5

a. Pour engine chocks or install solid steel shims and secure engine to foundation by appropriate procedures. *Do Not install fitted foundation bolt at this time.*

Note: Loose metal shims are not recommended for heavy engine mountings.

b. When part “a” is complete (be sure sufficient cure time has been allowed for poured chocks) recheck face and peripheral alignment readings per step 3. If readings have changed, which is often the case, do not re-align if limits outlined in Figure 5.29 have not been exceeded by more than 0.005 in. (0.127 mm) face and 0.010 in. (0.254 mm) periphery.

c. With condition “b” met install fitted bolt at rear engine mount on either left or right side. Install collision chocks if required.

d. Using bore aligning tools (tapered pins) align mating coupling members and install snug fit bolts at locations “X”. Do not hammer bolts in.

Press them in or squeeze them in with pliers. They should be installed with the heads to the engine side.

e. Remove instrumentation, reinstall block side cover, etc.

f. This completes the alignment process. If the alignment has been done in dry dock or on a new build in the yard, then alignment should be rechecked when vessel is floated and contains partial stores. This step is critical for vessels with less rigid foundation systems or those more sensitive to float conditions such as flat bottom types.

Record Final Readings

From steps 1 “d” & “e”:

Total flywheel vertical movement . . ___ in.
Total crankshaft movement fore/aft . . ___in.

FACE	PERIPHERY
0.000	0.000
A	A
___D B___	___D B___
C	C

Marine and Engine Gear Mounting

General Information

Preliminary

Proper mounting of the marine gear and propulsion engine in the vessel, once they have been aligned, is critical to maintaining good alignment and consequent smooth, quiet operation and so warrants close attention. This discussion describes the requirements and procedures for mounting marine gears and Caterpillar Engines to the ships foundation and propulsion driveline.

As an engine manufacturer, we can identify the requirements for proper mounting and alignment of the Caterpillar product, however, the responsibility for proper total mounting and alignment always rests with the equipment installer. Primary objectives are:

Mount the *marine gear* so that–

Full propeller thrust can be transmitted to ship structure (except where thrust bearing is separate from marine gear).

Transmitted thrust or other external forces do not adversely affect gear alignment to either the propeller shafting or the engine.

The forces it exerts on its foundation cause no damage.

The *engine* must be mounted so that it is not prestressed.

Movements of the hull cannot reach the engine cylinder block and crankshaft.

Driveline thrust forces are not allowed to reach the crankshaft.

Its natural thermal growth and shrinkage is not restrained.

The forces it exerts on its foundation cause no damage.

Rigid Mounting or *Resilient Mounting* may be used.

Foundations

The marine gear/engine foundation is that portion of the boat's structure which supports the propulsion machinery and holds it in proper relationship to the driveline components. It generally consists of two longitudinal rails – with liberal transverse bracing – which carry the weight, thrust, torque reaction and inertial loads of the gear/engine. It is good design practice to make the foundation members as long as possible. This helps to limit hull deflection by distributing the loads over more of the hull length.

The entire foundation must be strong enough to withstand continued operational forces due to torque, thrust, pitching, rolling, and occasional grounding. Since no structure is absolutely rigid, it is essential that the foundation have greater rigidity than the driveline, so that none of the components of the driveline are stressed beyond their limits when flexing of the hull occurs. Foundation structures may be of metal (steel or aluminum), wood, or fiberglass depending usually on the vessels hull composition. In fiberglass vessel's, foundations will generally be of the *foam filled* type, or wood:

Foam filled foundations require a metal raft between the machinery and the fiberglass foundation to distribute machinery loads more evenly.

Wood foundations allow for relatively simple mounting, using lag screws, and does not normally require special load distributing techniques.

Mounting Types

Engine and marine gear mounting generally falls into one of two categories, i.e. *rigid* or *resilient.*

Rigid Mounting. The engine supports and necessary shims are fastened directly to the boat's structure. The shims, used for positioning the engine or gear in proper alignment, are either steel or poured plastic (refer to the section on shims presented later in this document). With no vibration mounts between the engine supports and the boats structure, flexibility must be built into the engine supports to prevent the engine block from becoming stressed by motions of the hull. It is the simplest and least costly way to mount an engine.

Rigid mounted machinery is generally bolted to the engine foundation.

Resilient Mounting of machinery is usually done for isolation of noise and vibration from the ship structures. It is more expensive and requires more attention to detail than rigid mounting. Flexible fittings must be used for all connections (combustion air, coolant, fuel, exhaust gas, controls, etc.) when resilient mounts are used. A section on resilient mounts is presented later in this document.

Mounting Procedures

Note: In the procedures that follow, it is assumed the alignment processes, i.e., marine gear to shafting and engine to marine gear have been accomplished per procedures outlined in previous sections.

Marine Gear Mounting

For rigid mounting of free standing (separate from engine) marine gears proceed as follows:

1. Make a final check of the marine gear support structures for adequate size, strength, shim space, and sufficient clearances for mounting bolts. If the marine gear mounting brackets are of the bolt on type, make sure they are properly secured against further movement relative to the gear case (dowels in place, etc.).
2. If metal shims (chocks) will be used, machine and fit the shims to each side of the marine gear. Refer to the procedure outlined in the appendix for shim fitting and mounting.

   Note: In exception to the caution listed in appendix, it is permissible to use peel type shim packs, or a few loose shims in conjunction with a thick steel chock. In both cases, stainless steel is preferred. This exception is due to the relative lower linear vibration and greater stability of the marine gear as compared to the engine.
3. Taking care not to move or disturb the gear to shaft alignment, drill and ream the holes for the fitted foundation bolts. A minimum of two fitted bolts should be used. They should be installed on each side and directly (not diagonally) opposite each other. For some marine gears it is permissible, but seldom necessary, to use fitted bolts in the remaining bolt hole locations. The thrust capacity of the bolted marine gear foundation results from: (a) the fitted bolts *shear strength* and, (b) the *clamping force* of all the foundation bolts together.

4. Install all fitted and clearance foundation bolts loosely with the threaded ends up. It is best to have sufficient thread showing for installation of double nuts.

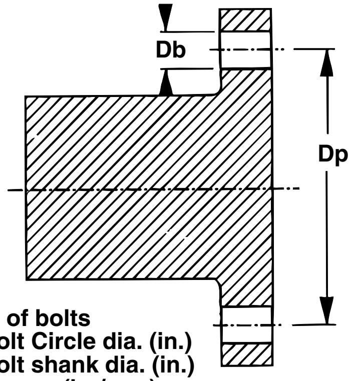
5. If poured *resin* shims are to be used, refer to procedures outlined in the appendix, and to the resin manufacturer's instructions. The basic steps are: (a) Prepare for the pour, i.e. dams around pads, spacers around clearance bolts, etc. (b) Recheck the gear to shaft alignment and reposition the gear as required to assure proper alignment. (c) Make the pour. Allow the poured shims to cure per manufacturers instructions and tighten the hold down nuts to the torque calculated per appendix, so that the recommended pressure on each chock will not be exceeded. (The pressure applied is the sum of the gear weight and bolt loads.)

6. If metal shims are being used, tighten the hold down bolt nuts per Figure 5.38 in the appendix.

7. Make a final alignment check and, if satisfactory, install the double nuts. Mark the nuts at the thread with a daub of paint for easier periodic visual checks of the bolt connections.

8. Draw the marine gear output flange and propeller companion flange connection tight with the connecting bolts. The connecting bolts are either fitted or clearance type. The fitted bolt connections carry the transmitted torque primarily by bolt shear strength, and by some degree of clamping force. As a rule of thumb, fitted bolts are usually required on propeller flange connections transmitting torque of 1 hp/rpm (0.75 kW/rpm) or greater. Below that torque level bolt load clamping force is often adequate to carry the transmitted torque with a high degree of safety, especially if grade 8 bolts at high tightening torque are used.

   If non fitted bolts are used, grade 8 bolts torqued to the standard *high* torque values should be used since full output torque will be carried by the bolt clamping force. The nominal *standard torque* and *high torque* values for $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. bolts, along with the resulting bolt load are given in Figure 5.32, (high torque values in bold print). Using these loads and the formula given in Figure 5.31, the torque that can be safely transmitted through the flange connection can be calculated.



N = no. of bolts
Dp = Bolt Circle dia. (in.)
Db = Bolt shank dia. (in.)
To = Torque (hp/rpm)
Bp = Bolt load (lb)

Allowable Transmitted Torque (non fitted bolts):

$$To = \frac{Dp \times N \times Bp}{2{,}800{,}000} \text{ (hp/rpm)}$$

FIGURE 5.31

Bolt Size	Torque (lb/ft)	Bolt Load "Bp" lb
0.375 – 16 & 24	32 **40**	5,200 **8,200**
0.738 – 14 & 20	50 **65**	7,100 **11,400**
0.500 – 13 & 20	75 **100**	9,200 **15,400**
0.563 – 12 & 18	110 **145**	12,000 **20,000**
0.625 – 11 & 18	150 **200**	14,800 **25,000**
0.750 – 10 & 16	265 **350**	22,000 **37,000**
0.875 – 9 & 14	420 **550**	30,000 **49,500**
1.000 – 8 & 14	640 **825**	40,000 **65,000**
1.125 – 7 & 12	800 **1,000**	44,400 **71,000**
1.250 – 7 & 12	1,000 **1,350**	50,000 **87,000**
1.375 – 6 & 12	1,200 **1,700**	55,000 **100,000**
1.500 – 6 & 12	1,500 **2,000**	63,500 **108,000**

FIGURE 5.32

If fitted bolts are used, drill and ream the mating bolt holes (if this has not already been done) and install the fitted bolts. Torque the fitted bolts to the standard torque values for the bolt size or to the suppliers' recommended torque if specified.

9. Install thrust or collision blocks if required. Install the blocks on both sides of the marine gear with sufficient clearance for thermal expansion of the gear case. The expansion that needs to be allowed for occurs over the distance from the collision block to the first fitted bolt connection. A clearance of 0.0008 in./in. of that distance should be provided for engine jacket water cooled gears. Provide clearance of 0.0006 in./in. of that distance for sea water or keel cooled gears.

Soft *Resilient* **Mounting of free standing marine gears**
Soft mounting of free standing marine gears is infrequent and done only in very special cases as a rule. Due to the various cautions and complexities involved in such installations, the procedure will not be addressed here in detail but the following features are common in these installations:

Remote mounted thrust bearing to isolate the marine gear from the thrust force component.

When the above is used, relative motion between the gear and thrust bearing have to be accommodated which, in turn, may require one or more of the following: a cardan shaft (with slip connection); a flexible drive coupling; or a sufficient length of unsupported shaft between the gear and thrust bearing to accommodate the movement.

Since the engine would also be soft mounted in these installations, special provision is required in the engine to marine gear connection to accommodate the relative movement between the engine and gear, which may be substantial.

One advantage to this type of installation is that resilient mounts may be selected specifically for either the engine or marine gear to tune out their particular sound/vibration frequencies. Due to the higher frequencies of the noise or vibration being isolated, the resilient mounts used for the marine gear will most likely be considerably more stiff than those used for the engine. The mounts will normally have stops incorporated in them to limit motion.

Combined Engine/Marine Gear Mounting

Rigid Mounting of pre-assembled marine gear/engine units
These units, already coupled, have either: (a) continuous rail type supports incorporated on either side (Figure 5.33a), or (b) a three point mounting support system (Figure 5.33b) incorporating a single point front trunnion mount.

When the marine gear and engine are connected at the bell and flywheel housings and mounted on rails, (Figure 5.33a), the package is very strong and can be considered as one unit. Its longitudinal stiffness and length make it very practical for soft mounting if the propeller shaft connection and relative movement are properly accommodated. A fitted bolt, or bolts, is used only at the rear location as indicated in the sketch below.

Further installation procedures for this arrangement are as outlined in the *engine mounting* section which follows this section.

Marine gear and propeller companion flange connections in both of the above arrangements are as covered previously.

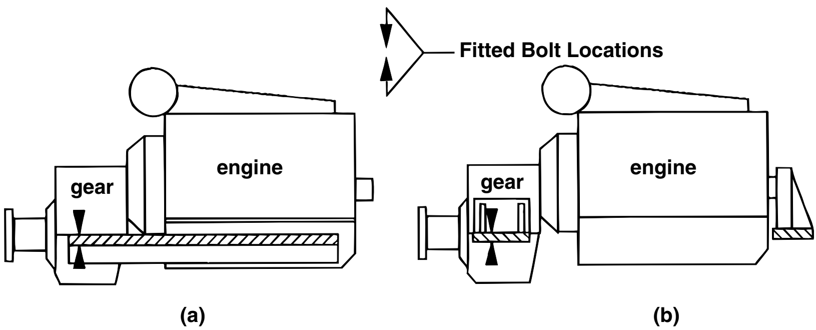


FIGURE 5.33

If the marine gear and engine are connected but not on common rails, as shown in Figure 5.33b, the marine gear is mounted as previously outlined. The front mount, in this case, is usually a trunnion type. The trunnion mount is attached to both ship rails but has a single swivel connection at the front of the engine with the swivel center on the crankshaft centerline. It often has some degree of fore/aft flexibility as well as a fair amount of rotational freedom. Clearance bolts are normally used for the front mounts. This is especially so if the front mount is rigid (not trunnion). In either case, clearance or flexibility of about 0.0008 in./in. of distance, from the fitted bolt or dowel at the marine gear mount, must be provided for thermal expansion of the engine and gear.

Resilient Mounting of pre-assembled marine gear/engine units
A common method of sound/vibration isolation is to have the gear and engine combined by flywheel housing connection and/or common rails (Figure 5.33) and the whole system then isolation mounted.

Resilient mounts under relatively small, close coupled engine/marine gear packages, such as pictured in Figure 5.33b, are commonly used on planing hull type vessels and performance craft.

However, as the size and power of engines increases, it becomes impractical to use very soft resilient mounts directly under the marine gear. This is because the flexibility of more than 2 in. (50 mm) propeller shafts is not adequate to accept large engine/marine gear motions [$\frac{1}{4}$ to 1 in. (6 to 24 mm)] without significant likelihood of damage to the stuffing box or the shaft bearings. It is preferable to mount large engines on resilient mounts and mount the marine gear rigidly to the structure of the boat. (This is a rule of thumb. Special shafting arrangements, such as cardan shaft with axial spline, or flexibility mounted stuffing boxes will allow tempering of this guideline.)

When making this type of installation final positioning of the gear and engine is often done by adjustments of the resilient mounts themselves. In any case, follow instructions provided by the mount manufacturer.

In resilient mount installations of gear and engine combined on common rails (Figure 5.33a), the following basic procedures apply:

- The marine gear must be doweled or attached with body fitted bolts to the common rails.
- The engine, *if not directly connected to the marine gear at the flywheel housing,* must be aligned to the marine gear and doweled, or fitted with a body fit bolt, at the left or right rear of the engine.
  Note: This step may be done toward the end of the installation process.
- The common rails are then positioned on the resilient mounts to be used and the package is aligned to the propeller shaft companion flange per previously outlined procedures. Appropriate shims or chocks are installed as required.
- Make sure propeller thrust or other externally applied forces are accommodated in the mounting system and limited by stops or other devices. (Refer to later sections in this document regarding resilient mounts and shim types.)

Engine Mounting

Three Point Mounting of Engines

Three point mounting systems are normally associated with combined engine/marine gear units. There are, however, some instances in which separately mounted engines will require the three point system such as in high performance patrol craft where weight reduction and system flexibility are premium factors.

The three point system for the engine normally involves mounts on both sides at the rear of the engine at the flywheel housing plus the trunnion mount at the front. This arrangement is very tolerant of flexing of the ships mounting rails which may be encountered in light high speed craft. Hard mounts are used most often but resilient mounts are not uncommon with this arrangement.

Mounting 3500 Family Engines equipped with Mounting Rails
When mounting engines in a vessel the effects of external and thermally induced stresses to the engine must be considered. This is a most important step in any quality installation.

Ships hulls will flex under the internal stresses of varying displacement and the external stresses of wind, water, and temperature. If the engine is too rigidly mounted to the ship's structure, or if it is restrained from its natural thermal growth, excessive stress may reach the blocks' internal support structure. This could in turn result in distortion of main bearing bores, bore alignment, etc. Severe engine damage or significant reduction of engine life could result.

On the 3500 family of engines, as with other Caterpillar engines, the main structural strength is the cast iron block. The plate steel oil pan which supports the engine is a deep, heavy weldment. Lugs or brackets are welded to the sides of the oil pan for attaching the standard mounting rails to the engine. These rails, when properly mounted to the ship rails, provide the flexibility required to isolate the engine from the hull. The holes in the mounting rails are located so that the rails are allowed to flex, isolating the ship's deflection from the engine.

These rails are also flexible enough to accommodate thermal growth from side to side in most cases but provision for thermal growth front to rear must be allowed for. *Under no circumstances should ground body anchor bolts be used forward of the engine's flywheel housing.*

Note: The steel oil pan to which the mounting rails are attached expands at the rate of about 0.0000063 in./in. for each Fahrenheit degree temperature change (or 0.0000113 mm per Celsius degree).

Example: A 3516 oil pan experiences a rise in temperature from 65° F to 205° F, or 140 F degrees. The distance from the fitted bolt at the rear of the rail to the forward most clearance bolt is 80 inches. The expansion, or thermal shift at the forward clearance bolt, is then:

$80 \times 140 \times 0.0000063 = 0.071$ in.

The following basic steps may be followed in mounting 3500 family engines with factory supplied mounting rails:

1. Preliminary . . . Marine gear in place, aligned to propeller shaft, and secured to foundation. (Reference gear alignment procedure document and gear mounting procedure in previous section of this document.)
2. Prepare engine bed (foundations) for poured or metal chocks. Foundation pads for metal chocks should be flat, preferably to within

plus or minus 0.005 inches flatness tolerance. Foundation pads for poured chocks are less critical for flatness but should be placed for best chock thickness, i.e. 0.5 to 1.75 in. (12.7 mm to 44.4 mm).

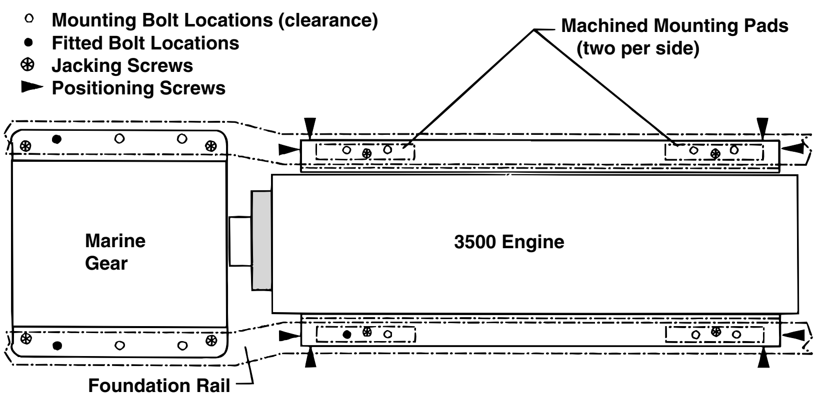
3. Place the engine on the foundation, supported by the jacking screws in the rails, and at final aligned position by sight. Install side to side and fore to aft positioning screws or devices per Figure 5.34. Align the engine to the gear per instructions in the previous document, *Installation/Alignment Instructions.*

4. *If steel chocks are used, a solid chock is recommended.* Fit and install the metal shims at each of the four rail mounting pads according to the steel shim fitting and installation procedures outlined in the appendix.

   It is not necessary to run the steel shim the full length and width of the machined pads incorporated with the 3500 family engine rails. Smaller steel chocks are easier to machine and fit. The shim's area can be considerably less as shown in the example of Figure 5.35, but, they should encompass the two retaining bolts, which are 6 in. (152 mm) apart, and cover at least 0.75 of the 4 in. (19 of the 101 mm) pad width. It is also a good rule of thumb to keep the applied unit pressure on soft steel shims under 5000 psi (34,475 kPa).

5. *If poured chocks are used* refer to the appendix for recommended installation procedures for poured chocks.

Each machined mounting pad on the 3500 family engine rails is about 91.4 in^2 (589 cm^2) in area, minus bolt and jacking screw area, and it is important to utilize all of the pad area when mounting on epoxy resin shims. This is especially so for 3516 engines.



TYPICAL SEPARATE MOUNTED ENGINE/GEAR FOUNDATION PLAN

FIGURE 5.34

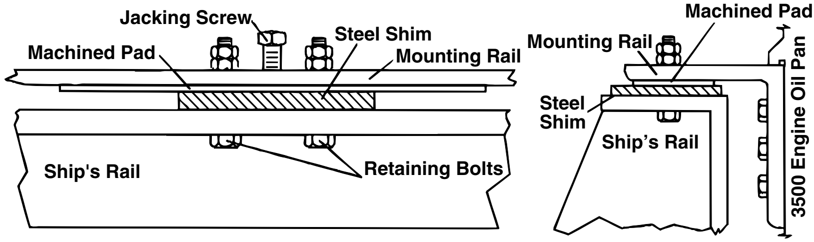
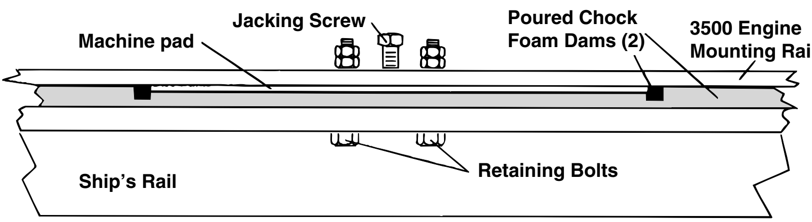


FIGURE 5.35



EXAMPLE OF CONTINUOUS POUR

FIGURE 5.36

The shim material can be poured at the mounting pad locations only (an interrupted pour), or it can be used under the full length of the engine rail, *except for immediately fore and aft of the machined mounting pads.*

This is referred to as a *continuous* pour.

Caution: (Figure 5.36). In either case, do not pour shim material inboard of the machined pad on the bottom of the mounting rail. Foam rubber strips must be installed on sides and both ends of each pad to provide for expansion. (Figures 5.36 and 5.37).

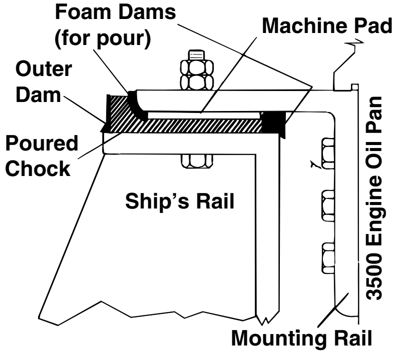


FIGURE 5.37

Mounting Bolt Torques for use with Poured Shims
After the shim material has sufficiently hardened according to the manufacturer's specification, tighten $\frac{7}{8}$, 1 and $1\frac{1}{8}$ in. (22.2, 25.4, and 28.6 mm) mounting bolts to a torque of 360 lb ft (490 N•m). This bolt torque is specified to prevent excessive unit pressure on the poured shims.

Use two nuts on each mounting bolt. Tighten the innermost nut to 360 lb ft (490 N•m). Use Figure 5.38 in the appendix for torques of the outermost nut.

Resilient mounting of 3500 Family Engines equipped with Mounting Rails
This procedure will be addressed here only in general terms due to the wide variation of resilient mounting systems available. It is very important that the resilient mount manufacturer's directions for installation and operational limits be adhered to. Additional general information regarding soft mounts is included in the appendix.

The following factors are common to most or all resilient engine mount installations, and, should be carefully considered along with the manufacturer's recommendations.

The resilient mounts are to be installed between the mounting pads of the rails and the ship's foundation. (Engine and gear on common rails was covered in an earlier section).

One or both of the rear mounts, nearest the flywheel housing, should be positively located to fix the engine relative to the marine gear. Positive location (doweling) of the engine mounting rail to these mounts will depend on manufacturer's instructions.

Positive stops for excessive vertical or horizontal movement must be provided with or incorporated in the resilient mounts. These are required to limit relative engine motion due to inherent engine motion, misfiring, or vessel pitching and rolling.

Collision blocks or stops will be required, in case of collisions or grounding.

The flywheel mounted flexible coupling must be selected with care. It must routinely tolerate the ranges of side to side and fore/aft motions predicted for the given set of soft mounts.

Similarly, all water, air, exhaust, hydraulic, control, and fuel system connections must be flexible enough to accommodate repeated, day to day movement without failure.

The foregoing applies to all soft mounted engine systems. If the marine gear, which is separately mounted, is also on soft mounts, the prior section on soft mounted gears should also be reviewed for additional factors of concern.

Appendix

Shims, Spacers, Chocks:

General

Shims, spacers, or chocks must be provided to fit the individual locations between the top surface of the supporting members and the bottom surface of the mounting pads of marine engines and gears. Marine Classification Society (MCS) rules often dictate the type of shim to be used. The two most common and effective types will be addressed here. They are: (1) poured epoxy (plastic) shims, and (2) solid steel shims.

Mounting With Poured Shims:

Poured shims, or chocks, have become the shim of choice today in most mounting systems for marine propulsion equipment. The advantages of poured shims over metal are several:

- The time consuming (and costly) process of selective machining and hand fitting of solid steel shims is avoided.
- The surface condition or flatness of mating foundation and support planes is less critical, eliminating further machining operations in many cases.
- The plastic chocking material offers some degree of noise damping between the engine or gear and the foundation member.
- Zero shrinkage of the poured shim material, when mixed and applied properly, allows the most precise retention of position and alignment when the mounting procedure has been properly completed and the retaining bolts secured.

Before installing poured shims, consult the manufacturer's instructions for using the shim material. Strictly adhere to such critical items as mixing ratios, cure times, temperature effects, allowable thickness, and maximum unit loading. The basic steps in installing poured epoxy shims are as follows:

1. Machine to be mounted is in final aligned position with mating mounting structures in proper place and condition. These mating pads should be of sufficient strength and area, reasonably flat and parallel.
2. Liquid shim materials, damming materials, blowers, grease-releasing agents, tools, etc. at hand per manufacturers recommendation.
3. Drill clearance holes through at all clearance bolt locations.

   Note: It is recommended that holes for the fitted bolts be drilled and reamed after: the chocks have cured; the clearance bolts have been torqued; and alignment rechecked (in case the pour and alignment might have to be repeated).

4. Install the foundation hold-down bolts threaded end up and with nuts hand tight. Sleeve or foam wrap the bolt shanks to provide clearance for thermal expansion of the machinery. An optional method is to grease the bolt shanks with high temperature (non melt) grease, then, remove the bolts and redrill the bolt holes for adequate clearance after the chock has cured.
5. Spray all chock contact surfaces with a suitable releasing agent to prevent adhesion of the chock to those surfaces.
6. Install damming material in preparation for the pour. In this operation, consider the following:
   a. Ship's trim…pour from the high end or from the side.
   b. On non pour sides of the chock, dams of non porous foam material is recommended. Use foam tape around edges of mounting pads to provide for pad movement during thermal expansion of the machine or flexing of the foundation members.
   c. Use rigid or semi rigid damming material around the pour area. Width of the pour area generally should not exceed 0.75 in. (20 mm), and should provide a riser of at least 0.5 in. (12 mm).
7. Mix the resin and hardener for the chocks and make the pour per the resin manufacturers instructions. Be sure to allow sufficient time for the chocking material to cure.
8. After making sure of sufficient clearance around clearance bolt shanks, torque all the clearance bolt nuts to obtain total bolt loading on the chocks equal to $2\frac{1}{2}$ times the weight of the mounted machinery but within the unit pressure limits for the individual chocks as set by the resin manufacturer. Unit pressure limits on the poured chock are usually 500 psi (3447 kPa) when maintenance of machinery alignment is required, (as in the case of propulsion engines and gears). To aid in determining the proper torque range the following formulas may be used in calculating bolt loads:

   $$\text{Bolt Load (lb)} = \frac{60 \times \text{Bolt Torque (lb ft)}}{\text{Bolt Dia. (in.)}}$$

   $$\text{Bolt Load (kg)} = \frac{500 \times \text{Bolt Torque (kg m)}}{\text{Bolt Dia. (mm)}}$$

   Unit load on a given chock is obtained by first summing the weight from the machine plus any machine torque load component plus the total bolt load, all of which is then divided by the chock area.
9. After the clearance bolts have been tightened, recheck for proper alignment or position of the machine. (Keep in mind that some slight shift is normal due to thermal effects on the ship's hull, instrument variations and so on.)

10. If positioning is still satisfactory, install the fitted bolt or bolts.
11. Install the second set of nuts and torque these against the first nuts per Figure 5.38. Be careful that the first, or primary, nut is not torqued to a higher level than that determined in step 8. Mark the nuts with a paint spot to aid in future pass by inspections for loose nuts.
12. Remove damming materials. Clean, dress, or chip away excess chock, where necessary, for appearance and to relieve any unintended restraint of the mounting pad.

Full Torque Values

Dia (in.)	0.500	0.563	0.625	0.750	0.875	1.000	1.125	1.250	1.375	1.500
Torque (lb ft)	75 ± 10	110 ±15	150 ± 20	265 ± 35	420 ± 60	640 ± 80	800 ± 100	1000 ± 120	1200 ± 150	1500 ± 200

FIGURE 5.38

Mounting With Steel Shims

Ideally, steel shims, or chocks, are one piece and are made to fit between the top of the ship's rail or machinery foundation and the bottom of the corresponding mounting pad of the engine or marine gear mounting rail or bracket. Mild steel plates are normally used and are surface-machined to specific dimensions at each corner of the plate as determined when the engine or gear has been placed in the final aligned position. The shims can be numbered to avoid confusion during installation. The machining of these shims must provide a uniform fit between the respective machine rails or brackets and the foundation pads.

To fit and install steel chocks the following procedures are suggested:

1. Foundation pads for metal chocks should be flat, preferably to within 0.005 inch flatness tolerance.
2. With the machinery to be mounted in its proper aligned position, measure the vertical gap between the pad and foundation at each corner of the shim area. If both the mounting pad and foundation pad are flat, the four corner gap dimensions will dictate the corner dimensions of the surface machined, finished shim.
3. To facilitate ease of fitting, the chock can be slotted to fit around jacking screws.
4. Check the proper fit of each chock by use of blueing dye, carbon paper, strip gauge (plastigage), or feeler gauges. This is a judgment operation by the fitter/installer. The objective is good even contact, (40% or more), over the major length and width of the mounting faces. Do selective grinding or machining as required to obtain the proper fit.

5. When all of the chocks have been fitted, drill clearance holes for the retaining bolts, making sure of sufficient clearance for thermal growth at all but the fitted bolt locations.
6. Install the bolts from the bottom up and draw the nuts down moderately tight.
7. Recheck alignment of the machine. If the alignment is still satisfactory, torque the nuts on all clearance bolts per torque values as listed in Figure 5.38. Drill and ream for the fitted bolt, or bolts, and install. Torque the nut on the fitted bolt also per Figure 5.38.
8. Install lock nuts on all bolts, torque, and mark with a spot of paint for future visual checks.

Miscellany

Warning Against Lead Shims – Do not use lead metal. Lead is easily deformed under weight and vibration and has poor supporting characteristics.

Warning Against Multiple Piece, Sheet Metal Shims – Using hand cut, sheet metal shims, is discouraged. The edge deformation of the sheet metal shims, caused by the use of hand sheet metal cutters (tin snips) will prevent a stack of such shims from lying flat and will eventually allow an engine, thus shimmed, to drop out of alignment, as its shims relax. Also repeated, small, relative movement between shims, along with inherent engine vibration may cause the shims to *beat out*, especially with 3500 family engines and larger.

Mounting Bolts – There are two types of mounting bolts:

Clearance bolts are nominally 0.06 in. (1.5 mm) diameter smaller than the holes in which they are installed. Clearance bolts are used to insure the engine does not move vertically on its foundation.

Fitted bolts have a tight fit in the holes in which they are installed. Fitted bolts, sometimes called ground body bolts, are used to insure the engine does not move around horizontally on its foundation.

Install both types of mounting bolts with the head down and the threaded end up for ease of routine periodic inspection of the bolted joints.

One fitted bolt must be used at the rear of the engine to maintain position and alignment. **Never use fitted bolts forward of the engines flywheel housing.** Use clearance bolts in all locations forward of the flywheel housing.

Resilient (Soft) Mounts

General

Resilient mounts are used to reduce the transmission of noise and/or vibration to the hull and various compartments of the vessel. This can have considerable effect on crew and passenger comfort, reduced crew fatigue, and consequent increased efficiency. It can even affect, to some extent, increased life of equipment and machinery sensitive to hull borne vibration. However, in installing resilient mounting systems, the following factors must be considered:

Motion Limit Devices

Any resilient mounting system must include some means of limiting the engine motion. Regardless of the type of mount, some means of limiting the overall motion of the engine must be present to prevent breaking the engines cooling and exhaust piping connections during bad weather or after collision/grounding accidents (when the engine might be subject to greater-than-normal inertia forces and motions).

Softness Versus Frequency

All noise/vibration has a frequency.

High frequencies*, such as those produced by turbochargers, gearing, and some hydraulic systems, can be isolated by small amounts of resilience.**

Lower frequencies, such as those produced by the firing of individual cylinders of the engine or driveline unbalance, require much higher amounts of resilience to achieve the best reduction in transmitted engine vibration.

Types of Vibration Mounts

Vibration mounts can be subdivided by the material of the resilient component. Spring mounts which use helical metal springs, rubber mounts which use rubber, either in shear or compression, and Combined Spring and Rubber Mounts-which use both methods of achieving resilience. Some characteristics of these mounts are:

Spring Mounts generally, will achieve the highest amount of resilience. They are also generally more costly. Even with spring mounts, it is good practice to put some rubber in the mounting system. Mounts which use only metal components can still transmit significant vibration/noise in the high frequencies.

Rubber Mounts are excellent at isolating the higher frequencies of engine vibration/noise – often better than the spring type. Rubber mounts are generally cost effective, as well. Rubber mounts require periodic inspection for hardening/cracking of the rubber elements.

Combined Spring and Rubber Type

Vibration mounts combine the best of both types.

Effects of Propeller Thrust on Resilient Mounts

Most inexpensive vibration mounts are designed to accept forces in only one direction, up-and-down. Propeller thrust forces are generally from the side. Make sure the vibration mounts chosen are suitable for the forces to which they will be subjected. Install vibration mounts so the fore-and-aft thrust forces acting on the mount are resisted with the least possible extension of the mount.

Need for Periodic Realignment

Vibration mounts can also settle or *take a set* – which can necessitate occasional realignment of the driveline. Annually check alignment of engines mounted on vibration mounts for misalignment.

*In the audible range of human hearing

****Amount of Resilience** can be described in terms of the motions of the engine. Engines whose mounting systems permit only small motions – on the order of 0.020 in. (0.5 mm) or less can be said to have only a *small amount of resilience.*

Miscellaneous Considerations

Collision Blocks

When marine classification societies or local marine practice requires the use of collision blocks, they should be located with sufficient clearance to allow for thermal growth of the engine. Prefabricate the collision blocks and install them while the engine is at operating temperature with approximately 0.005 in. (0.12 mm) hot clearance. Collision blocks are recommended to resist the shock loads encountered in hard docking collisions and groundings.

Caution: Any electric arc welding of scantlings (ships structural components) or engine support structures for engine or marine gear requires precaution against electrical grounding through engine or marine gear housings. *Under no circumstances is any welding of an engine or marine gear to its foundation* to be done, otherwise, failure within the first few hours of operation is likely to occur.

Crankshaft Deflection Test

General Procedure

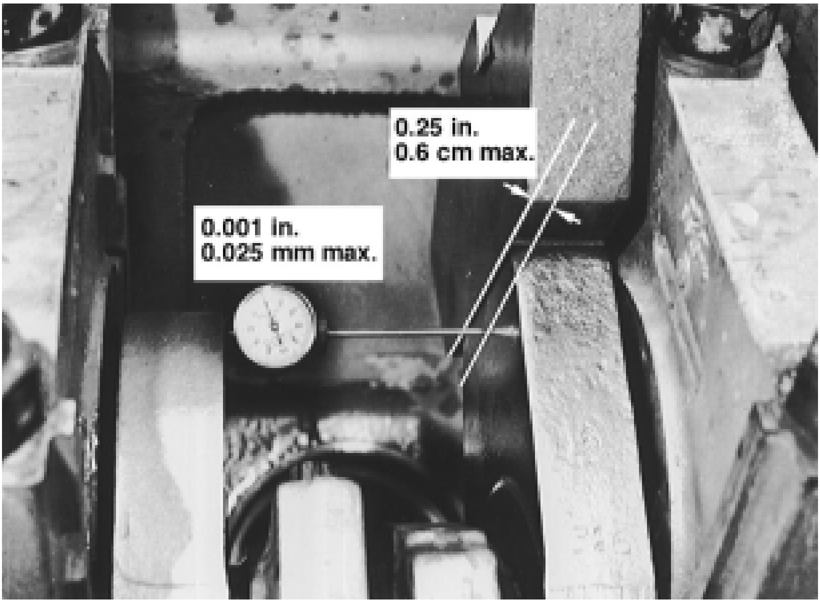
To assure the engine block is not unduly stressed during mounting, a crankshaft deflection test is recommended. This test should be performed on 3500 family engines. Marine applications require this test be conducted under hot conditions. To accomplish this test, proceed as follows:

1. Remove an inspection door from the block to expose the center crankshaft throw.

   Rotate the crankshaft in the normal rotation direction. When the cheeks of the center throw just pass the connecting rods, install a Starrett

No. 696 distortion dial indicator or similar tool. As a precaution, tie a string to the gauge and secure it outside the engine to facilitate retrieval should the assembly fall into the oil pan.

Zero the dial indicator's rotating bezel. Properly seat the indicator by rotating it on its own axis until it will hold a zero reading.



CRANKSHAFT DEFLECTION TEST

FIGURE 5.39

2. With the indicator still set at zero, rotate the crankshaft in the normal direction until the indicator nearly touches the connecting rods on the other side of the crankshaft. (Do not allow the indicator to touch the connecting rod.) The dial indicator reading must not vary more than 0.001 in. (0.3 mm) throughout the approximately 300 degrees of crankshaft rotation.

   Rotate the crankshaft back to its original position in the opposite rotation direction. The indicator must return to its original reading of zero to make a valid test. If not, the indicator shaft points were not properly seated and the test procedure must be repeated.

3. If the gauge reads more than 0.001 in. (0.03 mm), cylinder block distortion has occurred due to improper mounting.

   Loosen the hold-down bolts between the engine rails and mounting blocks. Check carefully for loose shims, improper locations of fitted bolts, interference from clearance bolts, or any other constraints to proper engine block movement.

Make any needed adjustments and secure the hold-down bolts, making sure alignment of the engine has not been disturbed.

4. Repeat the distortion check procedure. Consult your Caterpillar dealer if the engine block is still bent.

Auxiliary

This section is concerned with the mounting and alignment of auxiliary engines.

Auxiliary engines are power packages used to provide onboard power to drive generators, pumps, compressors, winches, etc. The engine driven equipment (load) is either directly mounted to the engine (close coupled) or is remote mounted from the engine and driven through a shaft and coupling. The major application of auxiliary engines is to provide shipboard electrical power. The following discussions, which refer primarily to engines driving generators, also apply to other types of auxiliary power packages.

The Caterpillar diesel auxiliary engine is built as a rigid, self-supporting structure within itself. If the engine is mounted on a foundation which is true (flat) or on a pair of longitudinal beams, the tops of which are in the same plane, the engine will hold its own alignment. If subjected to external forces or restrained from its thermal growth by the mounting, affected tolerances may result in bearing or crankshaft failure.

The power module must maintain the original alignment under all operational and environmental conditions. Misalignment between an engine and driven equipment can cause vibration and shorten the life of coupling and bearings.

The major cause of misalignment is flexing of the mounting structure due to weakness. Other causes are poor installation methods and incorrect alignment procedures.

Bases

Base Design

The most important function of an engine base is rigidity. It must maintain alignment between the auxiliary engine and its driven equipment.

An engine base must:

- Protect the engine block, drive train couplings, and load (generator gear reducer, or pump) from bending forces during shipment.
- Limit torsional and bending moment forces caused by torque reaction and subbase flexing.
- Have a natural frequency such that resonance does not occur during the machinery's normal work.
- Make proper alignment easy. Allow sufficient space for shimming in the alignment process.

Ease of initial installation, vibration isolation, or need of isolating from a flexing mounting surface are major reasons for use of fabricated bases. *No base of any type should be rigidly connected to a flexing surface.*

The type of load will determine the design features required in an engine base:

- If the load is close coupled – such as a single bearing generator, the base is subjected to relatively light twisting loads. Its rigidity need only be moderate.
- But if the load is remote-mounted – such as a two bearing generator, the base is subjected to far greater twisting loads and its rigidity must be very great.

Single Bearing Loads

When single-bearing generators or close coupled loads are used, the base does not have to withstand torque reaction. Bolting the generator housing to the flywheel housing eliminates the need for the base to absorb the driving torque of the engine.

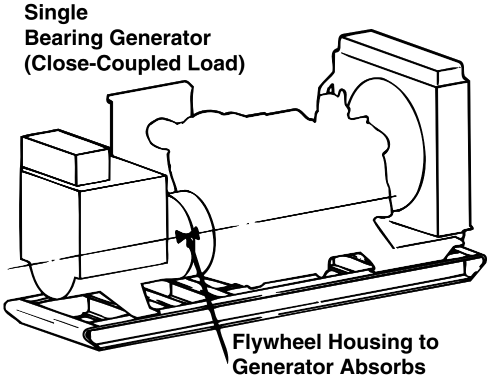


FIGURE 5.40

Two Bearing Loads

With the load remote-mounted, a more rigid structural base is required. The full load torque between the engine and load has to be absorbed by the base without causing excessive deflection in the coupling.

The stationary frame of the remote-mounted driven equipment tries to rotate in the same direction as the engine crankshaft. If the base were not rigid enough, engine torque would cause the base to flex excessively. The result is misalignment, proportional to the amount of load, which will not show up during a conventional static alignment check.

Severe cases of this problem result in bearing and coupling failures.

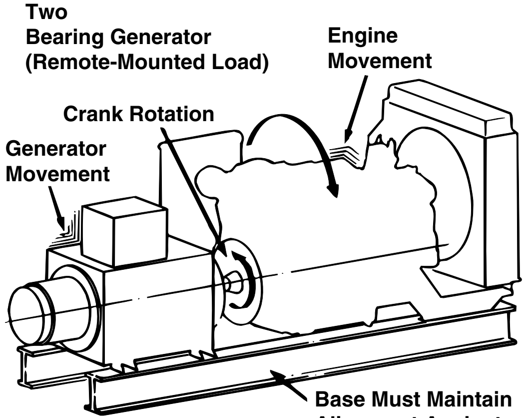


FIGURE 5.41

Bases for Engines with Close-Coupled Loads

Caterpillar does not recommend a specific section modulus for the longitudinal girders or cross members. Usually "I" beams or channel section steel beams in a ladder-type arrangement are acceptable.

Foot-Mounted Engines

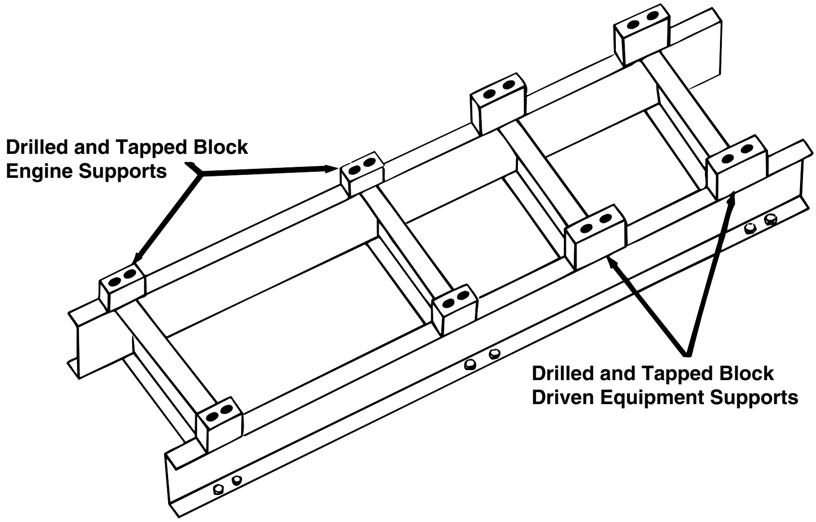
Base cross members must be as substantial as the longitudinal beams.

Place the cross members beneath each engine and generator support location.

Use drilled and threaded steel mounting blocks between the engine/driven equipment and the base. Bolt these blocks to the engine/driven equipment first and then weld to the base providing a flat surface for shimming and mounting. Mounting holes drilled into the structural members of the base are not recommended.

There should be sufficient space for shimming between the mounting blocks and the engine/driven equipment mounting surfaces.

Flexible mounts are not allowed between the mounting blocks and the engine/load mounting foot surfaces.



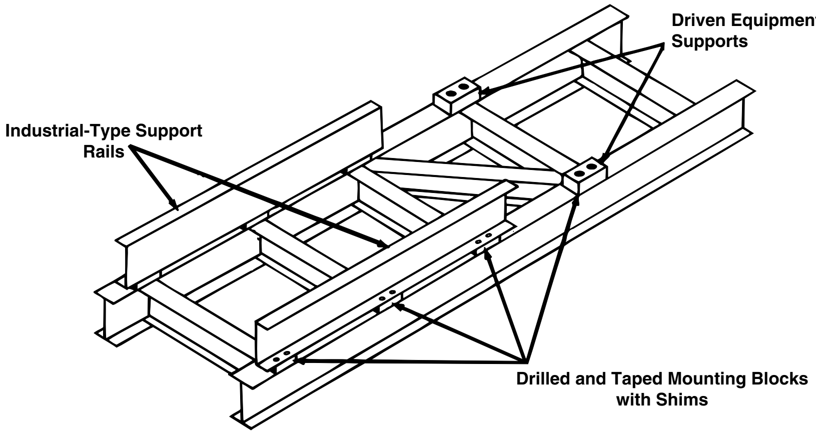
BASE FOR FOOT-MOUNTED ENGINE WITH CLOSE-COUPLED LOAD

FIGURE 5.42

Rail-Mounted Engines

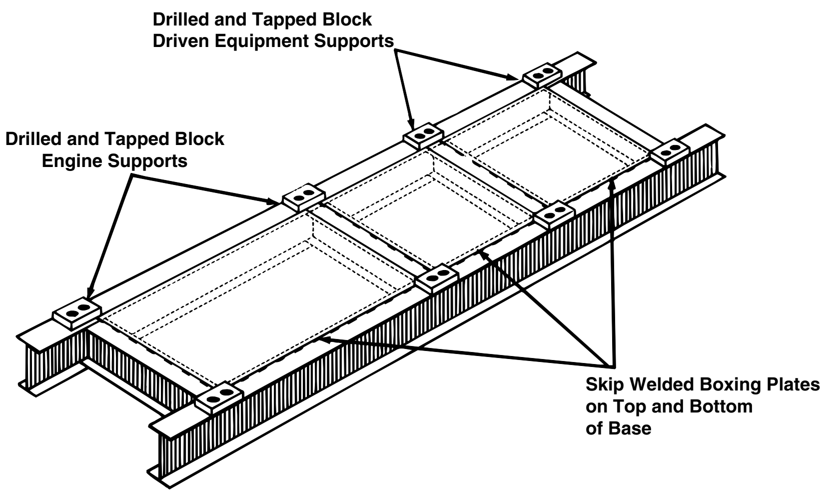
In addition to the requirements for foot mounted engines, the following applies for rail-mounted engines:

- The standard engine-mounted support rails (engine length) must be used between the engine and the structural base.
- Locate cross members directly beneath the front and rear engine-to-rail mounting locations.
- Place threaded mounting blocks at the front and rear of the engine-mounted rails with space available for shimming. Bolt these blocks to the engine/driven equipment first and then weld to the base to provide a flat surface for shimming and mounting.
- Do not weld the engine-mounted rail to the structural base.
- Bolt the engine-mounted rails to the threaded mounting blocks through clearance holes to provide for thermal growth.



BASE FOR RAIL MOUNTED ENGINE WITH CLOSE COUPLED LOAD

FIGURE 5.43



BASE FOR ENGINES WITH REMOTE MOUNTED DRIVEN EQUIPMENT

FIGURE 5.44

Bases for Engines with Remote-Mounted Loads

The requirements for close-coupled loads also apply to remote-mounted loads. With the load remote-mounted, a more rigid structural base is required. The full load torque between the engine and load has to be absorbed by the base without causing excessive deflection in the coupling.

The base shown above is a boxed beam design which provides a torsionally rigid base.

Boxing consists of welding steel plates on top and bottom surfaces of machinery base girders. The plates should be $\frac{3}{16}$ to $\frac{1}{4}$ in. (5 to 7 mm) thick. Skip-weld the plates to prevent excessive base distortion during welding. Boxing is done to make the base structure stiffer.

The additional stiffness is necessary to resist torque loads between the engine and remote-mounted driven equipment and to resist possible vibration loads. Vibration-induced base loads are difficult to predict. Experience has shown boxing is effective in preventing base cracking and misalignment.

Recommended Beam Height
The recommended heights of the longitudinal beams for the various engine generator sets are:

	Beam Height	
Engine Model	**English in.**	**Metric mm**
3304, 3306	8	200
3406, 3408	10	260
3412	12	300
3508	16	400
3512	18	450
3516	20	500

Alignment

In high speed applications, at normal operating temperatures and load, misalignment between the diesel engine and all mechanically driven equipment must be kept to a minimum. Many crankshaft and bearing failures can be traced to incorrect alignment of the drive systems. Misalignment at operating temperatures and under load will always result in vibration and/or stress loading.

Since there is no accurate and practical method for measuring alignment with the engine running at operating temperature and under load, all Caterpillar alignment procedures must be performed with the engine stopped and the engine and all driven equipment at ambient temperature.

For information on alignment principles and the use of dial indicators, please refer to the Mounting and Alignment section under propulsion engines in this manual.

Refer to the following Caterpillar Special Instruction for more detailed information and specific instructions on mounting and alignment procedures.

Form No.	Title
SEHS7654	Alignment – General Instructions
SEHS7259	Alignment of Single Bearing Generators
SEHS7073	Alignment of Two-Bearing Generators

Alignment of Remote-Mounted Driven Equipment
In order to achieve correct operating alignment, certain factors must be taken into consideration in determining cold alignment specifications.

Factors Affecting Alignment
The input shaft of remote-mounted equipment is always positioned higher than the engine crankshaft. This compensates for vertical thermal growth, flywheel sag, and main bearing oil film lift on crankshaft. These factors cause the relative positions of the crankshaft and load input shaft to shift between static and running conditions.

Bearing Clearances
The generator rotor shaft and engine crankshaft rotate in the center of their respective bearings, so their centerlines should coincide. Alignment is made under static conditions while the crankshaft is in the bottom of its bearings. This is not its position during operation. Firing pressures, centrifugal forces, and engine oil pressure all tend to lift the crankshaft and cause the flywheel to orbit around its true center. Generally, the driven equipment will have ball or roller bearings which do not change their rotational axis between static and running conditions.

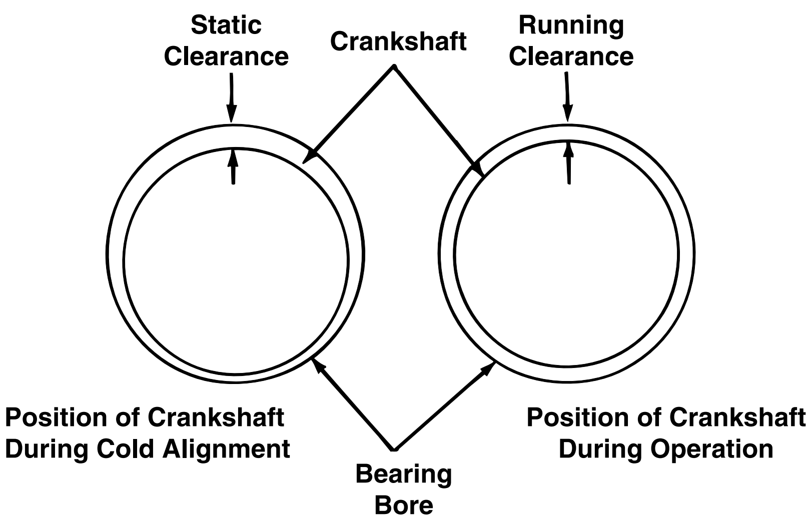


FIGURE 5.45

Flywheel Sag

With the engine not running, the weight of the overhanging flywheel and coupling causes the crankshaft to bend. This effect must be compensated for during alignment since it results in the pilot bore and outside diameter of the flywheel rotating lower than the true crankshaft bearing centerline during alignment. Caterpillar recommends alignment checks be performed with the coupling in place.

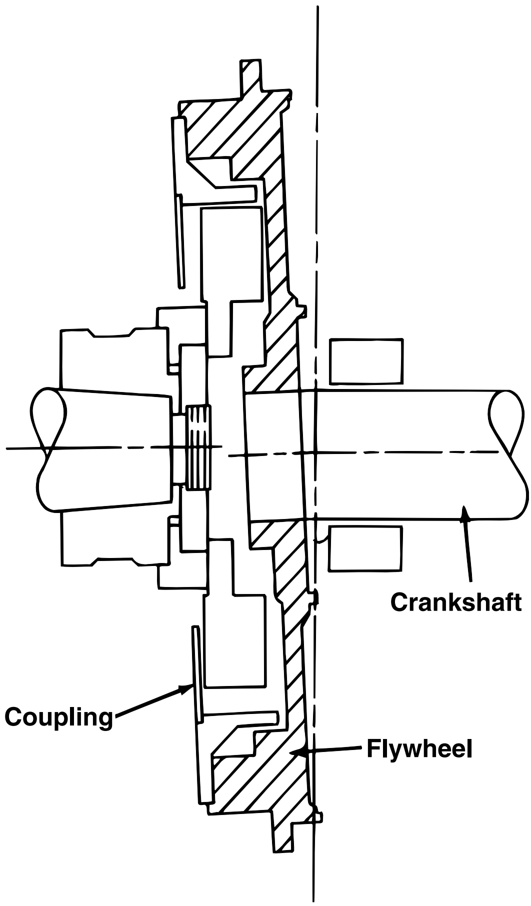


FIGURE 5.46

Torque Reaction

The tendency of the engine to twist in the opposite direction of shaft rotation and the tendency of the driven machine to turn in the direction of shaft rotation is torque reaction. It naturally increases with load and may cause a torque vibration. This type of vibration will not be noticeable at idle but will be felt with load. This usually is caused by a change in alignment due to insufficient base strength allowing excessive base deflection under torque reaction load. This has the effect of introducing a side to side centerline offset which disappears when the engine is idled (unloaded) or stopped.

Thermal Growth
As the engine and generator reach operating temperatures, expansion or thermal growth will occur. This growth is both vertical and horizontal. The vertical growth increases the vertical elevation between the component mounting feet and the respective centerlines of rotation. This thermal growth depends on the type of metals used, the temperature rise that occurs, and the vertical distance from the center of rotation to the mounting feet.

Crankshaft horizontal growth occurs at the opposite end of the engine from the thrust bearing. The location of thrust bearings on Caterpillar Engines is at the rear of the crankshaft. This growth has to be planned for when driven equipment is connected to the front end of the engine. The growth is slight if the driven equipment is bolted to the engine block, since the block and crankshaft grow at approximately the same rate. An example of this would be a front power takeoff clutch.

End Clearance
Horizontal compensation consists of using a coupling with sufficient end clearance that allows relative movement between the driving and driven members. The equipment must be positioned so the horizontal growth moves into the coupling operating zone, not away from it. Failure to do so will result in excessive crankshaft thrust bearing loading and/or coupling failure. Sufficient clearance has been allowed if it is determined during hot alignment check that the crankshaft still has end clearance.

Cat Viscous Damped Coupling
Caterpillar couplings use an internal gear design with a rubber element between the gears. Silicone grease aids in the dampening characteristics.

The clearances involved in internal gear design allow accurate alignment measurement to be made without removing the rubber element.

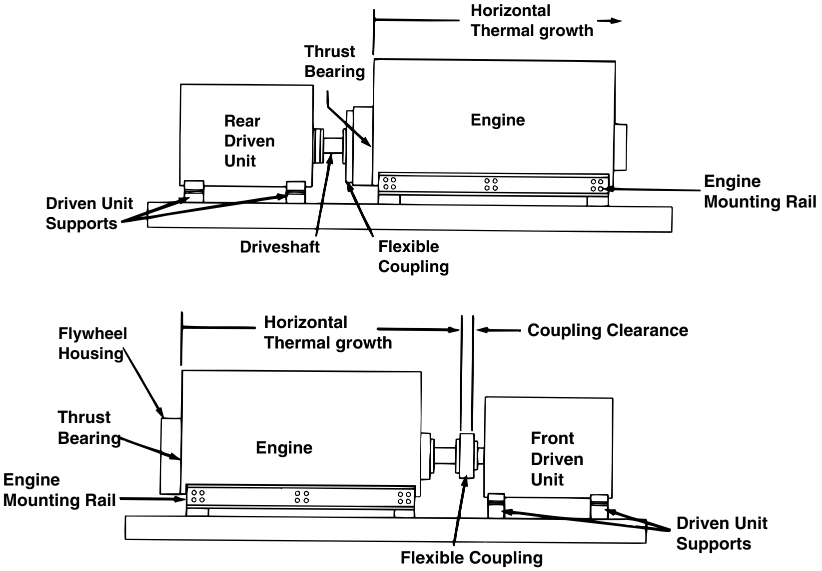


FIGURE 5.47

The coupling for front-driven equipment is similar to the rear-drive coupling illustrated below. On front drives, the driven element shown in Figure 5.47 is to be supported on the engine crankshaft as it does not weigh as much as the driving element.

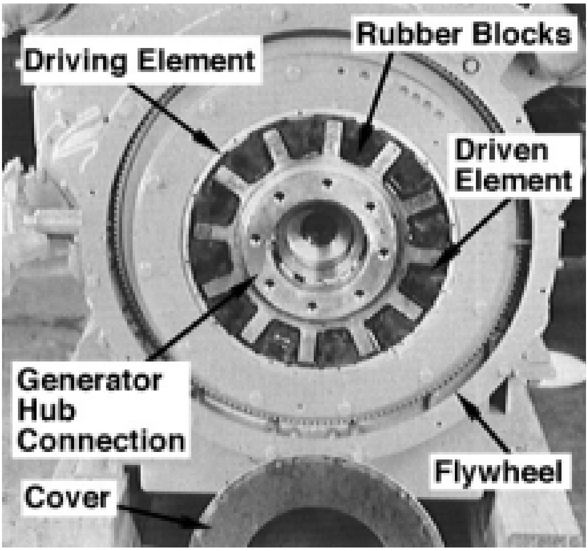


FIGURE 5.48

Other Couplings
The flexible element of other couplings must be removed during alignment checks. Element stiffness can prevent accurate alignment readings.

With the coupling element removed, the driving and driven members of the coupling should be rotated together during alignment checks. This prevents face or bore runout of the piece parts from affecting the dial indicator readings. When both members are rotated together, only equipment misalignment will register on the dial indicator readings.

Mounting Auxiliary Engines

The proper engine mounting system will ensure the dependable performance and long life for which the engine was designed and manufactured if all equipment is properly aligned.

The engine should be mounted on a pair of longitudinal beams, the tops of which are in the same plane. If the tops of the beams are not flat, add sufficient shims between the engine mounting surface and the mounting beams. Bolting the engines to an uneven surface can cause harmful distortions in the engine block, springing of the mounting beams, and high stress in welds or base metal.

If the engine is subjected to external forces, or if restrained from its natural thermal growth, tolerances are greatly affected and could easily result in bearing or crankshaft damage.

Three-Point Mounting
The three-point suspension system should be used when there is a possibility that the substructure supporting the base can deflect due to external forces or settling. Suspending the power unit on three points isolates the unit from deflection of the substructure, thus maintaining proper relationship and alignment of all equipment and preventing distortion of the engine block. More than three mounting points can cause base distortion (Figure 5.49.)

Objectionable vibration can occur if the power module is not mounted on well supported structures or is not anchored securely. In addition to the three-point mounting, vibration isolators may be required to isolate objectionable vibrations.

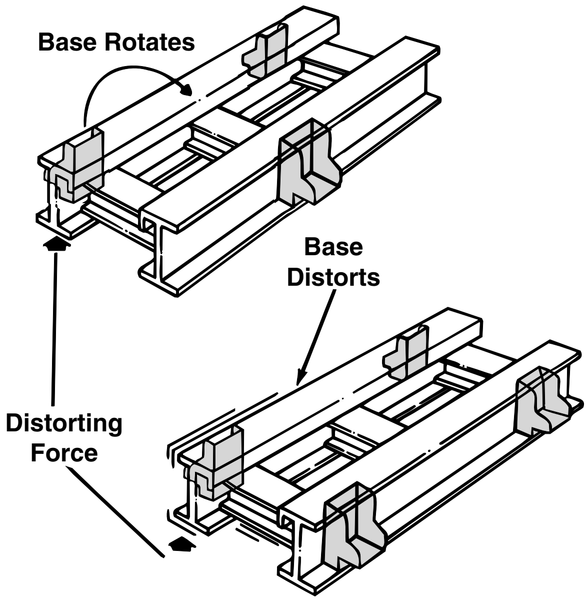


FIGURE 5.49

Anti-Vibration Mounting

Caterpillar Engines are capable of withstanding all self-induced vibrations and no isolation is required merely to prolong their service life. However, vibrations from surrounding equipment, if severe, can harm a generator set which is inoperative for long periods of time. Bearings and shafts can beat out and ultimately fail if these vibrations are not isolated. A running generator set will rarely be harmed by exterior vibrations. The method of isolating the unit is the same for exterior vibrations as it is for self-induced ones.

Caterpillar recommends the use of flexible mounts on all auxiliary engine installations. Refer to Vibration and Isolation section for information on types of vibration and isolation principles.

Some new generator packages have factory installed vibration isolators. Refer to the Price List to determine if they are standard or optional.

Sources of Disturbing Vibrations

Vibrations affecting auxiliary engines may be classified into four groups:

- Propulsion engines.
- Propeller-induced vibration caused by the propeller blades passing the hull, strut, or skeg.

- Twin or multiple screw propulsion installations running out of phase where vibrations will occur at frequencies depending on the differences in engine rpm.
- All first order vibrations caused by other engines and installed pumping equipment.

Vibration Limit (No Load)
The acceptable no load vibration limit for Caterpillar Engines is 4 mils (0.1 mm) peak to peak displacement for the engine only and 5 mils (0.13 mm) for engine and driven equipment.

Protection
In order to protect marine auxiliary engines, flexible spring-type mounts should be installed between the base and the ship's structure. Caterpillar and others can supply flexible mounts. To obtain the correct flexible mount, the supplier must know what protection is required.

Selecting Flexible Mounts
- Contact a suitable supplier and provide him with:
  - Equipment configuration and base drawing.
  - Expected frequency of the forcing vibrations.
  - Weight and center of gravity of the auxiliary unit to be isolated.
- To be effective, static conditions must load isolators close to the center of their optimum deflection range. Therefore, the weight that will rest on each isolator must be known and the isolators properly matched to the load.
- When using resilient materials in addition to spring-type mounts, select the lowest psi loading which gives the highest percentage reduction in transmitted vibration.
- Several types of resilient pads isolate noise but not vibration. Some may even amplify first order vibrations. As a general rule, resilient mounting pads should have at least $\frac{15}{64}$ in. (6 mm) static deflection; less than this results in reduced noise, but little or no vibration isolation. Consult the supplier for specific information.

Very Low Frequency Vibration
Vibrations at frequencies of 5 Hz and below are difficult to isolate.

The supplier of the flexible mounts is an excellent source for specific recommendations for very low frequency vibration mounting.

Installation of Flexible Mounts
Flexible mounts must be placed between the structural base of the auxiliary unit and the ship's structure. It is important that the base be of substantial design. When the ship structure is not sufficiently rigid, reinforcing supports should be added. When placing flexible mounts, the directions of the supplier should be followed.

The location of isolation mounts is important. On larger engines requiring three pairs of mounts, install one pair of isolators under the center of gravity and the other two sets equidistant from them at each end of structural base (Figure 5.50).

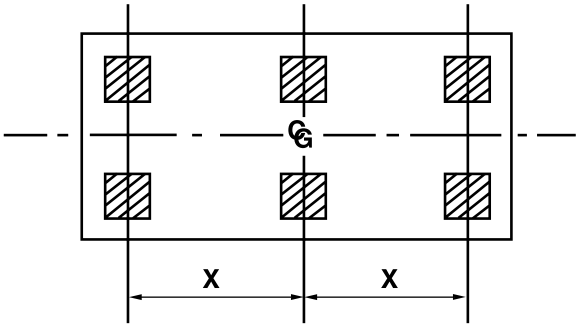


FIGURE 5.50

On smaller engines requiring only two pairs of mounts, locate one pair under front engine supports and the other pair under load supports.

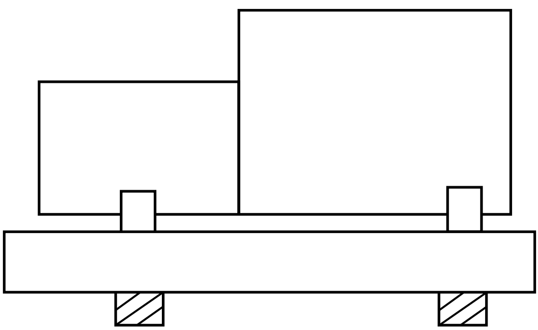


FIGURE 5.51

For three-point mounting of the engine base, arrange the isolators to obtain three point contact with the load equally distributed.

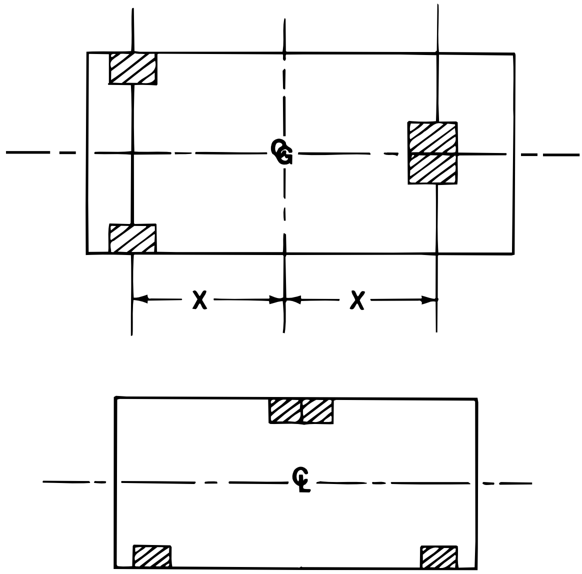


FIGURE 5.52

Determination of Center of Gravity of Combined Engine and Generator
The location of the center of gravity of the assembled unit can be determined after the total weight of the unit is established.

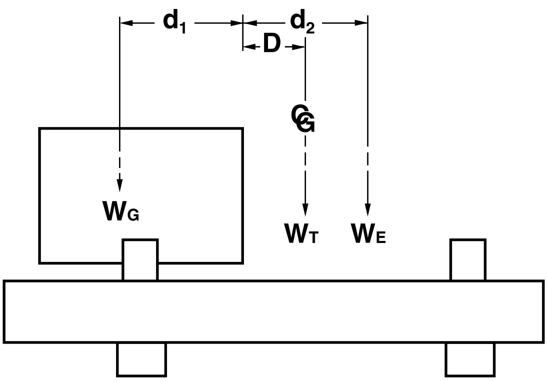


FIGURE 5.53

Assuming an engine and generator is assembled to a base, the assembled center of gravity (CG) can be calculated. A common reference point is needed. In this case, use the rear face of the flywheel housing.

Because measurements are to both sides of the reference, one direction can be considered negative. Therefore:

$$W_T\,(D) = W_G\,(-\,d_1) + W_E\,(d_2)$$

$$D = \frac{(W_E(d_2) - W_G(d_1))}{W_T}$$

If additional equipment is added, such as front power take-off, the process is repeated to determine a new center of gravity.

Having established the center of gravity for the total unit, the loading on each pair of isolators can be determined (Figure 5.54).

$$S_1 = W_T \left(\frac{b}{c} \right)$$

$$S_2 = W_T \left(\frac{a}{c} \right)$$

The location of the center of gravity of the assembled unit can be determined after the total weight of the unit is established.

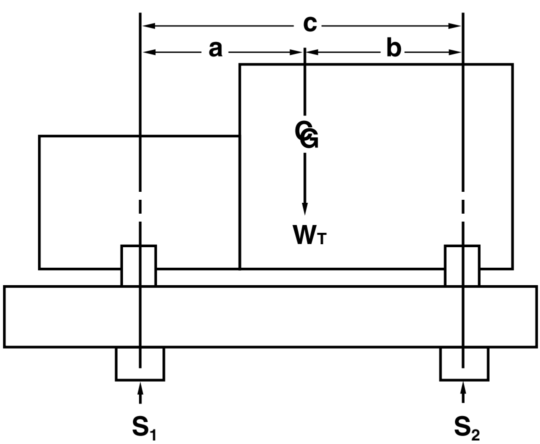


FIGURE 5.54

Commercial Isolators

Several commercial isolators are available which will provide varying degrees of isolation. Care must be taken to select the best isolator for the application. Generally the lower the natural frequency of the isolator (softer), the greater the deflection and the more effective the isolation. However, the loading limit of the isolator must not be exceeded.

Rubber Isolators

Rubber-type isolators are adequate for applications where vibration control is not severe. By careful selection, isolation of 90% is possible. They will isolate most noise created by transmission of vibratory forces. Care must be exercised to avoid using rubber isolators which have the same natural frequency as the engine-exciting frequencies in both the vertical and horizontal planes.

Fiberglass, Felt, Composition and Flat Rubber (Waffle) Isolators

Fiberglass, felt, composition and flat rubber of a waffle design do little to isolate major vibration forces, but do isolate much of the high frequency noise. The fabric materials tend to compress with age and become ineffective. Because deflection of these types of isolators is small, their natural frequency is relatively high compared to the engines. Attempting to stack these isolators or apply them indiscriminantly could force the total system into resonance. Pad-type isolators are effective for frequencies above 2,000 Hz.

Spring Isolators

The most effective isolators of low frequency vibration are the steel spring type. These can isolate approximately 96% of all vibrations. They also provide overall economy and allow mounting, of all but propulsion machinery, on surfaces that need only support the static weight. No allowance for torque or vibratory loads is required on nonpropulsion machinery. Steel spring-type isolators are effective in the vibration frequency range from 5 to 1,000 Hz.

Marine-type spring isolators should be used for auxiliary engine mounting. This type of isolator is equipped with all directional limit stops designed to restrict excessive movement of the engine and to withstand forces due to roll, pitch and slamming of sea-going vessels.

By the addition of a rubber pad beneath the spring isolator, the high frequency vibrations which are transmitted through the spring are also blocked. These high frequency vibrations are not harmful but result in annoying noise (Figure 5.56).

Follow the installation and adjustment instructions provided by the isolator supplier.

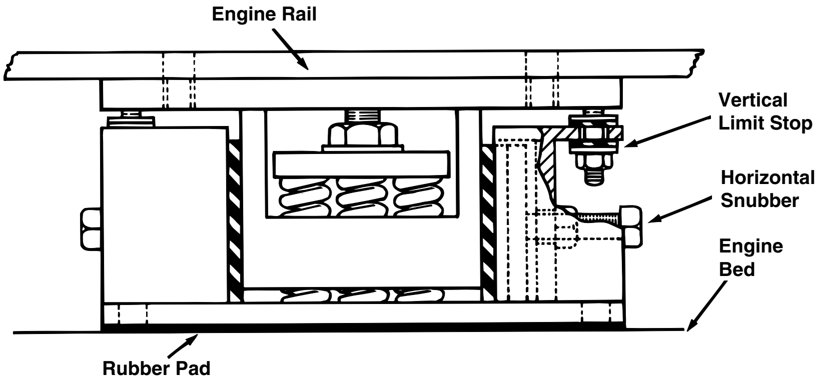
Many spring type isolators are equipped with horizontal limit stops (snubbers) but do not include built in vertical limit stops. If this type of isolator is used, external vertical limit stops should be added between the engine rail, or support, and the ship's engine bed.

Isolator snubbers and limit stops should be adjusted to permit only the amount of motion necessary for isolation purposes.

No matter what type of isolation is used, it should be sized to have its natural frequency as far removed from the exciting frequencies of the engine as possible. If these two frequencies were similar, the entire unit would be in resonance.

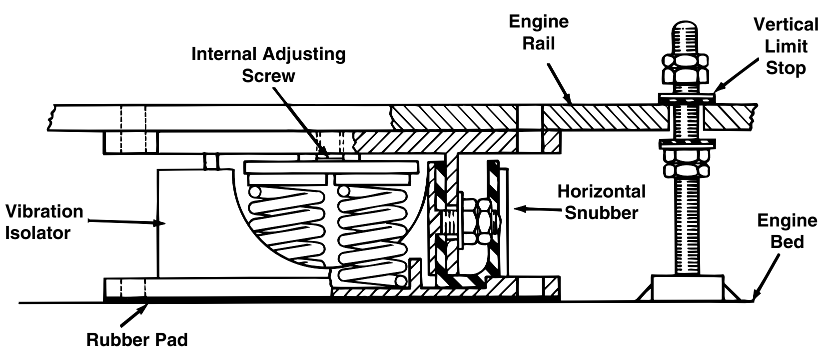
Flexible Connections

When using the marine spring isolator, ensure that each pipe, control system, electrical, and driveline connection is properly designed to allow for maximum engine motion without overstressing any of the connecting components.



MARINE-TYPE ISOLATOR

FIGURE 5.55



SPRING ISOLATOR WITH EXTERNAL LIMIT STOP

FIGURE 5.56

Collision Blocks

All spring-mounted equipment should have stops to restrict vertical and side movement within reasonable limits. Collision blocks may be provided for all auxiliary engine installations if they do not restrict thermal growth.

Shimming

Use shims as necessary between the generator mounting feet and the generator supports to maintain correct vertical alignment with the engine. All generator mounting feet must be in solid contact with the supports before installation of the anchor bolts. If the mounting feet are not in solid contact, distortion of the generator housing can result.

Shim packs under all equipment should be 0.2000 in. (5 mm) minimum thickness to prevent later corrections requiring the removal of shims when there are too few or zero shims remaining.

Shim packs should be of nonrusting material. Handle shims carefully.

Mounting Bolts

The diameter of the clearance-type bolts used to hold the engine rails or feet to the base must be 0.06 in. (1.6 mm) less than the diameter of the holes in the engine rails. This clearance is to allow the engine mounting rails or feet to grow without confinement. Refer to the section on thermal growth.

Mounting Bolt Location

Each engine or generator mounting bolt must bolt through solid material (refer to Figure 5.57).

Procedure for Tightening Equipment Mounting Bolts

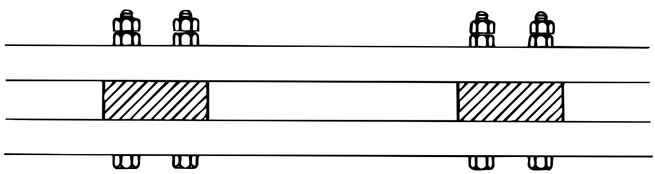
1. Torque mounting bolts in sequence shown in Figure 5.58 to $\frac{1}{2}$ torque values listed.
2. Install a dial indicator on support bracket as if bore alignment were to be checked. Rotate driving and driven shafts together until dial indicator is at top position.
3. Loosen bolts at mounting surface 1 and retorque bolts at mounting surface 3 to $\frac{1}{2}$ torque value as listed in Figure 5.58.
4. If indicator moves 0.002 in. (0.05 mm) or less, retorque bolts at mounting surface 1 and follow steps 6 and 7 below. If indicator moves more than 0.002 in. (0.05 mm), add shims under bolts at mounting surface 1 or 3. Loosen all bolts and repeat steps 1 through 5.
5. Loosen bolts at mounting surface 2 and retorque bolts at mounting surface 4 to $\frac{1}{2}$ torque value listed.
6. If indicator moves 0.002 in. (0.05 mm), or less, retorque bolts at mounting surface 2. If indicator moves more than 0.002 in. (0.05 mm), add shims under bolts at mounting surface 2 or 4. Repeat steps 1 thru 6.
7. With indicator and support bracket still at top position, retorque all bolts to full values. Reading should not change more than 0.002 in. (0.05 mm).

Bolt Torque

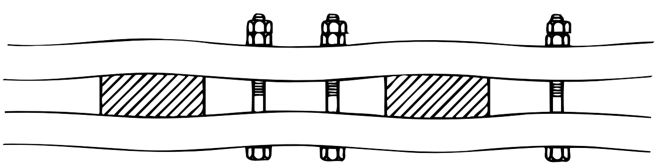
A bolt is properly torqued when it is stretched a calculated amount. The proper stretch clamps the machinery to the base securely. The clamping force is then maintained during movement caused by vibration (refer to Figure 5.59). A bolt that is undertorqued cannot maintain the clamping force while vibrations are present. It will gradually work loose and allow misalignment to occur.

Bolts of the size used on Caterpillar bases require very high torque values. As an example, a 1 in. (25.4 mm) bolt has a torque of 640±80 ft lb (868±108 N•m).

A torque wrench, extension and torque multiplier are required to obtain this high value. Do not use special bolt lubricants as the effective bolt clamping force can be excessive.

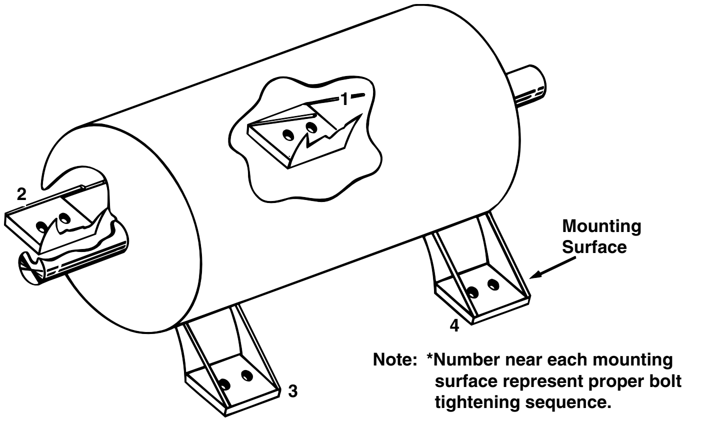


Proper Practice



Improper Practice

FIGURE 5.57



Full Torque Value

Bolt Diameter	mm	Torque lb-ft	Torque N•m
3/4 Inch	19	265 ± 35	360 ± 50
7/8	22	420 ± 60	570 ± 80
1 Inch	25	640 ± 80	875 ± 100

FIGURE 5.58

Caterpillar nuts and bolts are made of Grade 8 steel, one of the strongest available. They are identified by six raised or depressed lines on the nut or bolt head. Make sure mounting bolts are not bottomed out in hole, resulting in low effective bolt clamping force.

After completion of the final shimming and bolting operation, recheck the alignment.

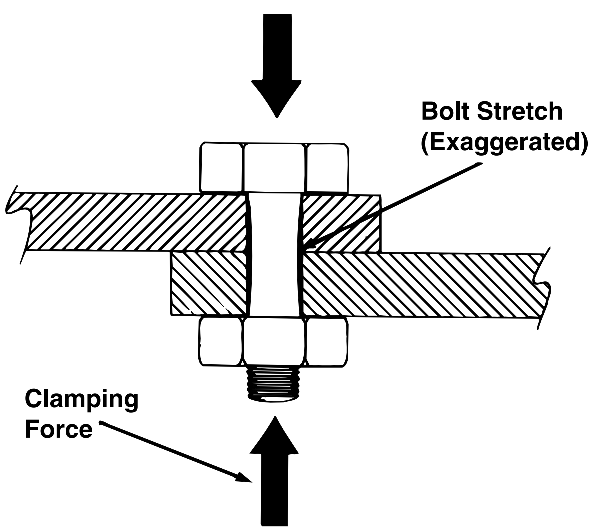


FIGURE 5.59

Crankshaft Deflection

Crankshaft deflection must be measured both cold and hot on certain specified engines. The allowable deflection must not exceed 0.001 in. (0.025 mm). Deflection must be measured at the center crankshaft throw. See Mounting and Alignment section for details on crankshaft deflection.

Mounting and Alignment

Available Installation and Alignment Instructions

Engine Data Sheet 102.2	Installation/Alignment Instructions for Caterpillar Engines with Reintjes Free Standing Marine Gears and Vulcan Rato Flexible Couplings
Special Instruction SEHS9162	Spring Isolator Group Installation and Adjustment Procedure
LEKM2005	3600 Marine Application & Installation Guide
LEKX1002	3600 Electric Power Generation Application & Installation Guide
Special Instruction SEHS7654	Alignment – General Instructions
Special Instruction SEHS7456-01	Alignment of Caterpillar Marine Transmissions and Marine Engines
Special Instruction SEHS7956	Alignment of Caterpillar Diesel Engines to Caterpillar Marine Transmission (7271-36W)
Special Instruction SEHS7073	Alignment of Two Bearing Generators

Marine Engine Final Alignment Conditions

Do not attempt final alignment of propulsion engines unless the following conditions are met:

1. The vessel is in the water.
2. All permanent ballast is in place.
3. Fuel, water, and temporary ballast tanks are filled to normal average operating levels, generally $\frac{1}{2}$ to $\frac{3}{4}$ filled.
4. All major machinery – weighing over 500 lbs (225 kg) – is either installed or simulated by equivalent weights appropriately located.

Make final alignment immediately prior to sea trials.

Marine Gear Output Flange Runout

Model	Face Runout		Bore Runout	
	inches	(mm)	inches	(mm)
MG502	0.004	(0.100)	0.004	(0.100)
MG506	0.004	(0.100)	0.004	(0.100)
MG507	0.004	(0.100)	0.004	(0.100)
MG509	0.004	(0.100)	0.004	(0.100)
MG514	0.004	(0.100)	0.004	(0.100)
Reintjes	0.004	(0.100)	0.004	(0.100)

Note: All alignment on Caterpillar engines is done with the engine at ambient temperature and static (not running).

Allowance for Expansion due to Thermal Growth

Cast iron has a thermal expansion coefficient of 0.0000066 in. per in. per Degree F (0.000012 mm per mm per Degree C). Steel has an average thermal expansion coefficient of 0.0000063 in. per in. per Degree F (0.000011 mm per mm per Degree C).

The engine mounting system must allow for this expansion through the proper use and placement of clearance bolts, fitted bolts, and dowels. Failure to allow for thermal expansion will result in driven equipment misalignment and engine block distortion.

Compensation offsets must be incorporated into alignment procedures to accommodate this growth when alignment is performed cold.

Thermal expansion = Expansion Coefficient $\times$ Linear Distance* $\times$ Δ T

*Linear distance is the length or width of engine for horizontal growth and the distance between the mounting surface and the crankshaft centerline for vertical growth.

Examples: 3606 – Cast Iron Block, Length of block between rear fitted bolt and front clearance bolt is 87.6 in. (2226 mm). Δ T = 130° F (72° C). Expansion allowance required is:

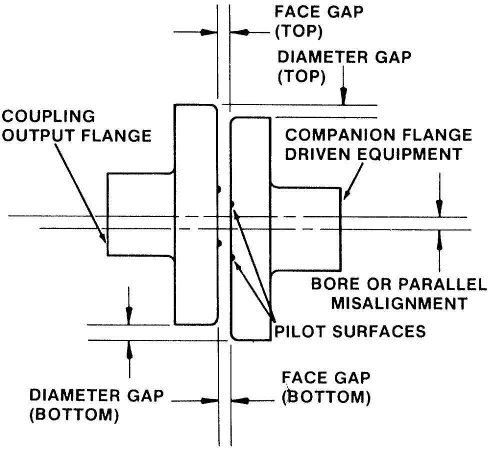
0.0000066 (0.000012) $\times$ 87.6 in. (2226 mm) $\times$ 130° F (72° C)
0.075 in. (1.9 mm)

Collision Blocks for Marine Engines

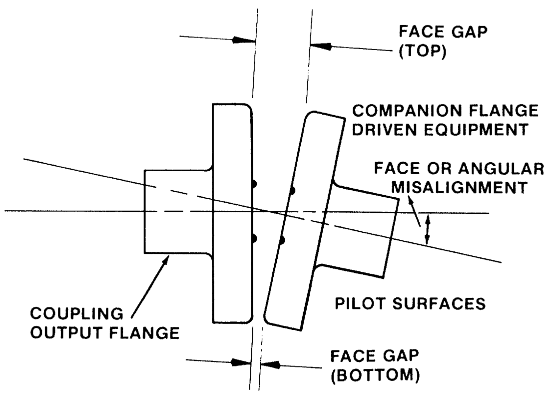
When marine classification societies or local marine practice requires the use of collision blocks, they should be located with sufficient clearance to allow for thermal growth of the engine. Prefabricate the collision blocks and install them while the engine is at operating temperature with approximately 0.005 in (0.12 mm) *hot* clearance. Collision blocks are recommended to resist the shock loads encountered in hard docking collisions and groundings.

Types of Misalignment

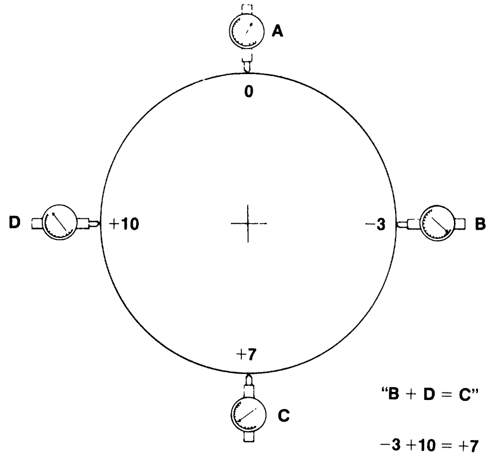
Parallel or bore misalignment occurs when centerlines of driven equipment and engine are parallel but not in the same plane.



Angular or face misalignment occurs when centerlines of driven equipment and engines are not parallel.



Dial Indicator Quick Check



When both shafts are rotated together, the algebraic sum of the readings at D and B should equal the reading at C. This check is useful for identifying improper indicator setup or procedure. The example shown is out of alignment.

Required Foundation Depth for Stationary Installations

Calculate foundation depth to equal generator set weight by:

$$FD = \frac{W}{D \times B \times L}$$

FD = foundation depth in feet (meter)

W = total wet weight of generator set in pounds (kg)
Use 125% of actual weight if vibration isolators are not used.

D = density of concrete in pounds per cubic foot (kg/m^3)
NOTE: Use 150 for English unit and 2402.8 for metric unit.

B = foundation width in feet (meter)

L = foundation length in feet (meter)

Pressure on Supporting Material

$$P\text{ (psi)} = \frac{W\text{ (Pounds)}}{A\text{ (inches)}^2} \qquad kPa = \frac{kg}{m^2}$$

$$P = \frac{W}{A}$$

Where: P = Pressure in psi (kpa)

W = Weight in pounds (kg)

A = Area in square inches (m^2)

Pressure imposed by the generator set weight must be less than the load-carrying capacity of supporting material.

General Torque Specifications

The following charts give general torque values for fasteners of SAE Grade 5 or better and Metric ISO Grade 8.8.

Torques for Bolts and Nuts With Standard Threads

Thread Size	Standard Torque	
Inch	N•m*	lb ft
1/4	12±4	9±3
5/16	25±7	18±5
3/8	45±7	32±5
7/16	70±15	50±10
1/2	100±15	75±10
9/16	150±20	110±15
5/8	200±25	150±20
3/4	360±50	265±35
7/8	570±80	420±60
1	875±100	640±80
1 1/8	1100±150	800±100
1 1/4	1350±175	1000±120
1 3/8	1600±200	1200±150
1 1/2	2000±275	1480±200

*1 Newton meter (N•m) is approximately the same as 0.1 mkg.

Torques for Taperlock Studs

Thread Size	Standard Torque	
Inch	N•m*	lb ft
1/4	8±3	6±2
5/16	17±5	13±4
3/8	35±5	26±4
7/16	45±10	33±7
1/2	65±10	48±7
9/16	90±15	65±11
5/8	110±15	80±11
3/4	170±20	125±15
7/8	260±30	190±22
1	400±40	300±30
1 1/8	500±40	370±30
1 1/4	650±50	480±37
1 3/8	750±50	550±37
1 1/2	870±50	640±37

*1 Newton meter (N•m) is approximately the same as 0.1 mkg.

Metric ISO Thread

Thread Size	Standard Torque	
	N•m*	**lb ft**
M6	12±4	9±3
M8	25±7	18±5
M10	55±10	40±7
M12	95±15	70±10
M14	150±20	110±15
M16	220±30	160±20
M18	325±50	240±35
M20	450±70	330±50
M22	600±90	440±65
M24	775±100	570±75
M27	1150±150	840±110
M30	1600±200	1175±150
M33	2000±275	1480±200
M36	2700±400	2000±300

Vibration

Vibration Summary

Vibrations can have many causes such as those listed in A through F:

A. Imbalance of rotating or reciprocating parts.

B. Combustion forces.

C. Misalignment of engine and driven equipment.

D. Inadequate anchoring of equipment.

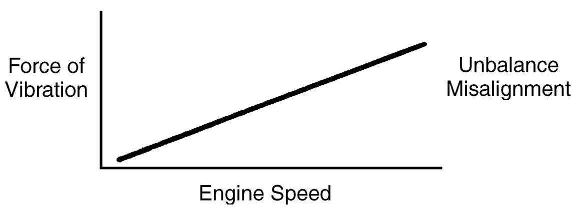
E. Torque reaction.

F. Resonance with the mounting structure.

Causes of vibrations can usually be identified by determining if:

1. Vibration forces increase with speed. These are caused by centrifugal forces bending components of the drive train.

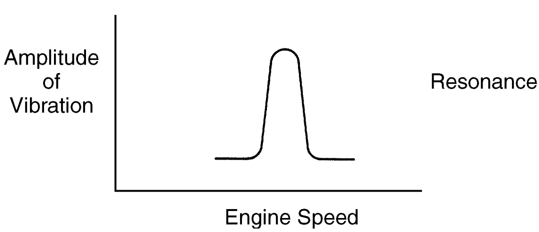
These are normally caused by A, B, or C.



2. Vibrations occur within a narrow speed range. This normally occurs on equipment attached to the engine-pipes, air cleaners, etc. When vibrations "peak out" in a narrow speed range, the vibrating component is in resonance.

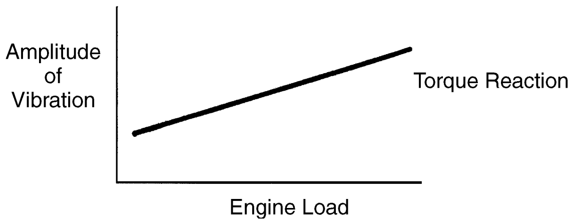
These vibrations can be modified by changing the natural frequency of the part by stiffening or softening its mounting. A defective viscous vibration dampener can also cause this.

These are normally caused by A, C, or F.



3. Vibrations increase as load is applied. This is torque reaction and can be caused by insecure mounting of engine or driven equipment, or by a base or foundation which is not sufficiently rigid to withstand the driving torque of the engine or defective worn couplings.

   These are normally caused by D or E.



Order of Vibration

$$\text{Order} = \frac{\text{Vibration Frequency (Hz)}}{\text{Engine RPM/60}}$$

Order of Firing Frequency

$$\begin{array}{c}\text{Firing Frequency}\\ \text{(4 Cycle Engines)}\end{array} = \frac{\text{Number of Cylinders}}{2}$$

Data Interpretation

Order of Vibration:	**Possible Cause:**
0.5 Order	Misfire of one or more cylinders
1.0 Order	Out of balance component rotating at crankshaft speed
2.0 Order	Out of time balancer gears rotating at twice engine speed. Misaligned U-Joint. Piston or upper end of connecting rod is too light or too heavy.
Order-Firing Frequency	Normal, may also occur at 0.5 orders adjacent to firing frequency

First Order Vibration Frequencies for Standard Rated Speeds

$$\text{Frequency (Hz)} = \frac{\text{RPM}}{60}$$

Engine RPM	First Order Frequency (Hz)
700	11.7
720	12
800	13.3
900	15
1000	16.7
1200	20
1225	20.4
1300	21.7
1350	22.5
1500	25
1600	26.7
1800	30
2000	33.3
2100	35
2200	36.7
2400	40
2600	43.3
2800	46.7
2900	48.3

Relationships of Sinusoidal Velocity, Acceleration, Displacement

English		Metric	
$V = \pi fD$		$V = \pi fD$	
$V = 61.44\ g/f$	D = inches pk-to-pk	$V = 1.56\ g/f$	D = meters pk-to-pk
$g = 0.0511\ f^2D$	V = inches/second	$g = 2.013\ f^2D$	V = meters/second
$g = 0.0162\ Vf$	f = Hz (cps) or RPM/60	$g = 0.641\ Vf$	f = Hz (cps) or RPM/60
$D = 0.3183\ V/f$	g = 386.1 in/sec^2	$D = 0.3183\ V/f$	g = 9.806 65 m/sec^2
$D = 19.57\ g/f^2$		$D = 0.4968\ g/f^2$	

Placement of Trial Weight

While it is usually not necessary to locate the imbalance in order to place the trial weight, occasionally you may want to do so. Some people try to decrease the imbalance on the trial run. On the other hand, it may be essential that the trial weight does not increase the vibration levels further.

If the analyzer/software being used has a trial weight option as part of the program, you can simply input the required information. If not, approximate the heavy spot by using the "Location of Imbalance" procedure and place the trial weight 180° from the heavy spot.

Amount of Imbalance

An estimation of weight needed to offset the imbalance can be made providing certain information is known. The total vibrating weight is needed. This is primarily the rotor weight, but also includes some vibratory mass contribution from bearings and bearing pedestals. A general rule of thumb is to use 110% of the rotor weight to allow for this effect. Once you have calculated the vibrating weight and have the data from the "reference run" the amount of imbalance can be estimated (neglecting any influence from amplification due to resonance) from the following equation:

$$Ub = w\left(\frac{Xf}{2000}\right)$$

where:

Ub = the amount of imbalance (oz.-in)

W = the vibratory weight (oz)

Xf = the amplitude of vibration (mils pk-pk)

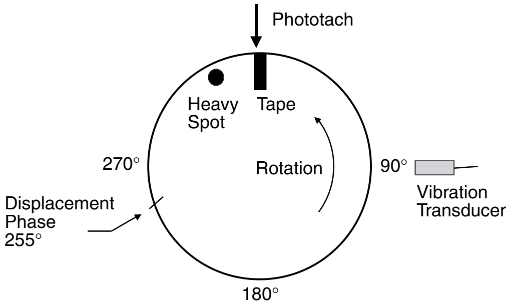
Location of Imbalance

Locate the vibratory high spot by locating the reference mark at the tach pick-up. Then, starting at the vibration transducer from which the phase was obtained, measure an angular distance equal to the phase reading against the direction of rotation. This is the vibratory high spot. Then move around the rotor in the direction of rotation an angular distance equal to the estimated system lag from the vibratory high spot. This is the location of the heavy spot. In summary:

Heavy Spot = Angle of Vibration Transducer + Phase + Units Type Adjustment – System Lag

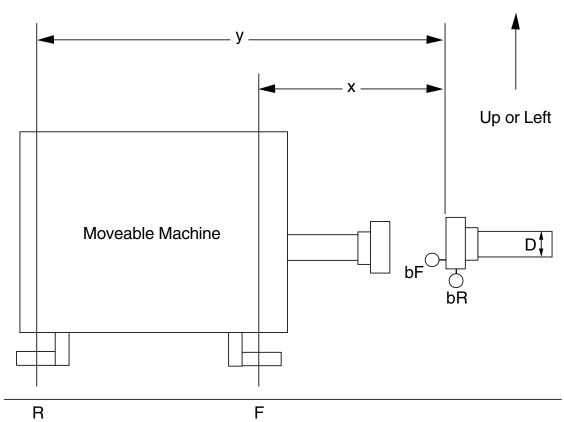
Example:

The system lag was determined to be approximately 15˚. The vibration transducer is at 90˚ relative to the phototach (as measured against rotation). An unbalance weight was placed at 330˚. The actual acquired phase data were as follows: 225˚ using a displacement transducer.



UNITS	Angle of Vibration Transducer	+	Phase Angle	+	Units Adjustment Factor	–	System Lag	=	Location of Heavy Spot
Displacement	90˚	+	255˚	+	0˚	–	15˚	=	330˚

Alignment



Parameters for Face and Bore Calculations

F – Required shimming at the front feet

R – Required shimming at the rear feet

x – Distance from measurement plane to front feet

y – Distance from measurement plane to rear feet

D – Diameter of dial indicator swing on face

bR – Bottom rim reading when zeroed at top

bF – Bottom face reading when zeroed at top

With the dial indicator readings and the three tape measurements, the required moves are:

$$F = \frac{bF \bullet x}{D} - \frac{bR}{2} \qquad R = \frac{BF \bullet y}{D} - \frac{bR}{2}$$

CATERPILLAR

MARINE ENGINES SEA TRIAL GUIDE

DESIGN, CONSTRUCTION, PERFORMANCE

Contents

Introduction

This Sea Trial Guide is available to provide a method to audit the quality of a vessel's propulsion systems to provide optimum performance. This is accomplished only when the equipment has been correctly sized and installed.

Effective sea trials provide data for the evaluation of propulsion system performance. This data will also aid in the identification of system problems that can lead to potential performance problems. This will help both the customer and the dealer to develop maintenance and repair schedules that will provide the most economical and efficient cost of operation.

This publication is intended for use as a guide for Certified Marine Analysts who have passed the Caterpillar service technician training qualification course *Marine Analyst* (Course Code 2500). For a more detailed discussion of correct application and installation of marine systems, refer to the *Caterpillar Marine Engine Application & Installation Guide*, form LEKM7142-7147.

This Sea Trial Guide provides a sequence of steps to follow to ensure proper engine installation. These steps are described in detail in this publication and are as follows:

1. **Sea Trial:** Conduct a sea trial upon completion of the engine installation to ensure the drive system, marine gear and engine are properly matched for maximum performance and fuel efficiency. The sea

trial verifies the installation of the various engine systems reviewed during the construction review.

2. **Cooling System Evaluation:** Performed during the sea trial to ensure proper performance of the engine cooling system.

This publication also identifies diagnostic measurements to be taken, their specific test locations, and the tools needed to conduct a performance audit. Actual Caterpillar factory performance specifications are required to conduct the marine engine and transmission performance audit outlined herein. Refer to Technical Marketing Information (TMI) for the following information:

1. **General max/min specifications:** see TMI – "Engine/Parts Data" (http://tmiweb.cat.com), Marine Aux/Prop Sea Trial or Marine Gear Sea Trial and Systems Data.
2. **Specific engine rating performance and component performance data:** see TMI – Engine and Component Performance (http://tmiweb.cat.com), "Engine/Parts Data", then "Advanced Search".

There are five steps to installing and commissioning marine engines into vessels. The first two relate to proper installation of the engine(s), and the remaining steps address sea trials for performance and system operation verification and documentation.

The Design Review

The *Caterpillar Design & Construction Review Form*, form SEHS8716, is available from Caterpillar and provides a checklist for dealer use only. The form can be ordered using the normal literature order procedure.

This form is a simple checklist. It is used to determine if sufficient information has been provided to the designer so the layout will comply with Caterpillar reference requirements.

There is provision to record the Caterpillar reference materials provided to the designer, and a complete checklist for the results of the design and serviceability review. Compliance with Caterpillar reference requirements is noted by placing a check in the box next to the system reviewed. If the design affecting a specific system does not comply, there is space to record the action required to follow-up and correct the problem area(s).

Vessel Construction Review

The *Caterpillar Design & Construction Review Form*, form SEHS8716, is available from Caterpillar and is intended to provide a checklist for dealer use only. The form can be ordered using the normal literature order procedure. The form is a simple checklist used to determine if the previously agreed upon design is being successfully implemented during the construction process.

Fill out the form with general information about the owner, vessel and builder/installer, including the vessel's physical features. A provision is made for recording the propulsion and auxiliary systems descriptions, including serial numbers, and the manufacturer, where applicable.

When the construction and installation are both in compliance with Caterpillar requirements, indicate this by placing a check in the box next to the system reviewed. If a system does not comply, there is a space to record the necessary corrective action. After the construction review and the construction review form are completed and any corrective action needed is agreed to, it is recommended that all parties concerned sign the construction review form at the designated location on the form.

Pre-delivery OEM Sea Trial
Sea trial performed at the OEM using Caterpillar Electronic Technician Sea Trial Data Logger for electronically controlled engines or PAR form (LEXM0581) for mechanically controlled engines. This sea trial is conducted on new vessels to document basic performance and installation information for vessels. The procedure for this sea trial is not as thorough as a Complete PAR Test and is used to provide the basic performance documentation.

This sea trial procedure documents and inspects the following:

- General customer and vessel information
- Engine Speed at full load conditions (20 rpm overrun minimum – pleasure craft only)
- Engine performance throughout the entire operating range
- Leaks
- Cooling system capability
- Unusual vibration observation
- Initial performance – observe start-up smoke, observe acceleration smoke
- Acceleration time to 90% rated speed
- Vertical measurement from gunnel (lower side of the rub rail at the starboard transom corner) to waterline – displacement documentation
- Exhaust backpressure initial check – reference TMI limits
- Electronic wiring/display functionality check
- Inlet air temperature to air cleaner

Complete PAR Sea Trial
Sea trial performed at the OEM or shipyard on new vessels for first hull of a production run, during any significant change to a production run,

custom boat and/or re-power installations. Data to be recorded using Caterpillar Electronic Technician Sea Trial Data Logger for electronically controlled engines or PAR form (LEXM0581) for mechanically controlled engines.

This sea trial procedure documents and inspects the following:

– General customer and vessel information
– Engine speed full load conditions (20 rpm overrun minimum – pleasure craft only)
– Engine performance throughout the entire operating range
– Caterpillar fuel flow meter comparison to electronic ECM fuel rate calculation
– Complete system performance for all 900 Series numbers
– Leaks
– Cooling system capability
– Unusual vibration observation
– Initial performance – observe start-up smoke, observe acceleration smoke
– Acceleration time to 90% rated speed
– Vertical measurement from gunnel (lower side of the rub rail at the starboard transom corner) waterline – displacement documentation
– Electronic wiring/display functionality check

This sea trial procedure should be performed once the vessel is completed and ready for delivery to the customer.

Performance Sea Trial
Sea trial performed on all new vessels prior to customer delivery or performance related complaints. Data to be recorded using Caterpillar Electronic Technician Sea Trial Data Logger for electronically controlled engines or PAR form (LEXM0581) for mechanically controlled engines.

This sea trial procedure documents and inspects the following:

– General customer and vessel information
– Engine speed full load conditions (20 rpm overrun minimum – pleasure craft only)
– Engine performance throughout the entire operating range
– Initial performance – observe start-up smoke, observe acceleration smoke
– Acceleration time to 90% rated speed

– Vertical measurement from gunnel (lower side of the rub rail at the starboard transom corner) to waterline – displacement documentation

– Exhaust backpressure initial check – reference TMI limits

– Inlet air temperature to air cleaner

All data recorded from the various types of Sea Trials will be analyzed with CAMPAR 4.0 or higher and must be uploaded to the Sea Trial Data Base. The Sea Trial Database located at: https://engines.cat.com/infocast/frames/marine/techinfo/seatrial/

User Interview

Before the sea trial test is performed, explain to the builder/installer and owner the purpose of the sea trial test. Discuss with them the systems that are to be evaluated, the expected results, and how the results are used to interpret performance conditions of the propulsion and auxiliary systems.

Preparation for a Sea Trial Test

Before a test of the propulsion and/or auxiliary engines and transmissions, install the diagnostic tool thermistors and pressure pickups needed to obtain the performance data that is required. This is accomplished in part by installation of Caterpillar self-sealing probe adapters. A listing of the manual channels with their corresponding 900 number designation are as follows:

900 Series Designation	Location Description
901	Jacket water outlet temperature. (Before the regulators)
902	Jacket water pump outlet temperature
903	Aftercooler water inlet temperature
903A	Aftercooler water outlet temperature
904	Auxiliary water pump inlet pressure
905	Auxiliary water pump outlet pressure
906	Intake manifold air temperature
907	Inlet air restriction
908	Exhaust stack backpressure
909	Crankshaft deflection
910	Engine speed
911	Intake manifold air pressure
912	Exhaust stack temperature
912A	Exhaust manifold right front turbo temperature
912B	Exhaust manifold right rear turbo temperature
912C	Exhaust manifold left front turbo temperature

900 Series Designation	Location Description
912D	Exhaust manifold left rear turbo temperature
913	Engine oil to bearings temperature
914	Engine oil to bearings pressure
915	Marine gear oil temperature
916	Marine gear oil pressure
917	Fuel pressure
918	Jacket water outlet pressure (before regulators)
919	Jacket water pressure at pump outlet
920	Jacket water pump inlet pressure at pump inlet
921	Jacket water pressure from cooling system
922	Jacket water inlet temperature from cooling system
923	Aftercooler water inlet pressure
924	Aftercooler water outlet pressure
925	Marine gear cooler inlet water temperature
926	Marine gear cooler outlet water temperature
927	Oil filter inlet pressure
928	Oil filter outlet pressure
929	Individual exhaust port temperatures
930	Air cleaner outlet temperature
931	Turbocharger compressor outlet temperature
932	Crankcase pressure
933	Jacket water temp to cooling system
935	Fuel inlet temperature
936	Fuel return line restriction
937*	Aftercooler water temperature between front and rear housing
938	Oil cooler water outlet temperature
939	Oil cooler water outlet pressure
940*	Aftercooler/oil cooler water outlet mixing box temperature
941*	Aftercooler/oil cooler water outlet mixing box pressure
942	Jacket water pressure at block outlet (before regulators)
943	Water temperature to combined circuit heat exchanger
944	Water pressure to combined circuit heat exchanger
945	Water temperature to temperature regulator from combined circuit heat exchanger
946	Water pressure to temperature regulator from combined circuit heat exchanger
947*	Water temperature at engine outlet to separate circuit jacket water heat exchanger
948*	Water pressure at engine outlet to separate circuit jacket water heat exchanger

900 Series Designation	Location Description
949*	Water temperature to temperature regulator from single circuit jacket water heat exchanger
950*	Water pressure to temperature regulator from single circuit jacket water heat exchanger
951*	Aftercooler/oil cooler water pump inlet temperature
952*	Aftercooler/oil cooler water pump inlet pressure
953*	Aftercooler/oil cooler water pump outlet pressure
954*	Raw water temperature to combined circuit heat exchanger
955*	Raw water temperature from combined circuit heat exchanger
956*	Raw water temperature to separate circuit jacket water heat exchanger
957*	Raw water temperature from separate circuit jacket water heat exchanger
958*	Raw water temperature from separate circuit aftercooler/ oil cooler heat exchanger
959*	Raw water temperature from separate circuit aftercooler/ oil cooler heat exchanger
960	Turbocharger compressor outlet pressure
961	Fuel pump inlet restriction
962	Raw water pump inlet pressure
963	Raw water pump outlet pressure
964	Raw water pressure after heat exchanger

*This location pertains to the 3600 series of engines only.

The location of these test points are given in the general *dimension drawings*, and are indicated by a system of 900 series numbers. The drawings also give the thread type and size at each location. The installation drawings showing specific test ports and corresponding sizes are available on CD-ROM, literature number LERM3233.

Sea Trial Definition

Note: Prior to conducting a sea trial, electronic and control functional tests should be conducted. Each test will include an electronic functionality test to verify proper operation of all gauge panels, electronic components, sensors, Data Link wiring (use Caterpillar specified wire – part numbers in SENR5002) shielded/non shielded, J1939 wiring requirements followed, compare vessel instrumentation to the service tool, throttle calibration (refer to electronic installation guide), mechanical throttle linkage check, switch operation if equipped (synchronization, slow vessel, trolling, trip clear and engine shut-off) and, if equipped, the Multi Station Control System (MSCS) operation.

There are three types of sea trials:

1. Pre-delivery OEM Sea Trial
2. Complete PAR Sea Trial
3. Performance Sea Trial for Delivery/Inspection

Pre-delivery OEM Sea Trial
This is a sea trial that is normally performed at the boat OEM using Caterpillar Electronic Technician Sea Trial Data Logger on electronically controlled engines. For mechanically controlled engines, parameters such as boost, fuel rate, engine speed and exhaust temperatures should be recorded to verify engine operation and loading using the LEXM0581 PAR form.

During sea trial, it is important to verify latest software in ECM if electronically controlled, check cooling system performance, engine performance, check for leaks, acceleration and exhaust system performance. Along with measuring engine performance, engine vibration, stability and mounted component resonance should also be physically observed. Mounted components include items such as belt guard, remote mount key switch panels, any engine mounted gauges or other equipment.

If the engine(s) are not able to achieve rated engine speed (not including bollard tests), the engine speed and boost pressure data acquired should be compared to the CAMPAR analysis. The boost pressure generated by the engine(s) should be at specification +/- the spec tolerance as compared to the Max Power Curve (curve 06). Exhaust temperatures may also be acquired during this sea trial for an added dimension of accuracy.

Complete PAR Sea Trial
This is a commissioning comprehensive sea trial. This test uses Caterpillar Electronic Technician Sea Trial Data Logger for electronically controlled engines, or for mechanically controlled engines, the PAR analysis form (LEXM0581) is used to document parameters for manual analysis. CAMPAR version 4.1 (LEXM7082) and higher will be used to analyze data from both electronic and mechanically controlled engines. All 900 number channels applicable to the sea trial are observed and recorded. Caterpillar fuel flow meters will be used during this sea trial to verify that the engine is operating to specifications and all systems are functioning properly. (The sea trial is designed to be conducted on the first hull of a custom re-power or production run, during any significant change to the hull or vessel loading.)

Data from this sea trial must be uploaded to the Caterpillar Inc. Sea Trial Database located at: https://engines.cat.com/infocast/frames/marine/techinfo/seatrial/

Performance Sea Trial
This is a test that will be performed on all new vessels prior to customer delivery, or performance related complaints. The test will use Caterpillar Electronic Technician Sea Trial Data Logger for electronically controlled engines or the PAR analysis form (LEXM0581) to document parameters for manual analysis. CAMPAR version 4.1 (LEXM7082) and higher will be used to analyze data from both electronic and mechanically controlled engines. This sea trial is to document vessel performance prior to the end customer taking delivery.

Data from this sea trial must be uploaded to the Caterpillar Inc. Sea Trial Database located at: https://engines.cat.com/infocast/frames/marine/techinfo/seatrial/.

Selection of a Sea Trial Test Site

A major consideration before performing the sea trial test should be the selection of a test site that will ensure valid test results and minimal vessel downtime. The site should be convenient, and not obstructive to other marine traffic.

When performing a normal (free running) test, the vessel must have a load that is typical of the load normally encountered. The test site must have adequate water depth and be long and wide enough to permit “straight rudder” throughout the duration of the test with minimum hull load from shallow water effect. The sea should be in a calm state to ensure good data.

NOTICE

Pleasure craft should always be tested under normal (free running) conditions.

All auxiliary engine applications should be evaluated under their maximum intended loads at full throttle, i.e. generator, pump, compressor, or bow thruster loads.

Review of Test Specifications

The data that is taken during sea trials will be compared to and plotted against the performance data that can be found in TMI by test specification number. CAMPAR 4.1 and later will prompt the user to update a database on the PC that CAMPAR 4.1 is resident if an update hasn’t been performed in a two-week time frame. This is done to insure that the most recent specifications are used during the data analysis.

Diagnostic Tools Needed – Electronically Controlled Engines

Laptop Computer with the following programs:

- **Sea Trial Data Reduction Software:** Computer-Aided Marine Performance Analysis Report (CAMPAR) Software (LEXM7082)
- **Electronic Technician (ET) with Sea Trial Data Logger:** ET is used on electronic engines to communicate ECM monitored engine parameters. For more information refer to ET instructions NEHS0679.

Comm Adapter
7X1700 or 171-4400 Comm Adapter II to communicate engine monitoring information between the engine ECM and ET.

Cat Data link "Y" Cable
Cable assembly 211-4988 that joins the data link between the port and starboard engines which provides the necessary connection to record both engines in sea trial data logger simultaneously. **Note:** This cable will not be required if the OEM has included the coupling of the engine's data links in the vessel wiring or the Plug and Run wiring system was ordered from Caterpillar Inc.

GPS Interface Module (if the vessel is not equipped)
The GPS interface module with the addition of a hand held Global Positioning System (GPS) will transmit the vessel's speed, latitude, longitude and heading to the Cat Data Link for recording these parameters via sea trial data logger. Refer to SENR5002 for GPS to GPSIM connections.

Pressure Gauge
1U5470 engine pressure group – six vacuum pressure gauges to permit a check of air cleaner restriction, oil pressure, manifold pressure and fuel pressure. Provides readings in psi and kPa. Group covers pressure ranges from 15 psi to 150 psi (100 kPa to 1000 kPa). See Special Instruction SEHS8524.

Temperature Indicator
The 4C6500 digital thermometer group is used in analyzing systems. They are capable of reading temperatures ranging from –20° F to 2500° F (–30° C to 1370° C). See Special Instructions SMHS7140 and SEHS8446.

Fuel Gravity (API)
1P7408 thermo-hydrometer and 1P7438 beaker are used to measure the API gravity and temperature of diesel fuel so corrected horsepower ratings can be calculated. See Special Instruction SMHS9224.

Digital Multimeter
146-4080 for measuring electrical values and type K thermocouples.

Infrared Thermometer II
123-6700 is for measuring surface temperatures.

Probe Seal Adapters
Probe seal adapter groups are for use with the temperature and pressure measuring diagnostic tools. They allow probe insertion through the center, and they seal when the probe is removed. The adapters can be permanently installed and are equipped with a hex head plug to eliminate leakage and debris accumulation. Probe seal adapters available:

- 5P2720: $\frac{1}{8}$" × 27 NPT
- 5P2725: $\frac{1}{4}$" × 18 NPT
- 5P2726: $\frac{9}{16}$" × 18 STO
- 4C4545: $\frac{3}{4}$" – 16 STO to $\frac{1}{4}$" NPT
- 4C4547: $\frac{1}{2}$" – 20 STO to $\frac{1}{4}$" NPT
- 164-2192 Male Pressure Probe

These probe seal adapters are used when measurements of temperature and pressure are needed. Probe seal adapter locations are given in the general *dimension drawings*, and are indicated by a system of 900 series numbers. The drawings also give the tap thread type and size at each location. The installation drawings showing specific test ports and corresponding sizes are available on CD-ROM, literature number LERM3233.

WARNING!

All fittings must be corrosive resistant in presence of sea water.

8T0452 Water Manometer
A water manometer provides an accurate measure of crankcase pressure and can be made with a 2 ft (610 m) length of flexible clear plastic $\frac{3}{8}$" (9.5 mm) I.D. tubing. See Special Instruction SEHS8524.

Diagnostic Tools Needed – Mechanically Controlled Engines

The following diagnostic tools are recommended for sea trial performance data measurements. Additional information is available on many of the tool groups in the *Caterpillar Tool Guide*, form NENG1000 and in the Special Instructions that are sent with the tools.

Laptop computer with the following program:
– **Sea Trial Data Reduction Program:** Computer-Aided Marine Performance Analysis Report (CAMPAR) Software (LEXM7082)

Tachometer
9U7400 Multitach II Group – used to directly convert the input signal to and rpm readout. See Special Instruction SEHS7807.

Pressure Gauge
1U5470 Engine Pressure Group – six vacuum pressure gauges to permit a check of air cleaner restriction, oil pressure, manifold pressure and fuel pressure. Provides readings in psi and kPa. Group covers pressure ranges from 15 psi to 150 psi (100 kPa to 1000 kPa). See Special Instruction SEHS8524.

Fuel Timing Indicator
8T5300 Engine Timing Indicator Group – diagnosis of timing faults that can cause lack of power and/or high fuel consumption. See Special Instruction SEHS8580.

Temperature Indicator
The 4C6500 Digital Thermometer Group is used in analyzing systems. They are capable of reading temperatures ranging from –20° F to 2500° F (–30° C to 1370° C). See Special Instructions SMHS7140 and SEHS8446.

Fuel Gravity (API)
1P7408 thermo-hydrometer and 1P7438 beaker are used to measure the API gravity and temperature of diesel fuel so corrected horsepower ratings can be calculated. See Special Instruction SMHS9224.

Set Point Indicator
6V4060 Set Point Indicator – provides an accurate method of determining the set point on Caterpillar Engines. See Special Instruction SEHS7931.

Crankshaft Deflection
Starrett 696 Crankshaft Deflection Dial Indicator – is used to ensure the cylinder block has not been unduly stressed by incorrect engine mounting, resulting with crankshaft deflection. Refer to Special Instruction SEHS7654 (3500 and 3600 engines).

Engine Pressure Group
8T0855 – can be used for pressures up to 580 psi (4000 kPa) when pressures exceed the limits of the 6V9450 Engine Pressure Group.

Digital Multimeter
146-4080 for measuring electrical values and type K thermocouples.

Infrared Thermometer II
123-6700 is for measuring surface temperatures.

Probe Seal Adapters
Probe seal adapter groups are for use with the temperature and pressure measuring diagnostic tools. They allow probe insertion through the center, and they seal when the probe is removed. The adapters can be

permanently installed and are equipped with a hex head plug to eliminate leakage and debris accumulation. Probe seal adapters available:

- 5P2720: $\frac{1}{8}$" × 27 NPT
- 5P2725: $\frac{1}{4}$" × 18 NPT
- 5P2726: $\frac{9}{16}$" × 18 STO
- 4C4545: $\frac{3}{4}$" – 16 STO to $\frac{1}{4}$" NPT
- 4C4547: $\frac{1}{2}$" – 20 STO to $\frac{1}{4}$" NPT
- 164-2192 Male Pressure Probe

These probe seal adapters are used when measurements of temperature and pressure are needed. Probe seal adapter locations are given in the general *dimension drawings*, and are indicated by a system of 900 series numbers. The drawings also give the tap thread type and size at each location. The Installation Drawings showing specific test ports and corresponding sizes are available on CD-ROM, literature number LERM3233.

WARNING!

All fittings must be corrosive resistant in presence of sea water.

8T0452 Water Manometer
A water manometer provides an accurate measure of crankcase pressure and can be made with a 2 ft (610 m) length of flexible clear plastic $\frac{3}{8}$" (9.5 mm) I.D. tubing. See Special Instruction SEHS8524.

Additional Tooling – Electronically and Mechanically Controlled Engines:

Fuel Flow Measurement System (if required by the sea trial type)

The Caterpillar fuel flow monitor system is an accurate and versatile fuel flow measurement tool that will be an aid to the Caterpillar Marine Analyst in the evaluation of engine performance and fuel consumption during the sea trial tests. The accuracy of the meters can be calculated using the following formula:

$$\pm\%\ \text{Accuracy, Max. Error} = \frac{(0.5 \times \text{Supply Rate})(0.5 \times \text{Return Rate})}{\text{Burn Rate}}$$

The Fuel Monitor System (FMS) is available in a few different arrangements.

Part Number	Gallons Per Hour (Liters Per Hour)	Engine Family
179-0710	1.05-69 (3.7-261)	3126B, 3176, 3196, C9, C12, 3406E, C18
154-8100	50-500 (189-3028)	C18, 3412E, C30, 3500
168-7740	146-1232 (552-4663)	3500, 3600
1U-5430 – Turbine Type	3-70 (11-264)	3126B, 3176, 3196, C9, C12, 3406E, C18
1U-5440 – Turbine Type	40-1000 (151-3785)	3126B, 3176, 3196, C9, C12, 3406E, C18, 3412E, C30, 3500, 3600

179-0710

The Caterpillar burn rate measurement system is available in two groups. The 179-0710 burn rate meter system contains a hand-held display and the 170-0711 burn rate meter system is available without a display. The burn rate measurement system has an operating range of 1.05 to 69 gph (4 to 260 Lph) burn rate and is designed to work with all Cat marine engines that don't exceed 69 gallons per hour fuel consumption. For more information on this system refer to Tool Operating Manual form NEHS0776.

The 179-0710 Burn Rate Meter Fuel Flow Measurement System is a portable test system designed to measure the burn rate on small to medium Caterpillar diesel engines. It has a built-in heat exchanger and electric fuel pump to cool the hot return fuel from the engine. The 179-0701 Burn Rate Meter Computer connects to the 179-0700 Burn Rate Meter with a 179-0702 cable. It provides power, automatic fuel temperature correction, and two outputs. A frequency output represents burn rate in gallons per hour and can be measured with the Caterpillar 131-5050 DataView (use a PC for monitoring) or 9U-7401 Multitach II. The RS485 output represents burn rate in gallons per hour and can be monitored with the Caterpillar 154-8106 hand held display.

The hand-held display shows the fuel temperature and the fuel burn rate for the engine. Internal memories will record the average burn rate for a designated period of time, and can also show the total amount of fuel burned. [Test results can be displayed in either English or Metric units of measurement. All fuel flow measurements are corrected to 60° F (15.5° C).]

154-8100 and 168-7740
Caterpillar FuelCom Fuel Flow Measurement Systems are portable test systems designed to help evaluate engine performance. They use two fuel flow meters and a fuel flow display to:

- Measure fuel flow and fuel temperature of both supply and return-to-tank fuel lines.
- Calculate the fuel burn rate of diesel engines.

Information on the average and total fuel burned by the engine over a period of time is also provided by the fuel flow display. Internal memory records the average fuel burn rate over a period of time and the total fuel burned. This information can be displayed in either Metric or English units.

154-8100
Caterpillar Fuel Flow Measurement System Arrangement has a maximum operating range of 50 gph to 500 gph. For more information on this system refer to Tool Operating Manual form NEHS0697.

168-7740
Caterpillar Fuel Flow Measurement System Arrangement has a maximum operating range of 146 gph to 1232 gph. For more information on this system refer to Tool Operating Manual form NEHS0740.

Note: Another type of Caterpillar FuelCom Fuel Flow Meter Group is also available which allows using the older Caterpillar 8T-9300 Fuel Flow Monitor as a display. The part number for this group is 154-8101 Fuel Flow Meter Group. It contains only the FuelCom Flow meters that will connect to the 8T-9300 Monitor and the necessary cables. The additional parts, such as the monitor and hose groups can be reused from existing 1U-5450, 1U5440 or 1U-5430 Caterpillar Fuel Flow Arrangements. For more information on this group, refer to Tool Operating Manual Form NEHS0698 “Using the Caterpillar FuelCom Fuel Flow Meter Group for Use With the 8T-9300 Fuel Flow Monitor”.

1U5430
Fuel Monitor Arrangement is for use with engine’s having fuel consumption between 3 to 70 gph (11-265 Lph).

1U5440
Fuel Monitor Arrangement is for use on the 3500, 3606 and 3608 engines. Larger engines can be measured by using a single meter, recirculating the return fuel and using a fuel cooler if it is required. The operating range for this arrangement is 40 to 1000 gph (151-3785 Lph).

Installation and Connection of a Fuel Monitor System (FMS)

When it is installed and connected correctly, the Caterpillar Fuel Monitor System can provide accurate fuel flow measurements for Caterpillar Marine Diesel Engines.

Before installation and/or connection of the unit, locate the fuel supply and return lines for the engine, and determine the best location to make a connection.

The fuel supply flow meter must be connected between the fuel supply tank and the fuel transfer pump.

The return fuel flow meter must be connected into the fuel line that goes to the fuel tank. Use the hoses and connections from the hose adapter groups, as needed, to make these connections.

NOTICE

Make sure the area for fuel line disconnections and fuel monitor line connections is absolutely clean. No debris or paint chips must be permitted to enter the fuel system or the meters. When connecting a meter, always connect it so the flow of fuel is in the same direction as the fuel flow arrow on the side of the flow meter.

Sea Trial Data Acquisition Procedure – Electronically Controlled Engines (Propulsion System)

WARNING!

Hot oil and components can cause personal injury. Do not allow hot oil or components to contact skin.

Before doing a sea trial performance evaluation, the vessel must have a load that is typical of the load that will be normally encountered. There should be at least a partial crew on board to oversee operation of the vessel during the test period. The crew should be notified of the test procedure and informed of what will be required of them during the test.

Use the General Information file within the Caterpillar Electronic Technician to record all physical aspects of the vessel being tested. At this point, begin the test by recording fuel gravity (API) (see Special Instruction SEHS9224), sea water depth and temperature, and ambient air temperature. Check all fluid levels and add fluid where necessary. (If applicable, intake and exhaust valve clearances and engine fuel timing must be measured, recorded and corrected as necessary.) (When performing a Complete PAR Sea Trial – On 3500 and 3600 engines mounted on rails, measure crankshaft deflection (cold) at the crankshaft center throw. Refer to Special Instruction SEHS7654.)

Install the diagnostic tooling needed according to the tests that are to be performed. A list of tools required can be reviewed with the Sea Trial type description in this manual.

Note: New or rebuilt engines must be operated on a break-in schedule before being subjected to full load operation. Refer to *Engine and Component Reconditioning Bulletin*, SEBF4564.

- To conduct a thorough sea trial, there are three steps that must be completed while on the vessel. General Information, Sea Trial Transient, and Sea Trial Steady State test must be completed. All three functions are completed with Cat ET. The General Information file contains:
  - General information such as vessel name, home port, customer, builder and dealer information
  - Vessel data pertaining to specifics such as hull type, lengths, displacement and capacities
  - Vessel type
  - Engine and transmission information with specific data recording model, serial number, arrangement, gear ratio, engine personality module identification, fuel settings, etc.
  - Pre-Test data acquiring fuel API, sea water and ambient temperatures and sea water conditions
  - Comments field for general explanation of important facts pertaining to the specific sea trial

Note: To complete the General Text file, the laptop and comm. adapter must be connected to the ECM(s) with the ECM(s) powered.

After completing the General Information file, the vessel should be operated until the engines, gears and related systems are at normal operating conditions. Prior to beginning the sea trial, the engine room hatch must be closed, the throttles in sync, and the trim tabs fully raised.

Acquiring Transient Data

Caterpillar Electronic Technician contains default groups of data channels. Group 1 contains the data channels that are required for the transient sea trial. Initialize the “Sea Trial Transient” recorder and select Group 1. Verify the recorder acquisition time is set for a sufficient amount of time to record 3 full throttle accelerations. 30 minutes of record time is recommended. The data recorder must be set to the fastest acquisition rate possible. Present capabilities are 120 samples per minute. Channel groups will have to be manually constructed for 3500 engines.

Start the recorder, idle in gear until a constant vessel speed is achieved. Verify the throttles are in sync, trim tabs are up, and then perform a rapid acceleration. Leave the engines at full throttle until the engines have reached their full speed. Then leave it at full throttle for another 5 seconds. Bring the throttles back to low idle. Let the vessel speed slow until a constant speed is achieved again. While the Transient recorder is still acquiring data, repeat the above 2 more times. At the end of the third acceleration, stop the data recorder. The transient acceleration test has been completed.

Acquiring Steady State Data

The setup of Cat ET requires that a default group of channels be selected prior to performing the Steady State test. There are three basic types of channel groups; Performance, Over Heat and Complete PAR. Choose the appropriate group to address the complaint being investigated. The Performance and Over Heat group contains all electronic and select manual (900 channels) that are pertinent to diagnosis of engine performance and cooling system issues. The Complete Par contains all electronic and manual parameters needed to conduct a complete PAR analysis of the application. The default group of channels can be modified if necessary. The manual channels that must be recorded along with the ECM channels are inlet air restriction, sea water pump inlet restriction, exhaust backpressure and exhaust temp before turbocharger if ports are available. If ports are not available prior to the turbocharger, then readings will have to be taken from the exhaust stack. These will have to be manually entered through the laptop's keyboard when prompted by Cat ET.

Note: During the sea trial using the steady state recorder, if the steady state recorder screen is left to go to any other screen within Cat ET, the present steady state recorder screen will not be able to be re-opened. A new file will have to be created and the sea trial started from the beginning.

Sea Trial Data Acquisition Procedure – Mechanically Controlled Engines (Propulsion System)

WARNING!

Hot oil and components can cause personal injury. Do not allow hot oil or components to contact skin.

Before doing a sea trial performance evaluation, the vessel must have a load that is typical of the load that will normally be encountered. There should be at least a partial crew on board to oversee operation of the vessel during the test period. The crew should be notified of the test procedure and informed of what will be required of them during the test.

Use the Caterpillar Marine Engine Performance Analysis Report (PAR – LEXM0581) instead of Cat ET to record all physical aspects of the vessel being tested. This form will also be used to manually record the data points generated during the sea trial.

At this point, begin the test by recording fuel gravity (API) (see Special Instruction SMHS9224), sea water depth and temperature, and ambient air temperature. Check all fluid levels and add fluid where necessary. (If applicable, intake and exhaust valve clearances and engine fuel timing must be measured, recorded and corrected as necessary.) (If applicable – On 3500 and 3600 engines mounted on rails, measure crankshaft deflection (cold) at the crankshaft center throw. Refer to Special Instruction SEHS7654.)

Install the diagnostic tooling needed according to the tests that are to be performed.

Note: New or rebuilt engines must be operated on a break-in schedule before being subjected to full load operation. Refer to *Engine and Component Reconditioning Bulletin*, SEBF4564.

Vessel Operating Procedure for Acquiring Sea Trial Data Points (Both Electronically and Mechanically Controlled Engines) (Propulsion System)

The frequency of data points acquired is dependant upon the rated engine speed. Refer to the following description for the engine speeds at which data points are to be taken:

Engines rated up to 1400 RPM – Low Idle, then 600 RPM and every 100 RPM up to full throttle.

Engines rated between 1401 to 1800 RPM – Low Idle, then 1000 RPM and every 100 RPM up to full throttle.

Engines rated 1801 and above – Low idle, then 1000 RPM and every 200 RPM up to 300 RPM below rated. Then every 100 RPM to full throttle.

Once the sea trial has begun, move the throttle lever to a position to achieve the desired engine speed and allow the engine speed to stabilize. This is necessary to obtain accurate steady state values.

Note: For the best results, acquire the entire data run traveling in one direction. Currents and wind have a definite factor in boat performance and engine loading.

Note: After completion of a Complete PAR on all 3500 and 3600 engines that are mounted on rails, again record crankshaft deflection at the crankshaft center throw while the engine is hot. Refer to Special Instruction SEHS7654. For 3600 instruction, refer to the 3600 A&I Guide LEKM7301.

Analysis of Sea Trial Test Results (Propulsion System)

CAMPAR Software Description (LEXM7082)

CAMPAR is an IBM or 100% compatible personal computer software program developed to aid certified marine analysts in:

- Formulating actual and factory-specified test results for marine propulsion engines and transmissions.
- Producing a graphic representation of the actual and factory-specified fuel rate, boost pressure and exhaust temperature results for propulsion systems utilizing fixed pitch propellers under normal operating conditions.
- Making consistent interpretations and recommendations from the test results, for marine propulsion engines and transmissions.

CAMPAR contains a Caterpillar specification database for the most common engine models and ratings. It also provides the analyst with the capability to formulate specification data for unique and non-current engine models and ratings.

For more information on CAMPAR (LEXM7082) software availability and hardware requirements, contact:

Caterpillar Inc.
Global Marine Division
P.O. Box 610
Mossville, IL 61552-0610

If desired, a fax can be used. Send a fax to the attention of:

Application Support Center
(765) 448-2300

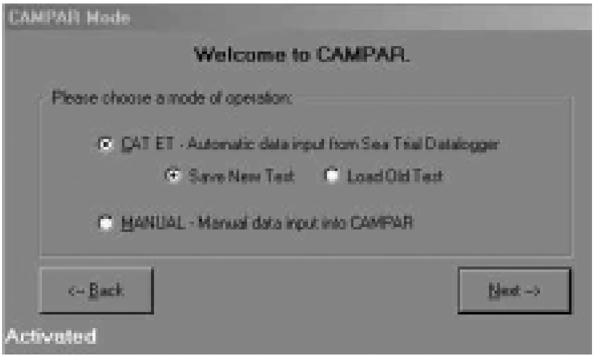
Or at:
https://engines.cat.com/infocast/frames/marine/techinfo/seatrial/

Electronic Engines

Once the operational test is completed, analyze the results using the Computer-Aided Marine Performance Analysis Report (CAMPAR) software program (LEXM7082) to analyze the data. Initial registration of the software will not be able to be completed if the user is not a Caterpillar Certified Marine Analyst. If a copy of CAMPAR is required, it can be ordered through the Caterpillar literature system. Once the CAMPAR software is installed, updates can be downloaded at: http://www.camparonline.com/. At the completion of the steady state data acquisition, the CAMPAR software can be initialized from within the steady state acquisition screen by clicking on the "CAMPAR" button.

Note: CAMPAR requires that the engine specification data files within the CAMPAR software program be updated. This requires that the computer performing the analysis periodically be connected to the Internet.

Once CAMPAR is initialized, the main menu of the program will list a button that states "Run Test". Click on this button to begin the analysis of a new test. The next screen shown below shows the default mode of operation choice. This is the correct selection for extracting steady state data from Cat ET to analyze new data.



After this window, a prompt will request to name the new PAR file, then to select the General Information, Steady State and Transient file for analysis. Following windows will be for data verification. Once completed with data verification, a window will appear to select various graphs for display. The graphs display the actual data taken from the sea trial, compared to the engine specifications. Once the graphs are reviewed, CAMPAR will then create a text report to be reviewed with the customer.

Analyze the results and discuss them with the customer. If a system problem exists, discuss a recommended course of action to correct that problem. Upon completion of the Caterpillar Marine Application

Performance Analysis Review, copies of the report should be presented to the builder/installer and to the owner for their permanent record. They should sign the form to indicate their acknowledgement of the results and recommendations of the test.

Mechanically Governed Engines

Use CAMPAR LEXM7082, software to plot the engine fuel rate for comparison to TMI specifications.

1. Start the CAMPAR program and update test spec files if prompted (requires an internet connection).

2. The following screens will prompt for the engine serial number and ask to verify the proper test spec number.
3. The next step is to input the data requested by CAMPAR pertaining to pre-test information such as fuel API, engine settings and speeds, ambient, seawater conditions, and vessel loading.
4. The following window will require the actual engine speed, fuel rate and boost pressures to be manually entered to complete the performance analysis. Listed above the input for the actual engine speed when the data was acquired at is a suggested engine speed. The actual engine speed does not have to equal the suggested speed.

Note: For additional assistance with CAMPAR software operation, reference the Help file within the CAMPAR software program.

Note: After entering the actual data and generating the graphic output, systems results and recommendations, review them carefully. In most instances, it will be necessary to explain the results and recommendations with the customer.

Analyze the results and discuss them with the customer. If a system problem exists, discuss a recommended course of action to correct that problem. Upon completion of the Caterpillar Marine Application Performance Analysis Review, copies of the report should be presented to the builder/installer and to the owner for their permanent record. They should sign the form to indicate their acknowledgement of the results and recommendations of the test.

Once the sea trial has been completed and analyzed, submit the "*file-name*.par" which was generated by CAMPAR to the Caterpillar Sea Trial Database. This data is stored for future reference. The url to access the database is as follows:
https://engines.cat.com/infocast/frames/marine/techinfo/seatrial/

Sea Trial Test Procedure (Auxiliary Systems)

In addition to evaluating the propulsion system's performance, the sea trial includes an evaluation of the auxiliary systems. Most auxiliary performance evaluations can be conducted dockside, under the intended load at full throttle. The crew should be notified of the test procedure, and informed as to what will be required of them during the test. Use the *Caterpillar Marine Application Performance Analysis Review*, form LEXM0581 to record all information, physical description, and performance data. Use one form for each auxiliary engine.

WARNING!

Conducting a MEGGAR test could result in serious shock and burns to the skin.

Note: Before operation of a generator set auxiliary engine, do a MEGGAR test on the generator field windings. Use the test procedures given in the generator Service Manual to do the MEGGAR test. Failure to perform this test can result in excessive generator and/or engine damage. Therefore, it is not recommended that the generator auxiliary performance analysis be conducted until acceptable MEGGAR results are obtained.

WARNING!

Hot oil and components can cause personal injury. Do not allow hot oil or components to contact skin.

As in the evaluation of the propulsion systems, the test should begin by recording fuel gravity (API), sea water temperature, and ambient air temperature. Check all fluid levels and correct them as necessary. For Complete PAR tests, intake and exhaust valve clearances and engine fuel timing must also be measured, recorded and corrected as necessary. On 12 and 16 cylinder engines that are mounted on rails, measure crankshaft deflection (cold) at the crankshaft center throw. Refer to Special Instruction SEHS7654. Install the diagnostic tools that will be needed. For 3600 instruction, refer to the 3600 Service Manual for proper crankshaft deflection measurement procedure.

Note: Operate a new or rebuilt engine on a run-in schedule before it is subjected to full load operation. (Refer to *Engine and Component Reconditioning Bulletin, SEBF4564*).

Operate the auxiliary engine at full throttle under normal intended load, long enough for the jacket water outlet temperature (901) to stabilize. Use the *Caterpillar Marine Application Performance Analysis Review*. Record the measured low and high idle speeds. Make sure there is no throttle linkage restriction, and that there is full throttle travel. Record the designated 900 Series systems temperatures and pressures. For Complete PAR tests upon completion of the performance evaluation, all 3500 12 and 16 cylinder engines mounted on rails and 3600, again check and record crankshaft deflection at the crankshaft center throw while the engine is still hot.

Analysis of Sea Trial Results (Auxiliary Systems)

After the Sea Trial test is completed, evaluate the results as follows:

1. Compare the 900 Series designated systems' pressures and temperatures, and the crankshaft deflection recorded values with the values given in the *TMI On-Line System Sea Trial Screen*. A complete system test will be necessary to find the source of any indicated problems. Refer to the *Cooling System Evaluation* section of this publication for the engine cooling system, and to the *Caterpillar Marine Engine Application and Installation Guide* for more information if crankshaft deflection is not within specifications.
2. Complete the *Caterpillar Marine Application Performance Analysis Review* to indicate the results and recommendations of the evaluation. The *Caterpillar Marine Application Performance Analysis Review* form is available from Caterpillar, and can be ordered, using the normal literature ordering procedure.

Caterpillar Marine Engine Performance Analysis Report (PAR) (Mechanically Governed Engines)

General:

Vessel Name ______________________________

Home Port ______________________ Area of Operation ______________________

Customer Name: ______________________ Builder/Installer ______________________

Customer Address: ______________________ Builder/Installer Address ______________________

______________________ ______________________

Vessel Data:

Hull Type: ☐ Displacement ☐ Semi-Displacement ☐ Planing

Overall Length: ______________________ Water Line Length: ______________________

Expected Hull Speed (Knots): Free Running ______________________

Propeller Manufacturer: ______________________

Propeller Material: ☐ Stainless Steel ☐ Brass ☐ Other ______________________

Propeller Size: Diam. __________ Pitch __________ No. of Blades __________

Cup __________

Vessel Type:

Fishing:	☐ Trawler/Dragger	☐ Long Liner	☐ Gilnetter	☐ Trap Fishing	
Tow Boat:	☐ River	☐ Ocean	☐ Intercoastal	☐ Lower Mississippi	
Cargo:	☐ Bulk	☐ General	☐ Container	☐ Fast Ferry	☐ Crew Boat
Pleasure:	☐ Sport Fishing	☐ Motor Cruiser	☐ Mega-Yacht		

Engine Information:

Engine Model: ______________________ Engine Serial Number: ______________________

Engine Arrangement Number: __________ OT Test Specification Number: __________

Sales Performance Number (TM or DM) __________

Engine Rating: ______________________ BHp BkW @ ______________________ rpm

Aspiration: ______________________

Aftercooler System: ☐ NA ☐ JW

☐ SC 85° F (29° C) ☐ SC 110° F (43° C) ☐ SC 122° F (50° C)

Engine Position in Vessel: ☐ Starboard ☐ Center ☐ Port

(or) Engine 1 Engine 2 Engine 3 Engine 4 Engine 5

Application: ☐ Propulsion ☐ Auxiliary ☐ Other __________

Marine Transmission Manufacturer: ______________________

Marine Transmission Model: ______________________ Serial Number: ______________________

Transmission Arrangement Number: ______________________

Transmission Ratio: Forward ______________________ Reverse ______________________

Maximum Expected Sea Water Temperature: ______________________

Pre-Test Data Information

API Gravity of Fuel at 60° F (16° C): ______________________________

Corrected Fuel Density @ 60° F (16° C): ______________________________ lb/gal or kg/l

Sea Water Temperature: ______________ °F or °C Sea Water Depth ______________

Ambient Air Temperature: ______________ °F or °C Hours on Engine ______________

Vessel Loaded to Normal Water Line:

☐ Yes ☐ No

Corrosion Inhibitor Used:

☐ Yes ☐ No

Fluid Levels Correct:

☐ Yes ☐ No

Valve Clearance Checked:

☐ Yes ☐ No

Inlet Air Ducted From Outside

☐ Yes ☐ No

Engine Fuel Timing Checked:

☐ Yes ☐ No

Engine Fuel Timing Specification: ______________________________

Unit Injector Timing Checked: (If Equipped)

☐ Yes ☐ No

Unit Injector Timing Specification: ______________________________

Static Full Load Fuel Setting: Measured ____________ in. (mm) Spec ____________ in. (mm)

Crankshaft Deflection Measurement: (909) __________ Cold in. (mm) __________ Hot in. (mm)

Measured High Idle: ______________ rpm Spec. High Idle ______________ rpm

Low Idle: ______________ rpm Low Idle ______________ rpm

Maximum Water Pump Flow ______________________________

B.S.F.C. __________ Turbocharger Cartridge __________ Unit Injector Part Number __________

PROPULSION ENGINE RATED FUEL RATE

Maximum gph (Lph)	rpm	Minimum gph (Lph)

PROJECTED ACCEPTABLE FUEL RATES

Top Curve

gph (Lph)	rpm

Bottom Curve

rpm	gph (Lph)

PROJECTED ACCEPTABLE (PART LOAD) INLET MANIFOLD PRESSURE (BOOST)

	1	2	3	4	5	Full Throttle
rpm						
Part Load Boost Specs						

MEASURED ENGINE RPM, FUEL RATE, AND INLET MANIFOLD PRESSURE (BOOST)

	High Idle	1	2	3	4	5	Full Throttle
rpm							
Fuel Rate gph (Lph)							
Boost psi (kPa) (911)							
Boost psi (kPa) Left* (911)							
Boost psi (kPa) Right* (911)							

*Left and Right Boost readings are for those engines with two intake manifolds.

935 Fuel Inlet Temperature ______ °F (°C) Fuel Outlet Temperature ______ °F (°C)

900 SERIES NUMBER	DESCRIPTION	ACTUAL MEASUREMENT	SPECIFICATION
930	Air Temp. @ Air Cleaner Outlet (L)		
930	Air Temp. @ Air Cleaner Outlet (R)		
907	Inlet Air Restriction (L)		
907	Inlet Air Restriction (R)		
906	Inlet Manifold Temperature (L)		
906	Inlet Manifold Temperature (R)		
903	A/C Inlet Water Temperature		
903A	A/C Outlet Water Temperature		
922	JW Inlet Temperature (From Cooling System)		
901	JW Outlet Temperature (Before Reg.)		
902	JW Pump Outlet Temperature		
913	Engine Oil to Bearings Temperature		
914	Engine Oil Pressure		
917	Fuel Pressure		
908	Exhaust Backpressure		
912	Exhaust Stack Temperature		
912A	Exhaust Manifold – Right Front Turbo Temperature		
912B	Exhaust Manifold – Right Rear Turbo Temperature		
912C	Exhaust Manifold – Left Front Turbo Temperature		
912D	Exhaust Manifold – Left Rear Turbo Temperature		
915	Transmission Oil Temperature		
916	Transmission Oil Pressure		
925	Transmission Oil Cooler Inlet Water Temperature		
926	Transmission Oil Cooler Outlet Water Temperature		
918	JW Outlet Pressure (Before Reg.)		
919	JW Pump Outlet Pressure		
920	JW Pump Inlet Pressure		
921	JW Pressure from Cooling System		
923	A/C Water Inlet Pressure		
924	A/C Water Outlet Pressure		
929	Individual Exhaust Port Temperatures		
932	Crankcase Base Pressure		
910	Min. Engine rpm During Emergency Reversal		
904	Raw Water Pump Inlet Pressure		
905	Raw Water Pump Outlet Pressure		
931	Turbocharger Compressor Outlet Temperature		
933	Jacket Water Temperature to Cooling System		
938	Oil Cooler Water Outlet Temperature		
939	Oil Cooler Water Outlet Pressure		
927	Oil Filter Inlet Pressure		
928	Oil Filter Outlet Pressure		

ADDITIONAL DATA FOR DIAGNOSTIC PURPOSES

900 SERIES NUMBER	DESCRIPTION	ACTUAL MEASUREMENT	SPECIFICATION
961	Fuel Pump Inlet Restriction		
943	Water Temp. to Combined Circuit Heat Exchanger		
944	Water Pressure to Combined Circuit Heat Exchanger		
945	Water Temp to Temp. Reg. from Combined Circuit Heat Exchanger		
946	Water Pressure to Temp. Reg. from Combined Circuit Heat Exchanger		
947*	Water Temperature at Engine Outlet to Separate Circuit Jacket Water Heat Exchanger		
948*	Water Pressure at Engine Outlet to Separate Circuit Jacket Water Heat Exchanger		
949*	Water Temperature to Temp. Reg. from Separate Circuit Jacket Water Heat Exchanger		
950*	Water Pressure to Temp. Reg. from Separate Circuit Jacket Water Heat Exchanger		
951*	Aftercooler/Oil Cooler Water Pump Inlet Temp.		
952*	Aftercooler/Oil Cooler Water Pump Inlet Pressure		
953*	Aftercooler/Oil Cooler Water Pump Outlet Pressure		
954*	Raw Water Temp. to Combined Circuit Heat Exchanger		
955*	Raw Water Temp. from Combined Circuit Heat Exchanger		
956*	Raw Water Temp. to Separate Circuit Jacket Water Heat Exchanger		
957*	Raw Water Temp. from Separate Circuit Jacket Water Heat Exchanger		
958*	Raw Water Temp. to Separate Circuit Aftercooler/Oil Cooler Heat Exchanger		
959*	Raw Water Temp. from Separate Circuit Aftercooler/Oil Cooler Heat Exchanger		
960	Turbo Compressor Outlet Pressure		
962	Raw Water Pump Inlet Pressure		
963	Raw Water Pump Outlet Pressure		
964	Raw Water Pressure After Heat Exchanger		

*Required for 3600 Engines Only

ACCELERATION TIME TO PLANE

Name of Boat									
Low Idle Out of Gear									
Low Idle in Gear									
Acceleration Runs	1	2	3	4	5	6			
w/o Trim & Upwind (sec.)									
w/o Trim & Downwind (sec.)									
w/Trim & Upwind (sec.)									
w/Trim & Downwind (sec.)									

Note: Before and during data taking time, start in low idle (in gear), keep rudder straight at start, let engine cool one (1) minute after each run.

ANALYSIS OF TEST DATA

System	Results of Analysis
Ventilation	
Aftercooler System	
Jacket Water System	
Keel Cooler/Heat Exchanger System	
Engine Lube System	
Fuel System	

Shaft Load

Exhaust System

Crankcase Pressure

Marine Transmission System

Minimum rpm During Reversal

Crankshaft Deflection

Note any Deviations from the Caterpillar Application and Installation Guide Book ______________________________

____

Additional Comments ______________________________

____

Recommended Actions ______________________________

____

Acknowledgement of Results and Recommended Action

Authorized Signature of Dealer ____________________________ Date ___________

Authorized Signature of Builder/Installer ____________________ Date ___________

Authorized Signature of Owner ____________________________ Date ___________

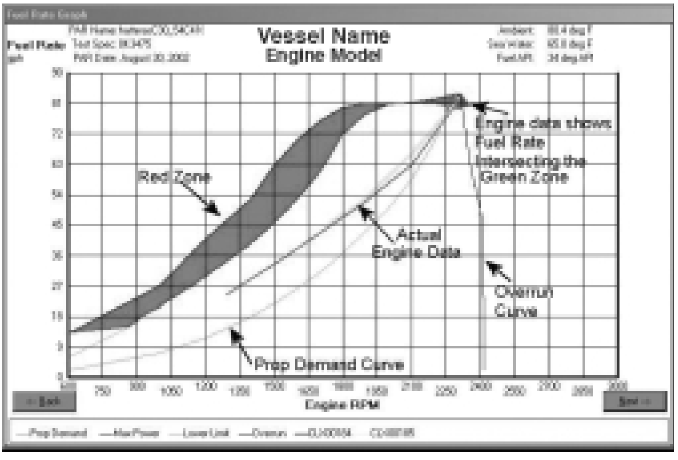
Using CAMPAR for Data Analysis

Fuel Rate and Performance Analysis

The Marine Engine Performance Analysis Report (PAR) compares the fuel rate of a Caterpillar Marine Propulsion Engine to the original factory performance specifications for that specific engine. This comparison is made for the entire operating range of the engine. If the fuel rate and boost pressure data from the Marine PAR test are within the acceptable range for load and performance specifications, it is an indication that the engine is operating correctly and the propulsion system was sized satisfactorily.

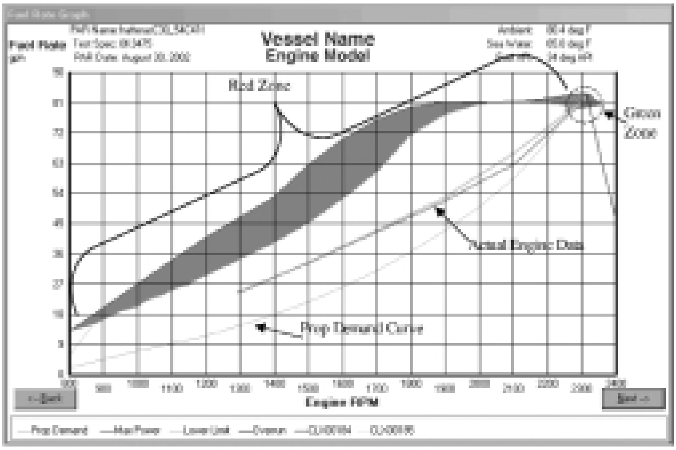
However, if the actual fuel rate and boost pressure curves fall outside the acceptable range for load and performance specifications, adjustments and/or repairs for the fuel system and/or engine loading conditions may be necessary. In addition, a further check may be needed for the hull, rudder, propeller, etc.

Analysis of the CAMPAR Fuel Rate Graph (Electronically Recorded Data from Cat ET)

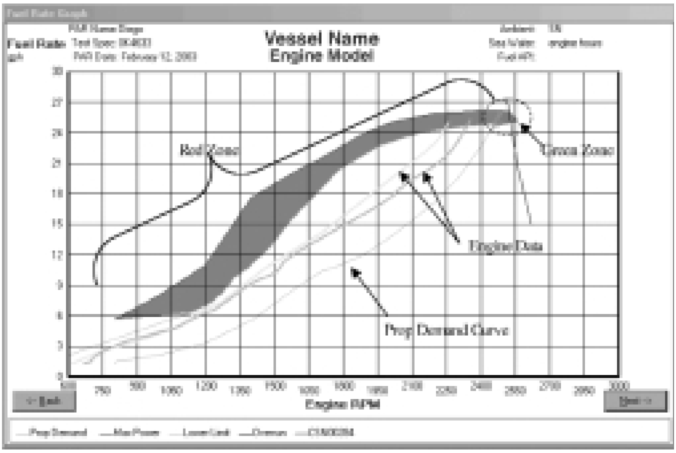


The Fuel Rate graph is generated from the CAMPAR program consisting of three parameters. The Red Zone is derived from engine specific data which is downloaded by the CAMPAR program from TMI. The Actual Engine Data generated by the sea trial, and the Propeller Demand (Prop Demand) curve from TMI is also represented. There are five possible results from the Fuel Rate graph as follows:

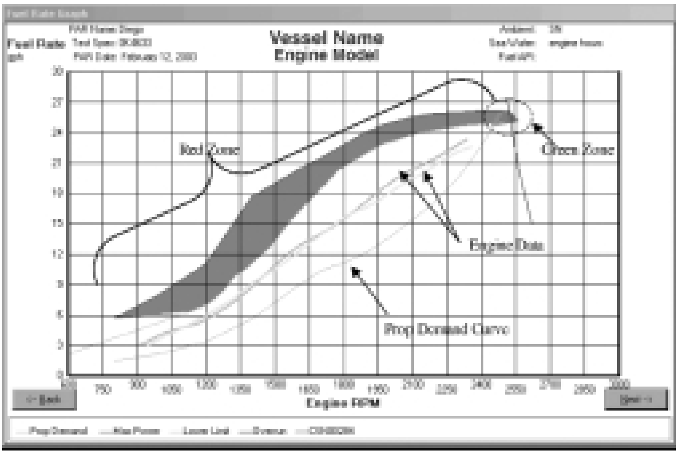
Fuel Rate at Maximum Engine Speed Intersects the Acceptable Green Zone. This is an indication that the engines are properly loaded to achieve rated speed or higher and consuming the amount of fuel that equals the rated fuel consumption specified in TMI. Engine performance conclusions should not be made on only one parameter. The boost pressure graph should also be taken into consideration prior to concluding the sea trial analysis.



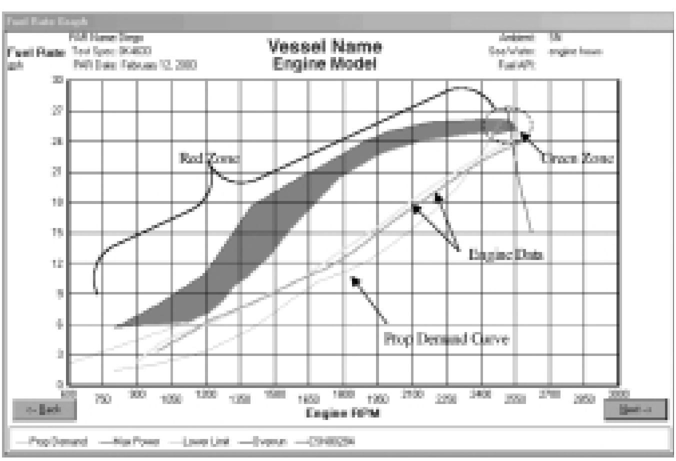
Fuel Rate at Maximum Engine Speed Intersects the Red Zone. This is an indication that the engine is consuming the maximum amount of fuel for a given engine speed, but has too much load to allow the engine to reach its rated speed. Engine performance conclusions should not be made on only one parameter. The boost pressure graph should also be taken into consideration prior to concluding the sea trial analysis.



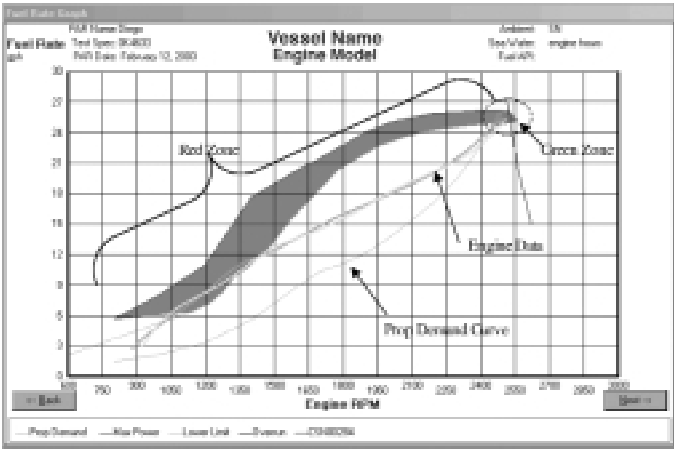
Fuel Rate at Maximum Engine Speed Does Not Intersect the Green or Red Zone and Engine Speed is Less than Rated Speed. This would be an indication of the throttle not reaching full throttle or the test spec from the General Information file is not compatible with the engine rating. Engine performance conclusions should not be made on only one parameter. The boost pressure graph should also be taken into consideration prior to concluding the sea trial analysis.



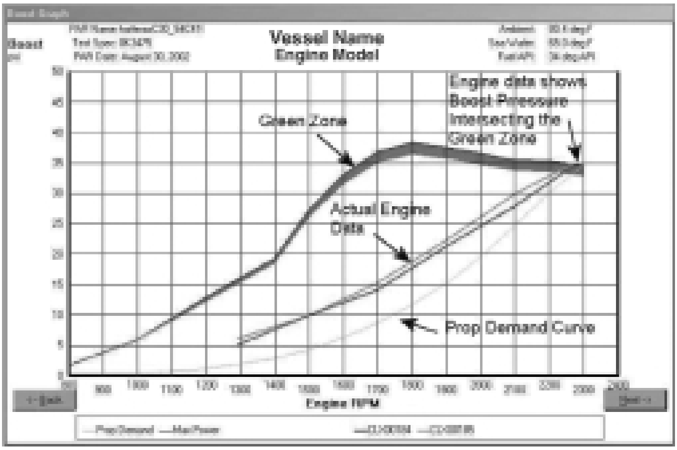
Fuel Rate at Maximum Engine Speed Does Not Intersect the Green Zone and Engine Speed is Greater than Rated Speed. This would be an indication that the load placed on the engines is not great enough to cause the engines to require a high enough rate of fuel, resulting in an under-loaded situation. Engine performance conclusions should not be made on only one parameter. The boost pressure graph should also be taken into consideration prior to concluding the sea trial analysis.



Fuel Rate from the Engine Data Intersects the Red Zone at Lower Engine Speeds, but the Fuel Rate at the Maximum Engine Speed Intersects the Green Zone. In the situation where the Maximum Engine Speed intersects Green or Acceptable portion of the graph, but data at lower engine speeds intersects the Red Zone, the engines are properly loaded, but a vessel response issue may occur. This situation could result in the vessel being difficult to plane, but once on plane results in acceptable performance. This typically is caused by vessel design issues. Engine performance conclusions should not be made on only one parameter. The boost pressure graph should also be taken into consideration prior to concluding the sea trial analysis.

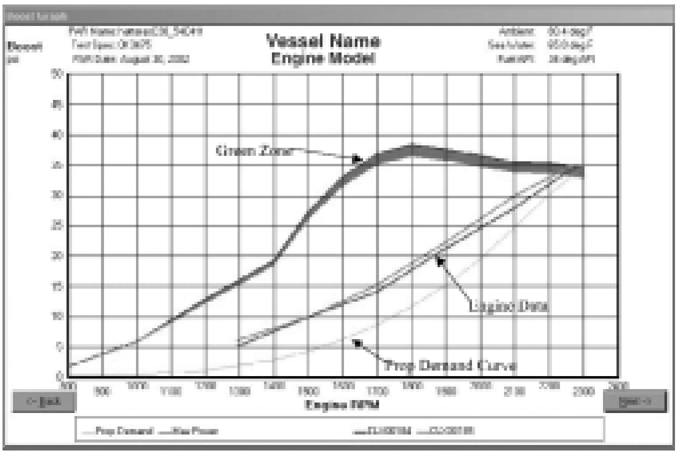


Analysis of the CAMPAR Boost Pressure Graph (Electronically Recorded Data from Cat ET)

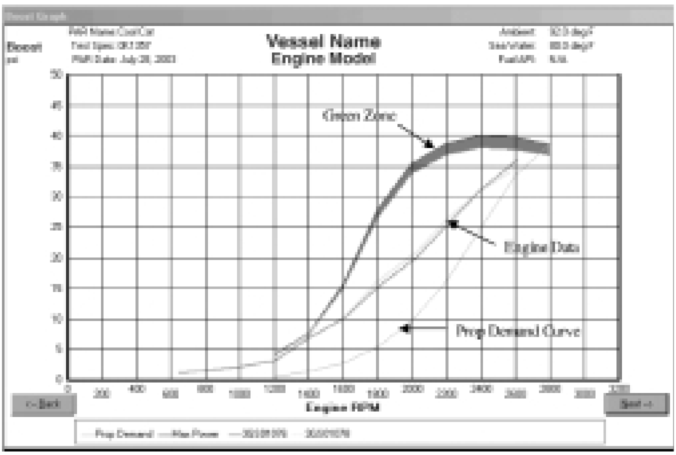


The Boost Pressure graph is generated from the CAMPAR program consisting of three parameters. 1. The Green Zone is derived from TMI engine performance data, 2. The Actual Engine Data generated by the sea trial, 3. The Theoretical Propeller Demand (Prop Demand) as displayed in TMI. Three different scenarios are possible results. They are as follows:

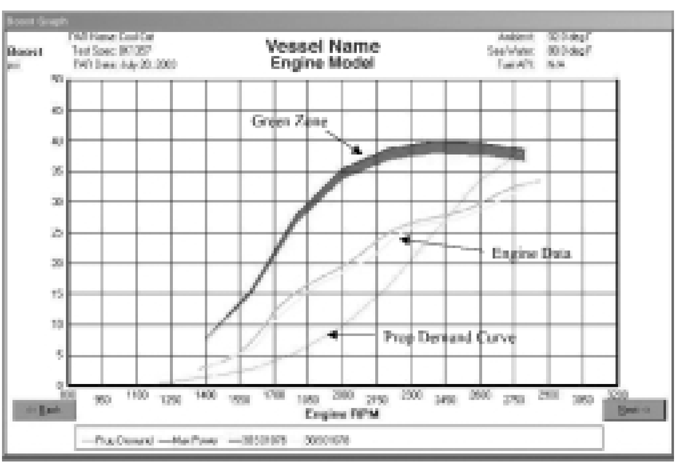
Maximum Boost Pressure Value Intersects the Green Zone. This is an indication that the engine(s) are able to produce acceptable boost pressure, which is one indication that the engine(s) are able to produce acceptable power. If the engine(s) are not able to achieve rated speed, but the highest engine speed and boost pressure achievable still intersects the Green Zone, the engines are operating properly. Engine performance conclusions should not be made on only one parameter. The fuel rate graph should also be taken into consideration prior to concluding the sea trial analysis.



Maximum Boost Pressure Value Does Not Intersect the Green Zone and Engine Speed is Less than Rated Speed. This would be an indication that the engine is deficient in the air system, full throttle not being achieved, fuel system or combustion (piston ring/liner wear and/or cylinder head valves) system. A restriction either in the intake or exhaust or an intake system leak after the turbocharger is present not allowing the engine to achieve the boost required to reach the Green Zone. Engine performance conclusions should not be made on only one parameter. The fuel rate graph should also be taken into consideration prior to concluding the sea trial analysis.



Maximum Boost Pressure Does Not Intersect the Green Zone and Engine Speed is Greater than Rated Speed. This would be an indication that the engine(s) are under-loaded.

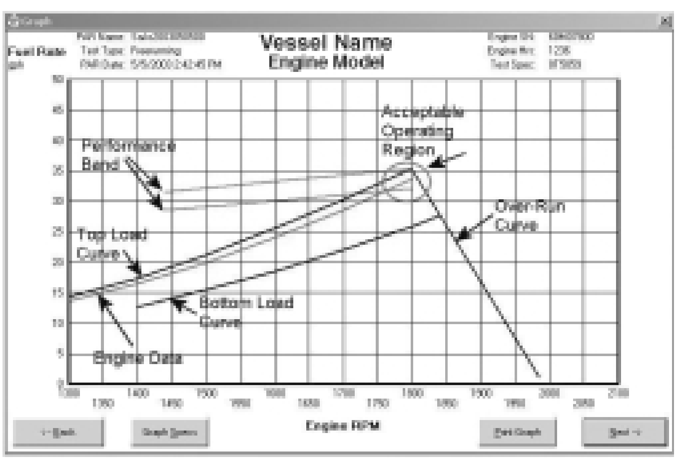


Analysis of the CAMPAR Fuel Rate Graph (Manual Data Input)

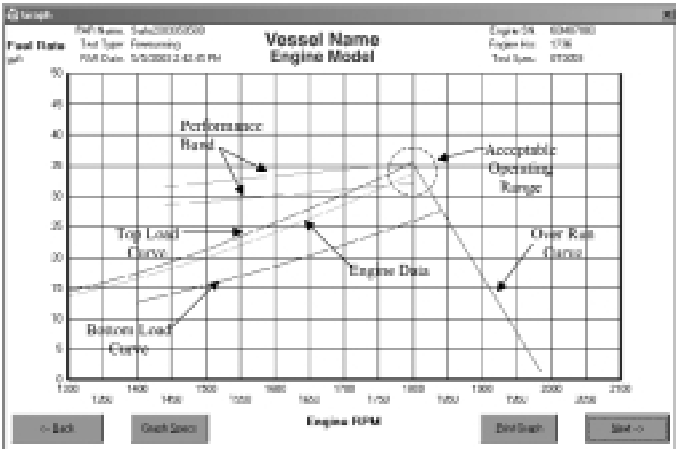
The Top Load Curve represents the maximum load that ends at 100% of full load engine speed. This end point of the Top Load Curve is equal to 5% above the nominal fuel consumption rate. The end point of the bottom load curve is minus 5% of the nominal fuel consumption rate, which also represents the load that ends at 103% of full load rpm. The Load Curve is then calculated from the equation that forms the Propeller Demand Curve. The top and bottom load curves are established by plotting the projected acceptable fuel rate specifications for normal operation on displacement hulls only. Planing hulls will vary due to hull demand and can be above the Top Load Curve.

The performance band is established by plotting engine rated fuel rate and represents the lug/fuel rate characteristics of the specific engine ±5% of the fuel rate. The top and bottom curves of the Performance Band are generated from ±5% of nominal maximum fuel rate between the engine's torque check and rated speeds.

As the sea trial is conducted and the data points are acquired throughout the speed range to wide-open throttle, the fuel consumption data from the sea trial should plot between the top and bottom load curves for Displacement hull applications. The area between the top and bottom lines of the Performance Band is the maximum fuel that the engine would consume if a great enough load was applied to the engine at any speed to limit it from achieving rated engine speed. There are 4 possible results of the Fuel Rate graph.

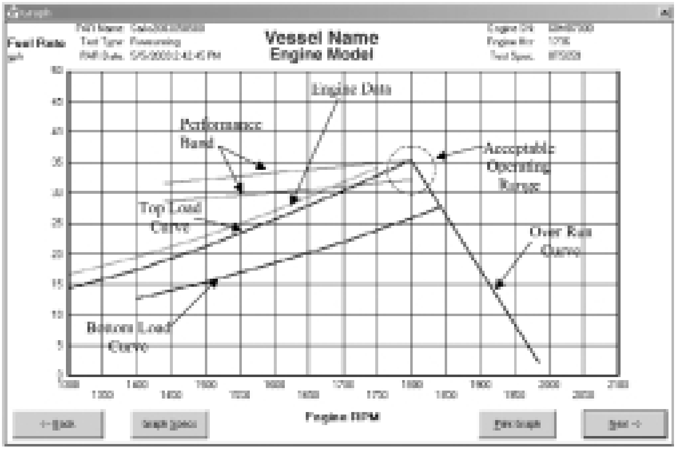


Fuel Rate at Maximum Engine Speed Intersects the Acceptable Region. This is an indication that the engines are properly loaded being able to achieve rated speed or higher, and requiring that the engine burn the amount of fuel that equals the prescribed rated fuel consumption for that rating.

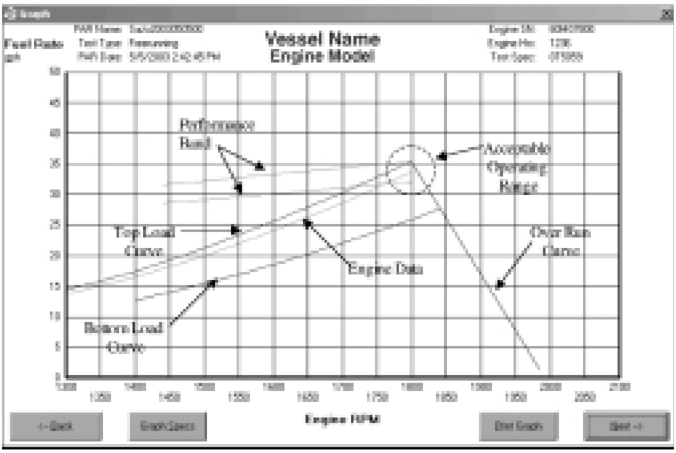


Note: The red circle on the graph is only to represent the acceptable operating region and is not part of the graph generated by CAMPAR.

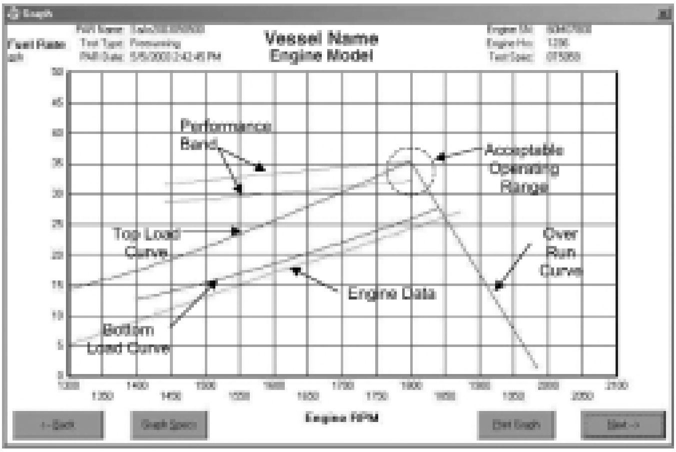
Fuel Rate at Maximum Engine Speed does not reach Rated Speed and Curves above the Top Load Curve and intersects the Performance Band. The maximum engine speed that is recorded during the sea trial is not able to reach rated engine speed. The data curve trends above the Top Load Curve and intersects the Performance Band. This is an indication that the engine is consuming the maximum amount of fuel for a given engine speed, but has too much load to allow the engine to reach its rated speed.



Fuel Rate at Maximum Engine Speed Does Not Intersect the Acceptable Zone, Engine Speed is Less than the Acceptable Zone and is within the Top and Bottom Load Curves. This would be an indication of the throttle not reaching full throttle or a mechanical fuel system problem not allowing the engine to burn the fuel required to achieve rated performance.



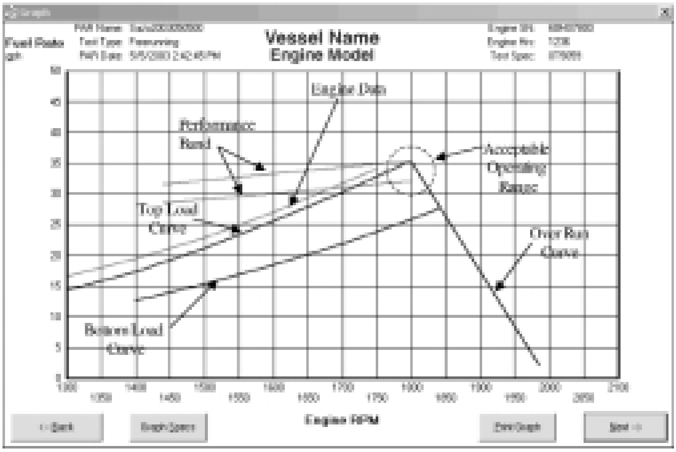
Fuel Rate at Maximum Engine Speed Does Not Intersect the Acceptable Zone and Engine Speed is Greater than Rated Speed. This would be an indication that the load placed on the engines is not great enough to cause the engines to require a high enough rate of fuel.



Marine Engine Loading

Overloaded conditions can be caused by hull fouling, damaged or bent rudders, incorrect propeller size, pitch and/or diameter, etc. This vessel deterioration can cause a higher load placed on the engine(s) causing higher fuel consumption and slower engine speed at wide-open throttle. This load placed on the engine(s) must be reduced to reduce the fuel consumption and regain acceptable engine speed.

CAMPAR Graph generated using the Manual input method on Mechanically governed engines.



Marine Engine and Transmission Performance Guidelines

Note: Refer to the Technical Marketing Information – Marine Sea Trial

Engine Air System:
Inlet Air Temp @ Air Cleaner....................................120° F/49° C Max.
Engine Room Temperature ....20° F/6.6° C above ambient air temp.
Inlet Air Restriction............................15 in. H_2O/4 kPa (new filter) Max.
25 in. H_2O/6.23 kPa (dirty filter) Max.

Engine Room Depression ....1/2 in. H_2O

Inlet Air Manifold Temp:
Naturally Aspirated, Turbocharged,
Turbocharged JWAC, Turbocharged SCAC 85° F,
Turbocharged SCAC 110° F............Refer to TMI "Test Spec" for Max.

Combined Cooling Circuit.......................................125° F/52° C Max.
3208 TA (425 hp)..140° F/60° C Max.

Engine Aftercooler System:
Aftercooler Inlet H_2O Temp:
Turbocharged JWAC ....210° F – ▲T*° F/99° C – ▲T*° C Max.
Turbocharged SCAC 90° F/**C..............................90° F/29° C Max.
Turbocharged SCAC 110° F/**C..........................110° F/43° C Max.

Engine Jacket Water System:
JW Temp (From Cooler):
All except 3208 TA ....210° F – ▲T*° F/99° C – ▲T*° C Max.
3208 TA ....215° F – ▲T*° F/102° C – ▲T*° C Max.

JW Outlet Temp (Before Reg.):
All except 3208 TA ....210° F/99° C Max.
3208 TA ....215° F/102° C Max.

JW Temp (After Water Pump):
All except 3208 TA ....195° F – ▲T*° F/90° C – ▲T*° C Max.
3208 TA ....200° F – ▲T*° F/93° C – ▲T*° C Max.

Engine Lubrication System:
Oil Temperature To Bearings:
3200 ....240° F/116° C Max.
3116, 3126, C9, 3176, 3196, 3300,
C12, 3400, C18, C30, C32, 3500.......................239° F/115° C Max.
D300 ....220° F/104° C Max.

Oil to Bearing Pressure:
3200 .... 50 psi/345 kPa Min.
3300 .... 30 psi/207 kPa Min.
D300, 3176, 3196, C12, 3400,
C18, C30, C32, 3500 .... 40 psi/276 kPa Min.
3116, 3126, 3126B, C9 .... 36 psi/250 kPa Min.

Engine Fuel System:
Fuel Transfer Pump Pressure:
All except 3500 .... Refer to TMI "Test Spec" for Min.
3500 .... 55 psi/379 kPa Min.

Engine Exhaust Backpressure:
Exhaust Backpressure:
Naturally Aspirated .... 34 in. H_2O/8.5 kPa Max.
A, B and C rated .... 27 in. H_2O/6.7 kPa Max.
D and E rated
(All models except 3500 & 3600) .... 40 in. H_2O/9.9 kPa Max.

Note: Reference "https://engines.cat.com/infocast/frames/marine/salesinfo/ratings/" for Rating Definition.

*▲ in °F/°C is the engine jacket water temperature differential. The actual ▲T (°F/°C) is the difference between the jacket water temperature after the water pump and the jacket water temperature at the outlet before the regulator(s). Determine the maximum jacket water temperature differential by dividing the jacket water heat rejection by the product of the minimum jacket water pump flow and the specific weight of the cooling water.

Engine Crankcase Pressure:
Crankcase Pressure:
All except 3208 .... 2 in. H_2O/0.5 kPa Max.
3208 .... 4 in. H_2O/1.0 kPa Max.

Transmission Lubrication System:
Transmission Oil Temp: Twin Disc
5050 .... 210° F/99° C Max.
502, 506, 507, 509, 514C, 521 .... 200° F/93° C Max.
514, 514M .... 180° F/82° C Max.

Transmission Minimum Oil Pressure: Twin Disc
502, 506, 507 .... 300 psi/2067 kPa Min.
514, 514C, 514M .... 185 psi/1275 kPa Min.
521 .... 210 psi/1447 kPa Min.
509 .... 175 psi/1206 kPa Min.
5050 .... 320 psi/2205 kPa Min.

Transmission Maximum Oil Pressure: Twin Disc

5050 .... 350 psi/2412 kPa Max.
502 .... 350 psi/2412 kPa Max.
506, 507 .... 320 psi/2205 kPa Max.
509 .... 200 psi/1378 kPa Max.
514, 514C, 514M .... 222 psi/1530 kPa Max.
521 .... 290 psi/1998 kPa Max.
506 w/3208 DIT 300 bhp
@2800 rpm Engine .... 370 psi/2549 kPa Max.

Transmission Oil Temp: 7200 Series

7211, 7221, 7231, 7271 .... 200° F/93° C Max.
7241, 7251, 7261 .... 175° F/79° C Max.

Transmission Minimum Oil Pressure: 7200 Series

7211, 7221, 7231, 7241 .... 255 psi/1757 kPa Min.
7251 .... 245 psi/1688 kPa Min.
7261 .... 265 psi/1826 kPa Min.
7271 .... 290 psi/1998 kPa Min.

Transmission Maximum Oil Pressure: 7200 Series

7211, 7221, 7231, 7241, 7261 .... 285 psi/1964 kPa Max.
7251 .... 275 psi/1895 kPa Max.
7271 .... 310 psi/2136 kPa Max.

Transmission Oil Temp: Reintjes/Caterpillar (Sea Water Cooled):

LAF, VAL, WAF, WAV, WVS .... 185° F/85° C Max.
WAF-LAP (Jacket Water Cooled) .... 212° F/100° C Max.

Transmission Minimum Oil Pressure: Reintjes/Caterpillar

LAF, VAL, WAF, WAV, WVS .... 232 psi/1600 kPa Min.

Transmission Maximum Oil Pressure: Reintjes/Caterpillar

LAF, VAL, WAF, WAV, WVS .... 290 psi/2000 kPa Min.

Transmission Cooling System:

Transmission Cooler Inlet Water Temp: Twin Disc

All .... 195° F/91° C Max.

Transmission Cooler Inlet Water Temp: 7200 Series

7211, 7221, 7231 .... 195° F/91° C Max.
7241, 7251, 7261, 7271 .... 120° F/49° C Max.

Transmission Cooler Inlet Water Temp: Reintjes/Caterpillar (Sea Water Cooled)

LAF, VAL, WAF, WAV, WVS .... 120° F/49° C Max.
WAF-LAF Reintjes/Caterpillar
(Jacket Water Cooled) .... 200° F/93° C Max.

Cooling System Evaluation

Cooling System Evaluation

Introduction

During operation, all internal combustion engines create heat. The cooling system must remove enough of this heat to keep the engine at a correct operating temperature, but it must not remove too much heat which will cause the engine to run cold. In a marine application, the cooling system must also remove heat from additional sources such oil coolers, aftercoolers, marine gear oil coolers, watercooled exhaust manifolds, watercooled turbochargers and watercooled exhaust.

The cooling system has a direct affect on engine operation and service life. If the cooling system is not sized correctly, is poorly maintained, or is not operated correctly, the result can be either overheating or overcooling. Since these problems can cause a reduction of engine life, it is important to find the cause of any cooling system problems and correct them at the time of the sea trial.

For more detailed information on Caterpillar marine engine cooling systems, refer to the following Caterpillar publications.

- Marine Engines – *Application and Installation Guides*, LEKM7142–7147. The Cooling Systems section of this publication provides detailed information on all Caterpillar marine engine jacket water and aftercooler cooling system circuits, and their specific components. The publication also discusses the sizing of circuit heat exchangers, keel coolers, lines and expansion tanks, as well as recommended systems protection.
- *Know Your Cooling System*, form SEBD0518. This publication details the functions, operation, maintenance and troubleshooting of Caterpillar Engine cooling systems. In addition, this publication discusses the available Caterpillar service tools for use in cooling system troubleshooting and provides the recommended procedures for cooling system reconditioning.

Troubleshooting the Cooling System

Three basic problems that are typical of cooling systems are as follows:

- Overheating
- Loss of Coolant
- Overcooling

Types of Overheating

The most common cooling system problem is overheating. It can be divided into two types: 1) where there is a loss of coolant, either from leakage or overflow, and 2) where there is no loss of coolant. It is not safe to assume that coolant shortage is the cause of overheating merely because the coolant level is low. To determine whether loss of coolant is the cause of overheating, or if it is the result of overheating, any test must be started with the correct coolant level in the cooling system.

Loss of Coolant

External Leakage: External leakage can usually be found by carefully inspecting the exterior of the engine, cooling system, and all connections. Look for leaks caused by pressure when cooling system temperature is normal. Look for rust streaks or spots left by coolant that has evaporated. To find slow leaks, make the inspection when the engine is cold, before evaporation takes place. Common causes of external leakage are as follows:

- Faulty hose(s) and/or clamps.
- Water pump leakage, most often around the shaft, or at the backing plate. Water can leak through the external weep hole at the bottom of the water pump.
- Leaking drain cocks. This can be caused by corrosion, poor seating or improper tightening.
- Leaking gaskets.
- Core plug holes.
- Cracked water pump housing or water temperature regulator housing.
- Cracked cylinder head(s) or cylinder block.
- Water cooled manifolds.

Internal Leakage: If external coolant loss cannot be found, then internal leakage could be the cause of coolant loss. Symptoms of internal leakage are: corroded parts, coolant in the crankcase or cylinders, hard starting or poor engine performance. Internal leakage is a serious condition which could lead to engine or transmission damage. Common sources of internal leakage are:

- Cylinder head gasket leakage.
- Cracked cylinder head(s) or cylinder block.
- Faulty engine oil cooler or transmission oil coolers.
- Cylinder liner O-rings.
- Cylinder wall pitting.
- Water cooled manifold failures.
- Aftercooler failures.

No Loss of Coolant
When overheating occurs and no shortage of coolant is found, the cause could be poor coolant flow, air in the cooling system, or from any of several other conditions. Engine overheating may not be the fault of the cooling system alone. Typical conditions that can cause overheating when loss of coolant is not the problem are as follows:

- Poor coolant flow.
- Incorrect or faulty water temperature regulators.
- Damaged water pump.
- Corrosion and scale buildup may collect in small passages of the engine water jacket and the heat exchangers. This can reduce heat transfer and restrict coolant flow.

  Note: Incorrect type of coolant (coolant without a conditioner, corrosion inhibitor or anti-freeze) has a direct effect on the efficiency and/or service life of both the cooling system and the engine.
- Incorrect fuel timing, cylinder head valve timing, oil level, fuel setting and other similar adjustments may cause overheating.
- If the engine is operated abnormally for a considerable period of time, overheating may result. Abnormal operation includes operating in a lug condition and operation beyond design load limits.

Overcooling
It is important to control the temperature range of the coolant to maintain engine efficiency. Though overcooling is not as common as overheating, it can cause equally serious damage to an engine. Overcooling occurs when normal operation temperature for the engine cannot be reached. The most common causes of overcooling are:

- A water temperature regulator that is held open.
- A water temperature regulator O-ring seal that is damaged.
- The lack or absence of a water temperature regulator.
- A water temperature regulator with a temperature range that is too low.
- The counterbores in the water temperature regulator housing have a defect and permit coolant to flow past the regulator.
- Light loads and low ambient temperature may also prevent the engine from reaching normal operating temperature.

Overcooling of an engine can be just as much of a problem as operating the engine at higher than normal temperature. It can affect the ability of the crankcase ventilating system to remove blowby gas and water vapor from the crankcase during low temperature operation. Low coolant temperatures promote condensation of water vapor from blowby gas, causing acids and sludge to form within the crankcase. Overcooling can result in the following engine problems:

- Poor engine performance.
- High fuel consumption.
- Decreased power.
- Increased piston ring and liner wear.
- Water vapor in the oil, producing sludge and corrosive acid in the lubrication system.

Test Conditions for Full Throttle Specifications

The specifications and charts that follow give the operating conditions at Full Load Speed. Refer to *TMI Online* for more specific information.

Note: Sea trial measurements and the review form are based on the instrumentation and monitoring points given in the marine product dimension drawings. As previously discussed, a system of 900 Series numbers was established to represent each measurement. The marine propulsion and auxiliary engine general dimension drawings give the 900 Series number and indicate which monitor points to use for connection of diagnostic tools.

(930) Temperature at Air Cleaner
Engine room temperature should not exceed 120° F (49° C). A correctly designed engine room ventilation system will maintain engine room air temperature at no more than 20° F (11° C) above the ambient air temperature.

Note: Engine room temperature should be checked with hatches, doors and windows closed.

(907) Inlet Air Restriction
The maximum restriction for the complete air induction system measured after the air filters should not exceed 25 inches (6.23 kPa) of water (dirty filter).

Note: 1 psi (6.9 kPa) = 27.7 in. (701 mm) of water. With a completely new installation, this measurement should not exceed 15 inches (4 kPa) of water.

Note: For naturally aspirated engines, maximum inlet air flow occurs when the engine is operating at high idle. Measure for inlet air restriction of a naturally aspirated engine when the engine is operating at high idle speed. A turbocharged engine must be at full throttle and load speed when it is tested for inlet air restriction.

(903A) Aftercooler Water Outlet Temperature
Aftercooler water outlet temperature should not be greater than the inlet manifold air temperature, except for jacket water aftercooled engines where the maximum is 210° F (99° C).

(922) Jacket Water Inlet Temperature (From Cooler)
Jacket water inlet temperature from the cooler is 210° F (99° C) – ▲T maximum. For 3208 T/A Pleasure Craft Engines, this temperature is 215° F (102° C) – ▲T.

(901) Jacket Water Outlet Temperature (Before Regulator)
Jacket water outlet temperature before the water temperature regulator is 210° F (99° C) maximum. For 3208 T/A Pleasure Craft Engines, this temperature is 215° F (102° C).

(902) Water Temperature (After Water Pump)
Jacket water temperature after the water pump is 210° F (99° C) – ▲T maximum. For 3208 T/A Pleasure Craft Engines, this temperature is 215° F (102° C) – ▲T.

(913) Engine Oil Temperature (After Oil Cooler)
Minimum oil temperature of 175° F (80° C). Maximum oil temperature of 230° F (110° C) except for 3208 Engines that have a maximum oil temperature of 240° F (115° C), and 6.25" bore engines that have a maximum oil temperature of 220° F (104° C).

Maximum oil to bearing temperature for 3600 engines is 208° F (92° C).

(906) Inlet Air Manifold Temperature

Type of Aspiration	Normal	Maximum	Temperature Difference**
Natural	85° F (29° C)	49° C (120° F)	
Turbocharged	300° F (149° C)	163° C (325° F)	
Turbocharged – Jacket Water Aftercooled	225° F (107° C)	118° C (245° F)	35° F ± ▲T
Turbocharged – Separate Circuit Aftercooled 85° F (29° C)		52° C (125° F) 60° C (140° F)	22° C (40° F)
3208 Pleasure Craft T/A Pleasure Craft		65° C (150° F)	30° C (55° F)
Turbocharged – Separate Circuit Aftercooled 110° F (43° C)			22° C (40° F)

*If temperature cannot be reduced below maximum, engine must be derated.

**Maximum difference in temperature between (906) Inlet Air Manifold Temperature and (903) Aftercooler Water Inlet Temperature.

(903) Aftercooler Water Inlet Temperature

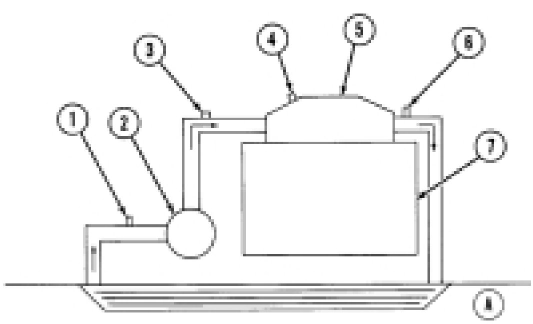
Type of Aftercooling	Maximum
Turbocharged – Jacket Water Aftercooled	210° F – ▲T (99° C – ▲T)
Turbocharged – Separate Circuit Aftercooled 85° F (29° C)	85° F (29° C)
Turbocharged – Separate Circuit Aftercooled 110° F (43° C)	110° F (43° C)
Turbocharged – Combined Circuit Aftercooled	125° F (52° C)

Cooling System Analysis

By comparing various temperatures in a system or circuit, problem areas can be identified. Overheating or overcooling of an engine can be caused by engine components outside the cooling system. Troubleshooting for correction of cooling system problems should not be confined strictly to that system only, but should be directed toward all possible causes. In each circuit, temperature differences are used to identify potential problems. When a problem is indicated, the circuit is probed with pressure gauges to locate the cause of the problem.

The cooling system analysis will address the aftercooler circuit and jacket water-cooling circuit separately.

Aftercooler Circuit Analysis Locations



A-Sea Water Temperature

1-903: Aftercooler Water Inlet Temperature
920: Water Pump Inlet Pressure (psi)

2-Water Pump

3-923: Aftercooler Water Inlet Pressure (psi)

4-906: Inlet Air Manifold Temperature

5-Aftercooler

6-903A: Aftercooler Water Outlet Temperature
924: Aftercooler Water Outlet Pressure (psi)

7-Engine

Temperature Differentials

Temperature differentials can be used to identify the cause of a problem if a test reading is above the full load specification. The analysis of aftercooler circuits will be addressed to three sections:

- Inlet Manifold Air-to-Aftercooler Inlet Water Temperature Differential
- Aftercooler Water Inlet Temperature-to-Aftercooler Water Outlet Temperature Differential
- Aftercooler Water Inlet Temperature-to-Sea Water Temperature Differential

Inlet Manifold Air-to-Aftercooler Inlet Water Temperature Differential
The first temperature differential to be determined is the inlet manifold air temperature-to-aftercooler inlet water temperature. Subtract Aftercooler Inlet Water Temperature (903) from Inlet Manifold Air Temperature (906).

Note: All temperatures should be taken at the same time.

Aftercooler Water Inlet to Inlet Manifold Air Temperature

	85 A/C	110 A/C
906 Actual = ________	Spec. 906 = 125° F (52° C)	Spec. 906 = 150° F (66° C)
– 903 Actual = ________	– Spec. 903 = 85° F (29° C)	– Spec. 903 = 110° F (43° C)
Actual Delta T =	Spec. Delta T = 40° F (22° C)	Spec. Delta T = 40° F (22° C)

3208 PLEASURE CRAFT RATING	JACKET WATER AFTERCOOLED MODELS
Spec. 906 = 140° F (60° C)	Spec. 906 = 245° F (118° C)
– Spec. 903 = 85° F (29° C)	– Spec. 903 = 210° F (99° C) – Engine Delta T
Spec. Delta T = 55° F (31° C)	Spec. Delta T = Varies with Model

If the temperature difference exceeds the maximum specification, the aftercooler circuit temperature and pressure differential test is required to identify the problem.

Aftercooler Water Inlet Temperature-to-Aftercooler Water Outlet Temperature Differential
Subtract Aftercooler Water Inlet Temperature (903), from Aftercooler Water Outlet Temperature (903A)

	85 A/C
903A Actual = ________	Spec. 903A = 95° to 100° F (35° to 38° C)
– 903 Actual = ________	– Spec. 903 = 85° F (29° C)
Actual Delta T =	Spec. Delta T = 10° to 15° F (6° to 8° C)

110 A/C	JACKET WATER A/C SYSTEM
Spec. 903A = 120° to 125° F (48° to 52° C)	Spec. 903A = 210° F (99° C)
– Spec. 903 = 110° F (43° C)	– Spec. 903 = 210° F (99° C) – Engine Delta T
Spec. Delta T = 10° to 15° F (6° to 8° C)	Spec. Delta T = Varies with Model

If the temperature difference is high, a low coolant flow rate is indicated. This will result in high inlet air temperature. Pressure differential tests are required to determine the cause of flow restriction.

If the temperature difference is low, an insulating coating on the aftercooler core, water side or air side, is indicated. This is an indication the aftercooler is not operating correctly. Remove and inspect the aftercooler.

If the temperature difference is correct, the engine aftercooler is operating correctly. However, if (906) Inlet Manifold Air Temperature and (903) Aftercooler Inlet Water Temperature are above specifications, water pressure differential tests are required.

Aftercooler Water Inlet Temperature-to-Sea Water Temperature Differential

Ambient sea water temperature should be measured at the location where the PAR test is conducted, and at the same depth as the sea water inlet or the keel coolers.

To determine the capacity of the heat exchanger, subtract the actual sea water temperature from the Aftercooler Inlet Water Temperature (903).

NOTICE

Operation in areas where the aftercooler water inlet temperature can exceed the engine rating temperature will require deration of the engine.

---

903 Actual = ____________
– Actual Sea Water = ____________
Actual Delta T =

85 A/C
SPEC. 903 = 95° to 100° F
– SPEC. Sea Water Max. = 85° F
Maximum Delta T = 10° F to 15° F

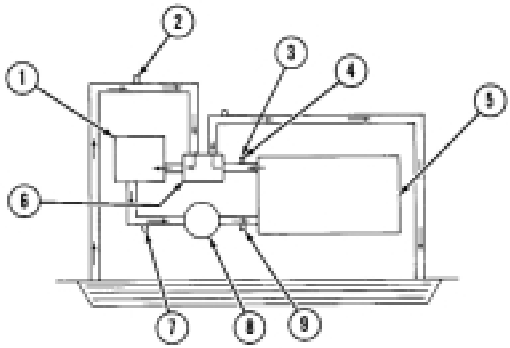
110 A/C
SPEC. 903 = 120° to 125° F
– SPEC. Sea Water Max. = 110° F
Maximum Delta T = 10° F to 15° F

If the temperature difference is above maximum specification, the heat exchanger/keel cooler capacity is too small, has a low coolant flow rate, seaweed or barnacles blocking the cooler inlet, or there is an insulating coating on internal or external surfaces.

To determine the maximum sea water temperature allowable, if temperature differential is less than maximum and inlet manifold air temperature is less than maximum specification, subtract Aftercooler Water Inlet Temperature (903) reading from the specification temperature. Add this value to the sea water temperature. This temperature would be the maximum allowable sea water temperature in which the vessel should operate, without derating the engine.

The aftercooler circuit is operating correctly if the three temperatures, differentials, and all other aftercooler temperatures are within specifications.

Jacket Water Circuit



1-Expansion Tank

2-991: Jacket Water psi (kPa) from Cooling System
992: Jacket Water Temperature from Cooling System

3-918: Jacket Water Outlet Pressure Test Location

4-901: Jacket Water Outlet Temperature

5-Engine

6-Water Temperature Regulator Housing

7-902: Jacket Water Pump Inlet Pressure

8-Water Pump

9-919: Jacket Water Pump Outlet Pressure
902: Jacket Water Pump Outlet Temperature

Temperature Differential

Jacket Water Pump Outlet Temperature-to-Jacket Water Outlet Temperature (Before Regulator Difference)

Determine the engine jacket water temperature differential by subtracting the jacket water temperature after the pump from the jacket water temperature at the outlet before the regulator(s).

Jacket Water Delta T
901 Actual = ____________________
– 902 Actual = ____________________
Actual Delta T = Varies with Engine Rating

3208 Engines Only
901 Spec. = 215° F (102° C)
– 902 Spec. = 215° F – Δ T (varies with engine rating)
Spec. Delta T = Varies with Engine Rating

All Engines (Except 3208)
901 Spec. = 210° F (99° C)
– 902 Spec. = 215° F – Δ T (varies with engine rating)
Spec. Delta T = Varies with Engine Rating

$$\blacktriangle T = \frac{\text{Heat Rejection to Coolant Total}}{(\text{Jacket Water Pump Flow})\ (8.1)}$$

902 = 210° F (98° C) – ▲T

Where Heat Rejection is in BTU/Min
Pump Flow is in Gallons per Minute

Maximum Sea Water Temperature Calculation Max Sea Water Temperature = 901 spec – 901 actual + (902 actual – 922 actual)/2 + Sea Water temperature actual. Example: 901 actual = 200° F, 902 actual = 190° F, 922 actual = 180° F, SW actual = 75° F. Then Max Sea Water Temperature = 210° F – 200° F + (190° F – 180° F)/2 + 75° F. So Max Sea Water Temperature = 90° F.

Note: If 901 actual exceeds 901 spec then the engine is currently overheating. The above equation can still be used to calculate the maximum acceptable sea water temperature. Keep in mind, that if the engine cooling system is outlet regulated, when 901 actual exceeds the stat full open temperature, 902 actual should be equal to 922 actual or if the engine cooling system is inlet regulated, when 902 actual exceeds the stat full open temperature, 902 actual should be equal to 922 actual, in either case if 902 actual is still greater than 922 actual, then (in both cases) a flow problem exists in the temperature regulator housing that is compromising heat exchanger water flow. This Maximum Sea Water calculation is based on the existing PAR test conditions, the biggest factor affecting heat exchanger performance is JW flow to the cooler. In cold sea water, the thermostats restrict JW flow to lower heat exchanger capacity. This calculation cannot account for this temporary reduction in capacity. So the engine could possibly operate in even warmer sea water as additional flow is allowed to flow to the heat exchanger.

Ventilation System

	930 Actual	= ______________
–	Actual Ambient	= ______________
	Maximum Delta T	= 15° F (8° C)

Maximum Air Temperature at the Air Cleaner

	930 Spec.	= 120° F (49° C)
–	930 Actual	= Varies with Installation
		= Delta T 2

	Actual Ambient	= Varies with Climate
+	Delta T 2	
	Maximum Ambient Air Capability	

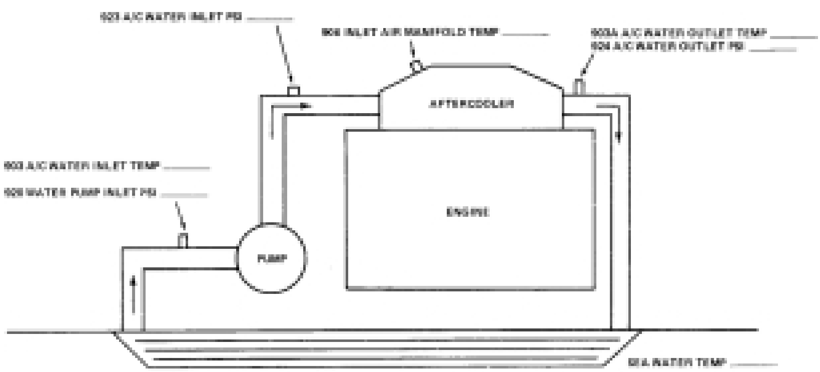
Engine Jacket Water Outlet Temperature to Oil to Bearings Delta T

913 Actual = ______________________
– 901 Actual = ______________________
Delta T 3 = Varies with Engine Family*

Maximum Delta T 3 Spec. for Engine Families
30° F (17° C) = 3208, 3176
25° F (14° C) = 3116, 3126
20° F (11° C) = 3300, 3400, 3500
10° F (6° C) = 6.25" Bore

(Fuel Burn Rate) (Fuel Density)
Brake Horsepower = Brake Specific Fuel Consumption

Worksheet – Aftercooler Circuit



Temperature
903 A/C Water Inlet ____ °F (°C)

906 Inlet Air Manifold ____ °F (°C)

903A A/C Water Outlet ____ °F (°C)

Sea Water ____ °F (°C)

Pressure
920 Water Pump Inlet _________ psi (kPa)

923 A/C Water Inlet _________ psi (kPa)

924 A/C Water Outlet _________ psi (kPa)

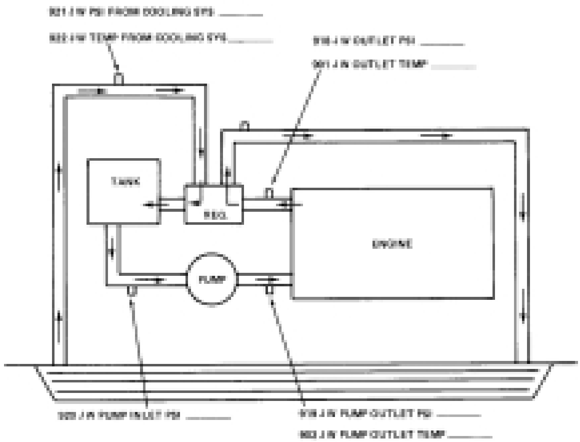
Temperature Difference (SCAC Only)

906	________	°F (°C)
Subtract 903	________	°F (°C)
Temp. Diff. I	________	°F (40° F Max) [°C (22° C Max)]
903A	________	°F (°C)
Subtract 903	________	°F (°C)
Temp. Diff. II	________	°F (40° F Max) [°C (5.6 to 8.4° C Max)]
903	________	°F (°C)
Actual Sea Water	________	°F (°C)
Temp. Diff. III	________	°F (15° F Max) [°C (8.4° C)]

Pressure Difference

923	________	psi (kPa)
Subtract 920	________	psi (kPa)
Pump Diff.	________	psi (kPa)
	________	psi (kPa)
Subtract 924	________	psi (kPa)
A/C Diff.	________	psi (kPa)
	________	psi (kPa)
Subtract 920	________	psi (kPa)
Heat Exchanger Diff.	________	psi (kPa)

Worksheet – Jacket Water Circuit



Temperature

902 JW Pump Outlet (Engine Inlet) ____°F (°C)

901 JW Outlet (Engine Outlet) ____°F (°C)

922 JW from Cooling System (to tank) ____°F (°C)

Sea Water ____°F (°C)

921 JW from Cooling System (to tank) _______ psi (kPa)

Temperature Difference (SCAC Only)

901 __________°F (°C)

Subtract 902 __________°F (°C)

Eng. Temp. Diff. I __________°F (°C)

922 __________°F (°C)

Subtract Sea Water __________°F (°C)

Heat Exchanger Temp. Diff. II __________°F (110° F Max)
[°C (61° C Max)]

Pressure

920 JW Pump Inlet _______ psi (kPa)

919 JW Pump Outlet _______ psi (kPa)

918 JW Outlet (Engine Outlet) _______ psi (kPa)

Pressure Difference

919	________	psi (kPa)
Subtract 920	________	psi (kPa)
Pump Diff.	________	psi (kPa)
919	________	psi (kPa)
Subtract 918	________	psi (kPa)
Engine Diff.	________	psi (kPa)
918	________	psi (kPa)
Subtract 920	________	psi (kPa)
Heat Exchanger Diff.	________	psi (kPa)

Explanation of the TMI Sea Trial TMI Data

Introduction

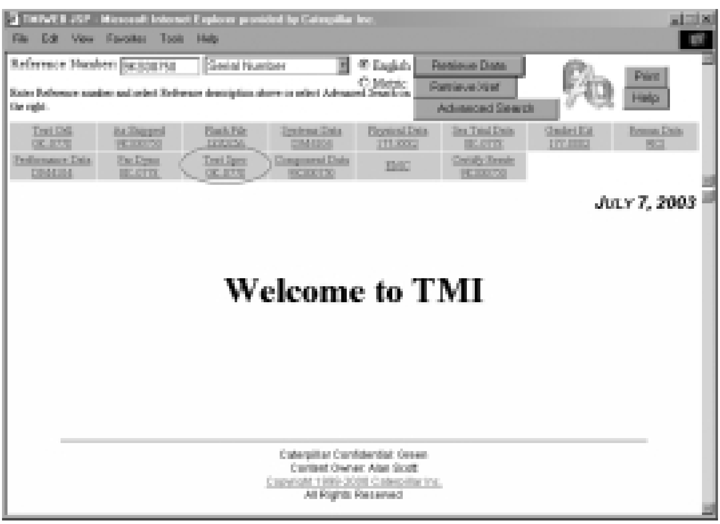
The on-line *Technical Marketing Information (TMI)* contains performance data for most current marine propulsion engines, marine auxiliary engines and marine transmissions. TMI contains applicable performance specifications that will enable the Caterpillar Marine Analyst to conduct a Sea Trial Performance Analysis Review.

Explanation

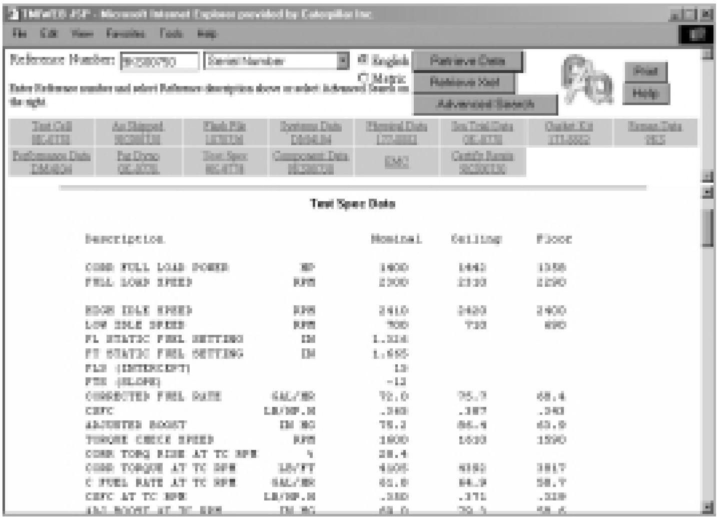
Each engine/transmission has sea trial performance information located on the web at:
http://tmiweb.cat.com/tmi/servlet/cat.edis.tmiweb.tmihome.TMIHomeServlet.

Once at the TMI Home screen, in the left-hand column of the screen are application selections. Marine engine data is found in the “Engine/Parts Data” portion of TMI Web. Below is the main screen of the “Engine/Parts Data” page. The pertinent number (part, serial, flash file, or test spec) is entered in the Reference Number window and the appropriate field is chosen from the pull-down window. In this example, a 3412E engine with the serial of 9KS00750 was selected and the “Retrieve Data” button pressed.

TMI Web will return all the fields that are available for the particular engine serial number requested. The available fields are hypertext and when clicked will retrieve the data requested. For this example the "Test Spec 0K-0778 was selected:



TMIWeb will return the selected information. This data can either be viewed on the screen or printed by pressing the print button in the upper right corner of the screen.



Additional Information Sources

The following publications are available from Caterpillar Inc. Use the normal literature ordering procedure to obtain a copy of a specific publication.

Title	Publication Type	Form Number
Marine Application and Installation Guide	Book & EMC	LEKM9213
Installation Guides for Electronically Controlled Marine Engines	CD & EMC	LERV2315
Engine Technical Manual Vol. 1 & II	On-Line	EMC
Marine Analyst Service Handbook	Book	LEBV4830
Marine Analyst Book I	Book	LEGV0907
Machinery Vibration Measurements & Analysis	Book	LEBV3801

3600 Performance Analysis Rules of Thumb

Air Intake System:

Air Temp at Air Cleaner	120° F (49° C) Max.
Inlet Air Restriction	15 in-H_2O/5 in New Max.
Intake Manifold Air Temperature	150° F (65° C) Nominal 197° F (92° C) Alarm
Intake Manifold Air Pressure	Nominal Values in Perf Book Measure at part and full load
Crankcase Pressure/ Vacuum	–1 to +2 in-H_2O (–0.25 to +0.5 kPa) 2.5 in-H_2O (1 kPa) Alarm

Exhaust System:

Exhaust Stack Temperature	Nominal Temp in Perf Book 1022° F (550° C) Alarm
Individual Cyl Exhaust Port Temperature	122° F (50° C) Maximum Variation between Cyl
Exhaust Backpressure	10 in-H_2O (2.5 kPa) Max. 0.8% Loss in fuel economy (increase in BSFC) for each 10 in-H_2O above 10 in-H_2O

Lubrication System:

Engine Oil to Bearing Temperature	185° F (85° C) Nominal 197° F (92° C) Alarm
Engine Oil to Bearing Pressure	65 psi (450 kPa) Nominal 46 psi (320 kPa) Alarm
Oil Filter Pressure Differential	15 psi (100 kPa) Max.

Fuel System:

Fuel Pressure	62-80 psi (425-550 kPa)
Fuel Supply Temperature	*Distillate Fuel 85° F (29° C) Max. Desired 1% Power reduction for each 10° F (6° C) increase above 85° F (29° C) 150° F (65° C) Max. to prevent injector damage
Fuel Filter Pressure Differential	10 psi (70 kPa) Max.
Fuel Pump Inlet Restriction	–6 psi (–39 kPa) Max.
Fuel Return Line Restriction	51 psi (350 kPa) Max.

3600 Performance Analysis Rules of Thumb (cont.)

Cooling System:

Heat Exchanger System External Resistance
(Combined & Separate Circuit)
— Measure at engine outlet and compare to heat exchanger outlet (before regulators)
— Temperature Regulators 100% OPEN (blocked)
SPECS:

1000 RPM	13 psi (90 kPa)
900 RPM	11 psi (73 kPa)
720 RPM	7 psi (47 kPa)

Aftercooler Water Inlet
Temperature . . . . 122° F (50° C) Nominal
*150° F (65° C) Max. under certain special conditions

Aftercooler Water Outlet
Temperature . . . . 122° F (50° C) + Delta T

Oil Cooler Water Inlet
Temperature . . . . 122° F (50° C) Nominal
*150° F (65° C) Max. under certain special conditions

Oil Cooler Water Outlet
Temperature . . . . 122° F (50° C) + Delta T

Jacket Water Pump Inlet
Temperature . . . . 185° F (85° C) Nominal

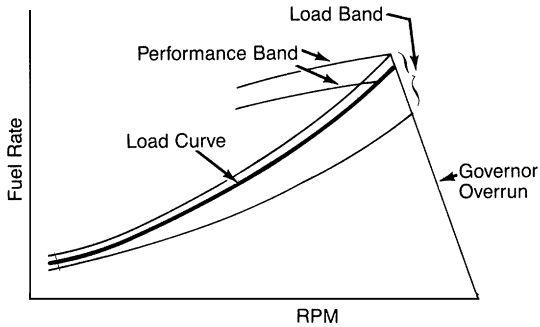
Jacket Water Block Outlet
Temperature . . . . 185° F (85° C) + Delta T

A/C & O/C Water Pump
Inlet Pressure . . . . –20 in-H_2O (–5 kPa) Min.

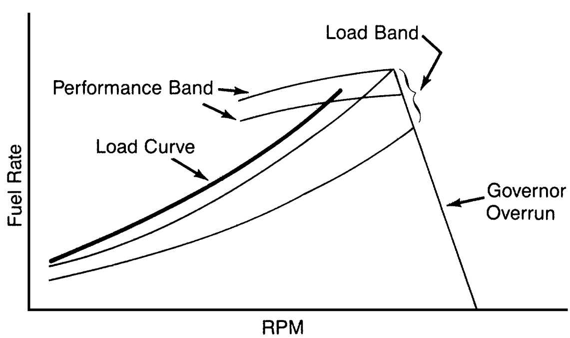
Jacket Water Pump Inlet
Pressure. 5 psi (30 kPa) Min.

Analysis of P.A.R. Fuel Rate Curves

Normal Test
Shaft Load and Fuel Rate Correct

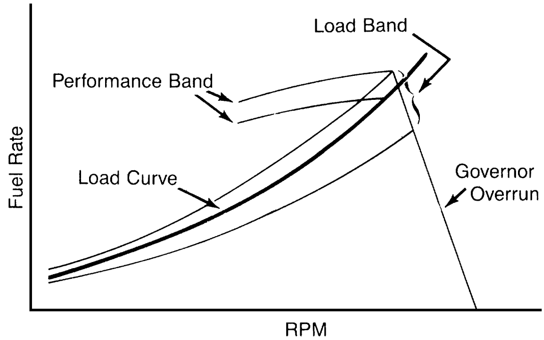


Normal Test
Shaft Load High, Fuel Rate Correct

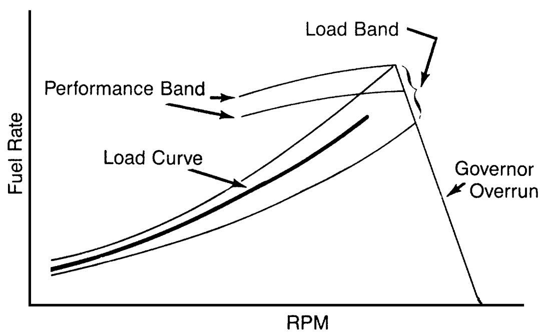


Charts are for illustrative purposes only.

Normal Test
Shaft Load Correct, Fuel Rate High

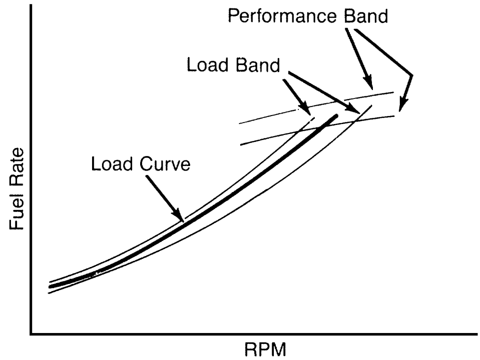


Normal Test
Shaft Load Correct, Fuel Rate Low

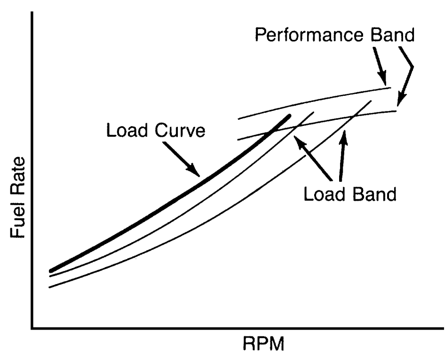


Charts are for illustrative purposes only.

Bollard Test
Shaft Load and Fuel Rate Correct

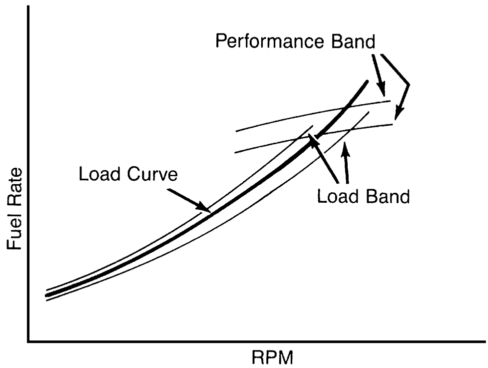


Bollard Test
Shaft Load High, Fuel Rate Correct

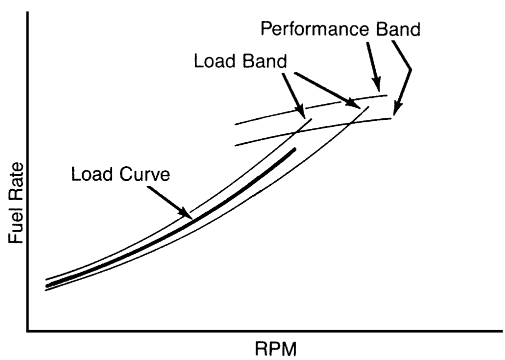


Charts are for illustrative purposes only.

Bollard Test
Shaft Load Correct, Fuel Rate High

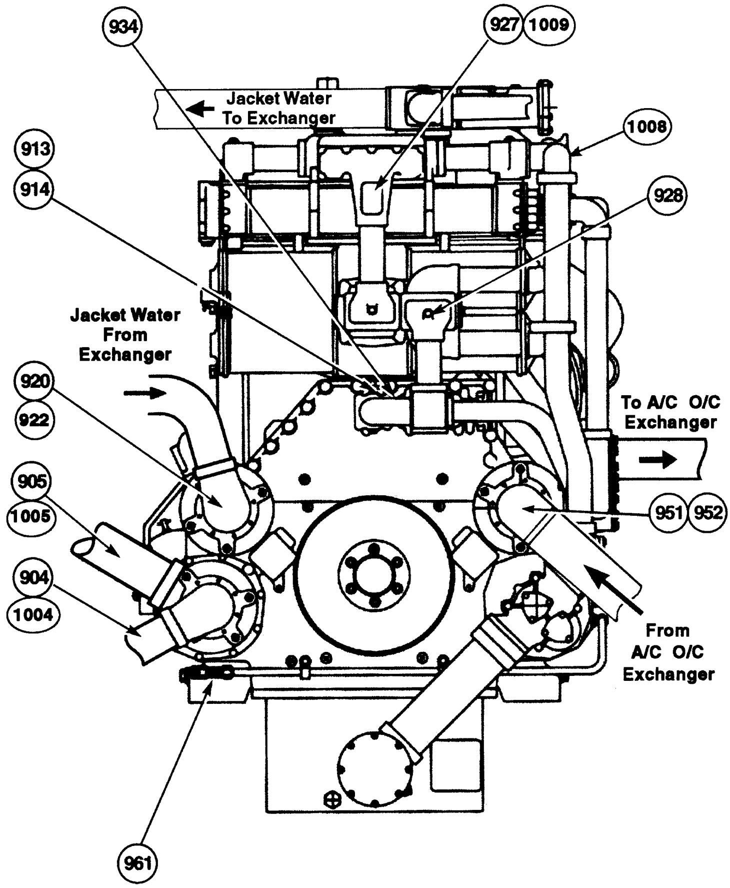


Bollard Test
Shaft Load Correct, Fuel Rate Low



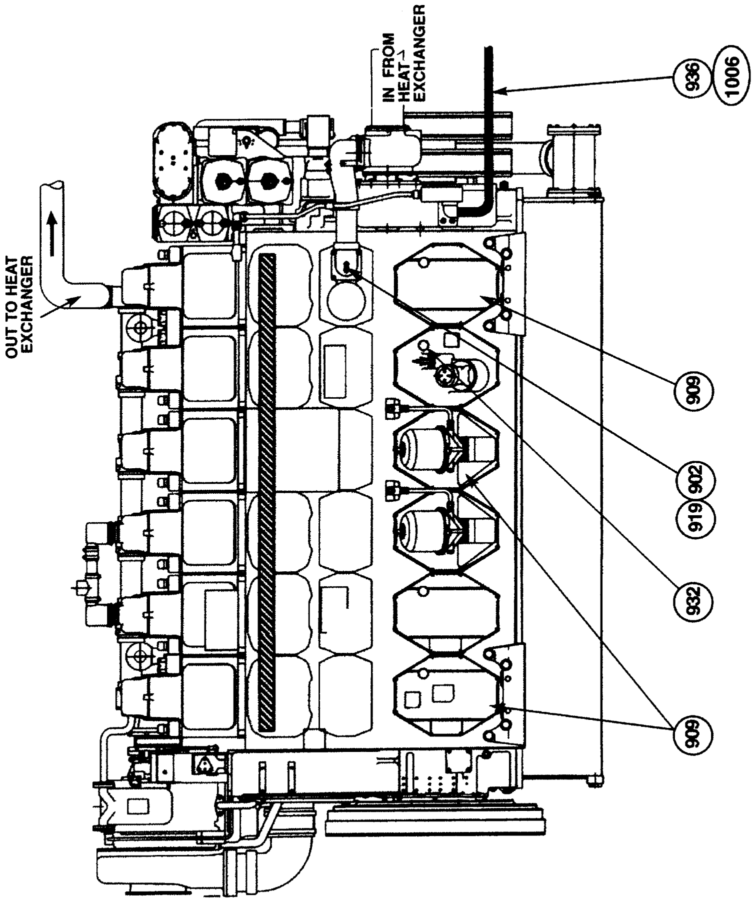
Charts are for illustrative purposes only.

900 Number Test Locations for 3600 Inline Separate Circuit



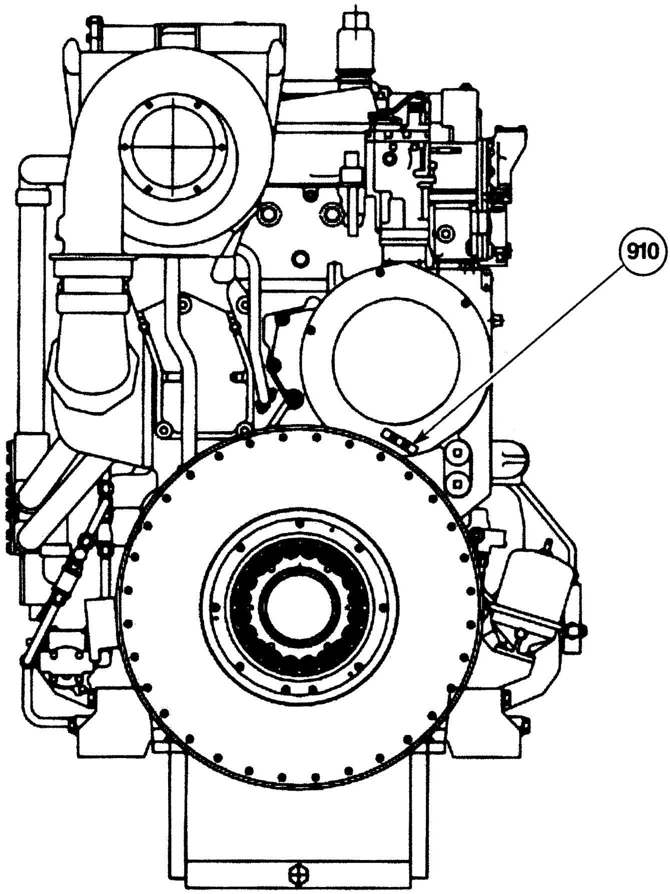
Front View

900 Number Test Locations for 3600 Inline Separate Circuit



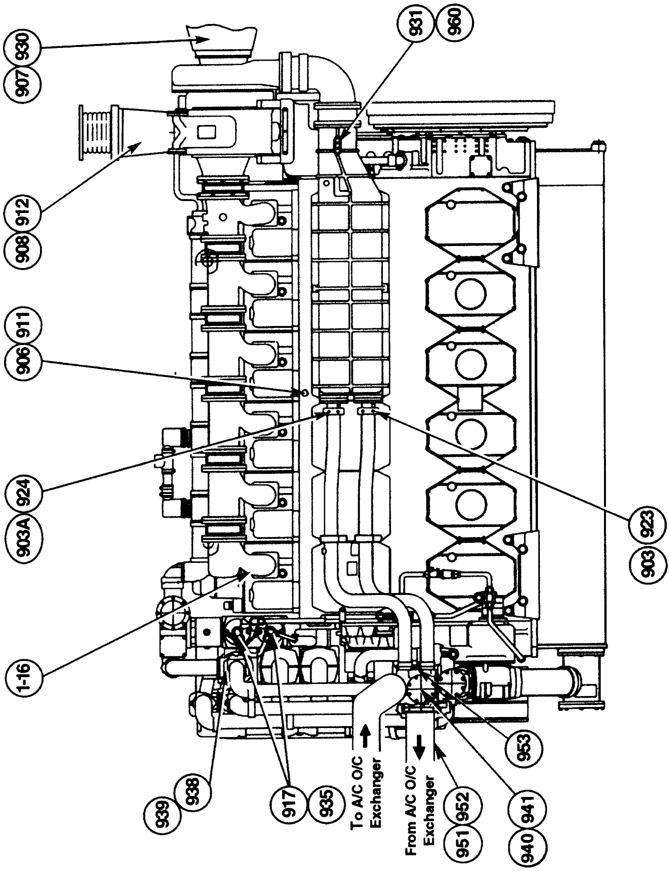
Right Side View

900 Number Test Locations for 3600 Inline Separate Circuit



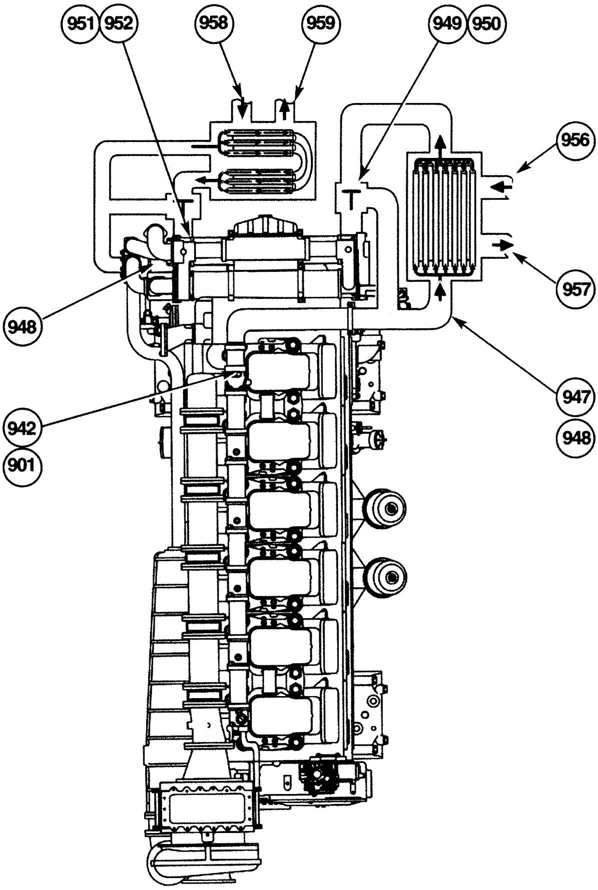
Rear View

900 Number Test Locations for 3600 Inline Separate Circuit



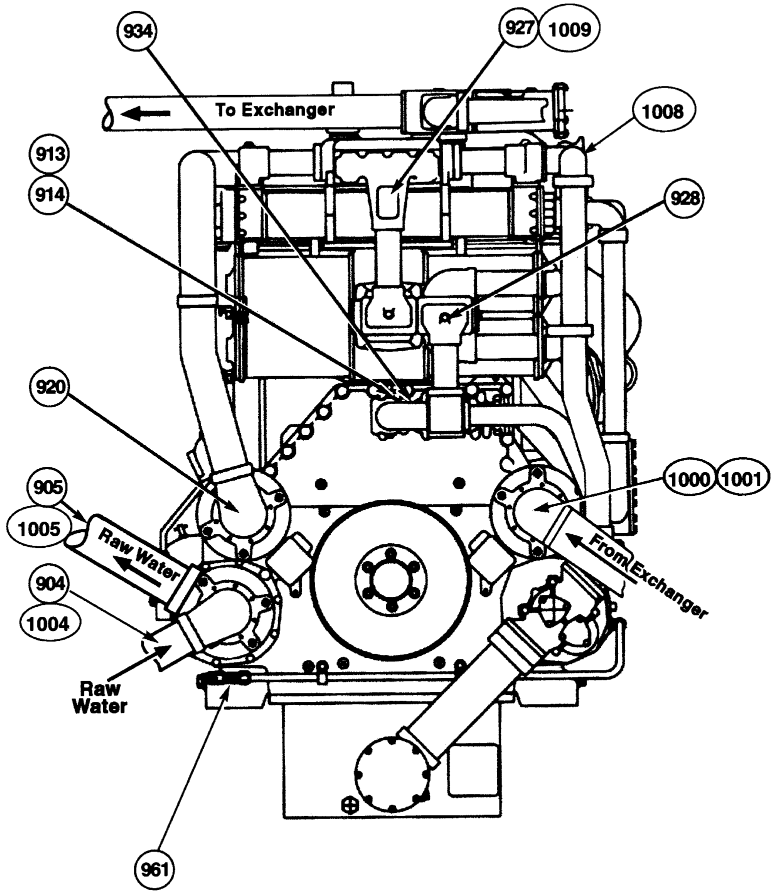
Left Side View

900 Number Test Locations for 3600 Inline Separate Circuit



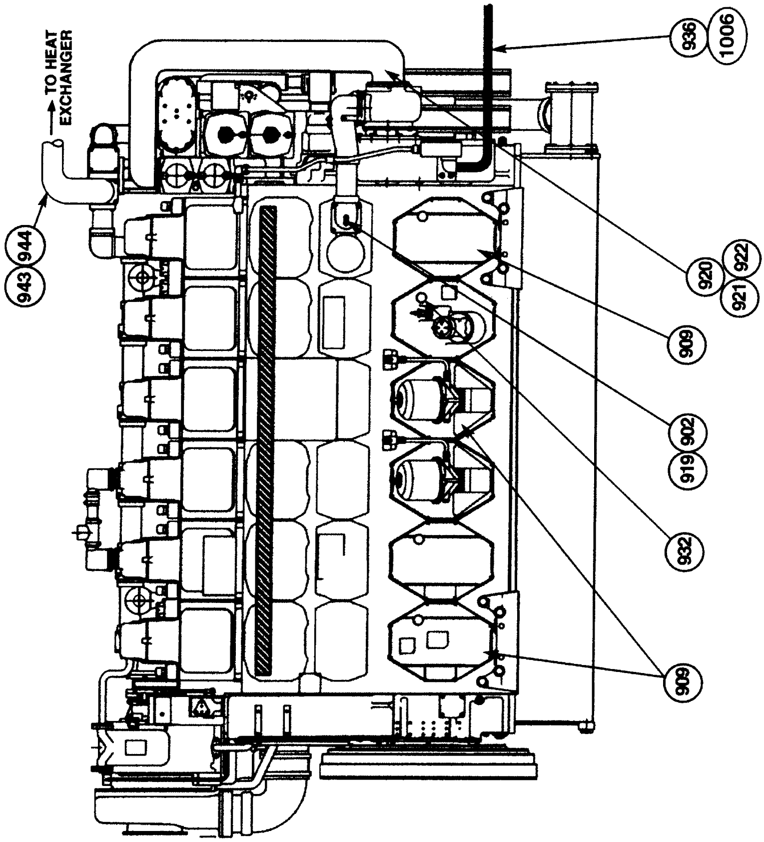
Top View

900 Number Test Locations for 3600 Inline Combined Circuit



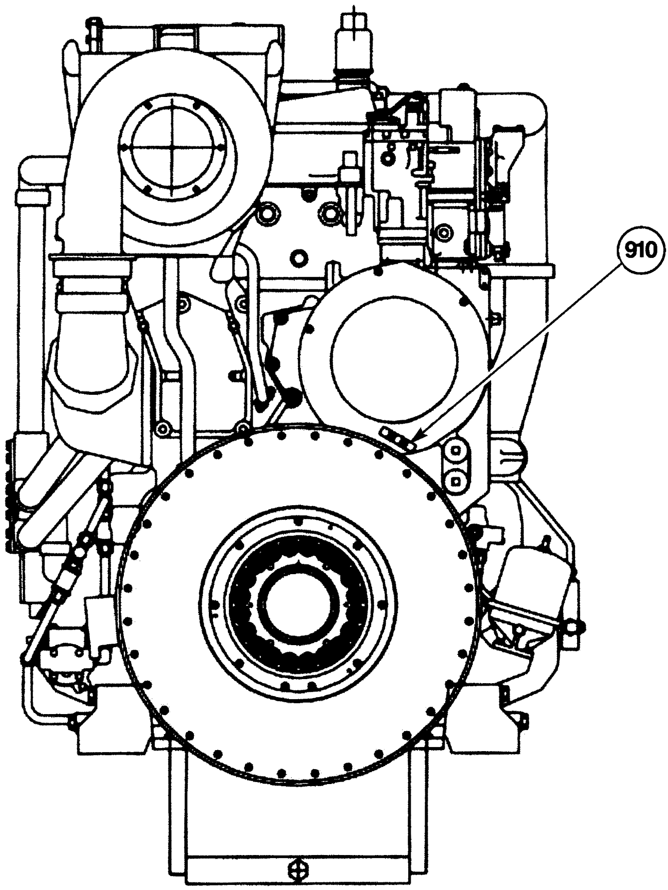
Front View

900 Number Test Locations for 3600 Inline Combined Circuit



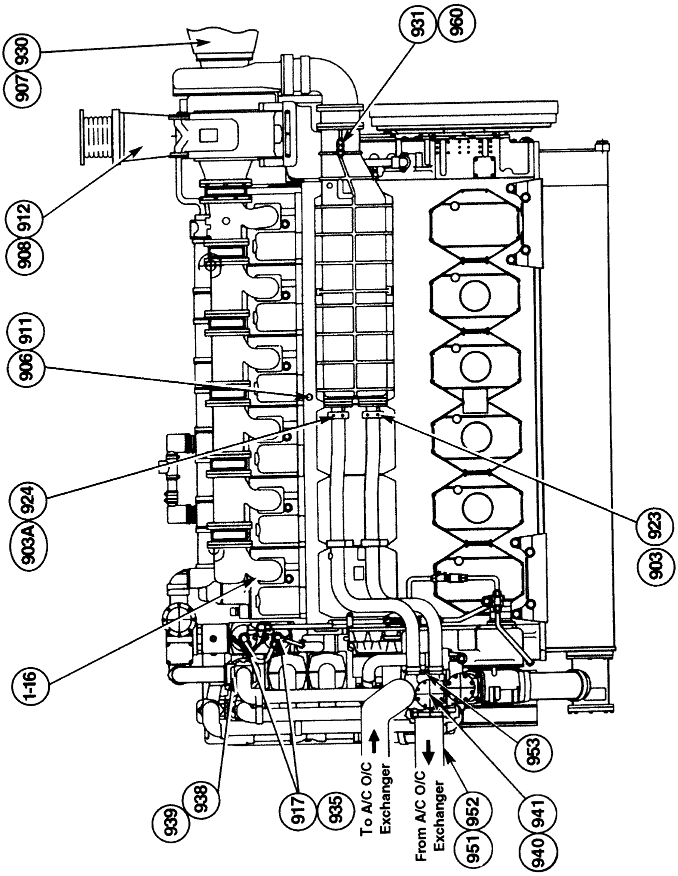
Right Side View

900 Number Test Locations for 3600 Inline Combined Circuit



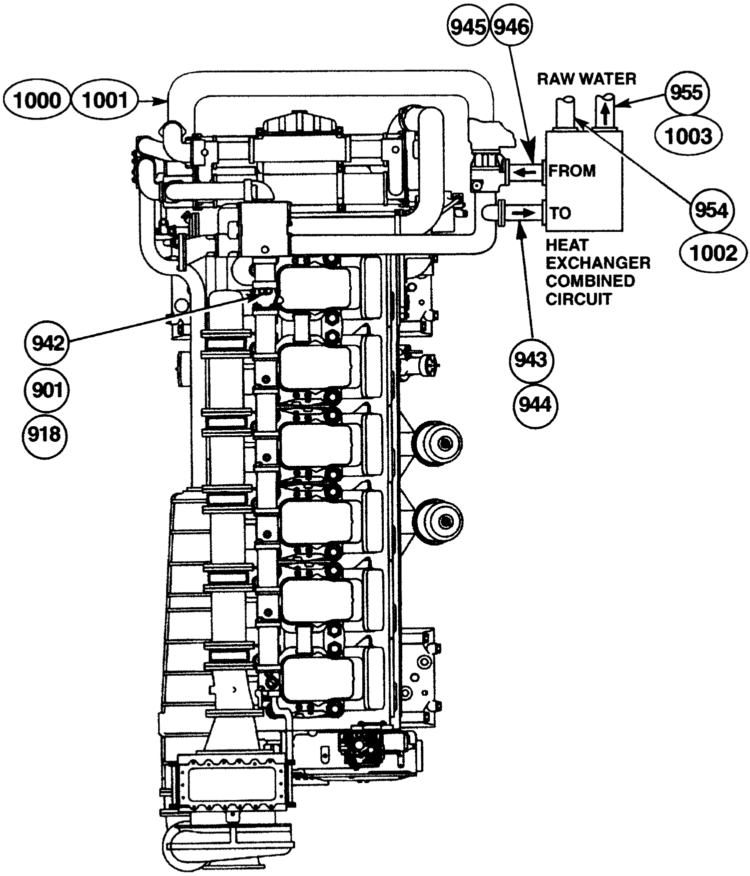
Rear View

900 Number Test Locations for 3600 Inline Combined Circuit



Left Side View

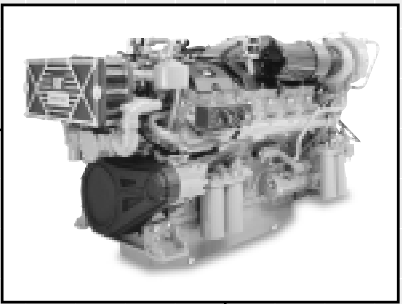
900 Number Test Locations for 3600 Inline Combined Circuit



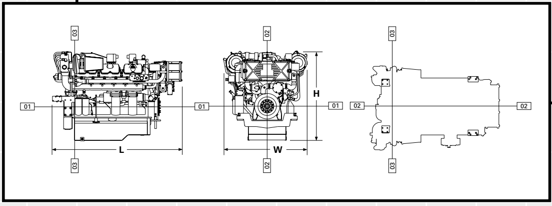
Top View

Design & Construction

REVIEW FORM



CATERPILLAR
MARINE
PROPULSION
ENGINES



CATERPILLAR®

Introduction

A well-planned design will aid reliability, performance, and serviceability. To be successful, the designer must be aware of the application and installation requirements for Caterpillar Marine Products. As a first step in this part of the operation, make the designer aware of Caterpillar reference publications, such as the *Marine Engine Application & Installation Guides*, LEKM7142-7147, Installation Guides for Electronically Controlled Marine Engines, RENR2315, which includes the following Electronic Installation Guides:

3126B, C9, C12 & C18	REHS1187
3176B	SENR6489
3176C, 3196 & 3406	SENR1187
3400C (PEEC)	
3JK1-171&8RG1-115	SENR6422
3JK172-up & 8RG116-up	SENR6446
3412E, C30 & C32	SENR5014
3500B	LEBM7301
Marine Engine Electronic Displays	SENR5002

and any other information that is available from Caterpillar.

The engine and transmission installation should be designed to give efficient and reliable operation. A poorly designed installation can hinder serviceability and make routine maintenance and in-hull repairs difficult. The neglect of specific design requirements for mounting and alignment, and support systems, can lead to poor performance and increased cost of operation.

In the event of OEM multiple (batch) production of vessels, it is extremely important to make the designer/builder aware of Caterpillar application and installation requirements. Any discrepancies must be discussed and corrected at this time to assure the integrity and compliance of the OEM design.

When the designer has completed a review of the Caterpillar application and installation requirements, discuss any concern he might have about specific areas of the design. This will establish a good working relationship in the design phase of the vessel. After the installation drawings for the vessel have been laid out, follow up with the designer to make sure the drawings meet the application and installation guide requirements. As an aid in the review of the design, use the *Design and Construction Review Form*, SEHS8716.

Explanation of Design and Construction Review Form

The *Design and Construction Review Form*, SEHS8716, is available from Caterpillar and provides a checklist for dealer use only. The form can be ordered using the normal literature order procedure.

This form is a simple checklist. It is used to determine if sufficient information has been provided to the designer so the layout will comply with Caterpillar reference requirements.

There is provision to record the Caterpillar reference materials provided to the designer, and a complete checklist for the results of the design and serviceability review. Compliance with Caterpillar reference requirements is noted by placing a check in the box next to the system reviewed. If the design affecting a specific system does not comply, there is space to record the action required to follow up and correct the problem area(s).

After the Design and Construction Review Form is completed, and any corrective action needed is agreed to, it is recommended that all parties concerned sign at the designated location on the form.

During the construction of the vessel, the design requirements will be checked to ensure the vessel will meet Caterpillar specifications for the installation. Any discrepancies of the design noted during the construction phase should be documented and discussed with the builder.

Design and Construction Review

Reference: *Caterpillar Marine Engines Application and Installation Guide and Electronic Installation Guide*

General

Selling Dealer____________________________ Vessel Builder ______________________________

Vessel Name (OEM Model) ____

Home Port_______________________________ Area of Operation ___________________________

Builder/Installer __________________________

Address ____

Type of Sale: Retail ☐ Wholesale ☐ Repetitive ☐ One Time Only ☐

Vessel Data

Hull Type: Displacement ☐ Semi-displacement ☐ Planing ☐

Length ___________ Waterline Length _______________ Beam ______________ Draft ____________

Displacement ____

Expected Hull Speed (Knots): Free Running _________________________

Vessel Type

Pleasure Craft: Cruiser ☐ Sportfish ☐ Yacht ☐ Sailboat ☐ Trawler ☐

Other:_______________________________________

Fishing: Trawler/Dragger ☐ Long Liner ☐ Gilnetter ☐ Trap Fishing ☐

Towboat: River ☐ Intercoastal ☐ Ocean ☐ Lower Mississippi ☐

Other:_______________________________________

Cargo: Bulk ☐ Container ☐ General ☐

Proposed Consist

Propulsion System

Propulsion Engine

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N ____

Major Attachments ____

Position in Vessel: Port ☐ Center ☐ Starboard ☐

(or) Engine 1 ☐ Engine 2 ☐ Engine 3 ☐ Engine 4 ☐ Engine 5 ☐

Marine Transmission

Manufacturer _______________________ Model _____________________

Arrangement(s) ____

Ratio: Forward __________________ Reverse ___________________ S/N __________________

Propeller

Fixed Pitch ☐ Controllable Pitch ☐ Surface Drive ☐ Jet Drive ☐

Manufacturer ____________________ Model __________________ Material _______________

Number of Blades ________________ Diameter ________________ Pitch __________________

Cup: Light ☐ Medium ☐ Heavy ☐ (or) 1-10 _______________

Propulsion Engine

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N ____

Major Attachments ____

Position in Vessel: Port ☐ Center ☐ Starboard ☐

(or) Engine 1 ☐ Engine 2 ☐ Engine 3 ☐ Engine 4 ☐ Engine 5 ☐

Marine Transmission

Manufacturer _______________________ Model _____________________

Arrangement(s) ____

Ratio: Forward __________________ Reverse ___________________ S/N __________________

Proposed Consist (cont.)

Propeller

Fixed Pitch ☐ Controllable Pitch ☐ Surface Drive ☐ Jet Drive ☐

Manufacturer ____________________ Model __________________ Material _______________

Number of Blades ________________ Diameter ________________ Pitch __________________

Cup: Light ☐ Medium ☐ Heavy ☐ (or) 1-10 _______________

Propulsion Engine

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N ____

Major Attachments ____

Position in Vessel: Port ☐ Center ☐ Starboard ☐

(or) Engine 1 ☐ Engine 2 ☐ Engine 3 ☐ Engine 4 ☐ Engine 5 ☐

Marine Transmission

Manufacturer _______________________ Model _____________________

Arrangement(s) ____

Ratio: Forward __________________ Reverse ___________________ S/N __________________

Propeller

Fixed Pitch ☐ Controllable Pitch ☐ Surface Drive ☐ Jet Drive ☐

Manufacturer ____________________ Model __________________ Material _______________

Number of Blades ________________ Diameter ________________ Pitch __________________

Cup: Light ☐ Medium ☐ Heavy ☐ (or) 1-10 _______________

Propulsion Engine

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N ____

Major Attachments ____

Position in Vessel: Port ☐ Center ☐ Starboard ☐

(or) Engine 1 ☐ Engine 2 ☐ Engine 3 ☐ Engine 4 ☐ Engine 5 ☐

Proposed Consist (cont.)

Marine Transmission

Manufacturer ______________________ Model ____________________

Arrangement(s) ____

Ratio: Forward _________________ Reverse __________________ S/N _________________

Propeller

Fixed Pitch ☐ Controllable Pitch ☐ Surface Drive ☐ Jet Drive ☐

Manufacturer ___________________ Model _________________ Material ______________

Number of Blades _______________ Diameter _______________ Pitch _________________

Cup: Light ☐ Medium ☐ Heavy ☐ (or) 1-10 ______________

Propulsion Engine

Model _____________ Rating _______ bhp bkW @ ___________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N ____

Major Attachments ____

Position in Vessel: Port ☐ Center ☐ Starboard ☐

(or) Engine 1 ☐ Engine 2 ☐ Engine 3 ☐ Engine 4 ☐ Engine 5 ☐

Marine Transmission

Manufacturer ______________________ Model ____________________

Arrangement(s) ____

Ratio: Forward _________________ Reverse __________________ S/N _________________

Propeller

Fixed Pitch ☐ Controllable Pitch ☐ Surface Drive ☐ Jet Drive ☐

Manufacturer ___________________ Model _________________ Material ______________

Number of Blades _______________ Diameter _______________ Pitch _________________

Cup: Light ☐ Medium ☐ Heavy ☐ (or) 1-10 ______________

Proposed Consist (cont.)

Vessel Controls

Manufacturer: ________________________________ Number of Stations: ________________

Vessel Instrumentation

Caterpillar provided instrumentation:

MPD Number of stations: _________________

Location(s): Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

EMS Number of stations: _________________

Location(s): Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

MAPD Number of stations: _________________

Location(s): Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Messenger Number of stations: _________________

Location(s): Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Engine Number of stations: _________________

Vision Location(s): Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Other manufacturers' instrumentation:

Make __________________________ Model ____

Location: Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Make __________________________ Model____

Location: Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Make __________________________ Model____

Location: Bridge ☐ Tower ☐ Flybridge ☐ Engine Room ☐ Portwing ☐
Starboardwing ☐ Bowstation ☐ Aftstation ☐

Proposed Consist (cont.)

Auxiliary Engine

Primary Use: Pump Drive ☐ Compressor ☐ Thruster ☐ Winch Drive ☐ Other ☐

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ______________________________________

Test Spec (0T, 2T, 0K, etc.) ______________________________________

Engine S/N ____

Major Attachments ____

Auxiliary Engine

Primary Use: Pump Drive ☐ Compressor ☐ Thruster ☐ Winch Drive ☐ Other ☐

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ______________________________________

Test Spec (0T, 2T, 0K, etc.) ______________________________________

Engine S/N ____

Major Attachments ____

Auxiliary Engine

Primary Use: Pump Drive ☐ Compressor ☐ Thruster ☐ Winch Drive ☐ Other ☐

Model ______________ Rating _______ bhp ☐ bkW ☐ @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ______________________________________

Test Spec (0T, 2T, 0K, etc.) ______________________________________

Engine S/N ____

Major Attachments ____

Proposed Consist (cont.)

Marine Generator Set

Engine

Model ______________ Rating _____________ ekW @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N(s) ____

Major Attachments ____

Generator

Manufacturer ____________ Model _________________ Rating _________ ekW ___________Hz

Marine Generator Set

Engine

Model ______________ Rating _____________ ekW @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N(s) ____

Major Attachments ____

Generator

Manufacturer ____________ Model _________________ Rating _________ ekW __________ Hz

Marine Generator Set

Engine

Model ______________ Rating _____________ ekW @ ____________ rpm

Engine Feature Code ____

Performance No. (TM or DM) ____

Test Spec (0T, 2T, 0K, etc.) ____

Engine S/N(s) ____

Major Attachments ____

Generator

Manufacturer ____________ Model _________________ Rating _________ ekW ___________Hz

Reference Documentation

Caterpillar reference publications provided and reviewed:

A&I Guide ☐ *General Dimension Drawings* ☐ *Electronic Installation Guide* ☐

Sea Trial Guide ☐ *Society Approval Guide* ☐ *Engine Technical Manual (EDS)* ☐ *TMI* ☐

Special Instructions:

____

____

Other (List):

____

____

Note: For later reference, attach copies of order forms to this design review.

Design and Construction Review Checklist

	Check if Used	Caterpillar Requirements	Units	Actual Measurement	Units	Design Review – Will it meet Caterpillar requirements?	Construction Review – Does it meet Caterpillar requirements?
MOUNTING & ALIGNMENT							
Propulsion Drive Line Type:							
Conventional							
Surface Drive							
Outdrive							
Vee Drive							
CP Propeller							
Paddle Wheel							
Belt Drive							
Electric Drive							
Auxiliary Drive Line Type:							
Thruster							
Single Bearing							
Two Bearing							
Hydrostatic							
Mounting Rail Installation:							
Collision Blocks							
Vibration Isolations							
Steel Shims							
Poured Shims							
Mounting Bracket Installation:							
Crankshaft Deflection							
Alignment							
Foundation							
COOLING SYSTEM							
Caterpillar supplied package? If yes, continue to Ventilation.							
Customer provided package?							
Heat Exchanger:							
Shell & Tube							
Plate Type							
Keel Cooler							
Fabricated							
Packaged							
Radiator							

Design and Construction Review Checklist (cont.)

	Check if Used	Caterpillar Requirements	Units	Actual Measurement	Units	Design Review – Will it meet Caterpillar requirements?	Construction Review – Does it meet Caterpillar requirements?
VENTILATION SYSTEM							
Fans Used on Intake							
Fans Used on Exhaust							
Natural Draft							
Distribution							
Exhaust							
Control							
Combustion Air:							
Drawn from engine room							
Ducted direct to air cleaner from outside							
Crankcase Ventilation							
Caterpillar supplied package? If yes, continue to Exhaust							
Discharge thru pipe to outside							
Closed System							
EXHAUST SYSTEM							
Wet w/Water Lift Muffler							
Wet w/o Water Lift Muffler							
Dry w/Muffler							
Dry w/o Muffler							
Backpressure							
Flexible Connections							
Mufflers							
Supports							
Insulation and Shielding							
Water Cooled Elbows							
Water Cooled Exhaust System							

Design and Construction Review Checklist (cont.)

	Check if Used	Caterpillar Requirements	Units	Actual Measurement	Units	Design Review – Will it meet Caterpillar requirements?	Construction Review – Does it meet Caterpillar requirements?
FUEL SYSTEM							
Fuel/Water Separator Installed							
Primary Filter Installed							
Tank Drains							
Duplex Filters							
Fuel Cooler							
Centrifugal							
Tank Sizing and Design							
Auxiliary (Day) Tanks							
Fuel Line Routing, Valves, Sizing, Material							
LUBRICATION SYSTEM							
Duplex Filters							
Centrifugal							
Pre-Lubrication							
Auxiliary Oil Sumps							
Emergency Systems:							
Engines							
Transmissions							
STARTING SYSTEM							
Caterpillar supplied package? If yes, proceed to Control System							
Electric							
Pneumatic							
Hydraulic							
CONTROL SYSTEM							
Type of Control							
Push/Pull Cable							
Pneumatic							
Electronic							
Hydraulic							

Design and Construction Review Checklist (cont.)

	Check if Used	Caterpillar Requirements	Units	Actual Measurement	Units	Design Review – Will it meet Caterpillar requirements?	Construction Review – Does it meet Caterpillar requirements?
SERVICE ACCESSIBILITY							
Adequate clearance for service, repair and/or removal							
Power Accessible For:							
Pneumatic Tools							
Electric Tools							
Lighting							
Parts Cleaning							
Adequate Lifting Equipment:							

The following parties have discussed and agreed to the results and required action during the design review process:

Authorized Signature of Dealer ________________________________ Date _______________

Authorized Signature of Designer________________________________ Date _______________

Authorized Signature of Builder/Installer __________________________ Date _______________

Authorized Signature of Owner ________________________________ Date _______________

Control Systems

General Information

The use of a reliable control system is essential. The controls must be precise, dependable, and easy to operate.

The control system, in its most basic form, is the equipment which allows the pilot to adjust the propulsion engine/s throttle (speed) and the marine gear's clutches – from *neutral* to *ahead* or *astern*.

To control throttle setting, a control system must rotate and hold the angular position of the governor control throttle.

To effectively control the marine gear with mechanically actuated hydraulic control valves, a control system must move a short lever on the hydraulic control valve to any of three positions (forward, neutral, reverse) and maintain the selected position without placing undue stress on the linkage or allowing the lever position to creep.

To effectively control the marine gear with solenoid-actuated hydraulic control valves, an electrical signal energizes one of two solenoids to pressurize either the forward or astern clutch. If neither solenoid is energized, the gear remains in neutral and neither clutch is pressurized.

Basic System Features

Two Lever Control
Two lever control systems use two levers for the pilot's control of the engine and the marine gear, hence the name.

The position of one of the levers determines the engine throttle setting.

The position of the other lever determines the transmission direction – neutral, astern, or ahead.

Two lever control systems are most simplified, and most economical, but have the possibility of changing the transmission direction while the engine is at a high throttle setting. Transmission clutch damage is likely if this occurs.

Single Lever Control
Single lever control systems provide automatic sequencing of the control functions, preventing the transmission from changing direction until the throttle lever is moved to the neutral position (refer to Figure 7.1).

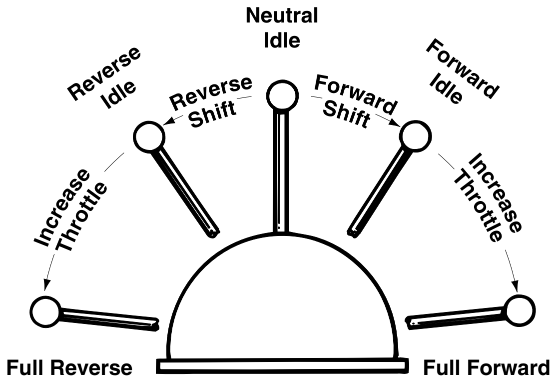


FIGURE 7.1

Neutral Throttle
Neutral throttle allows independent speed control when the marine gear is in neutral. This feature is useful when controlling the speed of engine-driven accessories such as generators, pumps or winches.

Multiple Control Stations
All vessels require one control station where the pilot controls engine and transmission. It is convenient to have other control stations when specific activities, such as docking and fishing, demand the pilot's close attention.

The simplest and, in most cases, most efficient multiple (dual) station system consists of two lever controls installed in a parallel system. Cables are run from the controls at each station directly to the clutch and throttle levers at the engine, and connected there with the appropriate parallel dual station kits.

A second type of multiple (dual) station system consists of two lever controls in series. Cables are run from the upper control station to the lower control station. A cable attachment kit is required to connect these cables to the lower station controls. Cables are then run from the lower station controls to the clutch and throttle levers at the engine and connected there with the appropriate engine connections kits. Series installations are less precise than parallel systems and should be used only when a parallel installation would be impractical due to long cable runs and excessive or sharp bends in the cable. The system selected is determined by the cable length and total degrees of cable bend required.

Engine/Gear Mounted Bracket Design
Brackets supporting the control systems cables/actuators at the engine/marine gear must be rigid. Good alignment of the cable-ends with the engine's throttle lever and gear's clutch control lever is necessary to

avoid binding. Control system manufacturers can provide suitable brackets to the user/installer.

Type

Push-Pull Cable System

Push-pull cable control systems are reliable and economical. The distance between the control head at the pilot station and the engine is limited by friction in the cables.

For best results, keep cable length under 30 ft (9 m).

The number and included angle of bends in the control cables add significantly to their internal friction. Avoid all unnecessary bends. Keep all bends in the cables as gradual as possible (minimum 8 in. [200 mm] bend radius).

Stiffness or binding in the operation of the hand lever can usually be traced to:

- Excessive number of bends in cable runs
- Sharp bend in the cables too close to the control head
- Bends smaller than the recommended minimum radius of 8 in. (200 mm)
- Tight or misaligned engine linkage
- Cable compressed too tightly by cable support
- Engine clutch lever hitting its limit stops at forward and/or reverse

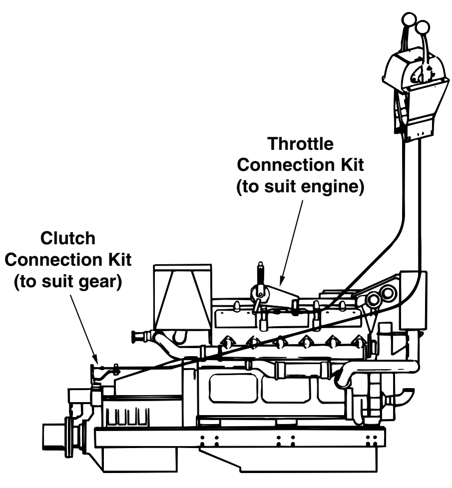
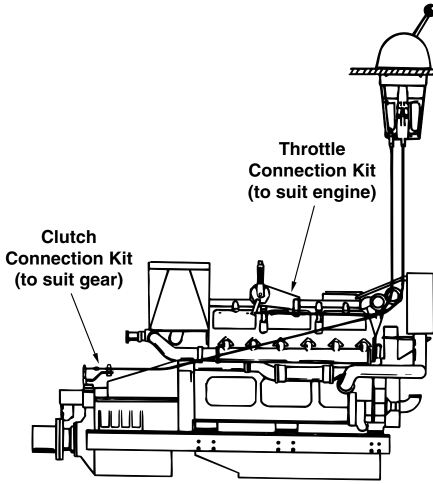
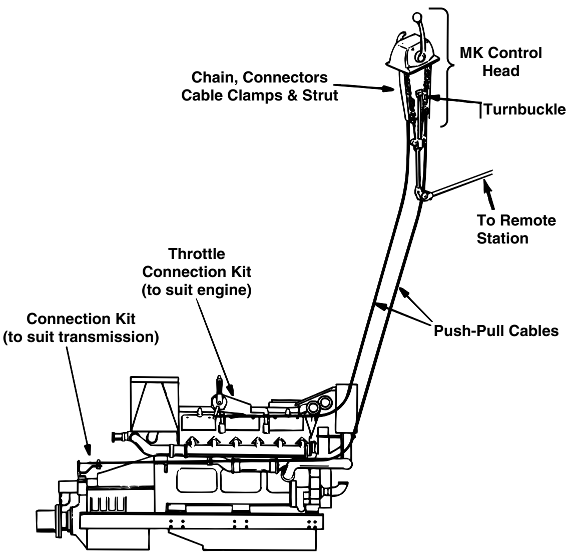


FIGURE 7.2



MT CONTROL SYSTEM

FIGURE 7.3



MK CONTROL SYSTEM

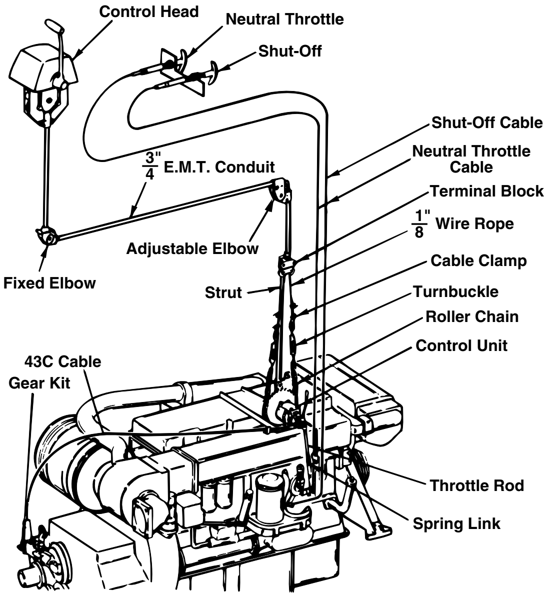
FIGURE 7.4

The installation of push-pull cable control systems is fairly simple.

Manufacturers' installation bulletins for both two-lever (Figure 7.2) and single-lever lever (Figures 7.3 and 7.4) systems illustrate the systems.

Cable-in-Tension System

Where a cable control system is preferred and long runs and numerous bends may be encountered, a system is used utilizing two cables in tension, running over pulleys mounted on antifriction bearings (refer to Figure 7.5). To reduce the number of cables and to maintain precision in the response of the system, a single lever type of control system is used. A control gearbox to the governor and reverse gear is installed on the engine.



MD 24 CONTROL SYSTEM

FIGURE 7.5

Hydraulic Control System

Hydraulic controls offer smooth, precise control of engine/marine gear without significant limitation on number of control stations or distance between control stations and the engines. The cost of hydraulic controls and the number of installation manhours are slightly higher than either of the mechanical cable controls.

Electronic Control System

Electronic control systems should be considered when the following control requirements are encountered.

- Electronically controlled engines
- Limiting the engine power during acceleration
- Engine overload protection

- Integration with controllable pitch propeller control systems
- Sharing of load between multiple engines, driving a single load
- Very long distances between the control station and the engine
- Integration with telemetry systems
- Adding additional control stations after vessel completion

Electronic Control System Components Control Station
The control station is generally simpler than a similarly functioned mechanical or hydraulic version. The forces involved in driving rheostats and switches are much less than those to operate push-pull cables or hydraulic cylinders. Electric control stations are very easy to install.

Most electric control systems will install an electric-to-mechanical converter box in the engine room/compartment. The electric-to-mechanical converter box accepts electrical signals from the various control stations and converts them to mechanical forces (generally via push-pull cables), suitable to operate the engine throttle and marine gear shifting valve. On newer mechanically controlled engines, control systems are capable of using electronic engine governors and electric marine gear control valves which eliminate the need for the electric-to-mechanical converter box.

Engine Throttle and Marine Gear Actuator
See electronic installation guide for electronic controlled engine.

3126B	RENR2233	
3176B	SENR6489	
3176C	SENR1187	
3196	SENR1187	
3406E	SENR1187	
3408	SENR6446	(PEEC)
3412	SENR6446	(PEEC)
3412E	SENR5014	

Mather's, ED Electric, Sturdy, Twin Disc and Kobelt are control manufacturers that can provide fully electronic control packages with our electronically controlled engines. They have electronic controls that are programmable for shifting and provide an electronic signal compatible with Caterpillar electronic engines.

Control Logic
Generally, the control logic is contained in the electric-to-mechanical converter box in the engine room/compartment. Larger systems will combine the logic circuitry with a propulsion system monitoring system in a cabinet in the engine room.

System Connectors
Electric control systems are generally interconnected by multiconductor electrical cable. This is much less expensive than mechanical cable or hydraulic tubing.

Pneumatic Control System
Pneumatic controls offer several advantages over other control systems:

- Ability to control engines at long distances. 300 ft (90 m) is a realistic distance to run air lines for pneumatic control. The only real limitation is the speed of response – in the case of very long lines.
- Ability to control from an unlimited number of control stations.
- Ability to add logic to the system, to protect against abuse of the driveline components.

There are some disadvantages to pneumatic control systems:

- A relatively heavy and expensive compressor with air storage tank is required.
- The tank and lines require regular maintenance (draining of condensation).

Engine Stall and Reversal
When a marine reduction transmission is shifted from forward to reverse or vice versa, sufficient engine torque must be available at idle speed to overcome propeller and driveline inertia, marine transmission inertia, and slip stream torque.*

If sufficient torque is not available or if sufficient engine safeguards are not installed, the engine will stall or reverse itself.

In vessels where rotating masses are moderate to small, clutch modulation and engine torque can control the reversing cycle. Heat buildup caused by the clutch slipping is normally well within the clutch capacity. Heat generated through increased modulation necessary to control large inertia forces can damage clutches. To prevent this buildup of heat, auxiliary devices may be necessary.

Also, under crash reversal conditions, it is conceivable that unless some device is used to counteract the inertia of large masses, the engine could stall or actually be motorized to run in reverse rotation.

Avoiding engine stalling and/or reversal with mechanical controls is difficult. One method is by careful clutch engagement and by allowing the boat to slow down before the shift is made. The adept operator can repeatedly engage and disengage the reversing clutch, until the vessel's speed

*Slip stream torque is the torque generated in a free-wheeling propeller, being turned by the water flowing past the hull. Slip stream torque can be as high as 75% of the engine's rated torque.

is checked sufficiently, and then complete the maneuver. Where large, heavy vessels, or those attached to a tow are concerned, this method may cause overheating of the reverse clutch. When this danger exists, other means must be employed.

Engine stalling and reversal problems can be avoided if close attention is paid to the engine and transmission control system.

Pneumatic and electronic controls which provide sequencing and timing of speed and directional signals offer optimum maneuvering as well as protection for the engine and transmission.

When Engine Stall and Reversal Could Be a Problem

The likelihood of this being a problem is significantly increased for vessels equipped with:

- Propulsion engines producing over 500 hp
- Fixed pitch propellers
- Deep ratio reduction gears, usually 4:1 and deeper

What the Operator Can Do

Loss of acceptable engine speed can be prevented by prudent use of the controls by the operator during maneuvering.

Engine Speed Limits During Emergency Maneuvers

It is imperative that engine speed does not drop below 300 rpm for slow speed engines (rated at nominally 1200 rpm) or 400 rpm for high speed engines (rated at nominally 1800 to 2300 rpm) in order to assure adequate lubrication and to prevent the possibility of stalling.

Need for Sequencing Control Systems

Sequencing and timing of the controls when using air control systems is necessary to:

- Reduce vessel maneuvering time
- Prevent excessively low engine speed
- Prevent excessive loading of driveline components
- Reduce the possibility of engine stalling

The possibility of engine speed reduction to the point of stalling due to sudden vessel maneuvering demands will be dependent upon the speed of the vessel when the maneuver is undertaken. During low vessel speed maneuvers, the engine torque capabilities are usually sufficient to respond adequately. However, if a sudden maneuver, such as a crash stop of the vessel, is demanded at full vessel speed, auxiliary driveline devices may be required to prevent stalling and loss of vessel control.

Sequencing Control System Features

To forestall the possibility of engine stall during high speed maneuvers in emergency situations, one or more of the following may be required:

- Raised low idle speed setting
- Throttle boost control
- Shaft brake
- Control system timing

3500 Family Engines equipped with 3161 governors will shut off their fuel if subjected to engine reversal.

Raised Low Idle Fuel System Setting
To increase the engine's low speed torque, the low idle setting may be increased if the vessel's low speed maneuvering is not jeopardized. This will help prevent the engine from stalling or reversing during maneuver. The setting should be accomplished by an authorized Caterpillar Dealer. Excessive shock loading and transmission clutch wear can occur if the engine low idle speed is too high.

Throttle Boost
Throttle boost momentarily raises the idling speed setting of the engine. The engine speed increase comes just before engagement of the marine gear clutch. This momentary speed increase occurs only during maneuvering, not at steady boat speed conditions.

Throttle boost is kept as low as possible because it tends to increase the load on the clutches during maneuvering. The control system should permit adjustment of both the amount and duration of throttle boost. The throttle boost for most Marine Gears should be set no higher than 750 rpm for 1800 rpm engines and 600 rpm for 1200 rpm engines at no load. Sea trials should determine the level of throttle boost necessary to ensure a safe shaft reversal and maintain engine speed above the minimum limits. Consult the marine transmission manufacturer for boosted-shift clutch capability.

Although reversing problems seldom occur with marine transmissions ratios more shallow than those previously mentioned, it is recommended that a throttle boost system be incorporated with more shallow ratioed transmissions as an additional safety feature.

Shaft Brake

In vessel applications where heavy maneuvering is required or if full speed reversals may be encountered, the use of a propeller shaft brake is recommended. A properly controlled shaft brake will stop the rotation of the propeller whenever the transmission clutches are disengaged and the engine is at low idle speed. This action reduces the amount of torque required from the engine in order to complete a shaft directional change. Several advantages are gained with the use of shaft brakes.

1. A propeller shaft brake can safely reduce vessel maneuvering time. A vessel will slow in half the time with a stopped propeller as compared to a windmilling propeller. The propeller slip stream torque, therefore, falls to a level lower than the slow speed torque of the engine in half the time.
2. The propeller shaft brake accepts half the speed reversal loads when maneuvering. The brake brings the propeller to a stop. This load is transmitted directly to the hull. The clutch and propulsion system are only asked to pick up a stopped propeller shaft rather than a windmilling propeller. Because load on the engaging clutch is greatly reduced, clutch life is extended. Transmission gears, engine and other major components of the propulsion system are subject to less shock.
3. The propeller shaft brake will prevent engine stall when attempting crash stops or when high vessel speed shaft reversals are attempted during maneuvers.

A propeller shaft brake should be considered on any marine propulsion system using engines over 500 hp where the reduction ratio is 4:1 or deeper and where high speed maneuvering is a requirement.

Disc brakes and drum-type brakes are available. The brake should be sized to handle at least 75% of the full rated shaft torque and should stop the shaft within three seconds during a crash reversal. Brake size requirements will vary with type of propeller, vessel speed, and vessel application.

Proper control and sequencing of a propeller shaft brake is very important. Overlap can occur if the clutch engages before the brake is released. This would show as an extra load on the engine, slowing it and even stalling the engine. Underlap is releasing the brake well ahead of the clutch making contact. The propeller will quickly begin to windmill in the wrong direction and much of the advantage of the brake is lost.

Event Sequence Timing

Sequencing and timing of engine governor, marine transmission clutch, and shaft brake action are critical and only systems of the following characteristics should be used:

Pilot House Control Movement

Full Ahead to Astern and Full Astern to Full Ahead

Event Sequence

1. Governor to Low Idle
2. Clutch to Neutral
3. Shaft Brake Applied Propeller Shaft Stops
4. Shaft Brake Released

5a. Throttle Boost Applied

5b. Clutch Engaged*

6. Throttle Boost Off, Governor to Full Open

With the above sequencing and timing, the shaft brake will engage any time the pilot house control lever is in the neutral position. Throttle boost will activate each time the pilot house control lever is shifted from neutral to a clutch-engaged position.

A proportional pause-type control system will allow for a variable time between Steps 3 and 4 in the event sequence when the shaft brake is applied. The pause is in proportion to the last-called-for speed. A crash reversal from full speed will leave the brake applied for a longer period than when slow speed maneuvering. This full speed reversal pause in neutral is made just long enough for the vessel speed to slow to a point that the propeller slip stream torque will not stall the engine when the reverse clutch is engaged.

Properly adjusted air controls should provide event sequence time in the area of 5 to 7 seconds for slow speed maneuvering and in the area of 7 to 12 seconds or more for full speed crash reversals. The timing is set as fast as the propulsion system can safely be operated. The timing should be set permanently at the time of sea trials.

Without a propeller shaft brake, a longer pause in neutral in place of Steps 3 and 4 in the event sequence will normally be required to allow reduced vessel speed.

The control system must be carefully maintained. Follow the manufacturer's maintenance recommendations explicitly.

Recommended Systems

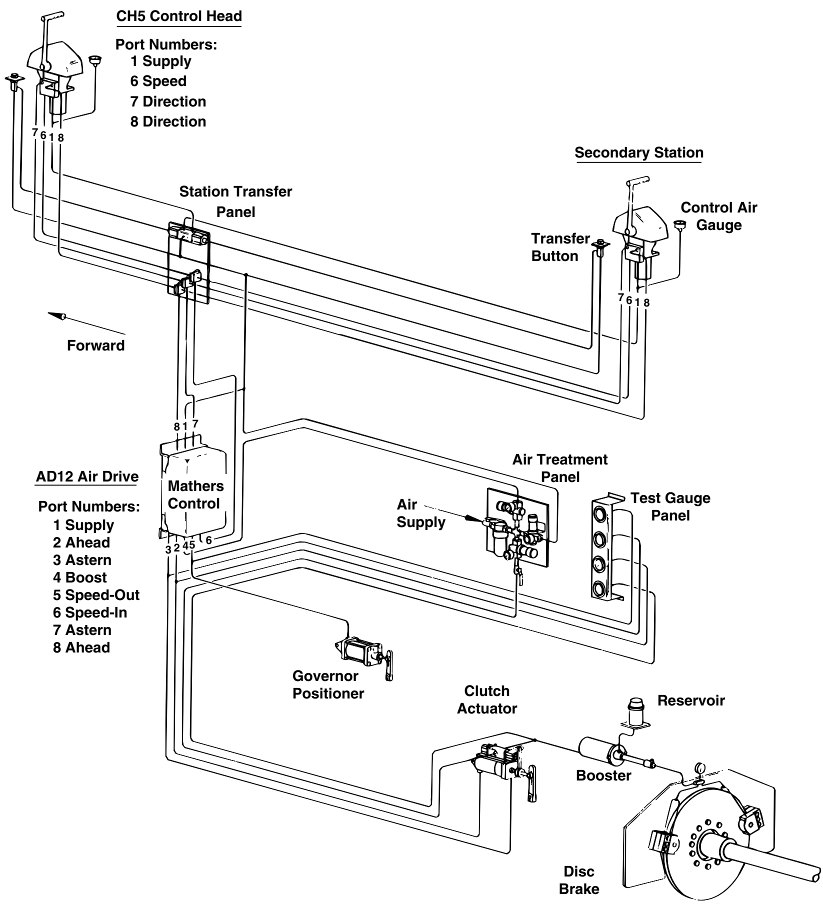
Consult with the manufacturers of control systems to determine their availability to provide event sequence systems as described previously.

*Timing sequence from brake release to clutch engagement should result in from one quarter to one revolution of the propeller shaft in the wrong direction to ensure there is no overlap between brake release and clutch engagement.

The shipyard should furnish a low air pressure alarm located at the supply air to the pneumatic control system. The alarm should be audible and visual and should be actuated if the air pressure should fall below a predetermined level – generally 90 psi (620.5 kPa).

Mathers

The Mathers control system offers single lever pneumatic control of speed, clutch, and brake (if required). The system uses fixed orifice timing with option for as many control stations as required. They also offer electronic controls with the same sequence timing adjustments.



Mathers Controls Inc.
AD12 Propulsion Control System
For
Hydraulic Clutches

FIGURE 7.6

WABCO

WABCO, a division of American Standard, also provide complete sequencing control systems. The following is an example.

LMAC-3C Logicmaster Air Clutch-Control Systems for 3600 Family of Caterpillar Engines

This control system provides interlocked and sequenced operation of proportional timing in ahead and astern clutch engagement and engine speed control to ensure proper operation of the propulsion machinery as the operator manipulates the remotely mounted control lever. The control system incorporates the following interlocks and the optional features.

1. Positive cross engagement interlocks ensure that one clutch is vented below 15 psi before the opposite clutch can be inflated.
2. The clutch engagement system incorporates a three-stage clutch fill. First, an initial quick fill to bring the clutch shoes into contact with the drum. Second, a controlled rate of fill. Third, a full flow *hard fill* inflation at maximum rate up to supply pressure.

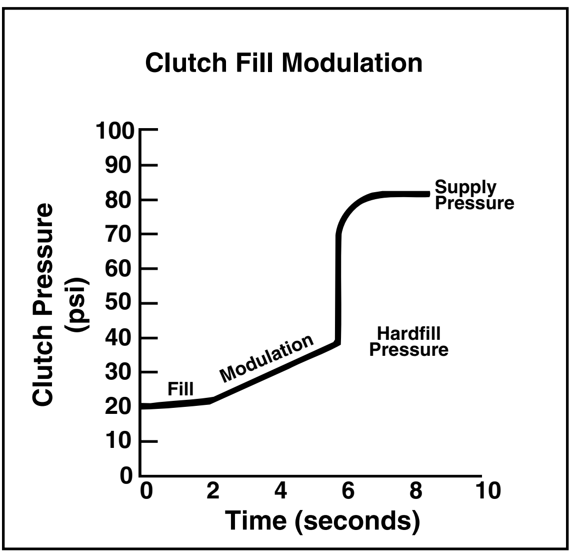


FIGURE 7.7

3. A governor power boost is applied during initial clutch engagement to prevent engine stalling. This boost is adjustable in magnitude and duration. Adjustment of timer unit controls rate of boost application and regulator controls the magnitude of boost delivered to the governor.

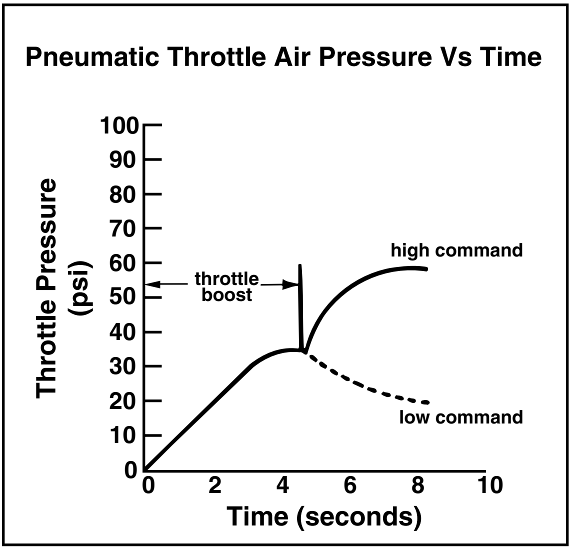


FIGURE 7.8

4. A clutch pressure-engine speed interlock to ensure that the clutch is inflated to lock-up pressure before engine speed can be increased from the remote operating station.
5. Proportional reversing interlock occurs in both directions. This time is adjustable and provides a neutral hold time proportion to the vessel speed. Normal maneuvers are accomplished with the minimum reversing time increasing in proportion.
6. The ahead clutch hold-in function to shorten the reversing time by holding in the ahead clutch which uses the engine's compression to slow down the propeller during high speed and crash reversals.
7. A shaft brake signal (optional) is provided to actuate a shaft brake in synchronization with the clutch engage/disengage control system. The brake is released when clutch engagement is initiated and is applied when both clutches are fully released. When a brake is used, the "interlocks" provide a neutral hold to permit the brake to be applied and the shaft stopped before reversal is initiated.

   Other manufacturers may also be able to provide suitable systems.

Controllable Pitch Propeller to Avoid Engine Stall and Reversal

The controllable pitch propeller allows smooth, well-controlled vessel reversals while the engine rpm and horsepower are kept at optimum levels. This is most desirable on vessels equipped with deep ratio marine transmissions that must be reversed while moving at full vessel speed. To reverse a vessel equipped with a controllable pitch propeller, reduce propeller pitch to the “neutral pitch” position, then increase pitch in the “astern” or reverse direction slowly enough to allow the engine to maintain its full load rpm and horsepower.

Determining Likelihood of Stalling During Sea Trial

Initial sea trials should determine the likelihood of the control system/engine combination stalling during a crash reversal maneuver. Adjustment and timing of air controls can be determined and properly set during sea trials. Suggested procedure is to start with a low forward vessel speed and make crash shifts into reverse at small increments of increased forward vessel speed until it is determined that the system will allow a crash reversal at the most severe condition the vessel will encounter.

Instrumentation and Monitoring Systems

Instrumentation is a valuable component of a well designed installation.

Instruments

The functions below are listed in their order of desirability for Helmsmans station instrument panel placement.

A = *Must Have* Instrumentation
B = Highly Desirable Instrumentation
C = Useful Instrumentation
D = Questionable, Without Special Requirements

A **Engine Lubrication Oil Pressure**
Loss of lube oil pressure while operating at full power is likely to result in severe engine damage. Quick action by the pilot in reducing stopping the engine can save an engine. To protect the engine, the pilot must be able to see the status of engine oil pressure continuously.

A **Jacket Water Temperature**
Increase of jacket water temperature is almost as serious as loss of lube oil pressure and somewhat more likely. Similar quick action by the pilot can minimize engine damage resulting from a high temperature condition.

A **Engine Speed (rpm)**
Rather than a safety-oriented engine function, engine speed is an operation related measurement. Observing the relationship between engine speed, vessel load, and throttle position will allow the pilot to make informed judgments about engine load and need for maintenance.

B **Transmission Oil Pressure**
Transmission oil pressure measurement shows the pilot when the transmission clutches have engaged and useful information concerning the condition of the pump, filters, or clutches. Excessive pressure can damage components in the hydraulic circuit.

B **Voltmeter**
Voltage of the starter/alternator circuit give the pilot useful information regarding battery condition, alternator condition, state of charge of the batteries, and condition of the battery cables.

C **Transmission Oil Temperature**
Many transmission problems, such as clutch slippage, insufficient clutch pressure, bearing wear, cooler blockage or loss of cooling water flow will be manifested as an increase in transmission oil temperature.

C **Exhaust Stack Temperature**
Changes from *normal* exhaust stack temperatures will give useful information concerning air filter restriction, aftercooler restriction, injector condition, valve problems, and engine load.

D **Individual Cylinder Exhaust Temperature**
While these instruments will give immediate warning of individual injector failure, the inevitable wide tolerance on the standard temperature (75° F) (±42° C) often causes undue operator concern. In general, advantages gained by this instrumentation are overshadowed by high cost (thermocouples need annual replacement) and need for special operator training.

Alarm/Shutdown Contactors

These are preset contactors (switches) that will activate a customer-supplied alarm, light, or engine shutdown solenoid, when certain limits are exceeded.

Alarm switches available from Caterpillar will operate on AC or DC, from 6 volts to 240 volts. These switches are of the singlepole double-throw type.

With the exception of the overspeed function, propulsion engines should not be automatically shutdown. The pilot should be warned of impending failure but should retain the authority to decide whether to shut down the engine or to continue to operate. Overspeed failures will result in loss of engine power. If the engine is equipped with an overspeed protection device, the engine will not be harmed as much as if the overspeed failure had proceeded unimpeded.

A = *Must Have* Instrumentation
B = Highly Desirable Instrumentation
C = Useful Instrumentation
D = Questionable, Without Special Requirements

A **Low Lube Oil Pressure**
There are two conditions that need to be alarmed: low lube oil pressure at low engine load (idle conditions) and low lube oil pressure at high engine speed and/or load. An oil pressure that would be perfectly safe while operating at very low loads and/or speeds would be too low at full load/speed conditions. A suitable system will include two pressure-sensitive contactors and a speed (rpm) switch to decide which pressure switch should have the authority to warn the operator.

A **High Coolant Temperature**
High coolant temperature contactors should be set to actuate within 5° F (2.8° C) of the highest normal temperature of the engine at the point of installation.

A **Overspeed**
Overspeed faults occur when some part of the engine fails, causing the fuel control mechanism to be locked in a high fuel flow condition. When the engine load goes to a low level, the engine will continue to receive a high fuel flow. Without the load, the engine speed increases

to a dangerously high level. Generally, the engine's air supply must be cut off to save the engine.

Overspeed contactors need to be set 12-15% over rated engine speed to avoid nuisance engine shutdowns during sudden reductions in engine load.

B **Water Level Alarm**
Warning of coolant loss could allow the operator to save an engine which would otherwise be lost to overheat failure.

Install level sensors in the highest part of the cooling system – generally in the auxiliary expansion tank. This will give warning of coolant loss at the earliest possible time, before the coolant level has fallen to a dangerous level.

C **Low Sea Water Pump Differential Pressure**
The sea water flow to a heat exchanger cooled engine is very important. It is a good idea to install a differential pressure contactor across the sea water pump to warn of any discontinuity in sea water flow.

C **Intake Manifold Temperature Alarm Switches**
Intake manifold temperature alarm switches are available for use on some engines. High intake manifold temperature will warn of sea water pump failure, sea strainer plugging, or any other condition which reduces or stops aftercooler water flow.

Alarm Panel

Caterpillar recommends the following features in alarm panels:

- Fault light lock-in circuitry keeps the fault light on when intermittent faults occur.
- Lockout of additional alarm lights prevents subsequent alarm lights from going on after the activated engine shutoff stops the engine. This aids in troubleshooting.
- Alarm silence allows the operator to acknowledge the alarm without having to continually listen to the alarm horn. The alarm light is left on.
- If more than one engine is connected to an alarm panel, a fault in a second engine should activate the alarm even though the alarm horn may have been silenced after a fault on another engine.
- Circuit test provides for periodic checking of alarm panel functions.

Instrumentation Problems

Without highly trained personnel and rigorous discipline, too much instrumentation can be detrimental.

The weak link in any instrumentation system is the sensor unit (transducer). Too often, an otherwise fine system is sabotaged because of frequent false alarms. Plan annual replacement of the sensor units unless unusually high quality sensors are used.

High water temperature sensors will not warn of overheat conditions unless their sensing bulbs are submerged in water. High water temperature sensors will not warn of coolant loss.

Electronically controlled engines

The engines have sensors needed to control the engines standard and there are panels available which monitor and display the values these sensors put out. Consult price list for optional pilot house panels for use with these engines.

Starting Systems

General Information

Startability of a diesel engine is affected primarily by ambient temperature, engine jacket water temperature, and lubricating oil viscosity. Any parasitic loads (usually associated with the driven equipment) can greatly influence the startability, as well.

The diesel engine relies on heat of compression to ignite fuel. When the engine is cold, longer cranking periods or higher cranking speeds are necessary to develop adequate ignition temperatures. The drag due to the cold lube oil imposes a great load on the cranking motor. Oil type and temperature drastically alter viscosity. SAE 30 oil approaches the consistency of grease below 32° F (0° C).

Starter Types

There are three different types of starting systems normally used for Caterpillar diesel engines. They differ in the method of storing and recharging the energy required for restarting the engine.

Electric Starting Systems
Use chemical energy stored in batteries, automatically recharged by an engine-driven alternator or by an external source.

Air or Pneumatic Starting Systems
Use compressed air in pressure tanks, automatically recharged by an electric motor-driven air compressor.

Hydraulic Starting Systems
Use hydraulic oil stored in steel pressure vessels under high pressure automatically recharged by a small engine-driven hydraulic pump with integral pressure relief valve.

The technology of the systems are well developed. Any of the systems are easily controlled and applied either manually or automatically. Several of the factors which influence the choice of systems have been tabulated below.

Electric

Battery-powered, electric motors utilize low voltage direct current and provide fast, convenient, pushbutton starting with lightweight, compact engine-mounted components. A motor contactor relieves control logic circuits of high cranking currents.

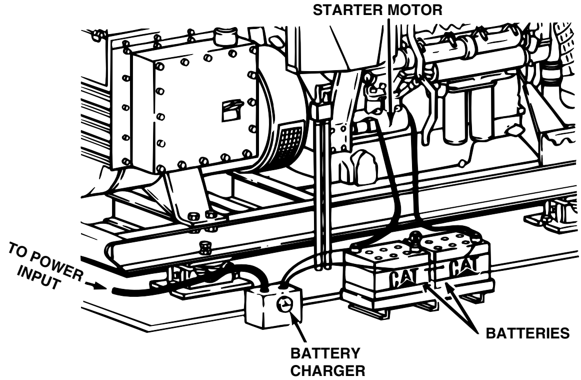


FIGURE 7.9

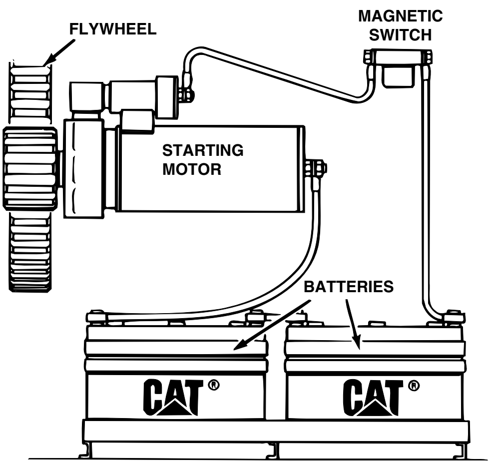


FIGURE 7.10

Storage Method

Lead/Acid storage batteries.

Relative Cost

Lowest.

Maintenance Requirements

Highest, the batteries require considerable maintenance.

Reliability of Starting

Good.

Special Concerns

Hydrogen gas, released from the batteries during charging, is very explosive, and compartments containing lead acid batteries must be properly vented.

Batteries

Batteries provide power for engine cranking. Lead-acid types are readily available, have high output capabilities, and are relatively inexpensive. Nickel-cadmium batteries are costly, but have long shelf life and require minimum maintenance. Nickel-cadmium types are designed for long life and may incorporate thick plates which decrease high discharge capability. Consult the battery supplier for specific recommendations.

Ambient temperatures drastically affect battery performance and charging efficiencies. When operating in cold climates, the use of battery heaters are recommended. The heaters should be set to maintain battery temperature in the range of 90° to 125° F (32° to 52° C) for maximum effectiveness. The significance of colder battery temperatures is described below.

All battery connections must be kept tight and coated with grease to prevent corrosion.

Temperature vs Battery Output

°F	°C	Percent of 80° F (27° C) Ampere Hours Output Rating
80	27	100
32	0	65
0	–18	40

Battery Location and Hydrogen Venting

Install batteries only in well ventilated compartments. Visual inspection for terminal corrosion and damage should be easy. Batteries emit hydrogen gas during the recharging cycle. Hydrogen gas is highly explosive and very dangerous in even small concentrations. Hydrogen gas is lighter than air and will escape harmlessly to atmosphere, if not trapped by rising into a chamber from which there is no upward path to atmosphere. Devices which can discharge electrical sparks or cause open flames must not be allowed in the same compartment or in the vent path for the escaping hydrogen gas.

Battery Disconnect Switches (Battery Isolating Devices)

Solid state electrical devices will suffer when installed in vessels whose electrical system includes battery disconnect switches which can interrupt loadbearing circuits. At the instant of a circuit disconnect, transient currents and voltages will often cause failure in any component whose transistors are not otherwise protected.

Use Battery Disconnect Switches (Battery Isolating Devices) which do not cause voltage transients (spikes).

Battery Chargers
Various chargers are available to replenish a battery. Trickle chargers are designed for continuous service on unloaded batteries and automatically shut down to milliampere current when batteries are fully charged. Overcharging shortens battery life and is recognized by excessive water losses.

Conventional lead-acid batteries require less than 2 oz (59.2 mL) of make-up water during 30 hours of operation.

Float-equalize chargers are more expensive than trickle chargers and are used in applications demanding maximum battery life. These chargers include line and load regulation, and current limiting devices which permit continuous loads at rated output.

Chargers must be capable of limiting peak currents during cranking cycles or have a relay to disconnect during cranking cycles. Where engine-driven alternators and battery chargers are both used, the disconnect relay is usually controlled to disconnect the battery charger during engine cranking and running.

Engine-driven generators or alternators can be used but have the disadvantage of charging batteries only while the engine runs. Where generator sets are subject to long idle periods or many short stop-start cycles, insufficient battery capacity could threaten dependability.

Continuous Cranking Time Limit with Electric Starter Motors
An engine should not be cranked continuously for more than 30 seconds to avoid overheating of the starter motors.

Starter Motor Cooling Period Between Cranking Periods
Allow the starter motor to cool for two minutes before resuming cranking.

Battery Cable Sizing (Maximum Allowable Resistance)
The start circuit between battery and starting motor, and control circuit between battery, switch, and motor solenoid must be within maximum resistance limits shown.

Magnetic Switch and Series-Parallel Circuit	Solenoid Switch Circuit	Starting Motor Circuit
12 Volt System 0.048 Ohm	0.0067 Ohm	0.0012 Ohm
24 Volt System 0.10 Ohm	0.030 Ohm	0.002 Ohm
32 Volt System 0.124 Ohm	0.070 Ohm	0.002 Ohm

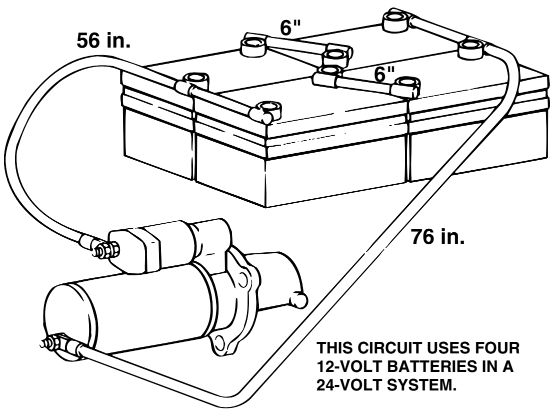
Not all this resistance is allowed for cables. Connections and contactors, except the motor solenoid contactor, are included in the total allowable resistance. Additional fixed resistance allowances are:

Contactors
Relays, Solenoid, Switches
0.0002 Ohm each

Connections
(series connector)
0.00001 Ohm each

The fixed resistance of connections and contactors is determined by the cable routing. Fixed resistance (Rf) subtracted from total resistance (Rt) equals allowable cable resistance (Rc): Rt - Rf = Rc.

Example:



SYSTEM	24-volt
STARTING MOTOR TYPE	HEAVY DUTY
MAXIMUM ALLOWABLE RESISTANCE	0.00200
MINUS FIXED RESISTANCE—	
6 CONNECTIONS @ 0.00001	0.00006 OHM
RESISTANCE REMAINING FOR CABLE	0.00194
BATTERY CABLE LENGTH	144 in.

FIGURE 7.11

With cable length and fixed resistance determined, select cable size using the following chart. Only full-stranded copper wire should be used. Arc welding cable is much more flexible and easier to install than full stranded copper wire cable, but welding cable is not so durable and will be damaged from corrosion in a much shorter time.

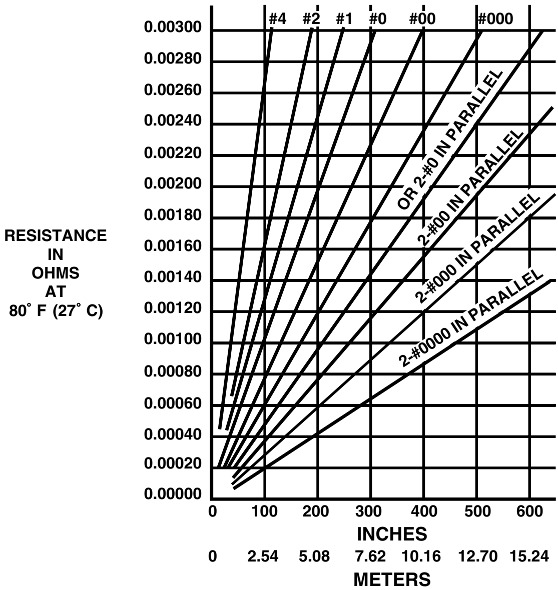


FIGURE 7.12

To meet cable length and resistance requirements, cable size must be No. 1. To determine fixed resistance in a parallel circuit, only series connections in one leg of the parallel circuit are counted.

Connections/Proper Practices

Electrical connections are often a source of problems for shipboard electrical systems.

Salt air and water are highly corrosive. Electrical connections are almost always made of dissimilar metals. Corrosion is more destructive between dissimilar metals.

The following table lists good practices for marine electrical systems.

When making electrical connections between wires, connect wires mechanically so tugging or pulling can be withstood without any other treatment of the joint. Then, coat the joint and the nearest portions of each wire with electrical solder. Do not expect solder to increase joint strength. The solder is for corrosion protection.

Do not use *crimp-type* connectors for marine service – The plastic sleeve tends to hide the corrosion from view rather than protecting the joint.

Pneumatic

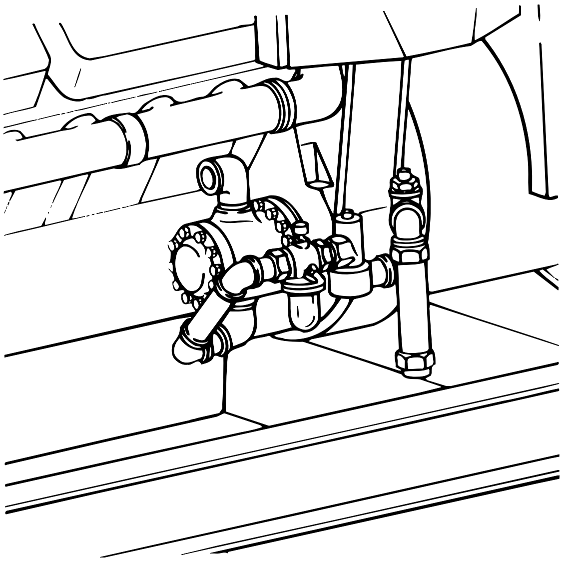


FIGURE 7.13

Air starting, either manual or automatic, is highly reliable. Torque available from air motors accelerate the engine to twice the cranking speed in about half the time required by electric starters.

Air is usually compressed to 110 to 250 psi (758 to 1723 kPa) and is stored in storage tanks. Stored air is regulated to 110 psi (759 kPa) and piped to the air motor. A check valve between the compressor and the air receiver is good practice, to protect against a failure of plant air which might deplete the air receivers supply. The air compressors are driven by external power sources.

Air starter air supply piping should be short and direct and at least equal in size to the motor intake opening. Black iron pipe is preferred. The piping requires flexible connections at the starter. Deposits of oil and water will accumulate in the air receiver and at low spots in the piping. The accumulation of oil and water must be removed daily to prevent damage to the starting motors. Manual or automatic traps should be installed at the lowest parts of the piping and all piping should slope toward these traps.

Air tanks are required to meet specific characteristics, such as the specifications of the American Society of Mechanical Engineers (ASME). Compressed air storage tanks must be equipped with a maximum pressure valve and a pressure gauge. Check the maximum pressure valve and pressure gauge often to confirm proper operation.

Air Storage Tank Sizing (except 3600 Engines)

Many applications require sizing air storage tanks to provide a specified number of starts without recharging. This is accomplished as follows:

$$V_t = \frac{V_s \times T \times P_a}{P_t - P_{min}}$$

Where:

V_t = Air Storage Tank Capacity (cubic feet or cubic meters)

V_s = Air consumption of the starter motor (ft^3/sec or m^3/sec) – See *Air Starting Requirements Chart*.

T = Total Cranking Time Required (seconds) if six (6) consecutive starts are required, use seven (7) seconds for first start (while engine is cold), and two (2) seconds each for remaining five (5) starts, or a total cranking time of seventeen (17) seconds.

P_a = Atmospheric Pressure (psia or kPaa) normally, atmospheric pressure is 14.7 psia or 101 kPaa.

P_t = Air Storage Tank Pressure (psia or kPaa). This is the storage tank pressure at the start of cranking.

P_{min} = Minimum Air Storage Tank Pressure Required to Sustain Cranking at 100 rpm (psia or kPaa) – See *Air Starting Requirements Chart*.

Cranking Time Required

The cranking time depends on the engine model, engine condition, ambient air temperature, oil viscosity, fuel type, and design cranking speed. Five to seven seconds is typical for an engine at 80° F (26.7° C). Restarting hot engines usually take less than two seconds.

Air Consumption of the Starter Motor

The starter motor air consumption depends on these same variables and also on pressure regulator setting. Normal pressure regulator setting is 100 psi (690 kPa). Higher pressure can be used to improve starting under adverse conditions up to a maximum of 150 psi (1034 kPa) to the starting motor. The values shown on the air requirements chart assume a bare engine (no parasitic load) at 50° F (10° C).

Air Starting Requirements

	Air Consumption of the Air Start Motor Versus ft³/sec (m³/sec) of Free Air Air Storage Tank Pressure -Pt-			Minimum Tank Pressure
	115 psia (793 kPaa)	140 psia (965 kPaa)	165 psia (1137 kPaa)	-Pmin-
Engine Model	100 psig (690 kPag)	125 psig (862 kPag)	150 psig (1034 kPag)	psia (kPaa)
3304	5.8 (0.16)	6.8 (0.20)	7.7 (0.21)	50 (345)
3306	5.9 (0.17)	6.8 (0.20)	7.8 (0.22)	51 (352)
3176/96	6.2 (0.17)	7.3 (0.21)	8.3 (0.23)	55 (379)
3406	6.2 (0.17)	7.3 (0.21)	8.3 (0.23)	55 (379)
3408	6.4 (0.18)	7.3 (0.21)	8.6 (0.24)	54 (372)
3412	9.0 (0.25)	10.3 (0.29)	11.8 (0.33)	45 (310)
3508	9.3 (0.26)	10.8 (0.30)	12.6 (0.36)	45 (310)
3512	9.8 (0.28)	11.4 (0.32)	13.3 (0.38)	50 (345)
3516	10.5 (0.30)	12.1 (0.34)	14.1 (0.40)	65 (448)

Note: For engines equipped with pneumatic prelube: add 1 ft³/sec (0.03 m³/sec) air consumption.

Operation

The supply of compressed air to the starting motor must be shut off as soon as the engine starts to prevent wasting starting air pressure and prevent damage to starter motor by overspeeding.

Air Storage Tank Sizing (3600 Engines)

The 3600 Air Start Sizing Curve shows required tank volume (for inline or vee engines) versus desired number of starts for different initial tank pressures. The curves for 230 psi (1600 kPa) and less allow for 6% pressure drop between tank and starter. For pressures greater than 230 psi (1600 kPa), the curves assume regulation to 125 psi (860 kPa) pressure at the starter. The pressure regulator should have capacity to flow 600 scfm (280 liters/second) per starter at regulator inlet pressures above 60 psi (415 kPa).

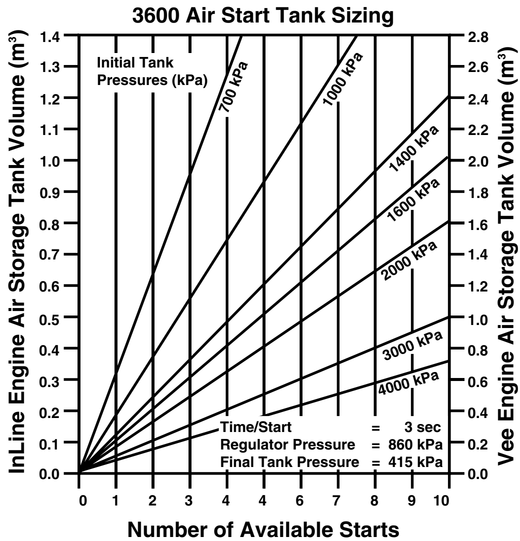


FIGURE 7.14

Air starters for 3600 Engines are designed to operate at a maximum air pressure of 225 psi (1550 kPa) at the starter. Minimum air pressure to provide adequate cranking speed for engine starting at 77° F (25° C) ambient temperature is 60 psi (415 kPa) at the starter.

The air pressure to the starter must be regulated when tank pressures greater than 225 psi (1550 kPa) are used.

These curves do not include air for a prelube pump.

The Caterpillar air prelube pump consumption rate is 60 scfm (28.2 L/s).

If the engine will be started at ambient temperatures lower than 77° F (25° C), additional storage tank volume will be required.

Prevention of Frost at the Starter Motor Air Discharge
Water vapor in the compressed air supply may freeze as the air is expanded below 32° F (0° C). A dryer at the compressor outlet or a small quantity of alcohol in the starter tank is suggested.

Hydraulic

Hydraulic starting provides high cranking speeds and fast starts. It is relatively compact. Recharging time, using the small engine-driven recharging pump, is fast. The system can be recharged by a hand pump provided for this purpose, although hand recharging is very laborious.

The high pressure of the system requires special pipes and fittings and extremely tight connections. Oil lost through leakage can easily be replaced, but because of high pressures in the accumulators (usually 3000 psi [20,700 kPa] when fully charged) recharging the accumulator/s requires special equipment.

Repair to the system usually requires special tools.

Hydraulic starting is most often used where the use of electrical connections could pose a safety hazard.

Hydraulic starting systems are not available from Caterpillar. Contact your local Caterpillar dealer for the nearest available supplier.

The Hydraulic Accumulators, if used, contain large amounts of stored mechanical energy. They must be very carefully protected from perforation or breakage.

Starting Aids

The diesel engine depends on the heat of compression of the air in a cylinder to ignite the fuel. Below some specified temperature, the cranking system will not crank the engine fast enough or long enough to ignite the fuel. One or more commonly used starting aids, such as jacket water heaters and/or ether may be required.

Jacket Water Heaters

Jacket water heaters are electrical heaters which maintain the jacket water at a temperature high enough to allow easy starting of the engine. More heaters of higher ratings may be required in areas of extremely cold temperature.

Ether

Ether is a volatile and highly combustible agent. Small quantities of ether fumes added to the engines intake air during cranking reduce the compression temperature required for engine starting. Caution is required when using ether to prevent spread of fumes to atmosphere. A proper ether system will meter the rate of ether consumption. Not more than 1 cm^3 (0.033 oz) of ether should be released per 100 rated hp for each 10 seconds of cranking. Very low ambient temperatures may require increasing the ether consumption rate. *Under no circumstances should ether be released into an engine while running.*

The 3126 Marine Engine is equipped with an air inlet heater. Under no circumstances should ether be used on this engine.

Manifold Heaters

Heat added to the intake manifold of an engine during cranking will significantly improve startability and reduce any white start-up smoke. Manifold heaters are not available from Caterpillar.

Starting Smoke

High performance engines are prone to have some white start-up smoke. The white smoke is composed of unburned fuel*. Caterpillar Engines have been designed to minimize this problem.

Operators can do several things to improve the situation:

- Use of jacket water heaters to raise the engine water temperature to 90 to 120° F (32-49° C) prior to starting.
- Keep warm-up idle speeds (rpm) low.
- Warm the air to the air cleaners and intake manifold.
- Increase the exhaust pipe restriction-flow (exhaust back pressure) during the warm-up period.

*Diesel engines which are designed to have high output power, yet still be relatively lightweight, generally have low compression ratios; i.e., in the range of 12.5 to 16:1. This design factor makes them prone to misfire and run rough until the engine reaches normal operating jacket water temperatures: 175 to 200° F (80 to 93° C).

Start-up Systems

General Information

Start-up is the *final* examination at the end of the engine installation process.

The start-up is:

- To confirm the engine is operating properly.
- To confirm the boat's systems associated with the engine (exhaust, cooling, ventilation, fuel, starting, etc.) are adequate to allow the engine to operate up to its full potential.
- To determine the causes of performance deficiencies in the engine or boat.

Testing/Instruments and Accessories

The following tools are recommended for measurement of the data for start-up and associated performance testing.

Tachometer
Used to measure the speed (rpm) of the engine.

Caterpillar Part Number – 6V3121 Multitach Group, See Special Instruction, SEHS7807

Pressure Measuring Device
Used to measure the pressure of the fluids (air, oil, water, and fuel) in many engine systems. There are both high and low limits on the pressure of all the fluids.

Caterpillar Part Number – 6V9450 Pressure Group, six vacuum/pressure gauges permit a check of air cleaner restriction, oil pressure, manifold pressure, and fuel pressure. Provides readings in psi and kPa. Pressure range – 15 psi to 150 psi (100 kPa to 1000 kPa), See Special Instruction SEHS8524.

Temperature Measuring Device
Used to measure the temperature of the fluids (air, oil, water, and fuel) in many engine systems.

Caterpillar Part Number – 9S9102/8T0470 Thermistor Groups, Temperature Range = –20° F to 2500° F (–30° C to 1370° C), See Special Instruction SMHS7140 and SEHS8446.

Fuel Density Measuring Device
Used to measure the relative amount of energy in the fuel. The heavier a quantity of fuel is, the more energy it contains and the more power it will generate in an engine.

Caterpillar Part Number – IP7408 Thermohydrometer and 1P7438 Beaker are used to measure the API gravity and temperature of diesel fuel, so corrected horsepower can be calculated.

Pyrometer
Used to measure the engine's exhaust temperature.

Caterpillar Part Number – IP3060 Pyrometer Group, Temperature Range = 0° F to 1600° F (18° C to 870° C), See Special Instruction SEHS7807.

Pitchometer
Used to measure the propeller's pitch; confirming their accuracy.

Caterpillar Part Number – 8T5322 Pitchometer accurately measures propeller blade pitch either on or off the propeller shaft. Pitch can be measured at any shaft angle and at any point along the length of the blade, even under water. See Special Instruction SEHS8643.

Probe Seal Adapters
Used to allow measurement of the various pressures and temperatures of the engine's systems without need to shut down and drain the fluids therein. Works like the valve in a soccer ball. The adapters can be permanently installed and are equipped with a hex head plug to eliminate leakage and debris accumulation.

Caterpillar Part No.	5P2720 $\frac{1}{8}$ in.-27 NPT Thread
	5P2725 $\frac{1}{4}$ in.-18 NPT Thread

See Special Instruction SMHS7140.

Water Manometer
Measures the exhaust backpressure and intake duct or air cleaner restriction to flow.

Caterpillar Part Number – 8T0452 Water Manometer can be locally made from 5 ft (1550 mm) length of flexible clear plastic $\frac{3}{8}$ in I.D. tubing. See Special Instruction SEHS8524.

Fuel Flow Measuring Device
Used in conjunction with the tachometer (engine speed), pressure measuring device (intake manifold pressure), and pyrometer (exhaust temperature) to determine the power demanded of the engine.

Caterpillar Part No. IU5430 Fuel Monitor Arrangement for use with 3100, 3208, 3300, and 3400 Engine Families. Fuel flow range 3 U.S. gph to 70 U.S. gph (11.4 Lph to 264 Lph). IU5440 Fuel Monitor Arrangement for use with 3500, 3606, and 3608 Engines fuel flow range 40 U.S. gph to 1,000 U.S. gph (151.4 Lph to 3785 Lph).

Boat Speed Measuring Device
Hand-held radar (like that used by traffic law enforcement officers to check vehicle speed) is effective for this purpose.

Serviceability

General Information

Well-designed engine compartments will include features which contribute to the serviceability of the machinery. For example, overhead lifting equipment, some engine subassemblies may be heavier than one man can safely lift by hand, particularly in the often close quarters of the machinery space.

Hatches located directly above engines, for simplified removal and reinstallation during overhaul.

Outlets of electricity and compressed air to drive high production mechanic's tools.

Access to those points on the engine which require periodic preventive maintenance such as:

- lube oil filters and drain plug – engine and transmission
- fuel and air filters
- sea water and jacket water pump
- turbochargers
- zinc plugs
- heat exchanger – for core cleaning

Overhead Clearance for Connecting Rods and Piston Removal

The following table gives the height above the crankshaft centerline requirements to allow removal of a connecting rod and piston from the engines. This information is offered to assist designers who wish to provide adequate overhead clearance for piston/connecting rod removal.

In-Line Engines

Engine	Height Above Crankshaft Center
3116, 3126, 3126B	24.6 in. (626 mm)
3304B, 3306B	28 in. (711 mm)
3176, 3196	25 in. (635 mm)
3406B, C&E	30.9 in. (786 mm)
D353	44.37 in. (1127 mm)
3606, 3608	82.16 in. (2087 mm)*

*Distance to remove cylinder liner

Vee Engines

Engine	Height Above Crankshaft Center
3408B&C, 3412C&E	27.28 in. (693 mm)
D346, D348, D349	35.94 in. (913 mm)
D379, D398, D399	48.58 in. (1234 mm)
3508, 3512, 3516	38.15 in. (969 mm)
3612, 3616	74.49 in. (1891 mm)*

*Distance to remove cylinder liner

Caterpillar Inc.
Marine Engine Flash Codes

Desired for All 6 Cylinders

Flash Code	Name
13	Fuel Temperature Sensor Fault
14	Injector Actuation Valve Fault
15	Fuel Level Sensor Fault
16	Low Fuel Level Warning
17	Battery Voltage Below Normal
21	Sensor Supply Voltage Fault
23	Engine Oil Temperature Sensor Fault
24	Engine Oil Pressure Sensor Fault
25	Turbo Outlet Pressure Fault
26	Atmospheric Pressure Sensor Fault
27	Engine Coolant Temperature Sensor Fault
28	Throttle Sensor Calibration
32	Throttle Position Sensor Fault
34	Engine Speed Sensor Fault
35	Engine Overspeed Warning
36	Unexpected Engine Shutdown
37	Fuel Delivery Pressure Sensor Fault
38	Inlet Air Manifold Temperature Sensor Fault
42	Check Sensor Calibration Check Timing Sensor Calibration Boost Pressure Sensor Calibration
43	Injector Actuation Pressure Sensor Fault
44	High Injector Actuation Pressure
45	Shut Off Solenoid
46	Low Oil Pressure Warning Very Low Oil Pressure Warning
48	Excessive Engine Power
51	Intermittent Battery
52	Programmed Parameter Fault
53	ECM Fault
56	Check Customer/System Parameters
58	Low Coolant Level Warning Very Low Coolant Level Warning
59	Incorrect Engine Software
61	High Coolant Temperature Warning Very High Coolant Temperature Warning
62	Engine Coolant Level Sensor Fault
63	Fuel Pressure Warning
64	High Inlet Air Temperature Warning Very High Inlet Air Temperature Warning
65	High Fuel Temp Warning
66	High Transmission Oil Temperature
67	Transmission Oil Temperature Sensor Fault
68	Transmission Oil Pressure Sensor Fault
69	High Transmission Oil Pressure Warning

Flash Code	Name
71	Injector Cylinder #1
72	Injector Cylinder #2
73	Injector Cylinder #3
74	Injector Cylinder #4
75	Injector Cylinder #5
76	Injector Cylinder #6

Desired for All 12 Cylinders

Flash Code	Name
13	Fuel Temperature Sensor Fault
14	Injector Actuation Valve Fault
15	Fuel Level Sensor Fault
16	Low Fuel Level Warning
17	Battery Voltage Below Normal
21	Sensor Supply Voltage Fault
23	Engine Oil Temperature Sensor Fault
24	Engine Oil Pressure Sensor Fault
25	Turbo Outlet Pressure Fault
26	Atmospheric Pressure Sensor Fault
27	Engine Coolant Temperature Sensor Fault
28	Throttle Sensor Calibration
32	Throttle Position Sensor Fault
34	Engine Speed Sensor Fault
35	Engine Overspeed Warning
36	Unexpected Engine Shutdown
37	Fuel Delivery Pressure Sensor Fault
38	Inlet Air Manifold Temperature Sensor Fault
42	Check Sensor Calibration
	Check Timing Sensor Calibration
	Boost Pressure Sensor Calibration
43	Injector Actuation Pressure Sensor Fault
44	High Injector Actuation Pressure
45	Shut Off Solenoid
46	Low Oil Pressure Warning
	Very Low Oil Pressure Warning
48	Excessive Engine Power
51	Intermittent Battery
52	Programmed Parameter Fault
53	ECM Fault
56	Check Customer/System Parameters
58	Low Coolant Level Warning
	Very Low Coolant Level Warning
59	Incorrect Engine Software
61	High Coolant Temperature Warning
	Very High Coolant Temperature Warning
62	Engine Coolant Level Sensor Fault
63	Fuel Pressure Warning
64	High Inlet Air Temperature Warning
	Very High Inlet Air Temperature Warning
65	High Fuel Temp Warning

Flash Code	Name
66	High Transmission Oil Temperature
67	Transmission Oil Temperature Sensor Fault
68	Transmission Oil Pressure Sensor Fault
69	High Transmission Oil Pressure Warning
71	Injector Cylinder #1
72	Injector Cylinder #2
73	Injector Cylinder #3
74	Injector Cylinder #4
75	Injector Cylinder #5
76	Injector Cylinder #6
77	Injector Cylinder #7
78	Injector Cylinder #8
81	Injector Cylinder #9
82	Injector Cylinder #10
83	Injector Cylinder #11
84	Injector Cylinder #12
85	Injector Cylinder #13
86	Injector Cylinder #14
87	Injector Cylinder #15
88	Injector Cylinder #16

C-9, 3126B Diagnostic Codes

CID-FMI	Description
01-11	Injector Cylinder 1 Mechanical Failure
02-11	Injector Cylinder 2 Mechanical Failure
03-11	Injector Cylinder 3 Mechanical Failure
04-11	Injector Cylinder 4 Mechanical Failure
05-11	Injector Cylinder 5 Mechanical Failure
06-11	Injector Cylinder 6 Mechanical Failure
41-03	Digital Sensor Power Above Normal
41-04	Digital Sensor Power Below Normal
42-05	Injection Actuation Pressure Control Valve Open Circuit
42-06	Injection Actuation Pressure Control Valve Short Circuit
42-11	Injection Actuation Pressure Control Valve Open/Short
91-08	Throttle Position Signal Abnormal
91-13	Throttle Position Sensor Calibration Required
100-03	Oil Pressure Sensor Open/Short To +Battery
100-04	Oil Pressure Sensor Short To –Battery
102-03	Boost Sensor Open/Short To +Battery
102-04	Boost Sensor Short To –Battery
105-03	Inlet Manifold Temperature Open/Short To +Battery
105-04	Inlet Manifold Temperature Short To –Battery
110-03	Coolant Temperature Sensor Open/Short To +Battery
110-04	Coolant Temperature Sensor Short To –Battery
127-03	Transmission Oil Pressure Sensor Open/Short To +Battery
127-04	Transmission Oil Pressure Sensor Short To –Battery
164-03	Injection Actuation Pressure Sensor Open/Short To +Battery

CID-FMI	Description
164-04	Injection Actuation Pressure Sensor Short To –Battery
164-11	Injection Actuation Pressure Sensor Mechanical Failure
168-00	Battery Voltage Above Normal
168-01	Battery Voltage Below Normal
168-02	Battery Voltage Intermittent
177-03	Transmission Oil Temperature Sensor Open/Short To +Battery
177-04	Transmission Oil Temperature Sensor Short to –Battery
190-02	Loss Of Primary Engine Speed/ Timing Signal
190-07	Primary Engine Speed/Timing Sensor Misinstalled
190-08	Primary Engine Speed/Timing Signal Abnormal
253-02	Personality Module Mismatch
254-12	ECM Fault
261-13	Timing Sensor Calibration Required
262-03	Analog Sensor Supply Above Normal
262-04	Analog Sensor Supply Below Normal
268-02	Check Programmable Parameters
320-11	Primary Speed/Timing Mechanical Failure
342-02	Loss Of Secondary Engine Speed/Timing Signal
342-07	Secondary Engine Speed/Timing Sensor Misinstalled
342-08	Secondary Engine Speed/Timing Signal Abnormal
342-11	Secondary Engine Speed/Timing Mechanical Failure
1249-08	Secondary Throttle Position Signal Abnormal
1249-13	Secondary Throttle Position Sensor Calibration Required

C-12, 3196, 3406E Diagnostic Codes

CID-FMI	Description
100-01	Low Oil Pressure Warning
100-11	Very Low Oil Pressure Warning
105-00	High Inlet Air Manifold Temperature Warning
105-11	Very High Inlet Air Manifold Temperature Warning
110-00	High Coolant Temperature Warning
110-11	Very High Coolant Temperature Warning
110-01	Low Coolant Level Warning
111-11	Very Low Coolant Level Warning
127-00	High Transmission Oil Pressure Warning
168-01	Battery To ECM Below Normal
168-02	Intermittent Battery
174-00	High Fuel Temperature Warning
177-00	High Transmission Oil Temperature Warning
190-00	Engine Overspeed Warning

3412E Diagnostic Codes

CID-FMI	Description
01-05	Injector Cylinder 1 Open Circuit
01-06	Injector Cylinder 1 Short
02-05	Injector Cylinder 2 Open Circuit
02-06	Injector Cylinder 2 Short
03-05	Injector Cylinder 3 Open Circuit
03-06	Injector Cylinder 3 Short
04-05	Injector Cylinder 4 Open Circuit
04-06	Injector Cylinder 4 Short
05-05	Injector Cylinder 5 Open Circuit
05-06	Injector Cylinder 5 Short
06-05	Injector Cylinder 6 Open Circuit
06-06	Injector Cylinder 6 Short
07-05	Injector Cylinder 7 Open Circuit
07-06	Injector Cylinder 7 Short
08-05	Injector Cylinder 8 Open Circuit
08-06	Injector Cylinder 8 Short
09-05	Injector Cylinder 9 Open Circuit
09-06	Injector Cylinder 9 Short
10-05	Injector Cylinder 10 Open Circuit
10-06	Injector Cylinder 10 Short
11-05	Injector Cylinder 11 Open Circuit
11-06	Injector Cylinder 11 Short
12-05	Injector Cylinder 12 Open Circuit
12-06	Injector Cylinder 12 Short
42-05	Injection Actuation Pressure Control Valve Open Circuit
42-06	Injection Actuation Pressure Control Valve Short To –Battery
91-08	Throttle Position Signal Abnormal
91-13	Throttle Position Calibration Required
94-03	Fuel Pressure Open/Short to +Battery
94-04	Fuel Pressure Short to –Battery
100-03	Engine Oil Pressure Open/Short To +Battery
100-04	Engine Oil Pressure Short To –Battery
100-13	Engine Oil Pressure Calibration Required
100-03	Engine Coolant Temperature Open/Short To +Battery
110-04	Engine Coolant Temperature Short To –Battery
127-03	Transmission Oil Pressure Open/Short To +Battery
127-04	Transmission Oil Pressure Short To –Battery
164-03	Injection Actuation Pressure Open/Short To +Battery
168-00	System Voltage High
168-01	System Voltage Low
168-02	System Voltage Intermittent
174-03	Fuel Temperature Open/Short To +Battery
174-04	Fuel Temperature Short To –Battery
175-03	Engine Oil Temperature Open/Short To +Battery
175-04	Engine Oil Temperature Short To –Battery
177-03	Transmission Oil Temperature Open/Short To +Battery
177-04	Transmission Oil Temperature Short To –Battery
190-02	Loss Of Primary Engine Speed Signal
190-03	Engine Speed Open/Short To +Battery

CID-FMI	Description
190-07	Primary Speed Sensor Misinstalled
190-08	Primary Speed Signal Abnormal
253-02	Personality Module Mismatch
254-12	ECM Fault
261-13	Engine Timing Calibration Required
262-03	5 Volt Sensor Supply Short To +Battery
262-04	5 Volt Sensor Supply Short To –Battery
263-03	Digital Sensor Supply Short To +Battery
263-04	Digital Sensor Supply Short To –Battery
268-02	Check Programmable Parameters
273-03	Turbo Outlet Pressure Open/Short To +Battery
273-04	Turbo Outlet Pressure Short To –Battery
273-13	Turbo Outlet Pressure Calibration Required
274-03	Atmospheric Pressure Open/Short To +Battery
274-04	Atmospheric Pressure Short To –Battery
342-02	Loss Of Secondary Engine Speed Signal
342-03	Secondary Engine Speed Open/Short To +Battery
342-07	Secondary Speed Sensor Misinstalled
342-08	Secondary Engine Speed Signal Abnormal
E015	High Engine Coolant Temperature Derate
E017	High Engine Coolant Temperature Warning
E030	High Transmission Oil Temperature Warning
E039	Low Engine Oil Pressure Derate
E057	Low Engine Coolant Level Derate
E059	Low Engine Coolant Level Warning
E100	Low Engine Oil Pressure Warning
E113	High Transmission Oil Pressure
E164	High Injection Actuation Pressure
E190	Engine Overspeed Warning

MID
(MODULE IDENTIFIER)

MID	DESCRIPTION
030	EMS II
033	PORT ECM
034	STARBOARD ECM
036	PRIMARY (CENTER) ECM
047	SECONDARY ECM
076	DE-NOX CONTROLLER
097	CCM
099	PMCM

DIAGNOSTIC CODES

CID	FMI	DESCRIPTION
001	05	CYLINDER 1 OPEN CIRCUIT
001	06	CYLINDER 1 SHORT
002	05	CYLINDER 2 OPEN CIRCUIT
002	06	CYLINDER 2 SHORT
003	05	CYLINDER 3 OPEN CIRCUIT
003	06	CYLINDER 3 SHORT
004	05	CYLINDER 4 OPEN CIRCUIT
004	06	CYLINDER 4 SHORT
005	05	CYLINDER 5 OPEN CIRCUIT
005	06	CYLINDER 5 SHORT
006	05	CYLINDER 6 OPEN CIRCUIT
006	06	CYLINDER 6 SHORT
007	05	CYLINDER 7 OPEN CIRCUIT
007	06	CYLINDER 7 SHORT
008	05	CYLINDER 8 OPEN CIRCUIT
008	06	CYLINDER 8 SHORT
009	05	CYLINDER 9 OPEN CIRCUIT
009	06	CYLINDER 9 SHORT
010	05	CYLINDER 10 OPEN CIRCUIT
010	06	CYLINDER 10 SHORT
011	05	CYLINDER 11 OPEN CIRCUIT
011	06	CYLINDER 11 SHORT
012	05	CYLINDER 12 OPEN CIRCUIT
012	06	CYLINDER 12 SHORT
013	05	CYLINDER 13 OPEN CIRCUIT
013	06	CYLINDER 13 SHORT
014	05	CYLINDER 14 OPEN CIRCUIT
014	06	CYLINDER 14 SHORT
015	05	CYLINDER 15 OPEN CIRCUIT
015	06	CYLINDER 15 SHORT
016	05	CYLINDER 16 OPEN CIRCUIT
016	06	CYLINDER 16 SHORT
091	08	THROTTLE SIGNAL OUTPUT IS ABNORMAL
094	03	FUEL PRESSURE SIGNAL OPEN/SHORT TO BATT+
094	04	FUEL PRESSURE SIGNAL SHORT TO GND
094	13	FUEL PRESSURE CALIBRATION
096	03	FUEL LEVEL SENSOR – SHORT HIGH OR OPEN CIRCUIT
100	03	OIL PRESSURE SIGNAL OPEN/SHORT TO BATT+
100	04	OIL PRESSURE SIGNAL SHORT TO GND
100	13	OIL PRESSURE CALIBRATION
101	03	CRANKCASE PRESSURE SIGNAL OPEN/SHORT TO BATT+
101	04	CRANKCASE PRESSURE SIGNAL SHORT TO GND
101	13	CRANKCASE PRESSURE SIGNAL CALIBRATION
110	03	COOLANT TEMP SIGNAL OPEN/SHORT TO BATT+
110	04	COOLANT TEMP SIGNAL SHORT TO GND
127	08	POWERTRAIN OIL PRESSURE – ABNORMAL SIGNAL
168	00	BATTERY VOLTAGE ABOVE NORMAL

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168	01	BATTERY VOLTAGE BELOW NORMAL
168	02	BATTERY VOLTAGE INTERMITTENT
172	08	AIR INLET TEMPERATURE - ABNORMAL SIGNAL
175	08	ENGINE OIL TEMPERATURE - ABNORMAL SIGNAL
177	08	POWERTRAIN OIL TEMPERATURE - ABNORMAL SIGNAL
190	02	LOSS OF ENGINE SPEED SIGNAL
190	03	ENGINE SPEED OPEN/SHORT TO BATT+
190	08	ENGINE SPEED SIGNAL ABNORMAL
248	02	CAT DATA LINE - DATA INTERMITTENT OR INCORRECT
253	02	PERSONALITY MODULE MISMATCH
254	12	ECM FAULT
261	13	TIMING CALIBRATION
262	03	ANALOG SENSOR SUPPLY SHORT TO BATT+
262	04	ANALOG SENSOR SUPPLY SHORT TO GND
263	03	DIGITAL SENSOR SUPPLY SHORT TO BATT+
263	04	DIGITAL SENSOR SUPPLY SHORT TO GND
268	02	PROGRAMMABLE PARAMETERS FAULT
271	03	ACTION ALARM - SHORT TO BATT+
271	05	ACTION ALARM - OPEN CIRCUIT
271	06	ACTION ALARM - SHORT TO GND
273	03	TURBO OUT PRESS SIGNAL OPEN/SHORT TO BATT+
273	04	TURBO OUT PRESS SIGNAL SHORT TO GND
273	13	TURBO OUT PRESSURE SIGNAL CALIBRATION FAULT
274	03	ATMOS PRESS SIGNAL OPEN/SHORT TO BATT+
274	04	ATMOS PRESS SIGNAL SHORT TO GND
274	13	ATMOS PRESSURE SIGNAL CALIBRATION FAULT
275	03	RIGHT TURBO IN PRESS SIGNAL OPEN/SHORT TO BATT+
275	04	RIGHT TURBO IN PRESS SIGNAL SHORT TO GND
275	13	RIGHT TURBO IN PRESS SIGNAL CALIBRATION FAULT
276	03	LEFT TURBO IN PRESS SIGNAL OPEN/SHORT TO BATT+
276	04	LEFT TURBO IN PRESS SIGNAL SHORT TO GND
276	13	LEFT TURBO IN PRESS SIGNAL CALIBRATION FAULT
279	03	AFTERCOOLER WATER TEMP SIGNAL OPEN/SHORT TO BATT+
279	04	AFTERCOOLER WATER TEMP SIGNAL SHORT TO GND
289	03	UNFILTERED FUEL PRESSURE OPEN/SHORT TO BATT+
289	04	UNFILTERED FUEL PRESSURE SHORT TO GND
289	13	UNFILTERED FUEL PRESSURE CALIBRATION
336	02	ECS INPUTS ARE COMPLIMENTARY
337	02	E-STOP INPUTS ARE COMPLIMENTARY
338	05	PRELUBE RELAY OPEN CIRCUIT
338	06	PRELUBE RELAY SHORT TO GND
342	02	LOSS OF BACKUP ENGINE SPEED SIGNAL
342	03	BACKUP ENGINE SPEED OPEN/SHORT TO BATT+
342	08	BACKUP ENGINE SPEED SIGNAL ABNORMAL
444	03	STARTER RELAY SHORT TO BATT+
444	05	STARTER RELAY OPEN CIRCUIT
444	06	STARTER RELAY SHORT TO GND
446	05	AIR SHUTDOWN RELAY OPEN CIRCUIT
446	06	AIR SHUTDOWN RELAY SHORT TO GND
542	03	UNFILTERED OIL PRESSURE OPEN/SHORT TO BATT+
542	04	UNFILTERED OIL PRESSURE SHORT TO GND
542	13	UNFILTERED OIL PRESSURE CALIBRATION
545	05	ETHER START RELAY OPEN/SHORT TO BATT+
545	06	ETHER START RELAY SHORT TO GND
546	05	ETHER HOLD RELAY OPEN/SHORT TO BATT+
546	06	ETHER HOLD RELAY SHORT TO GND
562	09	UNABLE TO COMMUNICATE WITH SCMS
819	02	DISPLAY DATA LINK - DATA INTERMITTENT OR INCORRECT
821	03	9V DISPLAY SUPPLY - SHORT TO BATT+
821	04	9V DISPLAY SUPPLY - SHORT TO GND
827	08	LEFT TURBINE INLET EXHAUST TEMP SIGNAL ABNORMAL
828	08	RIGHT TURBINE INLET EXHAUST TEMP SIGNAL ABNORMAL

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Conversion Factors

Handy Multipliers for Engineers

English measures — unless otherwise designated, are those used in the United States, and the units of weight and mass are avoirdupois units.

Gallon — designates the U.S. gallon. To convert into the Imperial gallon, multiply the U.S. gallon by 0.83267.

Exponents — the figures 10^{-1}, 10^{-2}, 10^{-3}, etc. denote 0.1, 0.01, 0.001, etc. respectively.

The figures 10^{1}, 10^{2}, 10^{3}, etc. denote 10, 100, 1000, etc. respectively.

Properties of water — it freezes at 32° F, and is at its maximum density at 39.2° F. In the multipliers using the properties of water, calculations are based on water at 39.2° F in a vacuum, weighing 62.427 pounds per cubic foot, or 8.345 pounds per U.S. gallon.

Parts Per Million — designated as P.P.M., is always by weight and is simply a more convenient method of expressing concentration, either dissolved or undissolved material. Usually P.P.M. is used where percentage would be so small as to necessitate several ciphers after the decimal point, as one part per million is equal to 0.0001 percent.

As used in the sanitary field, P.P.M. represents the number of pounds of dry solids contained in one million pounds of water, including solids. In this field, one part per million may be expressed as 8.345 pounds of dry solids to one million U.S. gallons of water. In the Metric system, one part per million may be expressed as one gram of dry solids to one million grams of water, or one milligram per liter.

In arriving at parts per million by means of pounds per million gallons or milligrams per liter, it may be mentioned that the density of the solution or suspension has been neglected and if this is appreciably different from unity, the results are slightly in error.

Multiply	**By**	**To Obtain**
Acres	43,560	Square feet
Acres	4047	Square meters
Acres	1.562×10^{-3}	Square miles
Acres	4840	Square yards
Acre – feet	43,560	Cubic feet
Acre – feet	325,851	Gallons
Acre – feet	1233.48	Cubic meters
Atmospheres	76.0	Cms of mercury
Atmospheres	29.92	Inches of mercury
Atmospheres	33.90	Feet of water
Atmospheres	10,332	Kgs/sq meter

Multiply	By	To Obtain
Atmospheres	14.70	Lbs/sq inch
Atmospheres	1.058	Tons/sq ft
Barrels – oil	42	Gallons – oil
Barrels – cement	376	Pounds – cement
Bags or sacks – cement	94	Pounds – cement
Board feet	144 sq in $\times$ 1 in	Cubic inches
British Thermal Units	0.2520	Kilogram – calories
British Thermal Units	777.6	Foot – lbs
British Thermal Units	3.927×10^{-4}	Horsepower – hrs
British Thermal Units	107.5	Kilogram – meters
British Thermal Units	2.928×10^{-4}	Kilowatt – hrs
BTU/min	12.96	Foot – lbs/sec
BTU/min	0.02356	Horsepower
BTU/min	0.01757	Kilowatts
BTU/min	17.57	Watts
Centares (Centiares)	1	Square meters
Centigrams	0.01	Grams
Centiliters	0.01	Liters
Centimeters	0.3937	Inches
Centimeters	0.01	Meters
Centimeters	10	Millimeters
Centimeters of mercury	0.01316	Atmospheres
Centimeters of mercury	0.4461	Feet of water
Centimeters of mercury	136.0	Kgs/sq meter
Centimeters of mercury	27.85	Lbs/sq ft
Centimeters of mercury	0.1934	Lbs/sq inch
Centimeters/sec	1.969	Feet/min
Centimeters/sec	0.03281	Feet/sec
Centimeters/sec	0.036	Kilometers/hr
Centimeters/sec	0.6	Meters/min
Centimeters/sec	0.02237	Miles/hr
Centimeters/sec	3.728×10^{-4}	Miles/min
Cms/sec/sec	0.03281	Feet/sec/sec
Cubic centimeters	3.531×10^{-5}	Cubic feet
Cubic centimeters	6.102×10^{-2}	Cubic inches
Cubic centimeters	10^{-6}	Cubic meters
Cubic centimeters	1.308×10^{-6}	Cubic yards
Cubic centimeters	2.642×10^{-4}	Gallons
Cubic centimeters	9.999×10^{-4}	Liters
Cubic centimeters	2.113×10^{-3}	Pints (liq)
Cubic centimeters	1.057×10^{-3}	Quarts (liq)
Cubic feet	2.832×10^{4}	Cubic cms
Cubic feet	1728	Cubic inches

Multiply	By	To Obtain
Cubic feet	0.02832	Cubic meters
Cubic feet	0.03704	Cubic yards
Cubic feet	7.48052	Gallons
Cubic feet	28.32	Liters
Cubic feet	59.84	Pints (liq)
Cubic feet	29.92	Quarts (liq)
Cubic feet/min	472.0	Cubic cms/sec
Cubic feet/min	0.1247	Gallons/sec
Cubic feet/min	0.4719	Liters/sec
Cubic feet/min	62.43	Pounds of water/min
Cubic feet/sec	0.646317	Millions gals/day
Cubic feet/sec	448.831	Gallons/min
Cubic inches	16.39	Cubic centimeters
Cubic inches	5.787×10^{-4}	Cubic feet
Cubic inches	1.639×10^{-5}	Cubic meters
Cubic inches	2.143×10^{-5}	Cubic yards
Cubic inches	4.329×10^{-3}	Gallons
Cubic inches	1.639×10^{-2}	Liters
Cubic inches	0.03463	Pints (liq)
Cubic inches	0.01732	Quarts (liq)
Cubic meters	10^{6}	Cubic centimeters
Cubic meters	35.31	Cubic feet
Cubic meters	61023	Cubic inches
Cubic meters	1.308	Cubic yards
Cubic meters	264.2	Gallons
Cubic meters	999.97	Liters
Cubic meters	2113	Pints (liq)
Cubic meters	1057	Quarts (liq)
Cubic yards	764,554.86	Cubic centimeters
Cubic yards	27	Cubic feet
Cubic yards	46,656	Cubic inches
Cubic yards	0.7646	Cubic meters
Cubic yards	202.0	Gallons
Cubic yards	764.5	Liters
Cubic yards	1616	Pints (liq)
Cubic yards	807.9	Quarts (liq)
Cubic yards/min	0.45	Cubic feet/sec
Cubic yards/min	3.366	Gallons/sec
Cubic yards/min	12.74	Liters/sec
Decigrams	0.1	Grams
Deciliters	0.1	Liters
Decimeters	0.1	Meters
Degrees (angle)	60	Minutes

Multiply	**By**	**To Obtain**
Degrees (angle)	0.01745	Radians
Degrees (angle)	3600	Seconds
Degrees/sec	0.01745	Radians/sec
Degrees/sec	0.1667	Revolutions/min
Degrees/sec	0.002778	Revolutions/sec
Dekagrams	10	Grams
Dekaliters	10	Liters
Dekameters	10	Meters
Drams	27.34375	Grains
Drams	0.0625	Ounces
Drams	1.771845	Grams
Fathoms	6	Feet
Feet	30.48	Centimeters
Feet	12	Inches
Feet	0.3048	Meters
Feet	1/3	Yards
Feet of water	0.0295	Atmospheres
Feet of water	0.8826	Inches of mercury
Feet of water	304.8	Kgs/sq meter
Feet of water	62.43	Lbs/sq ft
Feet of water	0.4335	Lbs/sq inch
Feet/min	0.5080	Centimeters/sec
Feet/min	0.01667	Feet/sec
Feet/min	0.01829	Kilometers/hr
Feet/min	0.3048	Meters/min
Feet/min	0.01136	Miles/hr
Feet/sec	30.48	Centimeters/sec
Feet/sec	1.097	Kilometers/hr
Feet/sec	0.5924	Knots
Feet/sec	18.29	Meters/min
Feet/sec	0.6818	Miles/hr
Feet/sec	0.01136	Miles/min
Feet/sec/sec	30.48	Cms/sec/sec
Feet/sec/sec	0.3048	Meters/sec/sec
Foot – pounds	1.286×10^{-3}	British Thermal Units
Foot – pounds	5.050×10^{-7}	Horsepower – hrs
Foot – pounds	3.240×10^{-4}	Kilogram – calories
Foot – pounds	0.1383	Kilogram – meters
Foot – pounds	3.766×10^{-7}	Kilowatt – hours
Foot – pounds/min	2.140×10^{-5}	BTU/sec
Foot – pounds/min	0.01667	Foot – pounds/sec
Foot – pounds/min	3.030×10^{-5}	Horsepower
Foot – pounds/min	5.393×10^{-3}	Gm – calories/sec

Multiply	By	To Obtain
Foot – pounds/min	2.260×10^{-5}	Kilowatts
Foot – pounds/sec	7.704×10^{-2}	BTU/min
Foot – pounds/sec	1.818×10^{-3}	Horsepower
Foot – pounds/sec	1.941×10^{-2}	Kg – calories/min
Foot – pounds/sec	1.356×10^{-3}	Kilowatts
Gallons	3785	Cubic centimeters
Gallons	0.1337	Cubic feet
Gallons	231	Cubic inches
Gallons	3.785×10^{-3}	Cubic meters
Gallons	4.951×10^{-3}	Cubic yards
Gallons	3.785	Liters
Gallons	8	Pints (liq)
Gallons	4	Quarts (liq)
Gallons – Imperial	1.20095	US gallons
Gallons – US	0.83267	Imperial gallons
Gallons water	8.345	Pounds of water
Gallons/min	2.228×10^{-3}	Cubic feet/sec
Gallons/min	0.06308	Liters/sec
Gallons/min	8.0208	Cu ft/hr
Grains (troy)	0.06480	Grams
Grains (troy)	0.04167	Pennyweights (troy)
Grains (troy)	2.0833×10^{-3}	Ounces (troy)
Grains/US gal	17.118	Parts/million
Grains/US gal	142.86	Lbs/million gal
Grains/Imp gal	14.254	Parts/million
Grams	980.7	Dynes
Grams	15.43	Grains
Grams	0.001	Kilograms
Grams	1000	Milligrams
Grams	0.03527	Ounces
Grams	0.03215	Ounces (troy)
Grams	2.205×10^{-3}	Pounds
Grams/cm	5.600×10^{-3}	Pounds/inch
Grams/cu cm	62.43	Pounds/cubic foot
Grams/cu cm	0.03613	Pounds/cubic inch
Grams/liter	58.416	Grains/gal
Grams/liter	8.345	Pounds/1000 gals
Grams/liter	0.06242	Pounds/cubic foot
Grams/liter	1000	Parts/million
Hectares	2.471	Acres
Hectares	1.076×10^{5}	Square feet
Hectograms	100	Grams
Hectoliters	100	Liters

Multiply	By	To Obtain
Hectometers	100	Meters
Hectowatts	100	Watts
Horsepower	42.44	BTU/min
Horsepower	33,000	Foot – lbs/min
Horsepower	550	Foot – lbs/sec
Horsepower	1.014	Horsepower (metric)
Horsepower	10.547	Kg – calories/min
Horsepower	0.7457	Kilowatts
Horsepower	745.7	Watts
Horsepower (boiler)	33,493	BTU/hr
Horsepower (boiler)	9.809	Kilowatts
Horsepower – hours	2546	BTU
Horsepower – hours	1.98×10^6	Foot – lbs
Horsepower – hours	641.6	Kilogram – calories
Horsepower – hours	2.737×10^5	Kilogram – meters
Horsepower – hours	0.7457	Kilowatt – hours
Inches	2.540	Centimeters
Inches of mercury	0.03342	Atmospheres
Inches of mercury	1.133	Feet of water
Inches of mercury	345.3	Kgs/sq meter
Inches of mercury	70.73	Lbs/sq ft
Inches of mercury (32° F)	0.491	Lbs/sq inch
Inches of water	0.002458	Atmospheres
Inches of water	0.07355	Inches of mercury
Inches of water	25.40	Kgs/sq meter
Inches of water	0.578	Ounces/sq inch
Inches of water	5.202	Lbs/sq foot
Inches of water	0.03613	Lbs/sq inch
Kilograms	980,665	Dynes
Kilograms	2.205	Lbs
Kilograms	1.102×10^{-3}	Tons (short)
Kilograms	10^3	Grams
Kilograms – cal/sec	3.968	BTU/sec
Kilograms – cal/sec	3086	Foot – lbs/sec
Kilograms – cal/sec	5.6145	Horsepower
Kilograms – cal/sec	4186.7	Watts
Kilogram – cal/min	3085.9	Foot – lbs/min
Kilogram – cal/min	0.09351	Horsepower
Kilogram – cal/min	69.733	Watts
Kgs/meter	6.720	Lbs/foot
Kgs/sq meter	9.678×10^{-5}	Atmospheres
Kgs/sq meter	3.281×10^{-3}	Feet of water
Kgs/sq meter	2.896×10^{-3}	Inches of mercury

Multiply	By	To Obtain
Kgs/sq meter	0.2048	Lbs/sq foot
Kgs/sq meter	1.422×10^{-3}	Lbs/sq inch
Kgs/sq millimeter	10^{6}	Kgs/sq meter
Kiloliters	10^{3}	Liters
Kilometers	10^{5}	Centimeters
Kilometers	3281	Feet
Kilometers	10^{3}	Meters
Kilometers	0.6214	Miles
Kilometers	1094	Yards
Kilometers/hr	27.78	Centimeters/sec
Kilometers/hr	54.68	Feet/min
Kilometers/hr	0.9113	Feet/sec
Kilomteters/hr	0.5399	Knots
Kilometers/hr	16.67	Meters/min
Kilometers/hr	0.6214	Miles/hr
Kms/hr/sec	27.78	Cms/sec/sec
Kms/hr/sec	0.9113	Ft/sec/sec
Kms/hr/sec	0.2778	Meters/sec/sec
Kilowatts	56.907	BTU/min
Kilowatts	4.425×10^{4}	Foot – lbs/min
Kilowatts	737.6	Foot – lbs/sec
Kilowatts	1.341	Horsepower
Kilowatts	14.34	Kg – calories/min
Kilowatts	10^{3}	Watts
Kilowatt – hours	3414.4	BTU
Kilowatt – hours	2.655×10^{6}	Foot – lbs
Kilowatt – hours	1.341	Horsepower – hrs
Kilowatt – hours	860.4	Kilogram – calories
Kilowatt – hours	3.671×10^{5}	Kilogram – meters
Liters	10^{3}	Cubic centimeters
Liters	0.03531	Cubic feet
Liters	61.02	Cubic inches
Liters	10^{-3}	Cubic meters
Liters	1.308×10^{-3}	Cubic yards
Liters	0.2642	Gallons
Liters	2.113	Pints (liq)
Liters	1.057	Quarts (liq)
Liters/min	5.886×10^{-4}	Cubic ft/sec
Liters/min	4.403×10^{-3}	Gals/sec
Lumber Width (in) $\times$ $\frac{\text{Thickness (in)}}{12}$	Length (ft)	Board feet
Meters	100	Centimeters

Multiply	By	To Obtain
Meters	3.281	Feet
Meters	39.37	Inches
Meters	10^{-3}	Kilometers
Meters	10^{3}	Millimeters
Meters	1.094	Yards
Meters/min	1.667	Centimeters/sec
Meters/min	3.281	Feet/min
Meters/min	0.05468	Feet/sec
Meters/min	0.06	Kilometers/hr
Meters/min	0.03728	Miles/hr
Meters/sec	196.8	Feet/min
Meters/sec	3.281	Feet/sec
Meters/sec	3.6	Kilometers/hr
Meters/sec	0.06	Kilometers/min
Meters/sec	2.237	Miles/hr
Meters/sec	0.03728	Miles/min
Microns	10^{-6}	Meters
Miles	1.609×10^{5}	Centimeters
Miles	5280	Feet
Miles	1.609	Kilometers
Miles	1760	Yards
Miles/hr	44.70	Centimeters/sec
Miles/hr	88	Feet/min
Miles/hr	1.467	Feet/sec
Miles/hr	1.609	Kilometers/hr
Miles/hr	0.8689	Knots
Miles/hr	26.82	Meters/min
Miles/min	2682	Centimeters/sec
Miles/min	88	Feet/sec
Miles/min	1.609	Kilometers/min
Miles/min	60	Miles/hr
Milliers	10^{3}	Kilograms
Milligrams	10^{-3}	Grams
Milliliters	10^{-3}	Liters
Millimeters	0.1	Centimeters
Millimeters	0.03937	Inches
Milligrams/liter	1	Parts/million
Million gals/day	1.54723	Cubic ft/sec
Miner’s inches	1.5	Cubic ft/min
Minutes (angle)	2.909×10^{-4}	Radians
Ounces	16	Drams
Ounces	437.5	Grains
Ounces	0.0625	Pounds

Multiply	By	To Obtain
Ounces	28.3495	Grams
Ounces	0.9115	Ounces (troy)
Ounces	2.790×10^{-5}	Tons (long)
Ounces	2.835×10^{-5}	Tons (metric)
Ounces (troy)	480	Grains
Ounces (troy)	20	Pennyweights (troy)
Ounces (troy)	0.08333	Pounds (troy)
Ounces (troy)	31.10348	Grams
Ounces (troy)	1.09714	Ounces (avoir.)
Ounces (fluid)	1.805	Cubic inches
Ounces (fluid)	0.02957	Liters
Ounces/sq inch	0.0625	Lbs/sq inch
Parts/million	0.0584	Grains/US gal
Parts/million	0.07015	Grains/Imp gal
Parts/million	8.345	Lbs/million gal
Pennyweights (troy)	24	Grains
Pennyweights (troy)	1.55517	Grams
Pennyweights (troy)	0.05	Ounces (troy)
Pennyweights (troy)	4.1667×10^{-3}	Pounds (troy)
Pounds	16	Ounces
Pounds	256	Drams
Pounds	7000	Grains
Pounds	0.0005	Tons (short)
Pounds	453.5924	Grams
Pounds	1.21528	Pounds (troy)
Pounds	14.5833	Ounces (troy)
Pounds (troy)	5760	Grains
Pounds (troy)	240	Pennyweights (troy)
Pounds (troy)	12	Ounces (troy)
Pounds (troy)	373.2417	Grams
Pounds (troy)	0.822857	Pounds (avoir.)
Pounds (troy)	13.1657	Ounces (avoir.)
Pounds (troy)	3.6735×10^{-4}	Tons (long)
Pounds (troy)	4.1143×10^{-4}	Tons (short)
Pounds (troy)	3.7324×10^{-4}	Tons (metric)
Pounds of water	0.01602	Cubic feet
Pounds of water	27.68	Cubic inches
Pounds of water	0.1198	Gallons
Pounds of water/min	2.670×10^{-4}	Cubic ft/sec
Pounds/cubic foot	0.01602	Grams/cubic cm
Pounds/cubic foot	16.02	Kgs/cubic meters
Pounds/cubic foot	5.787×10^{-4}	Lbs/cubic inch
Pounds/cubic inch	27.68	Grams/cubic cm

Multiply	By	To Obtain
Pounds/cubic inch	2.768×10^4	Kgs/cubic meter
Pounds/cubic inch	1728	Lbs/cubic foot
Pounds/foot	1.488	Kgs/meter
Pounds/inch	178.6	Grams/cm
Pounds/sq foot	0.01602	Feet of water
Pounds/sq foot	4.882	Kgs/sq meter
Pounds/sq foot	6.944×10^{-3}	Pounds/sq inch
Pounds/sq inch	0.06804	Atmospheres
Pounds/sq inch	2.307	Feet of water
Pounds/sq inch	2.036	Inches of mercury
Pounds/sq inch	703.1	Kgs/sq meter
Quadrants (angle)	90	Degrees
Quadrants (angle)	5400	Minutes
Quadrants (angle)	1.571	Radians
Quarts (dry)	67.20	Cubic inches
Quarts (liq)	57.75	Cubic inches
Quintal, Argentine	101.28	Pounds
Quintal, Brazil	129.54	Pounds
Quintal, Castile, Peru	101.43	Pounds
Quintal, Chile	101.41	Pounds
Quintal, Mexico	101.47	Pounds
Quintal, Metric	220.46	Pounds
Quires	25	Sheets
Radians	57.30	Degrees
Radians	3438	Minutes
Radians	0.637	Quadrants
Radians/sec	57.30	Degrees/sec
Radians/sec	0.1592	Revolutions/sec
Radians/sec	9.549	Revolutions/min
Radians/sec/sec	573.0	Revs/min/min
Radians/sec/sec	0.1592	Revs/sec/sec
Reams	500	Sheets
Revolutions	360	Degrees
Revolutions	4	Quadrants
Revolutions	6.283	Radians
Revolutions/min	6	Degrees/sec
Revolutions/min	0.1047	Radians/sec
Revolutions/min	0.01667	Revolutions/sec
Revolutions/min/min	1.745×10^{-3}	Radians/sec/sec
Revolutions/min/min	2.778×10^{-4}	Revs/sec/sec
Revolutions/sec	360	Degrees/sec
Revolutions/sec	6.283	Radians/sec
Revolutions/sec	60	Revolutions/min

Multiply	By	To Obtain
Revolutions/sec/sec	6.283	Radians/sec/sec
Revolutions/sec/sec	3600	Revs/min/min
Seconds (angle)	4.848×10^{-6}	Radians
Square centimeters	1.076×10^{-3}	Square feet
Square centimeters	0.1550	Square inches
Square centimeters	10^{-4}	Square meters
Square centimeters	100	Square millimeters
Square feet	2.296×10^{-5}	Acres
Square feet	929.0	Square centimeters
Square feet	144	Square inches
Square feet	0.09290	Square meters
Square feet	3.587×10^{-8}	Square miles
Square feet	1/9	Square yards
$\frac{1}{\text{Sq ft/gal/min}}$	8.0208	Overflow rate (ft/hr)
Square inches	6.452	Square centimeters
Square inches	6.944×10^{-3}	Square feet
Square inches	645.2	Square millimeters
Square kilometers	247.1	Acres
Square kilometers	10.76×10^{6}	Square feet
Square kilometers	10^{6}	Square meters
Square kilometers	0.3861	Square miles
Square kilometers	1.196×10^{6}	Square yards
Square meters	2.471×10^{-4}	Acres
Square meters	10.76	Square feet
Square meters	3.861×10^{-7}	Square miles
Square meters	1.196	Square yards
Square miles	640	Acres
Square miles	27.88×10^{6}	Square feet
Square miles	2.590	Square kilometers
Square miles	3.098×10^{6}	Square yards
Square millimeters	0.01	Square centimeters
Square millimeters	1.550×10^{-3}	Square inches
Square yards	2.066×10^{-4}	Acres
Square yards	9	Square feet
Square yards	0.8361	Square meters
Square yards	3.228×10^{-7}	Square miles
Temp (°C) + 273	1	Abs temp (°C)
Temp (°C) + 17.78	1.8	Temp (°F)
Temp (°F) + 460	1	Abs temp (°F)
Temp (°F) – 32	5/9	Temp (°C)
Tons (long)	1016	Kilograms
Tons (long)	2240	Pounds

Multiply	By	To Obtain
Tons (long)	1.12000	Tons (short)
Tons (metric)	10^3	Kilograms
Tons (metric)	2205	Pounds
Tons (short)	2000	Pounds
Tons (short)	32,000	Ounces
Tons (short)	907.1848	Kilograms
Tons (short)	2430.56	Pounds (troy)
Tons (short)	0.89287	Tons (long)
Tons (short)	29166.66	Ounces (troy)
Tons (short)	0.90718	Tons (metric)
Tons of water/24 hrs	83.333	Pounds water/hr
Tons of water/24 hrs	0.16643	Gallons/min
Tons of water/24 hrs	1.3349	Cu ft/hr
Watts	0.05686	BTU/min
Watts	44.25	Foot – lbs/min
Watts	0.7376	Foot – lbs/sec
Watts	1.341×10^{-3}	Horsepower
Watts	0.01434	Kg – calories/min
Watts	10^{-3}	Kilowatts
Watt – hours	3.414	BTU
Watt – hours	2655	Foot – lbs
Watt – hours	1.341×10^{-3}	Horsepower – hrs
Watt – hours	0.8604	Kilogram – calories
Watt – hours	367.1	Kilogram – meters
Watt – hours	10^{-3}	Kilowatt – hours
Yards	91.44	Centimeters
Yards	3	Feet
Yards	36	Inches
Yards	0.9144	Meters

Volume Conversion

	cc	cu in	quarts	liters	gallons	cu ft
cc	1.0	0.06102	0.001056	0.001	0.000264	0.0000353
cu in	16.387	1.0	0.0173	0.016387	0.00433	0.000578
quarts	946.3	57.75	1.0	0.9464	0.250	0.0334
liters	0.1000	61.02	1.056	1.0	0.264	0.0353
gallons	3785.4	231	4	3.785	1.0	0.1337
cu ft	28314.8	1728	29.92	28.315	7.4805	1.0

	drops	tsp	tbsp	cup	quart	gallons	ounces
drops	1.0	0.01666	0.00555	0.000347	0.0000866	0.0000216	0.00277
tsp	60	1.0	0.333	0.02083	0.0052	0.0013	0.166
tbsp	180	3.0	1.0	0.0625	0.0156	0.0039	0.5
cup	2,880	48.0	16	1.0	0.25	0.0625	8
quart	11,520	192	64	4.0	1.0	0.25	32
gallon	46,080	768	256	16.0	4.0	1.0	128
ounces	360	0.6	0.2	0.125	0.03125	0.00107	1

12 drops/ml
12,172 drops/l
29.576 ml/oz
0.03381 oz/ml

Celsius (Centigrade) Fahrenheit Conversion Table

F	C or F	C	F	C or F	C	F	C or F	C	F	C or F	C
–148.0	**–100**	–73.33	69.8	**21**	–6.11	141.8	**61**	16.1	230	**110**	43
–139.0	**– 95**	–70.56	71.6	**22**	–5.56	143.6	**62**	16.7	248	**120**	49
–130.0	**– 90**	–67.78	73.4	**23**	–5.00	145.4	**63**	17.2	266	**130**	54
–121.0	**– 85**	–65.00	75.2	**24**	–4.44	147.2	**64**	17.8	284	**140**	60
–112.0	**– 80**	–62.22	77.0	**25**	–3.89	149.0	**65**	18.3	302	**150**	66
–103.0	**– 75**	–59.45	78.8	**26**	–3.33	150.8	**66**	18.9	320	**160**	71
– 94.0	**– 70**	–56.67	80.6	**27**	–2.78	152.6	**67**	19.4	338	**170**	77
– 85.0	**– 65**	–53.89	82.4	**28**	–2.22	154.4	**68**	20.0	356	**180**	82
– 76.0	**– 60**	–51.11	84.2	**29**	–1.67	156.2	**69**	20.6	374	**190**	88
– 67.0	**– 55**	–48.34	86.0	**30**	–1.11	158.0	**70**	21.1	392	**200**	93
– 58.0	**– 50**	–45.56	87.8	**31**	–0.56	159.8	**71**	21.7	410	**210**	99
– 49.0	**– 45**	–42.78	89.6	**32**	0	161.6	**72**	22.2	413	**212**	100
– 40.0	**– 40**	–40.00	91.4	**33**	0.56	163.4	**73**	22.8	428	**220**	104
– 31.0	**– 35**	–37.23	93.2	**34**	1.11	165.2	**74**	23.3	446	**230**	110
– 22.0	**– 30**	–34.44	95.0	**35**	1.67	167.0	**75**	23.9	464	**240**	116
– 13.0	**– 25**	–31.67	96.8	**36**	2.22	168.8	**76**	24.4	482	**250**	121
– 4.0	**– 20**	–28.89	98.6	**37**	2.78	170.6	**77**	25.0	500	**260**	127
5.0	**– 15**	–26.12	100.4	**38**	3.33	172.4	**78**	25.6	518	**270**	132
14.0	**– 10**	–23.33	102.2	**39**	3.89	174.2	**79**	26.1	536	**280**	138
23.0	**– 5**	–20.56	104.0	**40**	4.44	176.0	**80**	26.7	554	**290**	143
32.0	**0**	–17.80	105.8	**41**	5.00	177.8	**81**	27.2	572	**300**	149
33.8	**1**	–17.20	107.6	**42**	5.56	179.6	**82**	27.8	590	**310**	154
35.6	**2**	–16.70	109.4	**43**	6.11	181.4	**83**	28.3	608	**320**	160
37.4	**3**	–16.10	111.2	**44**	6.67	183.2	**84**	28.9	626	**330**	166
39.2	**4**	–15.60	113.0	**45**	7.22	185.0	**85**	29.4	644	**340**	171
41.0	**5**	–15.00	114.8	**46**	7.78	186.8	**86**	30.0	662	**350**	177
42.8	**6**	–14.40	116.6	**47**	8.33	188.6	**87**	30.6	680	**360**	182
44.6	**7**	–13.90	118.4	**48**	8.89	190.4	**88**	31.1	698	**370**	188
46.4	**8**	–13.30	120.2	**49**	9.44	192.2	**89**	31.7	716	**380**	193
48.2	**9**	–12.80	122.0	**50**	10.00	194.0	**90**	32.2	734	**390**	199
50.0	**10**	–12.20	123.8	**51**	10.60	195.8	**91**	32.8	752	**400**	204
51.8	**11**	–11.70	125.6	**52**	11.10	197.6	**92**	33.3	770	**410**	210
53.6	**12**	–11.10	127.4	**53**	11.70	199.4	**93**	33.9	788	**420**	216
55.4	**13**	–10.60	129.2	**54**	12.20	201.2	**94**	34.4	806	**430**	221
57.2	**14**	–10.00	131.0	**55**	12.80	203.0	**95**	35.0	824	**440**	227
59.0	**15**	– 9.44	132.8	**56**	13.30	204.8	**96**	35.6	842	**450**	232
60.8	**16**	– 8.89	134.6	**57**	13.90	206.6	**97**	36.1	860	**460**	238
62.6	**17**	– 8.33	136.4	**58**	14.40	208.4	**98**	36.7	878	**470**	243
64.4	**18**	– 7.78	138.2	**59**	15.00	210.2	**99**	37.2	896	**480**	249
66.2	**19**	– 7.22	140.0	**60**	15.60	212.0	**100**	37.8	914	**490**	254
68.0	**20**	– 6.67							932	**500**	260

The bold face numbers refer to temperatures in either Centigrade or Fahrenheit degrees. If used to represent Centigrade degrees, the equivalent temperature in Fahrenheit is listed in the “F” column. If used to represent Fahrenheit the equivalent is listed in the “C” column.

Caterpillar Policy

One Worldwide Measurement System – SI
(SI – International System of Units – Modern Metric System)

Worldwide Interchangeability of Parts

Metric Drawing – Process and Inspect in Metric

Approximate Conversions

Multiply	By	To Get or Multiply	By	To Get
SI Unit	**Conv Factor**	**Non-SI Unit**	**Conv Factor**	**SI Unit**
		LENGTH		
millimeter (mm)	× 0.03937	= inch	× 25.4	= mm
(1 inch = 25.4 mm exactly)				
centimeter (cm) 10 mm	× 0.3937	= inch	× 2.54	= cm
meter (m) 1000 mm	× 3.28	= foot	× 0.305	= m
meter (m)	× 1.09	= yard	× 0.914	= m
kilometer (km) 1000 m	× 0.62	= mile	× 1.61	= km
		AREA		
millimeter^2 (mm^2)	× 0.00155	= inch^2	× 645	= mm^2
centimeter^2 (cm^2)	× 0.155	= inch^2	× 6.45	= cm^2
meter^2 (m^2)	× 10.8	= foot^2	× 0.0929	= m^2
meter^2 (m^2)	× 1.2	= yard^2	× 0.836	= m^2
hectare (ha) 10 000 m^2	× 2.47	= acre	× 0.405	= ha
kilometer (km) 1000 m	× 0.39	= mile^2	× 2.59	= km^2
		VOLUME		
centimeter^2 (cm^2)	× 0.061	= inch^3	× 16.4	= cm^3
liter	× 61	= inch^3	× 0.016	= L
milliliter (mL)	× 0.034	= oz.-liq	× 29.6	= mL
(1 mL = 1 cm^3)				
liter (L) 1000 mL	× 1.06	= quart	× 0.946	= L
liter (L)	× 0.26	= gallon	× 3.79	= L
meter^3 (m^3) 1000 L	× 1.3	= yard^2	× 0.76	= m^2
		MASS		
gram (g)	× 0.035	= ounce	× 28.3	= g
kilogram (kg) 1000 g	× 2.2	= pound	× 0.454	= kg
metric ton (t) 1000 kg	× 1.1	= ton (short)	× 0.907	= t
		FORCE (N = Kg – m/s^2)		
newton (N)	× 0.225	= pound	× 4.45	= N
kilonewton (kN)	× 225	= pound	× 0.00445	= kN

Working in SI will reveal its simplicity –
Try it you'll like it.

01-085464-01 (11.00)

Making Metric Parts – Use Metric Tools

Approximate Conversions

Multiply	**By**	**To Get or Multiply**	**By**	**To Get**
SI Unit	**Conv Factor**	**Non-SI Unit**	**Conv Factor**	**SI Unit**
		TORQUE		
newton meter (N•m)	× 8.9	= lb in	× 0.113	= N•m
newton meter (N•m)	× 0.74	= lb ft	× 1.36	= N•m
		PRESSURE (Pa = N/m^2)		
kilopascal (kPa)	× 4.0	= in H_2O	× 0.249	= kPa
kilopascal (kPa)	× 0.30	= in Hg	× 3.38	= kPa
kilopascal (kPa)	× 0.145	= psi	× 6.89	= kPa
		STRESS (Pa = N/m^2)		
megapascal (MPa)	× 145	= psi	× 0.00689	= MPa
		POWER (W = J/s)		
kilowatt (kW)	× 1.34	= hp	× 0.746	= kW
kilowatt (kW)	× 0.948	= Btu/s	× 1.055	= kW
watt (W)	× 0.74	= ft lb/s	× 1.36	= W
		ENERGY (J = N•m)		
kilojoule (kJ)	× 0.948	= Btu	× 1.055	= kJ
joule (J)	× 0.239	= calorie	× 4.19	= J
		VELOCITY AND ACCELERATION		
meter per sec^2 (m/s^2)	× 3.28	= ft/s^2	× 0.305	= m/s^2
meter per sec (m/s)	× 3.28	= ft/s	× 0.305	= m/s
kilometer per hour (km/h)	× 0.62	= mph	× 1.61	= km/h
		TEMPERATURE		
°C = (°F – 32) ÷ 1.8	°F = (°C × 1.8) + 32			

SI is a System of Tens like our Money System.

SI PREFIXES

AMOUNT	SYMBOL	NAME	
1 000 000 000	G	giga	jig' a (a as in about)
1 000 000	M	mega	as in megaphone
1 000	k	kilo	as in kilowatt
100	h	hecto	heck' toe
10	da	deka	deck' a (a as in about)
0.1	d	deci	as in decimal
0.01	c	centi	as in sentiment
0.001	m	milli	as in military
0.000 001	µ	micro	as in microphone
0.000 000 001	n	nano	nan' oh (an as in ant)

THINK METRIC!

Physics Formulas

$$\textbf{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

$$\textbf{Distance} = (\text{Velocity})(\text{Time})$$

$$\textbf{Time} = \frac{\text{Distance}}{\text{Velocity}}$$

$$\textbf{Acceleration} = \frac{\text{Difference in Velocity}}{\text{Difference in Time}}$$

$$\textbf{Force} = (\text{Mass})(\text{Acceleration})$$

$$\textbf{Mass} = \frac{\text{Force}}{\text{Acceleration}}$$

$$\textbf{Acceleration} = \frac{\text{Force}}{\text{Mass}}$$

$$\textbf{Momentum} = (\text{Mass})(\text{Velocity})$$

$$\textbf{Work} = (\text{Force})(\text{Distance})$$

$$\textbf{Work} = (\text{Mass})(\text{Acceleration})(\text{Distance})$$

$$\textbf{Power} = \frac{\text{Work}}{\text{Time}}$$

Heat = (Mass)(Specific Heat)(Temperature Change) or **Heat** = (M)(C)(ΔT)

Where:

M = Mass

C = Specific Heat

Δ**T** = Temperature Change

Btu = Heat required to raise 1 pound of water 1° F.

Calorie = Heat required to raise 1 gram of water 1° C.

Absolute zero is the temperature at which matter has given up all thermal energy.

Absolute zero = 0° Kelvin(K) or –460° Fahrenheit(F) or –273° Centigrade(C)

Physics Formulas

Boyle's Law: If temperature is kept constant, the volume of a given mass of gas is inversely proportional to the pressure which is exerted upon it.

$$\frac{\text{Initial Pressure}}{\text{Initial Volume}} = \frac{\text{Pressure Change}}{\text{Volume Change}}$$

Charles Law: If the pressure is constant, the volume of a given mass of gas is directly proportional to the absolute temperature.

$$\frac{\text{Initial Volume}}{\text{Initial Temperature °K}} = \frac{\text{Volume Change}}{\text{Final Temperature °K}}$$

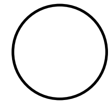
Theoretical Horsepower to Compress Air:

$$\text{Hp} = \text{CFM} \times \text{PSI} \times 0.0007575$$

Hp = Compressor Horsepower
CFM = Air flow in cubic feet per minute
PSI = Air pressure in pounds per square inch
(assumes Atmospheric Pressure = 14.7 psi, temperature 60° F)

Math Formulas

Circle

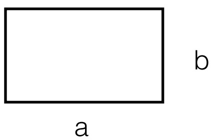


Circumference – $\pi \times$ diameter

Circumference = $2\pi r$

Area = πr^2

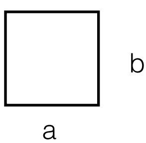
Area = $\pi \frac{d^2}{4}$



Rectangle

Area = (a) (b)

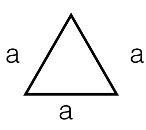
If a = b then it is a square



Perimeter = 2(a +b)

Diagonal = $\sqrt{a^2 + b^2}$

Equilateral Triangle = all side equal



Perimeter = 3 a

$Area = a^2 \frac{\sqrt{3}}{4}$ $\quad$ $Area = 0.433 a^2$

Atlantic Distance Table

Azores to

Bermuda 2,201	Cape Horn 6,282	Cape Town 5,040	Fastnet 1,377
Gibraltar 946	Halifax 1,785	Miami 2,900	New York 2,246
Norfolk 2,401	Panama 3,439	Rio 3,875	St. Thomas 2,393

Bermuda to

Azores 2,201	Cape Horn 6,300	Cape Town 6,269	Fastnet 2,651
Gibraltar 2,903	Halifax 756	Miami 956	New York 697
Norfolk 683	Panama 1,702	Rio 4,110	St. Thomas 872

Cape Horn to

Azores 6,282	Bermuda 6,300	Cape Town 4,731	Fastnet 7,151
Gibraltar 6,452	Halifax 6,800	Miami 6,882	New York 6,920
Norfolk 6,900	Panama 4,093	Rio 2,338	St. Thomas 5,886

Cape Town to

Azores 5,040	Bermuda 6,269	Cape Horn 4,731	Fastnet 5,880
Gibraltar 5,072	Halifax 6,492	Miami 6,800	New York 6,786
Norfolk 6,790	Panama 6,508	Rio 3,273	St. Thomas 5,904

Fastnet to

Azores 1,377	Bermuda 2,651	Cape Horn 7,151	Cape Town 5,880
Gibraltar 977	Halifax 2,364	Miami 3,578	New York 2,815
Norfolk 2,979	Panama 4,247	Rio 4,873	St. Thomas 3,279

Gibraltar to

Azores 946	Bermuda 2,903	Cape Horn 6,452	Cape Town 5,072
Fastnet 977	Halifax 2,708	Miami 3,800	New York 3,180
Norfolk 3,335	Panama 4,351	Rio 4,180	St. Thomas 3,323

Halifax to

Azores 1,785	Bermuda 756	Cape Horn 6,800	Cape Town 6,492
Fastnet 2,364	Gibraltar 2,708	Miami 1,413	New York 600
Norfolk 790	Panama 2,338	Rio 4,630	St. Thomas 1,595

Miami to

Azores 2,900	Bermuda 956	Cape Horn 6,882	Cape Town 6,800
Fastnet 3,578	Gibraltar 3,800	Halifax 1,413	New York 1,100
Norfolk 698	Panama 1,249	Rio 4,879	St. Thomas 991

New York to

Azores 2,246	Bermuda 697	Cape Horn 6,920	Cape Town 6,786
Fastnet 2,815	Gibraltar 3,180	Halifax 600	Norfolk 271
Miami 1,100	Panama 2,016	Rio 4,770	St. Thomas 1,434

Norfolk to

Azores 2,401	Bermuda 683	Cape Horn 6,900	Cape Town 6,790
Fastnet 2,979	Gibraltar 3,335	Halifax 790	New York 271
Miami 698	Panama 1,825	Rio 4,723	St. Thomas 1,296

Panama to

Azores 3,439	Bermuda 1,702	Cape Horn 4,093	Cape Town 6,508
Fastnet 4,247	Gibraltar 4,351	Halifax 2,338	New York 2,016
Miami 1,249	Norfolk 1,825	Rio 4,284	St. Thomas 1,072

Rio de Janeiro to

Azores 3,875	Bermuda 4,110	Cape Horn 2,338	Cape Town 3,273
Fastnet 4,873	Gibraltar 4,180	Halifax 4,630	Miami 4,879
New York 4,770	Norfolk 4,723	Panama 4,284	St. Thomas 3,542

St. Thomas to

Azores 2,323	Bermuda 872	Cape Horn 5,886	Cape Town 5,904
Fastnet 3,279	Gibraltar 3,323	Halifax 1,595	Miami 991
New York 1,434	Norfolk 1,296	Rio 3,542	Panama 1,072

Pacific Distance Table

Auckland to

Cape Horn 6,232	Hong Kong 5,060	Honolulu 3,820	Los Angeles 5,658
Pago Pago 1,565	Panama 6,516	Papeete 2,216	San Francisco 5,680
Sitka 6,176	Sydney 1,280	Vancouver 6,191	Yokohama 4,789

Cape Horn to

Auckland 6,232	Hong Kong 10,404	Honolulu 6,644	Los Angeles 6,100
Pago Pago 5,381	Panama 4,162	Papeete 4,333	San Francisco 6,458
Sitka 7,705	Sydney 7,301	Vancouver 7,248	Yokohama 9,642

Hong Kong to

Auckland 5,060	Cape Horn 10,404	Honolulu 4,857	Los Angeles 6,380
Pago Pago 4,948	Panama 9,195	Papeete 6,132	San Francisco 6,044
Sitka 5,136	Sydney 4,086	Vancouver 6,361	Yokohama 1,585

Honolulu to

Auckland 3,820	Cape Horn 6,644	Hong Kong 4,857	Los Angeles 2,228
Pago Pago 2,276	Panama 4,685	Papeete 2,381	San Francisco 2,091
Sitka 2,386	Sydney 4,420	Vancouver 2,423	Yokohama 3,395

Los Angeles to

Auckland 5,658	Cape Horn 6,100	Hong Kong 6,380	Honolulu 2,228
Pago Pago 4,163	Panama 2,913	Papeete 3,571	San Francisco 349
Sitka 1,640	Sydney 6,511	Vancouver 1,091	Yokohama 4,836

Pago Pago to

Auckland 1,565	Cape Horn 5,381	Hong Kong 4,948	Honolulu 2,276
Los Angeles 4,163	Panama 5,656	Papeete 1,236	San Francisco 4,151
Sitka 4,635	Sydney 2,377	Vancouver 4,549	Yokohama 4,135

Panama to

Auckland 6,516	Cape Horn 4,162	Hong Kong 9,195	Honolulu 4,685
Los Angeles 2,913	Pago Pago 5,656	Papeete 4,493	San Francisco 3,245
Sitka 4,524	Sydney 7,674	Vancouver 4,032	Yokohama 7,682

Papeete to

Auckland 2,216	Cape Horn 4,333	Hong Kong 6,132	Honolulu 2,381
Los Angeles 3,571	Pago Pago 1,236	Panama 4,493	San Francisco 3,663
Sitka 4,537	Sydney 3,308	Vancouver 4,396	Yokohama 5,140

San Francisco to

Auckland 5,680	Cape Horn 6,458	Hong Kong 6,044	Honolulu 2,091
Los Angeles 349	Pago Pago 4,151	Panama 3,245	Papeete 3,663
Sitka 1,302	Sydney 6,448	Vancouver 812	Yokohama 4,536

Sitka to

Auckland 6,176	Cape Horn 7,705	Hong Kong 5,136	Honolulu 2,386
Los Angeles 1,640	Pago Pago 4,635	Panama 4,524	Papeete 4,537
San Francisco 1,302	Sydney 6,595	Vancouver 823	Yokohama 3,640

Sydney to

Auckland 1,280	Cape Horn 7,301	Hong Kong 4,086	Honolulu 4,420
Los Angeles 6,511	Pago Pago 2,377	Panama 7,674	Papeete 3,308
San Francisco 6,448	Sitka 6,595	Vancouver 6,814	Yokohama 4,330

Vancouver to

Auckland 6,191	Cape Horn 7,248	Hong Kong 6,361	Honolulu 2,423
Los Angeles 1,091	Pago Pago 4,549	Panama 4,032	Papeete 4,396
San Francisco 812	Sitka 823	Sydney 6,814	Yokohama 4,262

Yokohama to

Auckland 4,789	Cape Horn 9,642	Hong Kong 1,585	Honolulu 3,395
Los Angeles 4,839	Pago Pago 4,135	Panama 7,682	Papeete 5,140
San Francisco 4,536	Sitka 3,640	Sydney 4,330	Vancouver 4,262

Geographic Range Table

The following table gives the approximate range of visibility for an object that may be seen by an observer at sea level. It also provides the approximate distance to the visible horizon for various heights of eye. To determine the geographic range of an object, you must add the range for the observer's height of eye and the range for the object's height. For instance, if the object seen is 65 feet, and the observer's height of eye is 35 feet above sea level, then the object will be visible at a distance of no more than 16.3 miles:

Height of eye: 35 feet Range = 6.9 nm
Object height: 65 feet Range = 9.4 nm
Computed geographic range = 16.3 nm

The standard formula is d = 1.17 × square root of H + 1.17 × square root of h. Where d = visible distance, H = height of the object, and h the height of eye of the observer.

HEIGHT		DISTANCE
Feet	Meters	International Nautical Miles
5	1.5	2.6
10	3.0	3.7
15	4.6	4.5
20	6.1	5.2
25	7.6	5.9
30	9.1	6.4
35	10.7	6.9
40	12.2	7.4
45	13.7	7.8
50	15.2	8.3
55	16.8	8.7
60	18.3	9.1
65	19.8	9.4
70	21.3	9.8
75	22.9	10.1
80	24.4	10.5
85	25.9	10.8
90	27.4	11.1
95	29.0	11.4
100	30.5	11.7
110	33.5	12.3
120	36.6	12.8
130	39.6	13.3

(continued)

HEIGHT		DISTANCE
Feet	Meters	International Nautical Miles
140	42.7	13.8
150	45.7	14.3
200	61.0	16.5
250	76.2	18.5
300	91.4	20.3
350	106.7	21.9
400	121.9	23.4
450	137.2	24.8
500	152.4	26.2
550	167.6	27.4
600	182.9	28.7
650	198.1	29.8
700	213.4	31
800	243.8	33.1
900	274.3	35.1
1000	304.8	37

Comments & Notes:

Periodic Table of the Elements

NOTE: Click on any element to learn more about it.

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Lanthanoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Elements Listed by Atomic Number

Atomic number	Name	Atomic symbol	Atomic number	Name	Atomic symbol
001	Hydrogen	H	039	Yttrium	Y
002	Helium	He	040	Zirconium	Zr
003	Lihtium	Li	041	Niobium	Nb
004	Beryllium	Be	042	Molybdenum	Mo
005	Boron	B	043	Technetium	Tc
006	Carbon	C	044	Ruthenium	Ru
007	Nitrogen	N	045	Rhodium	Rh
008	Oxygen	O	046	Palladium	Pd
009	Fluorine	F	047	Silver	Ag
010	Neon	Ne	048	Cadmium	Cd
011	Sodium	Na	049	Indium	In
012	Magnesium	Mg	050	Tin	Sn
013	Aluminium	Al	051	Antimony	Sb
014	Silicon	Si	052	Tellurium	Te
015	Phosphorus	P	053	Iodine	I
016	Sulphur	S	054	Xenon	Xe
017	Chlorine	Cl	055	Caesium	Cs
018	Argon	Ar	056	Barium	Ba
019	Potassium	K	057	Lanthanum	La
020	Calcium	Ca	058	Cerium	Ce
021	Scandium	Sc	059	Praseodymium	Pr
022	Titanium	Ti	060	Neodymium	Nd
023	Vanadium	V	061	Promethium	Pm
024	Chromium	Cr	062	Samarium	Sm
025	Manganese	Mn	063	Europium	Eu
026	Iron	Fe	064	Gadolinium	Gd
027	Cobalt	Co	065	Terbium	Tb
028	Nickel	Ni	066	Dysprosium	Dy
029	Copper	Cu	067	Holmium	Ho
030	Zinc	Zn	068	Erbium	Er
031	Gallium	Ga	069	Thulium	Tm
032	Germanium	Ge	070	Ytterbium	Yb
033	Arsenic	As	071	Lutetium	Lu
034	Selenium	Se	072	Hafnium	Hf
035	Bromine	Br	073	Tantalum	Ta
036	Krypton	Kr	074	Tungsten	W
037	Rubidium	Rb	075	Rhenium	Re
038	Strontium	Sr	076	Osmium	Os

Elements Listed by Atomic Number

Atomic number	Name	Atomic symbol	Atomic number	Name	Atomic symbol
077	Iridium	Ir	094	Plutonium	Pu
078	Platinum	Pt	095	Americium	Am
079	Gold	Au	096	Curium	Cm
080	Mercury	Hg	097	Berkelium	Bk
081	Thallium	Tl	098	Californium	Cf
082	Lead	Pb	099	Einsteinium	Es
083	Bismuth	Bi	100	Fermium	Fm
084	Polonium	Po	101	Mendelevium	Md
085	Astatine	At	102	Nobelium	No
086	Radon	Rn	103	Lawrencium	Lr
087	Francium	Fr	104	Unnilquadium	Unq
088	Radium	Ra	105	Hahnium	Ha
089	Actinium	Ac	106	Unnilhexium	Unh
090	Thorium	Th	107	Neilsbohrium	Ns
091	Protactinium	Pa	108	Hassium	Hs
092	Uranium	U	109	Meitnerium	Mt
093	Neptunium	Np			

Cat Marine Engines

Propulsion Ratings

Engine Model		bkW Rating Range	bhp Rating Range
3618	DITA	7200	**9655**
3616	DITA	4600-6180	**6169-8287**
3612	DITA	3460-4060	**4640-5444**
3608	DITA	2300-2710	**3084-3634**
3606	DITA	1730-2030	**2320-2722**
3516B	HP DITA SW	1790-2238	**2400-3000**
3516B	HD DITA SC	1398-2000	**1875-2682**
3516B	DITA SC	1231-1641	**1650-2200**
3512B	HP DITA SW	1342-1678	**1800-2250**
3512B	HD DITA SC	1119-1380	**1500-1850**
3512B	DITA SC	820-1231	**1100-1650**
3508B	HP DITA SW	895-1119	**1200-1500**
3508B	DITA SC	578-820	**775-1100**
3508	DITA JW**	526-858	**705-1150**
3512	DITA JW**	900-1305	**1207-1750**
3516	DITA JW**	1195-1641	**1603-2200**
C30	DITTA	1119-1156	**1500-1550**
3412E	DITTA	559-1044	**750-1400**
3412E	DITTA (fast craft)	559-895	**750-1200**
3412E	DITA	317-570	**425-764**
3412C	DITTA	615-746	**825-1000**
3412C	DITA	375-570	**503-764**
3408C	DITA	300-403	**402-540**
C18	DITTA	653-746	**875-1000**
3406E	DITA	336-597	**450-800**
3406C	DITA	186-433	**250-580**
C12	DITA	253-522	**340-700**
3196	DITA	253-492	**340-660**
3126	DITA	261-313	**350-420**
3126B	DITA	186-336	**250-450**
3056	DITA	138-153	**185-205**
3056	DINA*	93	**125**
3054	DIT	80	**108**
3054B	DINA	64	**86**
3034	DIT	60	**80**
3034	DINA	47	**63**

*Approval not required under 174 bhp (130 bkW).
**Non IMO compliant.

Generator Ratings

Engine Model		50 Hz ekW @ rpm	60 Hz ekW @ rpm
3616	**DITA**	4700/5200 @ 1000	4400/4840 @ 900
3612	**DITA**	3520/3880 @ 1000	3300/3640 @ 900
3608	**DITA**	2350/2600 @ 1000	2200/2420 @ 900
3606	**DITA**	1760/1940 @ 1000	1650/1820 @ 900
3516B	**DITA**	1460/1600 @ 1500	1825 @ 1800
3516B	**DITA**	1180 @ 1000	1285 @ 1200
3512B	**DITA**	965/1200 @ 1500	1070/1360 @ 1800
3512B	**DITA**	880 @ 1000	1030 @ 1200
3508B	**DITA**	630/800 @ 1500	715/910 @ 1800
3508B	**DITA**	590 @ 1000	600 @ 1200
3412C	**DITA**	350-500 @ 1500	400-590 @ 1800
3408C	**DITA**	280 @ 1500	370 @ 1800
3406C	**DITA**	200-245 @ 1500	250-320 @ 1800
3056	**DIT**	84 @ 1500	99 @ 1800
3054	**DIT**	60 @ 1500	72 @ 1800
3054	**DINA**	32-34 @ 1500	37-40 @ 1800

*Approval not required under 174 bhp (130 bkW).

For more information on IMO regulations and compliance contact:

- IMO headquarters for "Annex VI of MARPOL 73/78…" London, phone: 011-44 (0) 171-735-7611
- EPA paper "Frequently Asked Questions about MARPOL 73/78…" download from web site: epa.gov/oms/marine.htm or call Michigan: (734) 214-4822
- ABS guide "Notes on Prevention of Air Pollution from Ships," Texas, phone: (281) 877-6306, fax: (281) 877-5801, e-mail: jpatterson@eagle.org

For additional information on Cat Marine Power, see our new marine site: www.cat-marine.com

Caterpillar Web Sites

Note: ***All URL's that begin with https:// require a Caterpillar ID and password to be able to access the web site.***

https://psmktg.cat.com/srvtrng/index.htm – Service Training

https://engines.cat.com/infocast/frames/marine/ – Marine Business Group

https://engines.cat.com/infocast/frames/marine/applss/ – Cat Application & Support Center

https://sis.cat.com/sisweb/servlet/cat.cis.sis.PController.CSSISMainServlet – SIS Web

http://tmiweb.cat.com/tmi/servlet/cat.edis.tmiweb.tmihome.TMIHomeServlet – TMI Web

http://emc.cat.com/ – Cat Electronic Media Center

https://3500.cat.com/ – 3500 Web Site

https://3600.cat.com/ – 3600 Web Site

https://engines.cat.com/infocast/frames/ep/power/mak_sis/ – MaK

Non-Caterpillar Web Sites of Interest

http://www.howstuffworks.com/category.htm?cat=Powr – How Stuff Works Web Site

http://www.oceannavigator.com/ – Ocean Navigator Web Site

http://www.workboat.com/ – Work Boat Magazine Web Site

Electrical Fundamentals*

Ohm's Law

$$E = IR$$

where E = voltage in volts

I = current in amperes

R = resistance in ohms

By simple algebra this equation may be written:

$$I = \frac{E}{R}$$

or

$$R = \frac{E}{I}$$

Power

$$P = IE$$

where P = power in watts

I = current in amperes

E = voltage in volts

This equation for power may also be transposed to:

$$I = \frac{P}{E}$$

or

$$E = \frac{P}{I}$$

From Ohm's law it is known that E = IR. If this expression for voltage is substituted in the power law, we can derive the additional equation:

$$P = I^2R$$

If we use the equation for current from Ohm's law, $I = \frac{E}{R}$, the equation for power becomes:

$$P = \frac{E^2}{R}$$

*See "Ugly's Electrical Reference" (SEBD0983) for additional information.

Resistance

$$\text{Series Circuits } R_T = R_1 + R_2 + R_3 + \ldots R_N$$

$$\text{Parallel Circuits } R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_N}}$$

where R_N = resistance in the individual resistors

where R_T = total resistance in circuit

Reactance

$$X_L = 2 \pi f L$$

where X_L = inductive reactance in ohms

f = frequency in hertz

L = inductance in henries

$\pi = 3.1416$

$$X_C = \frac{1}{2\pi f C}$$

where X_C = capacitive reactance in ohms

f = frequency in hertz

C = capacitance in farads

$\pi = 3.1416$

Impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where Z = impedance in ohms

R = resistance in ohms

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

Note that the impedance will vary with frequency, since both X_C and X_L are frequency dependent. In practical AC power circuits, X_C is often small and can be neglected. In that case, the formula above simplifies to:

$$Z = \sqrt{R^2 + X_L^2}$$

Transformer Voltage Conversion

$$V_S = V_P \frac{N_S}{N_P}$$

where V_S = secondary voltage

V_P = primary voltage

N_S = number of secondary turns

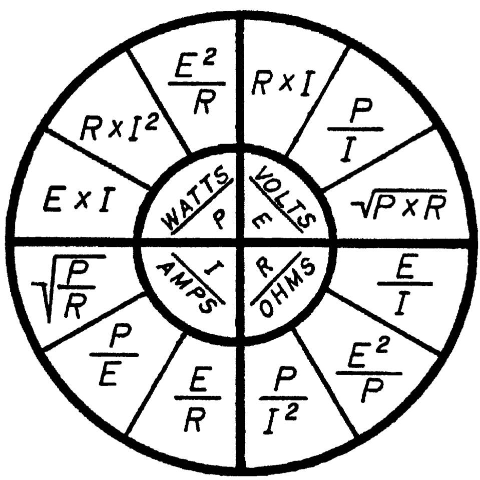
N_P = number of primary turns

Power Factor

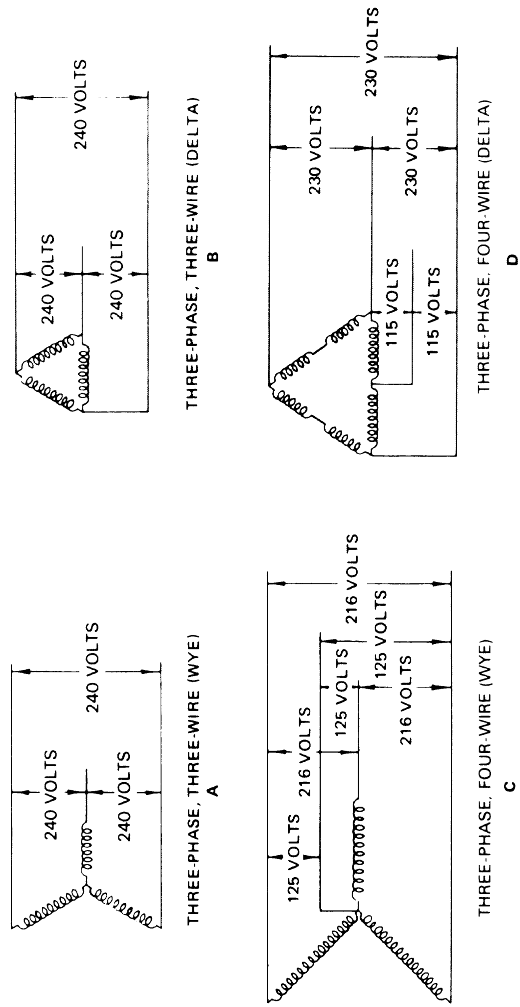
$$\text{Power Factor} = \frac{\text{Actual Power (watts)}}{\text{Apparent Power (V•A)}}$$

In mathematical terms, the power factor is equal to the cosine of the angle by which the current leads or lags the voltage. If the current lags the voltage in an inductive circuit by 60 degrees, the power factor will be 0.5, the value of the cosine function at 60 degrees. If the phase of the current in a load leads the phase of the voltage, the load is said to have a **leading power factor**; if it lags, **a lagging power** factor. If the voltage and current are in phase, the circuit has a **unity power factor**.

Equation Summary Diagram



Three Phase Connection Systems:



Electrical Enclosure Protection = IEC

The degrees of protection provided within an electrical enclosure is expressed in terms of the letters IP followed by two numerals. Mechanical protection against impact damage is defined by an optional third numeral.

First Numeral

	Protection against:
0	Non-protected
1	Object > 50 mm Dia.
2	Object > 12 mm Dia.
3	Object > 2.5 mm Dia.
4	Object > 1.0 mm Dia.
5	Dust-protected
6	Dust Tight

Second Numeral

	Protection against:
0	Non-protected
1	Dripping Water
2	Dripping Water (tilt up to 15°)
3	Rain (tilt up to 60°)
4	Splashing Water
5	Water Jets
6	Heavy Seas
7	Immersion Effects
8	Submersion Effects

Third Numeral

	Weight kg	Drop m	Impact J
0		Non-protected	
1	0.15	0.15	0.225
2	0.15	0.25	0.375
3	0.25	0.20	0.50
5	0.50	0.40	2
7	1.5	0.40	6
9	5.0	0.40	20

Example: An IP55 enclosure protects its contents against dust and spray from water jets.

References: DIN 40050 of July 1980, IEC 144 of 1963, IEC 529 of 1976, NF C 20-010 of April 1977

Electrical Enclosure Protection – NEMA

Type	Use	Protection against
1	Indoor	Contact with enclosed equipment.
2	Interior	Limited amounts of falling water and dirt.
3	Outdoor	Windblown dust, rain, sleet, and external ice formation.
3R	Outdoor	Falling rain, sleet, and external ice formation.
3S	Outdoor	Windblown dust, rain, sleet, and external ice formation. (Provision for external mechanism operation when ice laden).
4	Indoor or Outdoor	Windblown dust and rain, splashing and hose-directed water.
4X	Indoor or Outdoor	Corrosion, windblown dust and rain, splashing and hose-directed water.
5	Interior	Dust and falling dirt.
6	Indoor or Outdoor	Occasional temporary submersion at a limited depth.
6P	Indoor or Outdoor	Occasional prolonged submersion at a limited depth.
11	Indoor	Corrosive liquids and gases (protection accomplished by oil immersion).
12	Indoor	Dust, falling dirt, and dripping non-corrosive liquids.
12K	Indoor	Dust, falling dirt, and dripping non-corrosive liquids except at knockouts. (knockouts permitted)
13	Indoor	Lint, dust, seepage, external condensation and spraying water, oil, and non-corrosive liquids.

Table 1
Electrical Formulae

	Alternating Current		
To Obtain	**Single-Phase**	**Three-Phase**	**Direct Current**
Kilowatts	$\frac{V \times I \times P.F.}{1000}$	$\frac{1.732 \times V \times I \times P.F.}{1000}$	$\frac{V \times I}{1000}$
KV•A	$\frac{V \times 1}{1000}$	$\frac{1.732 \times V \times I}{1000}$	
Horsepower required when KW known (Generator)	$\frac{KW}{0.746\ 2\ EFF.\ (Gen.)}$	$\frac{KW}{0.746 \times EFF.\ (Gen.)}$	$\frac{KW}{0.746 \times EFF.\ (Gen.)}$
KW input when HP known (Motor)	$\frac{HP \times 0.746}{EFF.\ (Mot.)}$	$\frac{HP \times 0.746}{EFF.\ (Mot.)}$	$\frac{HP \times 0.746}{EFF.\ (Mot.)}$
Amperes when HP known	$\frac{HP \times 746}{V \times P.F. \times EFF.}$	$\frac{HP \times 746}{1.732 \times V \times EFF. \times P.F.}$	$\frac{HP \times 746}{V \times EFF.}$
Amperes when KW known	$\frac{KW \times 1000}{V \times P.F.}$	$\frac{KW \times 1000}{1.732 \times V \times P.F.}$	$\frac{KW \times 1000}{V}$
Amperes when KV•A known	$\frac{KV{\bullet}A \times 1000}{V}$	$\frac{KV{\bullet}A \times 1000}{1.732 \times V}$	

Table 1 – Electrical Formulae (cont.)

Frequency (c.p.s.)	$\frac{\text{Poles} \times \text{RPM}}{120}$	$\frac{\text{Poles} \times \text{RPM}}{120}$	
Reactive KV•A (KVAR)	$\frac{V \times I \times \sqrt{1 - (P.F.)^2}}{1000}$	$\frac{1.732 \times V \times I \times \sqrt{1 - (P.F.)^2}}{1000}$	
% Voltage Regulation	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$

The following abbreviations are used in the table:

V = voltage in volts
I = current in amperes
KW = power in kilowatts (actual power)
KV•A = kilovolt-amperes (apparent power)
HP = horsepower
RPM = revolutions per minute
KVAR = reactive kilovolt-amperes
EFF. = efficiency as a decimal factor
NL = no load
FL = full load

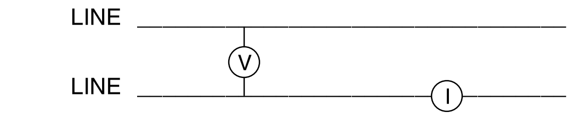
Because the basic units of electrical quantities are often inconveniently large or small, prefixes are often added to the terms which denote those units. The prefixes have the effect of multiplying or dividing the quantity by some factor, usually one thousand or one million. “kilo—” is used, for instance, to express a multiplication of one thousand. A kilovolt (kV) is therefore 1000 volts. A milliampere (mA) is one thousandth of an ampere. The commonly-used prefixes, their multiplying factors and their abbreviations are tabulated below:

Prefix	Factor	Symbol
kilo—	× 1000	k
mega—	× 1,000,000	M
milli—	÷ 1000	m
micro—	÷ 1,000,000	μ

Table 2
KV•A of AC Circuits

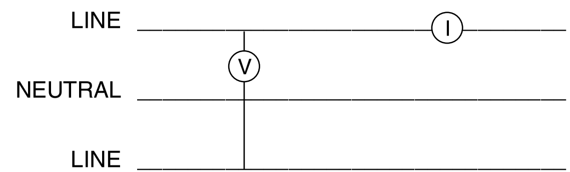
Single-Phase, Two-Wire

$$KV{\bullet}A = \frac{V \times I}{1000}$$



Single-Phase, Three-Wire – Balanced

$$KV{\bullet}A = \frac{V \times I}{1000}$$



Single-Phase, Three-Wire – Unbalanced

$$KV{\bullet}A = \frac{(V_1 \times I_1) + (V_2 \times I_2)}{1000}$$

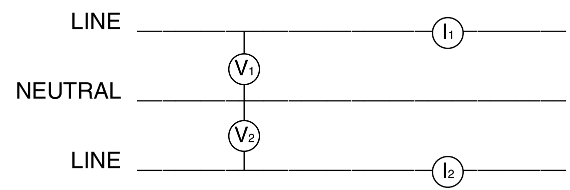
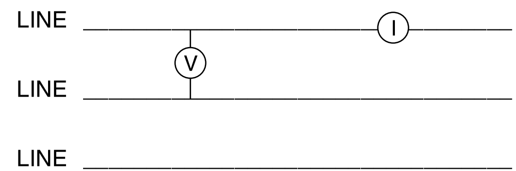


Table 2 – KV•A of AC Circuits (cont.)

Three-Phase, Three-Wire – Balanced

$$KV{\bullet}A = \frac{1.732 \times V \times I}{1000}$$



Three-Phase, Three-Wire – Unbalanced

$$KV{\bullet}A = \frac{1.732 \times V \times \left(\frac{I_1 + I_2 + I_3}{3}\right)}{1000}$$

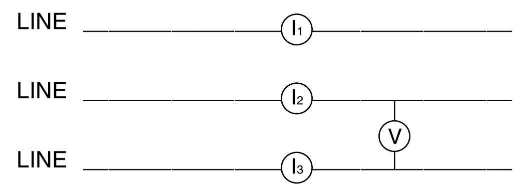
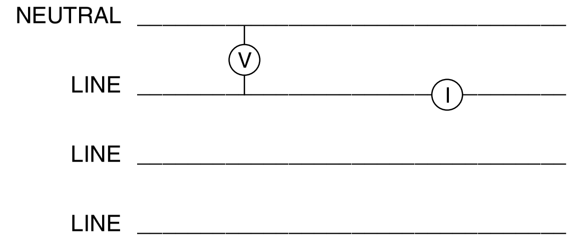


Table 2 – KV•A of AC Circuits (cont.)

Three-Phase, Four-Wire – Balanced

$$KV{\bullet}A = \frac{1.73 \times V \times I}{1000}$$



Three-Phase, Four-Wire – Unbalanced

$$KV{\bullet}A = \frac{1.73 \times V \times \left(\frac{I_1 + I_2 + I_3}{3}\right)}{1000}$$

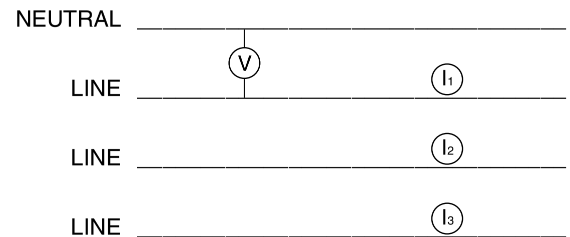


Table 3
Copper Wire Characteristics

Wire Size AWG (B & S)	Diam. in Mils	Circular mil Area	Ohms per 1000 ft. 77° F (25° C)	Diam. in mm	Nearest British SWG No.
1	289.3	83690	0.1264	7.348	1
2	257.6	66370	0.1593	6.544	3
3	229.4	52640	0.2009	5.827	4
4	204.3	41740	0.2533	5.189	5
5	181.9	33100	0.3195	4.621	7
6	162.0	26250	0.4028	4.115	8
7	144.3	20820	0.5080	3.665	9
8	128.5	16510	0.6405	3.264	10
9	114.4	13090	0.8077	2.906	11
10	101.9	10380	1.018	2.588	12
11	90.7	8234	1.284	2.305	13
12	80.8	6530	1.619	2.053	14
13	72.0	5178	2.042	1.828	15
14	64.1	4107	2.575	1.628	16
15	57.1	3257	3.247	1.450	17
16	50.8	2583	4.094	1.291	18
17	45.3	2048	5.163	1.150	18
18	40.3	1624	6.510	1.024	19
19	35.9	1288	8.210	0.912	20
20	32.0	1022	10.35	0.812	21

Table 4
Single-Phase AC Motors
Full Load Currents in Amperes

HP	115 V	208 V	230 V	440 V
¼	5.8	3.2	2.9	
⅓	7.2	4.0	3.6	
½	9.8	5.4	4.9	
¾	13.8	7.6	6.9	
1	16	8.8	8	
1½	20	11	10	
2	24	13.2	12	
3	34	19	17	
5	56	31	28	
7½	80	44	40	21
10	100	55	50	26

Table 5
Three-Phase AC Motors – 80% Power Factor
Full Load Current in Amperes – Induction-Type, Squirrel Cage and Wound Rotor

HP	110 V	208 V	220 V	440 V	550 V	2300 V
½	4	2.1	2	1	0.8	
¾	5.6	3.0	2.8	1.4	1.1	
1	7	3.7	3.5	1.8	1.4	
1½	10	5.3	5	2.5	2.0	
2	13	6.9	6.5	3.3	2.6	
3		9.5	9	4.5	4	
5		16	15	7.5	6	
7½		23	22	11	9	
10		29	27	14	11	
15		43	40	20	16	
20		55	52	26	21	
25		68	64	32	26	7
30		83	78	39	31	8.5
40		110	104	52	41	10.5
50		133	125	63	50	13
60		159	150	75	60	16
75		198	185	93	74	19
100		262	246	123	98	25
125		330	310	155	124	31
150		380	360	180	144	37
200		510	480	240	192	48
250		697	657	328	262	65.7
300		837	790	394.5	315	78.8
350		976	922	461	368	92.2
400		1114	1051	526	421	105.2
450		1254	1192	592	473	118.3
500		1393	1317	657	526	130
600		1672	1578	789	632	157
700		1950	1842	921	737	184
800		2220	2103	1051	842	210
900		2504	2365	1194	947	233
1000		2789	2639	1316	1050	265

Table 6
Direct Current Motors
Full Load Current in Amperes

HP	115 V	230 V	550 V
¼	3	1.5	
⅓	3.8	1.9	
½	5.4	2.7	
¾	7.4	3.7	1.6
1	9.6	4.8	2.0
1½	13.2	6.6	2.7
2	17	8.5	3.6
3	25	12.5	5.2
5	40	20	8.3
7½	58	29	12
10	76	38	16
15	112	56	23
20	148	74	31
25	184	92	38
30	220	110	46
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	184
150		534	220
200		712	295

Table 7
Conduit Sizes for Conductors

Size AWG or MCM	Number of Conductors in One Conduit or Tubing*								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	†1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1¼	1½	2	2½	2½	2½	3	3
0	¾	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	5
300	1¼	2½	2½	3	3½	4	4	5	5
350	1¼	3	3	3½	3½	4	5	5	5
400	1½	3	3	3½	4	4	5	5	5
500	1½	3	3	3½	4	5	5	5	6
600	2	3½	3½	4	5	5	6	6	6
700	2	3½	3½	5	5	5	6	6	
750	2	3½	3½	5	5	6	6	6	
800	2	3½	4	5	5	6	6		
900	2	4	4	5	6	6	6		
1000	2	4	4	5	6	6			
1250	2½	5	5	6	6				
1500	3	5	5	6					
1750	3	5	6	6					
2000	3	6	6						

†Where a service run of conduit or metallic tubing does not exceed 50 feet (15.3 m) in length and does not contain more than the equivalent of two quarter bends from end to end, two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch (25.4 mm) conduit or tubing.

*Rubber covered: Types RF-2, RFH-2, R, RH, RW, RH-RW, RU, RUH, RUW
Thermoplastic: Types TF, T, and TW

Table 8
Allowable Current-Carrying Capacities of Insulated Copper Conductors*

	60° C	75° C	85° C	110° C	125° C	200° C
	Types of Insulation					
	Rubber		Paper	Asbestos		
Size AWG or MCM	R, RW, RU, RUW 14-2 Thermoplastic T, TW	Type RH, RHW	Var-Cam-Type V 90° C Thermoplastic Asbestos-TA Asbestos-Var-Cam-AVB	Var-Cam Type AVA Type AVL	Impregnated Type A1 14-8 A1A	Type A 14-8 AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340

*With not more than three conductors in a raceway or cable and a room temperature of 86° F (30° C).

Table 8 – Allowable Current-Carrying Capacities of Insulated Copper Conductors* (cont.)

250	215	255	270	315	335	
300	240	285	300	345	380	
350	260	310	325	390	420	
400	280	335	360	420	450	
500	320	380	405	470	500	
600	355	420	455	525	545	
700	385	460	490	560	600	
750	400	475	500	580	620	
800	410	490	515	600	640	
900	435	520	555			
1000	455	545	585	680	730	
1250	495	590	645			

Correction Factors for Room Temperatures Over 30° C

F	C					
104	40	0.82	0.88	0.90	0.94	0.95
113	45	0.71	0.82	0.85	0.90	0.92
122	50	0.58	0.75	0.80	0.87	0.89

*With not more than three conductors in a raceway or cable and a room temperature of 86° F (30° C).

Table 9
Code Letters Usually Applied to Ratings of Motors Normally Started on Full Voltage

Code Letters		F	G	H	J	K	L
Horse-power	3-phase	15-up	10-7½	5	3	2-1½	1
	1-phase	—	5	3	2-1½	1-¾	½

Table 10
Identifying Code Letters on AC Motors*

NEMA Code Letter	Starting KV•A per HP
A	0.00-3.14
B	3.15-3.54
C	3.55-3.99
D	4.00-4.49
E	4.50-4.99
F	5.00-5.59
G	5.60-6.29
H	6.30-7.09
J	7.10-7.99
K	8.00-8.99
L	9.00-9.99
M	10.00-11.19
N	11.20-12.49
P	12.50-13.99
R	14.00-15.99
S	16.00-17.99
T	18.00-19.99
U	20.00-22.39
V	22.40-

*Wound rotor motor has no code letter.

NOTE: Code letters apply to motors up to 200 HP.

Table 11
Conversion – Heat and Energy

1 – Kilowatt =	1.341 horsepower 44,254 foot pounds/minute 56.883 Btu/minute
1 – Kilowatt Hour =	1.341 horsepower hours 2,655,217 foot pounds 3413 Btu
1 – British Thermal Unit (Btu) =	777.97 foot pounds 1054.8 watt seconds 0.000293 kilowatt hours 0.293 watt hours 0.000393 horsepower hours
1 – Horsepower Hour =	0.7457 kilowatt hours 1,980,000 foot pounds 2545 Btu
1 – Horsepower =	0.7457 kilowatt 745.7 watts 33,000 foot pounds/minute 42,418 Btu/minute 1.0139 metric horsepower

Table 12
Approximate Efficiencies – Squirrel Cage Induction Motor

HP	Full Load KW Required	Full Load Efficiency
½	0.6	68%
¾	0.8	71%
1	1.0	75%
1½	1.5	78%
2	1.9	80%
3	2.7	82%
5	4.5	83%
7½	6.7	83%
10	8.8	85%
15	13.0	86%
20	16.8	89%
25	21.0	89%
30	24.9	90%
40	33.2	90%
50	41.5	90%
60	49.2	91%
75	61.5	91%
100	81.2	92%
125	101.5	92%
150	122.0	92%
200	162.5	92%
250	203.0	92%
300	243.0	92%
350	281.0	93%
400	321.0	93%
450	362.0	93%
500	401.0	93%
600	428.0	93%

NOTE: Efficiencies listed are approximate only for new or near new motors. For accurate efficiency figures check motor nameplate data with motor manufacturer or manufacturer's representative.

Table 13 – Approximate Electric Motor Efficiency to Use in Calculating Input

Motor Sizes	1 to 3 HP			5 to 15 HP			30 to 60 HP		
Load	½	¾	4/4	½	¾	4/4	½	¾	4/4
Direct Current (a) Shunt wound (b) Compound wound (c) Series wound	78	82	83	80	83	85	86	87	88
Alternating Current Single-Phase (a) Commutator type	65	72	75	75	78	80			
Two- or Three-Phase Squirrel Cage (a) General Purpose Normal starting current Normal starting torque	78	80	80	84.5	85	85	85	88	89
(b) Low starting current Normal starting torque			82	83	83	88	89	89	
(c) Low starting current High starting torque			83	83	82	88	89	89	
Slip Ring Motor			81	82	83	88	89	90	
Synchronous Motor						85	88	89	

It is to be noted that efficiency of electric motors varies with speed, type and line voltage. The above percentages are therefore approximate and are intended only to assist in calculating input. Where the margin of power of generator over actual requirements is shown to be quite close, it is well to obtain true efficiency of motors from motor manufacturer.

Table 14
Reduced Voltage Starters

Type of Starter	Motor Voltage % Line Voltage	Line Current % Full Voltage Starting Current	Starting Torque % of Full Voltage Starting Torque
Full Voltage Starter	100	100	100
Auto Transformer			
80% tap	80	68	64
65% tap	65	46	42
50% tap	50	30	25
Resistor Starter			
Single Step (adjusted for motor voltage to be 80% of line voltage)	80	80	64
Reactor			
50% tap	50	50	25
45% tap	45	45	20
37.5% tap	37.5	37.5	14
Part Winding (low speed motors only)			
75% winding	100	75	75
50% winding	100	50	50

Generator Set Start-up Checklist

All 3500 Engine Generator Sets

Exhaust Temperature Sensitivity Calculation

High exhaust temperature in an engine is a major contributor to reduced engine component life. The life of turbochargers and valves are greatly affected by continued exposure to exhaust temperatures in excess of the maximum inlet to turbocharger temperatures, as published in the Technical Marketing Information (TMI). This exhaust temperature sensitivity calculation is applicable to all 3500 Series Engines.

There are several variables in every engine installation that can have a significant impact on engine exhaust temperature. The “Exhaust Temperature Sensitivity Calculation” ensures that the system design takes all the different variables into consideration prior to engine installation.

The “Exhaust Temperature Sensitivity Calculation Worksheets” on the following pages should be used as a guide by customers and dealers when sizing a system for 3500 and 3500B Engines. This worksheet will help determine the critical factors that must be considered at the time an engine installation is being planned. When the worksheet calculation is completed using the expected maximum altitude, ambient temperature, restriction (air inlet and exhaust), and aftercooler temperature for the engine, the result will be an “expected inlet to turbocharger temperature”.

If the calculated temperature is below the maximum “inlet-to-turbocharger” temperature, as shown in TMI, and the charts in this publication, normal engine life can be expected. If the temperature is above the maximum “inlet-to-turbocharger” temperature, changes in the installation must be made to reduce the maximum expected exhaust temperature. If changes are not made, engine component life can be affected.

Do not perform any procedure outlined in this article or order any parts until you have read and understood the information contained within this article.

TMI Exhaust Maximum (measured at inlet to turbocharger)

MAXIMUM EXHAUST TEMPERATURES

	Normal Operating Temperature (maximum)	Extreme Condition Temperature (maximum)
EPG Dry Manifold		
Continuous	1200° F (650° C)	1275° F (692° C)
Prime	1250° F (677° C)	1325° F (718° C)
Standby	1300° F (704° C)	1375° F (746° C)

Exhaust Temperature Sensitivity Worksheet Metric Units

(A)	(B)	(C)	(D)	(E)	(F)
	Site Data	**TMI Standard**	**B – C**	**Sensitivity Factor**	**D × E**
Air filter inlet temperature		25° C		1.8° C increase per 1.0° C (D)	
Aftercooler water temperature		TMI		1.25° C increase per 1.0° C (D)	
Air inlet restriction		4 kPa		6.8° C increase per 1 kPa (D)	
Exhaust restriction		0 kPa		4.0° C increase per 1 kPa (D)	
Altitude		0 meters		3.6° C increase per 100 meters (D)	
				Total Column “F”	

Air Filter Inlet Temperature

1. Record, in column B, temperature at engine’s air filters when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 1.8 times column D and record the answer in column F.

Aftercooler Water Temperature

1. Record, in column B, the engine's aftercooler water when operating at rated.
2. Record, in column C, the engine's TMI aftercooler water temperature. Example: 3500 MUI Engines are 90° C for JWAC and 30° C for SCAC, and 3500 EUI Engines may be 30° C, 60° C, or 90° C.
3. Subtract column C from column B and record the answer in column D.
4. Multiply 1.25 times column D and record the answer in column F.

Air Inlet Restriction

1. Record, in column B, engine's air filter restriction when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 6.8 times column D and record the answer in column F.

Exhaust Restriction

1. Record, in column B, engine's exhaust restriction when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 4.0 times column D and record the answer in column F.

Altitude

1. Record in column B, altitude of installation.
2. Subtract column C from column B and divide by 100, then record the answer in column D.
3. Multiply 3.6 times column D and record the answer in column F.

Total Column "F"

1. Degrees Centigrade that ambient site operating conditions affect the turbocharger inlet exhaust temperature.
2. Add "Total Column F" to engine's TMI "EXH MANF TEMP" and the answer is the expected turbocharger inlet exhaust temperature of the engine at rated, when operating at these ambient site conditions.

Exhaust Temperature Sensitivity Worksheet English Units

(A)	(B)	(C)	(D)	(E)	(F)
	Site Data	**TMI Standard**	**B – C**	**Sensitivity Factor**	**D × E**
Air filter inlet temperature		77° F		1.8° F increase per 1.0° F (D)	
Aftercooler water temperature		TMI		1.25° F increase per 1.0° F (D)	
Air inlet restriction		16 inches H_2O (0.6 psi)		3.0° F increase per 1 inch H_2O (0.036 psi) (D)	
Exhaust restriction		0 inches H_2O		1.8° F increase per 1 inch H_2O (0.036 psi) (D)	
Altitude		0 feet		20.0° F increase per 1000 feet (D)	
				Total Column "F"	

Air Filter Inlet Temperature

1. Record, in column B, temperature at engine's air filters when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 1.8 times column D and record the answer in column F.

Aftercooler Water Temperature

1. Record, in column B, the engine's aftercooler water when operating at rated.
2. Record, in column C, the engine's TMI aftercooler water temperature. Example: 3500 MUI Engines are 194° F for JWAC and 86° F for SCAC, and 3500 EUI Engines may be 86° F, 140° F, or 194° F.
3. Subtract column C from column B and record the answer in column D.
4. Multiply 1.25 times column D and record the answer in column F.

Air Inlet Restriction

1. Record, in column B, engine's air filter restriction when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 3.0 times column D and record the answer in column F.

Exhaust Restriction

1. Record, in column B, engines exhaust restriction when operating at rated.
2. Subtract column C from column B and record the answer in column D.
3. Multiply 1.8 times column D and record in column F.

Altitude

1. Record, in column B, altitude of installation.
2. Subtract column C from column B and divide by 1000, then record the answer in column D.
3. Multiply 20.0 times column D and record the answer in column F.

Total Column “F”

1. Degrees Fahrenheit that ambient site operating conditions affect the turbocharger inlet exhaust temperature.
2. Add “Total Column F” to engine’s TMI “EXH MANF TEMP” and the answer is the expected turbocharger inlet exhaust temperature of engine at rated, when operating at these ambient site conditions.

3500 Engine Performance Parameters

Air System

Air filter inlet ducting (design)	2 inches H_2O (0.5 kPa)
Maximum temperature differential (inlet to air filter vs. ambient)	20° F (11° C)
Maximum dirty air filter restriction	25 inches H_2O (6.5 kPa)
Maximum air inlet temperature (filter)	120° F (49° C)
Maximum intake air manifold temperature	245° F (118° C)
Maximum air intake room pressure differential	0.5 inches H_2O (0.1245 kPa)
Boost pressure range	Consult your dealer
Ventilation	120° F (49° C) maximum inlet to air cleaner at maximum ambient

Exhaust System

Exhaust temperature (ITT) Inlet-to-turbocharger	Consult with your dealer
Cylinder head port temperatures (CHP)	@ rated load
Normal (hottest to coldest cylinder)	100° F to 125° F (56° C to 70° C)
Alert condition (deviation from average)	90° F (50° C)
Corrective action (deviation from average)	180° F (100° C)
Maximum exhaust back pressure of the system	20[1] inches H_2O (5 kPa)
Maximum design exhaust back pressure of system	10 inches H_2O (2.5 kPa)

[1]Certain ambient conditions and rating criteria may allow up to 27 inches H_2O back pressure. Consult your Caterpillar dealer.

Oil System

Oil pressure range	45 to 61 psi (310 to 420 kPa)
Alarm	40 psi (276 kPa)
Shutdown	30 psi (207 kPa)
Oil filter differential pressure	15 psi (105 kPa)
Maximum oil temperature	230° F (110° C)

Fuel System

Fuel rate	Consult with your dealer
Maximum fuel temperature	150° F (65° C)
Fuel pressure range	55 to 90 psi (379 to 620 kPa)
Fuel filter differential pressure	10 psi (70 kPa)

Water System

Alarm	215° F (101° C)
Shutdown	225° F (107° C)

Generator

Bearing bracket temperature		
Standby	Alarm	185° F (85° C)
	Shutdown	203° F (95° C)
Prime	Alarm	185° F (85° C)
	Shutdown	203° F (95° C)
Main stator winding temperature		
Standby	Alarm	356° F (180° C)
	Shutdown	401° F (205° C)
Prime	Alarm	284° F (140° C)
	Shutdown	329° F (165° C)
Air temperature differential across generator		
Standby		130° F (54° C)
Prime		105° F (41° C)

3500 Generator Set Start-up Checklist

Customer Data							
Name					Start-up date		
Contact					Time		
Telephone							
Site							
Type of installation							
Application	PP	Continuous	Peak Shaving	Standby	Marine	Industrial	Other

Engine Data			Generator Data
Engine model			Serial number
Serial number			Arrangement
Arrangement			Rating
TMI specification			Voltage
Rating	bhp	bkw	Amperage

Environment					
Ambient temperature			Room temperature		
Elevation			Relative humidity		
Atmospheric condition	Salty	Dusty	Wet	Clean	Comments

Storage Information	
Location	Clean _____________ Dry _____________
Megger voltage	
Initial megger reading	Temperature corrected
Megger readings during shortage	Temperature corrected

Safety			
Heat shields on engine	OK Not OK N/A	All guards in place	OK Not OK N/A
Emergency stops operate	OK Not OK N/A	Floor openings covered	OK Not OK N/A
Engine room noise level	OK Not OK N/A	Floors clean	OK Not OK N/A
Warning decals and plates installed	OK Not OK N/A	Hot pipes wrapped	OK Not OK N/A
Fire extinguisher	OK Not OK N/A	Secure wiring	OK Not OK N/A
Fire suppression system activated	OK Not OK N/A	Secure hoses and piping	OK Not OK N/A
Access to fluid fill areas prevent spills	OK Not OK N/A		OK Not OK N/A

Serviceability			
Overhead clearance		Gauges accurate	
Side clearance		Oil	
Air filters accessible	OK Not OK N/A	Water	OK Not OK N/A
Oil filters accessible	OK Not OK N/A	Fuel	OK Not OK N/A
Fuel filters accessible	OK Not OK N/A	Air	OK Not OK N/A
Site glasses visible	OK Not OK N/A	Exhaust	OK Not OK N/A
Level indicators accessible	OK Not OK N/A	Other	OK Not OK N/A

Customer Orientation	
Safety practices (refer to Operation and Maintenance Manual)	OK Not OK N/A
Maintenance Schedule and preventive maintenance practices (refer to O&M manual)	OK Not OK N/A
Manuals	OK Not OK N/A
“Operation and Maintenance Manual” delivered and explained	OK Not OK N/A
Reviewed start-up procedure	OK Not OK N/A
“Service Manual” delivered and explained	OK Not OK N/A
“Parts Manual” delivered and explained	OK Not OK N/A
Proper levels	OK Not OK N/A
Proper fluids	OK Not OK N/A
Warranty information	OK Not OK N/A
S•O•S advantages	OK Not OK N/A
Maintenance contract advantages	OK Not OK N/A

Engine Checklist

Governor		
Governor/actuator type		
Linkage free	OK Not OK N/A	
Oil level		
Fuel System Information		
High idle set	Specification	
Low idle setting	Specification	
Fuel type	Fuel treatment	OK Not OK N/A
Fuel API	Fuel line isolated	OK Not OK N/A
Fuel filter ΔP (pressure change across fuel filter)	Fuel tanks full and valves open	OK Not OK N/A
Fuel pressure	Check for leaks	OK Not OK N/A
Cooling System Protection		
Fuel load temperature	Check coolant level	OK Not OK N/A
Antifreeze	Check for leaks	OK Not OK N/A
ΔT radiator (temperature change across radiator)	Corrosion protection	OK Not OK N/A
Lubrication System		
Oil filter ΔP	Check level	OK Not OK N/A
Oil pressure	Check for leaks	OK Not OK N/A
Combustion Air		
Temperature in	Duct isolation	OK Not OK N/A
Temperature AC	Check for leaks	OK Not OK N/A
Air filter ΔP (pressure change across air filter)		
Boost (inlet manifold pressure)		
Exhaust System		
Exhaust back pressure	Exhaust pipe isolation	OK Not OK N/A
Exhaust temperature before turbocharger	Check for leaks	OK Not OK N/A
Exhaust temperature stack		
Port temperatures		
Right-hand bank Cylinder 1	Left-hand bank Cylinder 2	
Cylinder 3	Cylinder 4	
Cylinder 5	Cylinder 6	
Cylinder 7	Cylinder 8	
Cylinder 9	Cylinder 10	
Cylinder 11	Cylinder 12	
Cylinder 13	Cylinder 14	
Cylinder 15	Cylinder 16	

Mechanical			
Loose bolts	OK Not OK N/A	Attachments	OK Not OK N/A
Inspect belts	OK Not OK N/A	Alternator	OK Not OK N/A
Inspect fan	OK Not OK N/A	Air shut-off	OK Not OK N/A
Inspect hoses and connections	OK Not OK N/A	Other	OK Not OK N/A
Inspect supports	OK Not OK N/A	Other	OK Not OK N/A
Check for leaks	OK Not OK N/A	Other	OK Not OK N/A
Unusual noises	OK Not OK N/A		
Lubrication points	Fan drive ________	Air starter ________	Other ________
	Prelube pump ____	Other ___________	Other ________
Vibration isolators correct	OK Not OK N/A		

Vibration Levels						
Locations	EFV	EFH	ERV	ERH	ERA	Comments
Mils						
In/sec						
Locations	GRV	GRH	GRA	Other	Other	Comments
Mils						
In/sec						

Batteries			
Charged	OK Not OK N/A	Trickle charger	OK Not OK N/A
Electrolyte	OK Not OK N/A	Charge rate	OK Not OK N/A
Isolated from floor	OK Not OK N/A		

Jacket Water Heaters		
Block temperature	Wired correctly	OK Not OK N/A
	Power on	OK Not OK N/A

Starter		
Type	Inspect wiring	OK Not OK N/A

Alarms			
High water temperature	OK Not OK N/A	Low water	OK Not OK N/A
Low oil pressure	OK Not OK N/A	Shutdown devices	OK Not OK N/A
High oil temperature	OK Not OK N/A	Other	OK Not OK N/A
High air inlet manifold	OK Not OK N/A	Other	OK Not OK N/A

Generator Check List

Rating Information	
Engine serial number	Arrangement number
Generator serial number	Arrangement number
Generator Name Plate Information	
Voltage	Package (prime, continuous, standby)
Amperage	Kilowatts
Storage location ____________________________	
Main stator megger reading: Before storage	After storage
Generator dried for 24 hours prior to start-up? (Y/N)	Drying method

	Space Heaters	Yes	No	Comments
	Space heaters operating properly			
	Space heaters operated 24 hours prior to start-up			
	Space heaters OFF when engine is running			

Megger Test (SEHS9124)		30 second reading	60 second reading	30 second corrected	60 second corrected	Ambient temperature	Comments
Beginning of storage	Main stator						
	Main rotor						
	Exciter stator						
	Exciter rotor						
	PMG stator						
Start-up	Main stator						
	Main rotor						
	Exciter stator						
	Exciter rotor						
	PMG stator						

	Regulator	Voltage	Amps	Comments
No load	F1 to F2	DC		
	20 to 22	AC		
	20 to 24	AC		
	22 to 24	AC		
	26 to 28 (PM only)	AC		
	26 to 30 (PM only)	AC		
	28 to 30 (PM only)	AC		
Full load	Generator excitation name plate information	DC		Compare to “F1” to “F2”
	F1 to F2	DC		
	20 to 22	AC		
	20 to 24	AC		
	22 to 24	AC		
	26 to 28 (PM only)	AC		
	26 to 30 (PM only)	AC		
	28 to 30 (PM only)	AC		

Generator Check List (continued)

Electrical	Yes	No	Comments
Unit properly grounded			
Check diodes			
Overcurrent protection			
Overvoltage protection			
Check for loose wiring			
Adjust voltage			
Adjust frequency			

Mechanical	Data	Comments
Bearing temperature readings at full load	Front ______ Rear ______	
Stator temperature readings at full load	A______ B______ C ______	
Air gap on main stator	Top _______ Bottom_____	
Air gap on exciter stator	Top _______ Bottom_____	
Air gap of PMG	Top _______ Bottom_____	
Ambient air to generator @ full load	Temperature _____________	
Supplier air opening to generator	Size of opening __________	

Switch Gear/Parallel Operation

Manufacturer:

	Setting 1	Setting 2	Setting 3	Comments
Circuit breaker type				
Overload setting				
Reverse power relay				
VAR/PF Controller				
Load share				
Droop or cross current compensation				

Installation and Load Information

Neutral grounding system	UPS
Enclosure type	Size
Motor	Other loads
Total SKVA	Lighting
Total HP	Computers
	Welding
	Non-linear
	Other

Full Load Data

Voltage	Amps	KW	KYARS	P.F.				

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GLOSSARY OF TERMS

A *Ampere*

ABDC *After Bottom Dead Center*

ABS *American Bureau of Shipping Absolute*

ABRASION – Wearing or rubbing away of a part.

ABSOLUTE HUMIDITY – Amount of moisture in the air, indicated in grains per cubic foot.

ABSOLUTE PRESSURE – Gauge pressure plus atmospheric pressure (14.7 lb per in^2).

ABSOLUTE TEMPERATURE – The temperature measured using absolute zero as a reference. Absolute zero is –459.69° F (–273.16° C) and is the lowest point of temperature known.

AC *Alternating Current*

A/C *Aftercooler*

ACCELERATION – The rate of increase of velocity per time unit (example: $\frac{\text{feet/sec}}{\text{sec}}$ or feet/sec^2).

ACCOMMODATION LADDER – The stairs used to go aboard a ship.

ACCUMULATOR – A device used for storing liquid under pressure (sometimes used to smooth out pressure surges in a hydraulic system).

ACTIVE POWER – The real power supplied by the generator set to the electrical load. Active power creates a load on the set's engine and is limited by the horsepower of the engine. Active power does the work of heating, turning motor shafts, etc., and is measured in watts, kilowatts, and megawatts.

ACTUATOR – A device which uses fluid power to produce mechanical force and motion.

ADDITIVE – 1. A compound which is added to improve fuel. 2. A substance added to oil to give it certain properties. For example, a material added to engine oil to lessen its tendency to congeal or thicken at low temperatures.

ADVANCE – To move the timing of the injection pump or injectors to an earlier injection point.

ADVANCED DIESEL ENGINE MANAGEMENT (ADEM) – The name for current generation of the electronic engine control system.

AFRC *Air-Fuel Ratio Control*

AFTS *Automatic Fuel Transfer System*

A/F DYNAMIC SETTING – The dynamic (engine running) setting of a device on the engine which limits the amount of fuel injected per stroke as a function of the boost.

AFT – Toward, at, or near the stern.

AFTERCOOLER – A heat exchanger inserted into the induction system of an engine after any device used to compress combustion air.

Ah *Ampere-hour*

AIMS *A (cluster) – Information Management System*

AIR BLEEDER – A device used to remove air from a hydraulic system. Types include a needle valve, capillary tubing to the reservoir, and a bleed plug.

AIR CLEANER – A device (filter) for removing unwanted solid impurities from the air before the air enters the intake manifold.

AIR COMPRESSOR – A device used to increase air pressure.

AIR CONDITIONING – The simultaneous control of all or at least the first three of the following factors affecting the physical and chemical conditions of the atmosphere within a structure: temperature, humidity, motion, distribution, dust, bacteria, odors, toxic gases and ionization – most of which affect, in greater or lesser degree, human health or comfort.

AIR COOLED CONDENSER – Heat of compression is transferred from condensing coils to surrounding air. This may be done either by convection or by a fan or blower.

AIR DIFFUSER – Air distribution outlet designed to direct airflow into desired patterns.

AIR-FUEL RATIO – The ratio (by weight or by volume) between fuel and air.

AIR-FUEL RATIO CONTROL (AFRC) – A feature on Cat engines which measures actual engine speed and boost pressure to reduce smoke and lower fuel consumption.

AIR GAP – The distance between two components; clearance between internal rotating member and stationary outside member. Refers to gap per side.

AIR INLET SHUTOFF – An engine protection measure used to supplement the fuel shutoff, when blocking the air supply is the quickest way to stop the engine. Often this approach is used on larger engines when operating in combustible environments or to achieve fast shutdowns. Air shutoffs are not used for routine shutdowns.

AIR POLLUTION – Contamination of the earth's atmosphere by pollutants such as smoke, harmful gases, etc.

AIR (SPECIFIC HEAT OF) – The quantity of heat absorbed by a unit weight of air per unit temperature rise.

AIR (STANDARD) – Air with a density of 0.075 lb per ft^3 and an absolute viscosity of 0.0379 $\times$ 10-5 lb mass per (ft) (sec). This is substantially equivalent to dry air at 70° F and 29.92 in. Hg barometric pressure.

AIR STARTING VALVE – A valve which admits compressed air to the air starter for starting purposes.

AIR-TO-AIR AFTERCOOLER (ATAAC) – A means of cooling intake air after the turbocharger, using ambient air for cooling. The intake air is passed through an aftercooler (heat exchanger) mounted in front of the radiator before going to the intake manifold.

ALDEHYDES – A chemical compound formed by incomplete combustion.

ALIGN – To bring two or more components of a unit into the correct positions with respect to one another.

ALLOWANCE – The difference between the minimum and the maximum dimensions of proper functioning.

ALLOY – A mixture of two or more different metals, usually to produce improved characteristics.

ALTERNATING CURRENT (AC) – An electric current that reverses its direction at regularly recurring intervals such as 50 or 60 times per second in 50 Hz and 60 Hz, respectively.

ALTERNATING CURRENT (AC) METERING MODULE – An apparatus which displays generator set volts, amps, and frequency.

ALTERNATOR – An electromechanical device which produces alternating current.

AMBIENT – The surrounding atmosphere; encompassing on all sides; the environment surrounding a body but undisturbed or unaffected by it.

AMBIENT TEMPERATURE – Temperature of fluid (usually air) which surrounds object on all sides.

AMD *Authorized Marine*

AMMETER – An instrument used to indicate, in amperes, the current flowing through the phases from a generator to the load.

AMMONIA – Chemical combination of nitrogen and hydrogen (NH_3). Ammonia refrigerant is identified by R-117.

AMORTISSEUR WINDINGS – Apparatus formed by copper rotor end plates and damper bars to help stabilize a generator set during parallel operation.

AMPERAGE – A measure of the current or number of electrons passing a given point per unit of time.

AMPERE (A) – A unit of measurement defined as the current that 1 V can send through 1W resistance.

AMPERE-HOUR CAPACITY (Ah) – A measurement of the battery's capacity to deliver a specified current over a specified length of time.

ANALOG – A continuous performance signal representing the value of an engine performance characteristic.

ANEROID – A pressure-measuring device containing no liquid.

ANGLE – Inclination of two lines to each other.

ANGULARITY – Having or being at an angle.

ANNEAL – To toughen metals by heating and then cooling.

ANNULAR – In the form of an annulus; ring-shaped.

ANNULUS – A figure bounded by concentric circles or cylinders (e.g., a washer, ring, sleeve, etc.).

ANNUNCIATOR – An alarm which produces audible and/or visual signals to give warnings of shutdown or fault conditions. Annunciators are typically used in applications where the equipment monitored is not located in a portion of the facility that is normally attended.

ANSI *American National Standards Institute*

ANTIFREEZE – A chemical such as alcohol, glycerin, etc., added to the coolant in order to lower its freezing point.

ANTIFRICTION BEARING – A bearing constructed with balls, rollers or the like between the journal and the bearing surface to provide rolling instead of sliding friction.

API GRAVITY – Gravity expressed in units of standard API (hydrometer).

ARC – Portion of a curved line or of the circumference of a circle.

AIR GAP – The clearance between internal rotating member and stationary outside member. Refers to gap per side.

AIR WELDING – A method of utilizing the heat of an electric current jumping an air gap to provide heat for welding metal.

API *American Petroleum Institute*

APU *Auxiliary Power Unit*

ARMATURE – The movable part of a relay, regulator, or horn, or the rotating part of a generator or starter.

AS *Air Shut-off (Solenoid)*

ASBESTOS – A heat-resistant and nonburning organic mineral.

ASME *American Society of Mechanical Engineers*

asp *Engine aspiration*

ASPHALT EPOXY – Additional protective coating on winding coil heads on the intake end of a generator.

ASPIRATE – To breathe (to draw out gas by suction).

ASPIRATION – The method used to move inlet air into the combustion chamber; e.g. Naturally Aspirated (NA), Turbocharged (T), and Turbocharged-Aftercooled (TA).

ASTM *American Society of Testing Materials*

ATAAC *Air-To-Air AfterCooling*

ATA LINK – An analog terminal adapter that allows a Northern Transcom Norstar digital phone system to use analog devices such as a fax, answering machine, or modem.

ATDC *After Top Dead Center*

ATHWARTSHIP – Across the ship, at right angles to the fore-and-aft center line of the ship.

ATMOSPHERE – The mass or blanket of gases surrounding the earth.

ATMOSPHERIC PRESSURE (BAROMETRIC PRESSURE) – The pressure exerted by the atmosphere, averaging 14.7 psi at sea level with a decrease of approximately ½ lb per 1000 ft of altitude gained.

ATOM – The smallest particle of an element.

ATOMIZER – A device which disperses liquid (e.g. fuel) into fine particles (pulverized spray).

ATS *Automatic Transfer Switch*

ATTRITION – Wearing down by rubbing or by friction: abrasion.

AUSTEMPERING – A method of hardening steel by quenching from the austenitizing temperature into a heat extracting medium (usually salt) which is maintained at some constant temperature level between 400° F and 800° F (usually near the higher temperature) and holding the steel in this medium until transformation is substantially complete and then cooling to room temperature.

AUTOMATIC DEFROST – System of removing ice and frost from evaporators automatically.

AUTOMATIC SYNCHRONIZER – A magnetic-type control relay which will automatically close the generator switch/circuit breaker when the conditions for paralleling are satisfied.

AUTOMATIC TRANSFER SWITCH (ATS) – Automatically switches electrical load from the normal (or preferred) power source to an alternate supply, should normal voltage fail or be substantially reduced. It retransfers load to the normal source when voltage has been restored.

AUTOMATIC VALVE – A valve assisted by a spring, which is opened by a difference of pressure acting in one direction and closed by a difference in pressure acting in the opposite direction.

AUTOMATIC VOLTAGE REGULATOR – Controls the output voltage produced by a generator by controlling excitation.

AUX GEN *Auxiliary Generator*

AUXILIARY – An aid to the main device which may only be used occasionally.

AVOIDED COSTS – The decremental cost for the electric utility to generate or purchase electricity that is avoided through the purchase of power from a cogeneration facility.

AVR *Automatic Voltage Regulator*

AXIAL FAN – A shaft mounted fan on some designs between bearing and revolving field assembly to provide additional air movement within the unit for cooling; also used for balancing.

AVOIDED COST (Regulatory) – The amount of money that an electric utility would need to spend for the next increment of electric generation production to produce or purchase elsewhere the power that it instead buys from a cogenerator or small power producer.

BABBITT – An antifriction metal used to line bearings, thereby reducing the friction of the moving components.

BACKFIRE – Ignition of the mixture in the intake manifold by flame from the cylinder such as might occur from a leaking inlet valve.

BACKLASH – The distance (play) between two movable components such as meshed gears.

BACKPRESSURE – A pressure exerted contrary to the pressure producing the main flow. Also called suction pressure or low side pressure.

BACK-UP POWER – Electric energy available from or to an electric utility during an unscheduled outage to replace energy ordinary generated by the facility or the utility. Frequently referred to as standby power.

BAFFLE OR BAFFLE PLATE – A device which slows down or diverts the flow of gases, liquids, sound, etc.

BAINITE – The structure that is obtained when steel is quenched as a constant subcritical temperature.

BALL BEARING – A bearing using steel balls as its rolling element between the inner and outer ring (race).

BALL CHECK VALVE – A valve consisting of a ball held against a ground seat by a spring. It is used to check the flow or to limit the pressure.

BALLAST – Weight added in a ship's inner bottom to balance her top-side weight, or to keep her down in the water under light loads. Some ships carry permanent concrete ballast. Others pump salt water into the tanks for the same purpose.

BAROMETER – An instrument which measures atmospheric pressure.

BARS – The term "bars" includes rounds, squares, hexagons, etc.; small standard shapes (angles, channels, tees, etc.) under 3"; flats 6" or under in width and 13⁄64" or over in thickness.

BASE LOAD – The lowest level of power production needs during a season or year.

BASE LOAD UNIT – A power generating facility that is intended to run constantly at near capacity levels, as much of the time as possible.

BASE LOADING – Use of on-site generating equipment to supply a set amount of power for a specific time period – usually on a daily basis.

BASELINE FORECAST – A prediction of future energy needs which does not take into account the likely effects of new conservation programs that have not yet been started.

BASIC SIZE – The theoretical or nominal standard size from which all variations are made.

BAT *Battery*

BATTERY – A connected group of cells storing an electrical charge and capable of furnishing a current from chemical reactions.

BBDC *Before Bottom Dead Center*

BDC *Bottom Dead Center*

BEAM – An athwartship horizontal member supporting a deck or flat. Also, the extreme width of a ship.

BEARING – The contacting surface on which a revolving part rests.

BEARING CLEARANCE – The distance between the shaft and the bearing surface.

BELL HOUSING (CLUTCH HOUSING) – The metal covering around the clutch or torque converter assembly.

BELOW DECK/GO BELOW – To move to a deck located under the main deck.

BENDIX-TYPE STARTER DRIVE (Inertia Starter Drive) – A type of starter drive that causes the gear to engage when the armature starts rotating and to automatically disengage when it stops.

BERNOULLI'S PRINCIPLE – Given a fluid flowing through a tube, any constriction or narrowing of the tube will create an increase in that fluid's velocity and a decrease in pressure.

BERNOULLI'S THEOREM – In a stream of liquid, the sum of elevation head, pressure head, and velocity remains constant along any line of flow provided no work is done by or upon the liquid in its course of flow, and decreases in proportion to energy lost in the flow.

BES *Brushless Excitation System*

BESSEMER PROCESS – A process for making steel by blowing air through molten pig iron contained in a suitable vessel. The process is one of rapid oxidation mainly of silicon and carbon.

bhp *Engine brake horsepower without fan*

BILGE – Curved section between the bottom and the side of a ship; the recess into which all water drains.

BILGE KEELS – Long, narrow fins fitted to both side of the hull at the turn of the bilge to prevent the ship from rolling.

BIMETAL STRIP – Temperature regulating or indication device which works on the principle that two dissimilar metals with unequal expansion rates, welded together, will bend as temperatures change.

bkW *Engine brake kilowatts without fan*

BLACK SMOKE – A soot-like substance emitted by engines resulting from incomplete combustion.

BLACK START – Refers to the starting of a power system with its own power sources, without assistance from external power supplies.

BLENDED OR HEAVY FUEL – A mixture or residual fuel and a lighter fuel. This fuel type tends to create more combustion chamber deposit formations which can cause increased cylinder and ring wear, especially in smaller, higher speed engines.

BLISTER – A defect in metal produced by gas bubbles either on the surface or formed beneath the surface.

BLOCK RATE SCHEDULES – Utility rate schedules that charge different rates for certain increments of energy consumed. For example: 3 cents for the first 1000 kW-hr, 4 cents for the next 1000 kW-hr, 5 cents for the next 1000 kW-hr, etc.

BLOCK WALL – A concrete structure which is sometimes used to muffle the noise from an operating generator set.

BLOWBY – Combustion gas leakage into the engine crankcase. The leakage is normally from the combustion chamber past the piston rings or through the valve guides. Specific blowby is the volume of blowby at atmospheric pressure divided by the engine power.

BLOWER – A low-pressure air pump, usually of one rotary or centrifugal type.

BLOWHOLE – A hole produced during the solidification of metal by evolved gas which, in failing to escape, is held in pockets.

BLUE BRITTLENESS – Brittleness occurring in steel when worked in the temperature range of 300-700° F or when cold after being worked within this temperature range.

B/M *Bill of Material*

BMEP *Brake Mean Effective Pressure*

BOILING POINT – The temperature at which bubbles or vapors rise to the surface of a liquid and escape.

BOILING TEMPERATURE – Temperature at which a fluid changes from a liquid to a gas.

BOND – The holding together of different parts.

BOOST – The gauge pressure as measured in the inlet manifold of a diesel engine. Adjusted boost is calculated value or boost that would exist if an engine were running at nominal power. Boost is not synonymous with inlet manifold pressure.

BORE – The diameter of each cylinder in an engine.

BORING– Enlarging the cylinders by cutting or honing them to a specified size.

BORING BAR (Cylinder) – A tool used to machine the cylinders to a specific size.

BOSCH METERING SYSTEM – A metering system with a helical groove in the plunger which covers or uncovers ports in the pump barrel.

BOTTOM DEAD CENTER (BDC) – The lowest point a piston reaches in its movement within a cylinder.

BOTTOMING CYCLE – A means to increase the thermal efficiency of a steam electric generating system by converting some waste heat from the condenser into electricity rather than discharging all of it into the environment.

BOUND ELECTRONS – the inner-orbit electrons around the nucleus of the atom.

BOW – The front part of a ship, where the two sides meet. To move in that direction is to go forward.

BOYLE'S LAW OF PHYSICS – The absolute pressure which a given quantity of gas at constant temperature exerts against the walls of the containing vessel is inversely proportional to the volume occupied. Examples: If pressure is doubled on the quantity of gas, volume becomes one-half. If volume becomes doubled, gas has its pressure reduced by one-half.

BRAKE HORSEPOWER (bhp) – A measurement of the power developed by an engine in actual operation. It subtracts the F.H.P. (friction losses) from the I.H.P. (pure horsepower).

BRAKE MEAN EFFECTIVE PRESSURE (BMEP) – Mean effective pressure acting on the piston which would result in the given brake horsepower output, if there were no losses due to friction, cooling, and exhaustion. Equal to mean indicated pressure times mechanical efficiency.

BRAKE SPECIFIC FUEL CONSUMPTION (BSFC) – The quantity of fuel burned to produce one horsepower for one hour.

BRAKE THERMAL EFFICIENCY – Ratio of power output in the form of brake horsepower to equivalent power input in the form of heat from fuel.

BRAZE – To join two pieces of metal using a comparatively high-melting-point material. An example is to join two pieces of steel by using brass or bronze as a solder.

BREAK-IN – The process of wearing in to a desirable fit between the surfaces of two new of reconditioned parts.

BREATHER – A device that allows fumes to escape from the crankcase.

BREATHER PIPE – A pipe opening into the crankcase to assist ventilation.

BRIDGE – A crosswise platform above the main deck of a ship from which the ship is controlled.

BRINE – Water saturated with chemical such as salt.

BRINELL HARDNESS – The surface hardness of a metal, alloy, or similar material according to J.A. Brinell's method of measurement. A metal's surface is struck at a given force by a rigid steel ball of given diameter, and the indentation is measured.

BRITISH GALLON (Imperial Gallon, gal [Imp.]) – A gallon measurement of 277.4 in^3.

BRITISH THERMAL UNIT (Btu) – Approximate definition: The amount of heat required to raise 1 lb of water 1° F. Exact definition: The amount of heat required to raise 1 lb. of water from freezing to boiling at standard atmospheric pressure.

BROAD VOLTAGE – A term used to denote 12-lead unit, which allows low and high voltage connections by customer.

BROWNOUT – A controlled power reduction in which the utility decreases the voltage on the power lines, so customers receive weaker electric current.

BRUSH – The pieces of carbon or copper that make a sliding contact against the commutator or slip rings.

BRUSHLESS – A synchronous machine having a brushless exciter with its rotating armature and semiconductor devices on a common shaft with the field of the main machine.

BSFC *Brake Specific Fuel Consumption*

BSOC *Brake Specific Oil Consumption*

BTDC *Before Top Dead Center*

Btu *British therma unit*

BULKHEADS – This refers to inner walls of a ship, also called partitions.

BULWARKS – Vertical extensions above the deck edge of the shell plating. Bulwarks are built high enough to keep men and equipment from going overboard.

BUOYANCY – The upward or lifting force exerted on a body by a fluid.

BURNING – The heating of a metal to temperatures sufficiently close the melting point to cause permanent damage to the metal.

BURNISH – To polish or shine a surface with a hard, smooth object.

BURSTS – Ruptures made in forging or rolling.

BUS – An electrical conductor that serves as a common connection for two or more electrical circuits.

BUS – Refers to the devices that connect the generators and loads in a paralleling system, or any point fed by multiple sources and/or supplying multiple loads.

BUS BARS – A set of common conductors on the load side of a circuit breaker used to conduct generator output to the distribution system.

BUS CAPACITY – The maximum load that can be carried on a system without causing degradation of the generator frequency. In other words, the full load capacity of the system.

BUSHING – A metallic or synthetic lining for a hole which reduces or prevents abrasion between components.

BUTANE – A hydrocarbon gas formed synthetically by the action of zinc or ethyl iodide. This gas becomes a liquid when under pressure.

BUTTERFLY VALVE – A valve in the venturi to control the airflow.

BYPASS FILTER – An oil filter that only filters a portion of the oil flowing through the engine lubrication system.

BYPASS VALVE – A valve that opens when the set pressure is exceeded. This allows the fluid to pass through an alternative channel.

CAC *Charge Air Cooler*

CACo *Caterpillar Americas Company*

CAGE – A housing in which a valve operates and seats.

CALCIUM SULFATE – Chemical compound ($CaSO_4$) which is used as a drying agent or desiccant in liquid line driers.

CALIBRATE – To make an adjustment to a meter or other instrument so that it will accurately indicate its input.

CALIPER – A tool for measuring diameter, usually having curved legs and resembling a pair of compasses.

CALORIE – Heat required to raise temperature of one gram of water one degree centigrade.

CALORIFIC VALUE – The amount of heat produced by burning one pound of fuel. (See *Heating Value.*)

CALORIMETER – Device used to measure quantities of heat or determine specific heats.

CAM – A component of irregular shape. It is used to change the direction of the motion of another part moving against it, e.g., rotary into reciprocating or variable motion.

CAM FOLLOWER (Valve Lifter) – A part which is held in contact with the cam and to which the cam motion is imparted and transmitted to the pushrod.

CAM-GROUND PISTON – A piston ground to a slightly oval shape which under the heat of operation becomes round.

CAM NOSE – That portion of the cam that holds the valve wide open. It is the high point of the cam.

CAMPAR *Computer Aided Marine PAR*

CAMSHAFT – The shaft containing lobes or cams to operate the engine valves.

CAMSHAFT GEAR – The gear that is fastened to the camshaft.

CAPABILITY – The maximum load which a generating unit, generating station, or other electrical apparatus can carry under specified conditions for a given period of time, without exceeding approved limits of temperature and stress.

CAPACITOR – An arrangement of insulated conductors and dielectrics for the accumulation of an electric charge with small voltage output.

CAPACITY (electric utility) – The maximum amount of electricity that a generating unit, power plant, or utility can produce under specified conditions. Capacity is measured in megawatts and is also referred to as the nameplate rating.

CAPACITY CREDITS – The value incorporated into the utility's rate for purchasing energy, based upon the savings due to the reduction or postponement of new generation capacity resulting from the purchase of power from cogenerators.

CAPACITY FACTOR – The ratio of the actual annual plant electricity output to the rated plant output.

CAPACITY-NET COOLING – The cooling capacity of an air-conditioning system or heat pump on the cooling cycle is the amount of Sensible and Latent heat (total heat) removed from the inside air.

CAPSTAN – A revolving device with a vertical axis, used for heaving-in mooring lines.

CARB *California Air Resources Board*

CARBON – One of the nonmetallic elements constituting fuel and lubricating oil.

CARBON DIOXIDE (CO_2) – A "greenhouse" gas produced as a result of combustion of any hydrocarbon fueled engine, including a human. The highest efficiency engines produced the least CO_2.

CARBON MONOXIDE (CO) – A poisonous gas formed by combustion taking place with a shortage of oxygen. Measured in parts per million by volume.

$$\text{CO Concentration (ppm)} = \frac{1034 \times \text{CO mass emissions (g/hr)}}{\text{Exhaust mass flow (kg/hr)}}$$

CARBON PILE – Carbon disks or plates capable of carrying high current.

CARBON TETRACHLORIDE – A colorless liquid, the fumes of which are toxic. Used in fire extinguishers and for cleaning.

CARBONIZE – The process of carbon formation within an engine, such as on the spark plugs and within the combustion chamber.

CARBURETOR – A device for automatically mixing gasoline fuel in the proper proportion with air to produce a combustible vapor.

CARBURETOR "ICING" – A term used to describe the formation of ice on a carburetor throttle plate during certain atmospheric conditions.

CARBURIZING (cementation) – Adding carbon to the surface of iron-base alloys by heating the metal below its melting point in contact with carbonaceous solids, liquids, or gases.

CAT DATA LINK – A communication data link which displays status of various engine parameters on the Computerized Monitoring System.

CAT PC *Caterpillar Engine Power Connection*

CB *Circuit Breaker*

CDL *Cat Data Link*

CEILING – The absolute maximum to which the high limit of an engine performance specification may rise.

CEMENTITE – A compound of iron and carbon always containing 6.68% carbon and 93.32% iron.

CENTRAL COOLING – Same as central heating except that cooling (heat removal) is supplied instead of heating; usually a chilled water distribution system and return system for air conditioning.

CENTRAL HEATING – Supply of thermal energy from a central plant to multiple points of end-use, usually by steam or hot water, for space and/or service water heating. Central heating may be large-scale as in plants serving central business districts, university campuses, medical centers, and military installations or in central building systems serving multiple zones; also district heating.

cemf *counterelectromotive force*

CETANE – Measure of ignition quality of diesel fuel – at what pressure and temperature the fuel will ignite and burn.

CHAMFER – A bevel or taper at the edge of a hole.

CHARGE AIR COOLER (CAC) – An air-to-air or water-to-air heat exchanger to cool turbocharged combustion air.

CHASE – To straighten up or repair damaged threads.

CHOKE – A device such as a valve placed in a carburetor air inlet to restrict the volume of air admitted.

CHP *Combined Heat and Power (also referred to as cogeneration)*

CIM *Customer Interface Module*

CIPS *Caterpillar International Power Systems*

CIRCUIT – The complete path of an electric current including, usually, the source of electrical energy.

CIRCUIT BREAKER – A device used to open and close a circuit by nonautomatic means, and to open the circuit automatically on a predetermined overload of current.

CIS *Corporate Information Services*

CLOSING RATING – The maximum fault current into which an automatic transfer switch of a generator set can close.

CLS *Caterpillar Logistics Services*

CMS *Computerized Monitoring System*

COEFFICIENT OF EXPANSION – The change in length per unit length or the change in volume per unit volume per degree change in temperature.

COEFFICIENT OF PERFORMANCE (COP) – The ratio of the rate of heat removal to the rate of energy input in consistent units.

COFFERDAM – A narrow empty space between two bulkheads that prevents leakage into the adjoining compartments.

COGENERATION – Utilizing a prime power generator set, this process involves harnessing "free" heat energy from engine cooling and exhaust systems for heating or steam generation, or to power air conditioning, absorption chillers, or other equipment.

COHESIVE STRENGTH – The strength property of a metal that resists the tensile, disruptive stress across a plane at right angles to the load applied.

COIL SPRING – A spring-steel wire wound in a spiral pattern.

COIL WEDGE – A mechanical device which prevents coil bundle from coming out of rev. field slot passage during rotation of rev. field. Two types: expansion wedges – 360, 440, and 580, 680 frames; compression wedges – 800 frame.

COLD – Cold is the absence of heat; a temperature considerably below normal.

COLD DRAWING – The process for finishing a hot rolled rod or bar at room temperature by pulling it through the hole of a die of the same shape but smaller in size.

COLD FINISHING – The process of reducing the cross sectional area without heating by cold rolling, cold drawing, cold and grinding, turning and polishing, or turning and grinding.

COLD ROLLING – The cold working of hot rolled material by passing it between power-driven rolls. The process applies to flat bars of such a size that they cannot be pulled through a die.

COLD WORKING – Plastic deformation of a metal at a temperature low enough to ensure strain hardening.

COLOR CODE – Colored markings or wires to identify the different circuits.

COMBUSTION – The process of burning.

COMBUSTION CHAMBER – The chamber in reciprocating engines between the cylinder head and piston, in which combustion occurs.

COMBUSTION-CHAMBER VOLUME – The volume of the combustion chamber (when the piston is at TDC) measured in cubic centimeters.

COMBUSTION CYCLE – A series of thermodynamic processes through which the working gas passes to produce one power stroke. The cycle is: intake, compression, power, and exhaust.

COMFORT AIR-CONDITIONING – A simultaneous control of all, or at least the first three, of the following factors affecting the physical and chemical conditions of the atmosphere within a structure of the purpose of human comfort; temperature, humidity, motion, distribution, dust, bacteria, odors, toxic gases, and ionization, most of which affect in greater or lesser degree human health or comfort.

COMMUTATOR – A number of copper bars connected to the armature windings but insulated from each other and from the armature. Rotation of the armature will, in conjunction with fixed brushes, result in unidirectional current output.

COMPARTMENT – A subdivision of space or room in a ship.

COMPOUND – A combination of two or more elements that are mixed together.

COMPRESSED AIR – Air that at any pressure in excess of atmospheric pressure is considered to be compressed.

COMPRESSIBILITY – The property of a substance (e.g., air) by virtue of which its density increases with increase in pressure.

COMPRESSION – The process by which a confined gas is reduced in volume through the application of pressure.

COMPRESSION CHECK – A measurement of the compression of each cylinder at cranking speed or as recommended by the manufacturer.

COMPRESSION GAUGE – A test instrument used to test the cylinder compression.

COMPRESSION IGNITION – The ignition of fuel through the heat of compression.

COMPRESSION PRESSURE – Pressure in the combustion chamber at the end of the compression stroke, but without any of the fuel being burned.

COMPRESSION RATIO – Compares the minimum and maximum volumes between the piston crown and the cylinder head.

COMPRESSION RELEASE – A device to prevent the intake or exhaust valves from closing completely, thereby permitting the engine to be turned over without compression.

COMPRESSION RING – The piston rings used to reduce combustion leakage to a minimum.

COMPRESSION STROKE – That stroke of the operating cycle during which air is compressed into a smaller space, creating heat by molecular action.

COMPRESSOR – A mechanical device to pump air, and thereby increase the pressure. The pump of a refrigerating mechanism which draws a vacuum or low pressure cooling side of refrigerant cycle and squeezes or compresses the gas into the high pressure or condensing side of the cycle.

COMPRESSOR-BRAKE HORSEPOWER – A function of the power input to the ideal compressor and to the compression, mechanical, and volumetric efficiency of the compressor.

COMPRESSOR EFFICIENCY – A measure of the deviation of the actual compression from the perfect compression cycle. Is defined as the work done within the cylinders.

COMPRESSOR, OPEN-TYPE – Compressor in which the crankshaft extends through the crankcase and is driven by an outside motor.

COMPRESSOR OUTLET PRESSURE – Gauge pressure of the combustion air at the turbocharger compressor outlet of a spark ignited engine.

COMPRESSOR, RECIPROCATION – Compressor which uses a piston and cylinder mechanism to provide pumping action.

COMPRESSOR, ROTARY – Compressor which uses vanes, eccentric mechanisms, or other rotating devices to provide pumping action.

COMPUTERIZED MONITORING SYSTEM (CMS) – An electronic display for marine or industrial engines to display engine parameters and diagnostics.

CONCENTRIC – Having the same center.

CONCEPTUAL DESIGN – The specification of the major components of a system and their operating characteristics, layout, space needs, and operating and maintenance requirements.

CONDENSATE – Fluid which forms on an evaporator.

CONDENSATE PUMP – Device used to remove fluid condensate that collects beneath an evaporator.

CONDENSATION – Liquid or droplets which form when a gas or vapor is cooled below its dew point.

CONDENSE – Action of changing a gas or vapor to a liquid.

CONDENSER, AIR-COOLED – A heat exchanger which transfers heat to surrounding air.

CONDENSER, ELECTRICAL – An arrangement of insulated conductors and dielectrics for the accumulation of an electric charge.

CONDENSER, EVAPORATIVE – A condenser in which heat is absorbed from the surface by the evaporation of water sprayed or flooded over the surface.

CONDENSER, THERMAL – The part of a refrigeration mechanism which receives hot, high pressure refrigerant gas from the compressor and cools gaseous refrigerant until it returns to liquid state.

CONDENSER, WATER-COOLED – Heat exchanger which is designed to transfer heat from hot gaseous refrigerant to water.

CONDENSING UNIT – The part of the refrigeration mechanism which pumps vaporized refrigerant from the evaporator, compresses it, liquifies it in the condenser, and returns the liquid refrigerant to refrigerant control.

CONDUCTION, THERMAL – The process of heat transfer through a material medium in which kinetic energy is transmitted by the particles of the material from particle to particle without gross displacement of the particles.

CONDUCTIVITY, THERMAL – “k” factor – The time rate of heat flow through unit area of a homogeneous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to the area. In English units its value is usually expressed in Btu per (hour) (square foot) (Fahrenheit degree per inch of thickness). Materials are considered homogeneous when the value of “k” is not affected by variation in thickness or in size of sample within the range normally used in construction.

CONDUCTOR – Any material whose properties allow electronic to move with relative ease. Typical examples are copper and aluminum.

CONNECTING ROD – A reciprocating rod connecting the crankshaft and piston in an engine.

CONSERVATION – Steps taken to cause less energy to be used than would otherwise be the case.

CONSTANT-PRESSURE COMBUSTION – Combustion which occurs without a change in pressure. In an engine, this is obtained by a slower rate of burning than with constant-volume combustion.

CONTAMINANT – A substance (dirt, moisture, etc.) foreign to refrigerant or refrigerant oil in system.

CONTAMINATION – The presence of harmful foreign matter in a fluid or in air.

CONTINUOUS CYCLE ABSORPTION SYSTEM – System which has a continuous flow of energy input.

CONTINUOUS POWER – Output available without varying load for an unlimited time. Continuous power in accordance with ISO8528, ISO3046/1, AS2789, DIN6271, and BS5514.

CONTOUR – Outline.

CONTRACT – To reduce in mass or dimension; to make smaller.

CONTROL – To regulate or govern the function of a unit.

CONTROL VOLTAGE TERMINAL STRIP – Strips provided to allow easy customer connections of generator sets to regulators, space heaters, or other devices.

CONVECTION – Transfer of heat by means of movement or flow or a fluid or gas.

CONVECTION, FORCED – Transfer of heat resulting from forced movement of liquid or gas by means of fan or pump.

CONVECTION, NATURAL – Circulation of a gas or liquid due to the difference in density resulting from temperature difference.

CONVENTIONAL – According to the most common or usual mode.

CONVERGE – To incline to or approach a certain point; to come together.

CONVERTER – As used in connection with LP gas, a device which converts or changes LP gas from a liquid to a vapor for use by the engine.

CONVOLUTION – One full turn of a screw.

COOLANT – A liquid used as a cooling medium.

COOLING LOAD – The rate of heat removed from the chilled water passing through the evaporator – measured in tons.

COOLING SYSTEM – The complete system for circulating coolant.

COOLING TOWER – Device which cools water by water evaporation in air. Water is cooled to wet bulb temperature of air.

COOPERATIVE (electric utility) – A joint venture organized by consumers to make electric utility service available in their area.

COP *Coefficient of Performance*

COPRODUCTION – The conversion of energy from a fuel (possibly including solid or other wastes) into shaft power (which may be used to generate electricity) and a second or additional useful form. The process may entail a series topping and bottoming arrangement for conversion to shaft power and either process or space heating. Cogeneration is a form of coproduction; however, the concept also includes a single heat producer serving several different mechanical and/or thermal requirements in parallel.

CORE – The central or innermost part of an object.

CORRECTION FACTOR – A number by which an engine performance characteristic is multiplied to show the value which would have been obtained if the engine were operating under some other set of conditions.

CORROSION – The slow destruction of material by chemical agents and electromechanical reactions.

COUNTERBALANCE – A weight, usually attached to a moving component, that balances another weight.

COUNTERBORE – A cylindrical enlargement of the end of a cylinder bore or bore hole.

COUNTERELECTROMOTIVE FORCE (cemf) – The electromotive force (voltage) that opposes the applied voltage.

COUNTERSINK – To cut or shape a depression in an object so that the head of a screw may set flush or below the surface.

COUNTERWEIGHT – Weights that are mounted on the crankshaft opposite each crank throw. These reduce the vibration caused by putting the crank in practical balance and also reduce bearing loads due to inertia of moving parts.

COUPLING – A device used to connect two components.

CPS *Cycles Per Second*

C/R *Compression Ratio*

CRANKCASE – The lower housing in which the crankcase and many other parts of the engine operate.

CRANKCASE DILUTION – When unburned fuel finds its way past the piston rings into the crankcase oil, where it dilutes or “thins” the engine lubricating oil.

CRANKCASE SCAVENGING – Scavenging method using the pumping action of the power piston in the crankcase to pump scavenging air.

CRANKING – Rotating an engine with a source of power external to the engine.

CRANKPIN – The portion of the crank throw attached to the connecting rod.

CRANKSHAFT – The main drive shaft of an engine which takes reciprocating motion and converts it to rotary motion.

CRANKSHAFT COUNTER-BALANCE – A series of weights attached to or forged integrally with the crankshaft to offset the reciprocating weight of each piston and rod.

CRANK THROW – One crankpin with its two webs (the amount of offset of the rod journal).

CRANK WEB – The portion of the crank throw between the crankpin and main journal. This makes up the offset.

CREST – The top surface joining the two sides of a thread.

CREST CLEARANCE – Defined on a screw form as the space between the top of a thread and the root of its mating thread.

CRITICAL COMPRESSION RATIO – Lowest compression ratio at which any particular fuel will ignite by compression under prescribed test procedure. The lower the critical compression ratio the better ignition qualities that fuel has. (Gasoline engine, 4:1; oil engine, 7:1; diesel engine, 12.5:1.)

CRITICAL PRESSURE – Condition of refrigerant at which liquid and gas have the same properties.

CRITICAL SPEEDS – Speeds at which the frequency of the power strokes synchronize with the crankshaft's natural frequency of torsional damper. If the engine is operated at one of its critical speeds for any length of time, a broken crankshaft may result.

CRITICAL TEMPERATURE – Temperature at which vapor and liquid have the same properties.

CROCUS CLOTH – A very fine abrasive polishing cloth.

CROSS CURRENT COMPENSATING TRANSFORMER – A unit which senses circulating currents between generators in parallel operation.

CROSS CURRENT COMPENSATION – Method of controlling the reactive power supplied by generators in a paralleling system so that they equally share the total reactive load on the bus, without significant voltage droop.

CROWNED – A very slight curve in a surface (e.g. on a roller or raceway).

CRUDE OIL – Petroleum as it comes from the well (unrefined).

CRUSH – A deliberate distortion of an engine's bearing shell to hold it in place during operation.

CRYOGENIC FLUID – Substance which exits as a liquid or gas at ultra-low temperatures (–250° F or lower).

CRYOGENICS – Refrigeration which deals with producing temperatures at –250° F and lower.

CSFC *Corrected Specific Fuel Consumption*

CSTG *Caterpillar Service Technology Group*

CT *Current Transformer, Crank Terminate (ESS)*

cu in *cubic inch*

CURRENT – A flow of electric charge and the rate of such a flow measured in amperes.

CURRENT TRANSFORMER – An auxiliary instrument used to reduce generator current to that of the instruments and apparatus. Current transformers are used to step down the higher line current to the lower currents that the control system is designed for. These signals are utilized by AC meters, protective relays, and control devices.

CUSTOM ALARM MODULE (CAM) – A Cat unit which provides flexible annunciation capabilities for engines.

CUSTOMER COMMUNICATION MODULE (CCM) – Apparatus which allows users of electronic engines to monitor up to eight Cat power systems remotely, perform system diagnostics, and receive parameter readouts in real time.

CUSTOMER INTERFACE MODULE (CIM) – A device which decodes Cat electronic engine monitoring information and provides a link to remote alarms and annunciators.

CUT-IN – Temperature or pressure valve which closes control circuit.

CUTLESS BEARING – The bearing used in conjunction with the "stern strut" to support the propeller and or propeller shaft. This bearing usually water lubricated.

CUT-OUT – Temperature or pressure valve which opens the control unit.

CYANIDING – Surface hardening by carbon and nitrogen absorption of an iron-base alloy article portion of it by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

CYCLE – One complete rise and fall of the voltage of alternating current, from zero to maximum positive/back to zero and from zero to maximum negative and back to zero again.

CYCLIC – Variation in the performance characteristics which vary as the engine runs; especially, but not exclusively, those characteristics which vary in a repetitive fashion.

CYCLIC IRREGULARITY – A nondimensional ratio describing the degree of crankshaft twist occurring between two successive firings of cylinders of an engine during steady-state operation.

$$\text{Cyclic Irregularity} = \frac{\text{rpm (maximum)} - \text{rpm (minimum)}}{\text{rpm (average)}}$$

CYLINDER – The chamber in which a piston moves in a reciprocating engine.

CYLINDER BLOCK – the largest single part of an engine. The basic or main mass of metal in which the cylinders are bored or placed.

CYLINDER HEAD – The replaceable portion of the engine fastened securely to the cylinder block that seals the cylinder at the top. It often contains the valves, and in some cases, it is part of the combustion chamber.

CYLINDER HONE – A tool used to bring the diameter of a cylinder to specification and at the same time smooth its surface.

CYLINDER LINER – A sleeve or tube interposed between the piston and the cylinder wall or cylinder block to provide a readily renewable wearing surface for the cylinder.

CYLINDER, REFRIGERANT – Cylinder in which refrigerant is purchased and dispensed. The color code painted on cylinder indicates the kind of refrigerant the cylinders contains.

D – Diode; Distance from plane of reference to assembled unit center of gravity location.

D1 – Distance from plane of reference aft to generator center of gravity.

D2 – Distance from plane of reference forward to engine center.

DALTON'S LAW – Vapor pressure exerted on container by a mixture of gases is equal to sum or individual vapor pressures of gases contained in mixture.

DAVIT – Any of various small cranes used on ships to hoist boats, anchors and cargo.

DC *Direct Current*

DDT *Digital Diagnostic Tool*

DEAD BUS – The de-energized state of the power connections between outputs of paralleled generator sets.

DEAD CENTER – Either of the two positions when the crank and connecting rod are in a straight line at the end of the stroke.

DEAD FRONT – A term used to describe the lack of accessibility of bare connections or apparatus on the panel face of controls or switchgear.

DECARBURIZATION – The removal of carbon (usually refers to the surface of solid steel) by the (normally oxidizing) action of media which react with carbon.

DECELERATION – Opposite of acceleration; that is, implying a slowing down instead of a speeding up. Also called *negative acceleration.*

DECIBEL – Unit used for measuring relative loudness of sounds. One decibel is equal to the approximate difference of loudness ordinarily detectable by the human ear, the range of which is about 103 decibels on a scale beginning with one for faintest audible sound.

DECK – The floor. There may be several decks to a ship. The main deck is the deck exposed (open) to atmosphere.

DEFERRABLE OR SCHEDULED LOADS – Loads which can be disconnected for extended periods of time and restarted later without a great effect on a facility's operation. Delaying energy use to a time or lower demand is effective in minimizing peak demand.

DEFLECTION – Bending or movement away from the normal position, due to loading.

DEGLAZER – A tool used to remove the glaze from cylinder walls.

DEGREE, CIRCLE – $\frac{1}{360}$ of a circle.

DEGREE-DAY – Unit that represents one degree of difference from given point in average outdoor temperature of one day and is often used in estimating fuel requirements for a building. Degree-days are based on average temperature over a 24-hour period. As an example, if an average temperature for a day is 50° F, the number of degree-day for that day would be equal to 65° F minus 50° F or 15 degree-days (65–15=50). Degree-days are useful when calculating requirements for heating purposes.

DEGREE WHEEL – A wheel marked in degrees to set the lifter height.

DEHUMIDIFY – To remove water vapor from the atmosphere. To remove water or liquid from stored goods.

DEHUMIDIFY EFFECT – The difference between the moisture contents, in pounds per hour, of the entering and leaving air, multiplied by 1.060.

DEHYDRATE – To remove water in all forms from matter. Liquid water, hygroscopic water, and water of crystallization or water of hydration are included.

DEHYDRATED OIL – Lubricant which has had most of water content removed (a dry oil).

DEHYDRATION – The removal of water vapor from air by the use of absorbing or absorbing materials; the removal of water from stored goods.

DELTA CONNECTION – the connection of the three windings of a generator into a triangular or delta configuration. Most commonly used by utility companies. Has no neutral point.

DELTA-T – The temperature rise of the engine coolant from the jacket water pump inlet to the engine coolant outlet.

DEMAND (UTILITY) – The level at which electricity or natural gas is delivered to users at a given point in time. Electric demand is expressed in kilowatts.

DEMAND, ANNUAL – The greatest of all demands which occurred during a prescribed demand interval in a calendar year.

DEMAND CHARGE – The sum to be paid by a large electricity consumer for its peak usage level.

DEMAND, COINCIDENT – The sum of two or more demands which occur in the same demand interval.

DEMAND, INSTANTANEOUS PEAK – The maximum demand at the instant of greatest load.

DENDRITES – A crystal formed by solidification, or in any other way, having many branches and a tree-like pattern; also termed “pine tree” and “fir tree” crystals.

DENSITY (FUEL) – The mass of fuel per unit volume. The units of density used in this specification are degrees API at 60 degrees Fahrenheit. (API = American Petroleum Institute)

DEO *Diesel Engine Oil*

DEPTH OF ENGAGEMENT – The depth of a thread in contact with two mating parts measured radially. It is the radial distance by which their thread forms overlap each other.

DESIGN VOLTAGE – The nominal voltage for which a line or piece of equipment is designed. This is a reference level of voltage for identification and not necessarily the precise level at which it operates.

DETERGENT – A compound of a soap-like nature used in engine oil to remove engine deposits and hold them in suspension in the oil.

DETONATION – Burning of a portion of the fuel in the combustion chamber at a rate faster than desired (knocking).

DEW POINT – Temperature at which vapor (at 100 percent humidity) begins to condense and deposit as liquid.

DFD *Diode Fault Detector*

DI *Direct Injection*

DIAGNOSIS – In engine service, the use of instruments to troubleshoot the engine parts to locate the cause of a failure.

DIAL INDICATOR (dial gauge) – A precision measuring instrument.

DIAPHRAGM – Any flexible dividing partition separating two compartments.

DICHLORODIFLUOROMETHANE – Refrigerant commonly known as R-12. Chemical formula is CCl_2F_2. Cylinder color code is white. Boiling point at atmospheric pressure is –21.62° F.

DIE, THREAD – A thread-cutting tool.

DIELECTRIC – A nonconductor of direct electric current.

DIESEL ENGINE – A type of internal combustion engine that burns fuel oil; the ignition is brought about by heat resulting from air compression, instead of by an electric spark, as in a gasoline engine.

DIESEL INDEX – A rating of fuel according to its ignition qualities. The higher the diesel index number, the better the ignition quality of the fuel.

DIFFERENTIAL – As applied to refrigeration and heating, the difference between cut-in and cut-out temperature or pressure of a control.

DIFFERENTIAL FUEL PRESSURE – The gas pressure supplied to the carburetor of a spark ignited engine minus the carburetor inlet pressure.

DIFFERENTIAL PRESSURE FUEL VALVE – A closed fuel valve with a needle or spindle valve which seats onto the inner side of the orifices. The valve is lifted by fuel pressure.

DIFFERENTIAL PROTECTION (Line) – Leads pass through current transformers for the purpose of sensing current imbalance line-leads.

DIGITAL – A numeric valve representing the valve of an engine performance characteristic.

DIGITAL VOLTAGE REGULATOR (D.V.R.) – A microprocessor-based unit which regulates voltage output of a generator.

DILUTION – Thinning, such as when fuel mixes with lubricant.

DINA *Direct Injection Naturally Aspirated*

DIODE – A device which allows current to pass but only in one direction.

DIP AND BAKE – The process of treating a wound electrical element with varnish to provide protection/insulation and to secure the winding in place.

DIPSTICK – A device to measure the quantity of oil in the reservoir.

DIRECT CURRENT (DC) – An electric current flowing in one direction only.

DIRECT-COOLED PISTON – A piston which is cooled by the internal circulation of a liquid.

DIRECTIONAL CONTROL VALVE – A valve which selectively directs or prevents flow to or from specific channels. Also referred to a *selector valve, control valve, or transfer valve.*

DISCHARGE – A draw of current from the battery.

DISPLACEMENT – The total weight of the ship when afloat, including everything aboard, equals the weight of water displaced. Displacement may be expressed in either cubic feet or long tons. A cubic fool of sea water weighs 64 pounds and one of fresh water weighs 62.5 pounds; consequently, one long ton is equal to 35 cubic feet of sea water or 35.9 cubic feet of fresh water. One long ton equals 2240 pounds.

DISPLACEMENT OR SWEPT VOLUME – In a single-acting engine, the volume swept by all pistons in making one stroke each. The displacement on one cylinder in cubic inches is the circular area (in square inches) times the stroke (in inches) times the number of cylinders.

DISTA *Direct Injection Series Turbocharged-Aftercooled*

DISTILLATION – Heating a liquid and then condensing the vapors given off by the heating process.

DISTILLING APPARATUS – Fluid reclaiming device used to reclaim used refrigerants. Reclaiming is usually done by vaporizing and then recondensing refrigerant.

DISTORTION – A warpage or change in form from the original shape.

DISTRIBUTION CIRCUIT BREAKER – A device used for overload and short circuit protection of loads connected to a main distribution device.

DISTRIBUTION SWITCHGEAR – May include automatic transfer switches, circuit breakers, fusible switches, or molded case breakers. This equipment distributes utility or generator power to the site electrical loads.

DIT *Direct Injection Turbocharged*

DITA *Direct Injection Turbocharged-Aftercooled*

DITA–JW *Direct Injection Turbocharged-Aftercooled Jacket Water*

DITT *Direct Injection Turbocharged (Dual Turbo)*

DITTA *Direct Injection Turbocharged-Aftercooled (Dual Turbo)*

DIVISION PLATE – A diaphragm surrounding the piston rod of a crosshead-type engine, usually having a wiper ring to remove excess oil from the piston rod as it slides through. It separates the crankcase from the lower end of the cylinder.

D/N *Dealer/Net*

DOG LEG – A colloquialism applied to the shape of a torque curve which has been modified to provide a steep torque rise at a speed just above the full load point to prevent excessive shifting of transmissions.

DOUBLE ACTING – An actuator producing work in both directions.

DOUBLE FLARE – A flared end of the tubing having two wall thicknesses.

DOWEL – A pin, usually of circular shape like a cylinder, used to pin or fasten something in position temporarily or permanently.

DOWN DRAFT – A type of carburetor in which the fuel-air mixture flows downward to the engine.

DRAFT – The vertical distance from the waterline to the keel. Draft is measured in feet and inches, by scaled marked on the hull at the stem and stern post. Draft numbers are six inches high and spaced six inches apart. The bottom of each number indicates foot marks, the top indicates half-foot marks.

DRAW-OUT RELAY – An AC protective relay that is door mounted, and can be removed from its case without disturbing the wiring to the case, or interrupting the connected circuits. This allows for easy testing and calibration of the relay.

DRAW-OUT UNIT – A structure that holds a circuit breaker in an enclosure. It has a movable carriage and contact structures that permit the breaker to be removed from the enclosure without manually disconnecting power cables and control wires.

DRAWBAR HORSEPOWER – Measure of the pulling power of a machine at the drawbar hitch point.

DRIBBLING – Unatomized fuel running from the fuel nozzle.

DRILL – A tool used to bore holes.

DRILL PRESS – A fixed machine to drive a tool in rotary motion.

DRIVE FLANGE – Presses on shaft of revolving field rabbet pilot and mounting bolt pattern for mounting to engine drive discs.

DRIVE FIT– A fit between two components, whose tolerance is so small that the two parts must be pressed or driven together.

DROOP LOAD SHARING – A method of making two or more parallel generator sets share a system kW load. This is accomplished by having each governor control adjusted so that the sets have the same droop (reduction of speed).

DROOP (or Speed Droop) – The decrease from no load speed to full load speed when full load is applied to a generator set, expressed as a percentage of the full load speed.

DROOP TRANSFER – A small transformer provided for mounting current flow through output line leads. A loop of one or two turns of one of the line leads passes through the coil/plane of the transformer to produce sensing.

DROP-FORGED – Formed by hammering or forced into shape by heat.

DRY BULB – An instrument with a sensitive element which measures ambient (moving) air temperature.

DRY BULB TEMPERATURE – Air temperature as indicated by an ordinary thermometer.

DRY CELL, DRY BATTERY – A battery that uses no liquid electrolyte.

DRY-CHARGED BATTERY – A battery in a pre-charged state but without electrolyte. The electrolyte is added when the battery is to be placed in service.

DRY SLEEVE – A cylinder sleeve (liner) where the sleeve is supported over its entire length. The coolant does not touch the sleeve itself.

DST *Detonation Sensitive Timing*

DSU *Data Sending Unit*

DUAL ELEMENT (DE) – Number of elements in an assembly, especially filters.

DUAL FUEL – A term used to describe an engine which starts on one type of fuel and runs on another type.

DUAL SERVICE – Utilizing a prime power generator set for a regular, but noncritical load. When a utility outage occurs, the unit automatically switches to provide emergency power immediately.

DUAL VALVES – Refers to cylinders having two valves performing one function, e.g. two intake valves, two exhaust valves.

DUAL VOLTAGE – The term used to denote 10-lead machine – 240/480, 300/600.

DUCTILITY – The ability of a metal to withstand plastic deformation without rupture.

D.V.R. *Digital Voltage Regulator*

DYNAMIC BALANCE – Condition when the weight mass of revolving object is in the same plane as the centerline of the object.

DYNAMIC PRESSURE – The pressure of a fluid resulting from its motion, equal to one-half the fluid density times the fluid velocity squared. In incompressible flow, dynamic pressure is the difference between total pressure and static pressure.

DYNAMOMETER – A device for absorbing the power output of an engine and measuring torque or horsepower so that it can be computed into brake horsepower.

EBULLIENT COOLED ENGINE – An engine cooled by boiling water The cooling is accomplished by turning water into steam. The latent heat of evaporation absorbed in this process cools the engine.

EBULLIENT SYSTEM – A type of high temperature heat recovery system. Also known as solid water system.

ECAP *Electronic Control Analyzer Programmer*

ECCENTRIC – One circle within another circle but with different center of rotation. An example of this is a driving cam on a camshaft.

ECM *Electronic Control Module*

ECS *Electronic Control System*

ECU *Electronic Control Unit*

ECONOMIZER – A device installed in a carburetor to control the amount of fuel used under certain conditions.

EDGE FILTER – A filter which passes liquid between narrowly separated disks or wires.

EDS *Engine Data System*

EFFICIENCY – In general, the proportion of energy going into a machine which comes out in the desired form, or the proportion of the ideal which is realized.

EFH *Engine Front Horizontal*

EFV *Engine Front Vertical*

EIS *Electronic Ignition System, Engine Information System, Environmental Impact Statement*

EkW *Electrical kilowatts with fan*

ELAPSED TIME METER – Totals the hours of generator set operation

ELASTIC LIMIT – The greatest stress which a material is capable of developing without a permanent deformation remaining upon complete release of the stress.

ELECTRIC POWER GENERATION (EPG) – Producing energy through the use of a generator set.

ELECTRIC POWER GENERATION DESIGNER (EPG DESIGNER) – A Cat software program which guides Cat dealers and consulting engineers through "specing" and installing generator set packages.

ELECTRICAL OPERATOR – The electric motor-driven closing and tripping (opening) devices that permit remote control of a circuit breaker.

ELECTROLYTE – A solution of sulfuric acid and water.

ELECTROMOTIVE FORCE (emf) – Forces that move or tend to move electricity.

ELECTRONIC CONTROL ANALYZER PROGRAMMER (ECAP) – An electronic service tool developed by Caterpillar used for programming and diagnosing a variety of Caterpillar electronic controls using a data link.

ELECTRONIC CONTROL MODULE (ECM) – The engine control computer that provides power to the truck engine electronics. It accepts inputs that monitor and outputs that control or change to act as a governor to control engine rpm.

ELECTRONIC MODULAR CONTROL PANEL (EMCP) – A microprocessor-based feature on all Cat generator sets which provides improved reliability through precise engine control.

ELECTRONIC TECHNICIAN (ET) – A software program to run on a service tool like a personal computer (PC). This program will supplement and eventually replace ECAP.

ELEMENT, BATTERY – A group of plates – negative and positive.

ELONGATION – The amount of permanent extension in the vicinity of the fracture in the tension test, usually expressed as a percentage of the original gauge length, such as 25 percent in two inches.

EMBEDDED STATOR TEMPERATURE DETECTOR – Thermocouple embedded in a generator's stator winding.

EMCP *Electronic Modular Control Panel*

EMERGENCY SYSTEM – Independent power generation equipment that is legally required to feed equipment or systems whose failure may present a hazard to persons or property.

emf *electromotive force*

EMISSION STANDARD – The maximum amount of a pollutant legally permitted to be discharged from a single source.

EMISSIONS – The gaseous products emitted in engine exhaust.

EMS *Engine Monitoring System, Equipment Management System*

EMULSIFY – To suspend oil in water in a mixture where the two do not easily separate.

ENCAPSULATION – An impervious material to surround and protect an item from the environment.

END MOUNTED TERMINAL BOX (EMTB) – The latest design on very large generators; 580, 680, and 800 frames; for covering customer line lead connections (bus bars or circuits breakers) and regulator assemblies.

END PLAY – The amount of axial movement in a shaft that is due to clearance in the bearings or bushings.

ENDURANCE LIMIT – A limiting stress, below which metal will withstand without fracture an indefinitely large number of cycles of stress.

ENERGIZE – To make active.

ENERGIZED SYSTEMS – A system under load (supplying energy to load) or carrying rated voltage and frequency, but not supplying load.

ENERGY – Capacity for doing work.

ENERGY CHARGE – That portion of the billed charge for electric service based upon the electric energy (kilowatt-hours) supplied, as contrasted with the demand charge.

ENERGY CONSUMPTION – The amount of energy consumed in the form in which it is acquired by the user (excluding electrical generation and distribution losses).

ENERGY EFFICIENCY RATIO (EER) – The heat transfer ability of the refrigeration system, expressed in Btu/h, compared to watts of electrical energy necessary to accomplish the heat transfer. This comparison is expressed in Btu/h/Watt of electrical energy.

ENGINE – The prime source of power generation used to propel the machine.

ENGINE COOLANT LEVEL – On the EMS II module, a flashing red light and horn annunciate when a customer-provided coolant level switch is activated. This information is provided to EMS II directly and then sent on the datalink. In the event that coolant level input is not provided, the input will be shorted on the terminal strip.

ENGINE DISPLACEMENT – The volume each piston displaces when it moves from BDC to TDC times the number of cylinders. (Also see *Displacement.*)

ENGINE LOAD – The Engine power is determined as a function of manifold pressure and speed from dynamometer test data.

ENGINE MONITORING SYSTEM (EMS) – An electronic display for marine or industrial engines to display engine parameters and diagnostics.

ENGINE MOUNTING RING – A rabbet fit ring with mounting holes on end of the stator frame for engine mounting.

ENSIGN STAFF – A flagstaff at the stern of a vessel from which the national ensign maybe flown.

ENTHALPY – Total amount of heat in one pound of a substance calculated from accepted temperature base. Temperature of 32° F is the accepted base for water vapor calculation. For refrigerator calculations, the accepted base is 40° F.

ENVIRONMENTAL PROTECTION AGENCY (EPA) – A Federal agency.

EPA *Environmental Protection Agency*

EPG *Electric Power Generation*

ERH *Engine Rear Horizontal*

ERODE – To wear away.

ERR *Engine Rear Roll*

ERV *Engine Rear Vertical*

ESC *Extended Service Coverage, Energy Service Company*

ESS *Electronic Speed Switch, Engine Supervisory System*

ET *Engine Test, Electronic Technician*

ETCHING – A process which determined the structure and defects in metals.

ETDS *Engine Technical Data System (TMI)*

ETHER – A volatile, colorless, and highly flammable chemical compound which is used as a starting aid.

ETHYLENE GLYCOL – A compound added to the cooling system to reduce the freezing point.

ETR *Energize To Run*

EUI *Electronic Unit Injector*

EUTECTOID – Nearly all iron contains some carbon. In annealed steel, iron carbide mixes with iron (ferrite) in alternate thin layers and is called pearlite. As the carbon content increases, it causes an increase in pearlite and a decrease in ferrite. At the point of increase where all the ferrite is in combination with carbon, the structure will be entirely of pearlite. This is called the eutectoid, and the structure is the eutectoid composition.

EVAPORATION – The process of changing from a liquid to a vapor, such as boiling water to produce steam. Evaporation is the opposite of condensation.

EVAPORATIVE COOLING SYSTEM – A cooling system in which the heat finally passes to the atmosphere by evaporation. This system may be either open or closed.

EVAPORATOR – Part of a refrigerating mechanism in which the refrigerant vaporizes and absorbs heat.

EVAPORATOR, DRY TYPE – An evaporator into which refrigerant is fed from a pressure reducing device. Little or no liquid refrigerant collects in the evaporator.

EVAPORATOR, FLOODED – An evaporator containing liquid refrigerant at all times.

EXCESS AIR – Air present in the cylinder over and above that which is theoretically necessary to burn the fuel.

EXCESS OXYGEN – The amount of free oxygen in the products of combustion. It may be expressed as a percentage of either volume or mass.

EXCITATION – The power required to energize the magnetic field of generators in an electric generating station.

EXCITATION CURRENT – Amperage required by the exciter to produce a magnetic field.

EXCITE – To pass current through a coil or starter.

EXCITER – A generator or static rectifier assembly that supplies the electric current used to produce the magnetic field in another generator.

EXHAUST – Air removed deliberately from a space by fan or other means, usually to remove contaminants from a location near their source.

EXHAUST ANALYZER (SMOKE METER) – A test instrument used to measure the density of the exhaust smoke to determine the combustion efficiency.

EXHAUST FAN – Normally shipped with MCE generators, designed to mount on engine drive disc to run inside of generator exhaust opening.

EXHAUST GAS – The products of combustion in an internal-combustion engine.

EXHAUST GAS ANALYZER – An instrument for determining the efficiency with which an engine is burning fuel.

EXHAUST MANIFOLD – The passages from the engine cylinders to the muffler which conduct the exhaust gases away from the engine.

EXHAUST PORT – The opening through which exhaust gas passes from the cylinder to the manifold.

EXHAUST VALVE – The valve which, when opened, allows the exhaust gas to leave the cylinder.

EXPANSION – An increase in size. For example, when a metal rod is heated it increases in length and perhaps also in diameter. Expansion is the opposite of contraction.

EXPANSION RATIO – Ratio of the total volume when the piston is at BDC to the clearance volume when the piston is at TCD. (Nominally equal to compression ratio.)

EXPANSION VALVE – A device in refrigerating system which maintains a pressure difference between the high side and low side and is operating by pressure.

EXTENDED SERVICE COVERAGE (ESC) – A Cat service offering maintenance and or repair (up to five years) beyond that offered in a particular product's warranty.

EYE BOLT – A bold threaded at one end and bent to a loop at the other end.

FAHRENHEIT (°F) – A designated temperature scale in which the freezing temperature of water is 32° F and boiling point 212° F (at standard atmospheric pressure).

FANTAIL – The rear portion of the main deck of a ship.

FATHOM – A measure of length, equivalent to 6 linear feet, used for depths of water and lengths of rope or chain.

FATIGUE – Deterioration of material caused by constant use.

FAULT – (1) The failure of an operating piece of equipment, and the specific reason for the failure, or (2) an electrical distribution system failure, where there is a line-to-ground or line-to-line short circuit.

FEDERAL ENERGY REGULATORY COMMISSION (FERC) – An independent regulator commission within the U.S. Department of Energy that has jurisdiction over energy producers that sell or transport fuels for resale in interstate commerce; the authority to set oil and gas pipeline transportation rates and to set the value of oil and gas pipelines for rate making purposes; and regulates wholesale electric rates and hydroelectric plant licenses.

FEEDER – An electric line for supplying electric energy within an electric service are of sub-area.

FEELER GAUGE – A strip of steel ground to a precise thickness used to check clearance.

FERC *Federal Energy Regulator Commission*

FERRITE – Solid solutions in which alpha iron (or delta iron) is the solvent.

FGR *Flue Gas recirculation*

fhp *friction horsepower*

FID *Flame Ionization Detector*

FIELD – A space or region where magnetism exists.

FIELD COIL – An insulated wire wound around an (iron) pole piece.

FILLET – A curved joint between two straight surfaces.

FILTER: OIL, WATER, GASOLINE, ETC. – A unit containing an element, such as a screen of varying degrees of fineness. The screen or filtering element is made of various materials depending upon the size of the foreign particles to be eliminated from the fluid being filtered.

FIN (Flash) – A thin fin of metal formed at the sides of a forging or weld where a small portion of th metal is forced out between the edges of the forging or welding dies.

FINISHING STONE (hone) – A honing stone with a fine grid.

FIRE POINT – Lowest temperature at which an oil heated in standard apparatus will ignite and continue to burn.

FIRING ORDER – The order in which the cylinders deliver their power stroke.

FIRING PRESSURE – The highest pressure reached in the cylinder during combustion.

FIRM ENERGY – Power supplies that are guaranteed to be delivered under terms defined by contact.

FIT – The closeness of contact between machined components.

FIXED DISPLACEMENT PUMP – A type of pump in which the volume of fluid per cycle cannot be varied.

FLAKE – Internal fissures in large steel forgings or massive rolled shapes. In a fractured surface or test piece, they appear as sizeable areas of silvery brightness and coarser grain size than their surroundings. Sometimes known as “chrome checks” and (when revealed by machining) “hairline cracks.” Not to be confused with “woody fracture.”

FLAME HARDENING (Shorterizing) – A method for hardening the surface without affecting the remainder of the part, used mainly for gears or other parts where only a small portion of the surface is hardened and where the part might distort in a regular carburizing or heat-treating operation. The operation consists of heating the surface to be hardened by an acetylene torch to the proper quenching temperature followed immediately by a water-quench and proper tempering. A special tool is required, and either the torch or part may be rotated wo that the flame passes over the surface at a speed that will produce the proper quenching temperature. Water quenching follows immediately, and the part is neither scaled nor pitted by the operation.

FLANGE – A metal part which is spread out like a rim; the action of working a piece or part spread out.

FLANK, SIDE OR THREAD – The straight part of the thread which connects the crest with the root.

FLANK ANGLES – The angle between a specified flank of a thread and the plane perpendicular to the axis (measured in an axial plane).

FLARE – To open or spread outwardly.

FLARING TOOL – A tool used to form a flare on a tubing.

FLASH POINT – The temperature at which a substance, usually a fluid, will give off a vapor that will flash or burn momentarily when ignited.

FLAT CRANK – A crankshaft in which one of the bearing journals is not round.

FLOATING PISTON PIN – A piston pin which is not locked in the connecting rod or the piston, but is free to turn or oscillate in both the connecting rod and the piston.

FLOODING – Act or filling a space with a liquid.

FLOOR – The absolute minimum to which the low limit of an engine performance specification may fall.

FLOW CONTROL VALVE – A valve which is used to control the flow rate of fluid in a fluid power system.

FLOWMETER – An instrument used to measure the quantity of flow rate of a fluid in motion.

FLSFS *Full Load Static Fuel Setting*

FLUCTUATING – Wavering, unsteady, not constant.

FLUID – A liquid, gas, or mixture thereof.

FLUID FLOW – The stream or movement of a fluid; the rate of a fluid's movement.

FLUID POWER – Power transmitted and controlled through the use of fluids, either liquids or gases, under pressure.

FLUSH – An operation to remove any material of fluids from refrigeration system parts by purging them to the atmosphere using refrigerant or other fluids.

FLUTE – The grooves of a tap that provide the cutting rake and chip clearance.

FLUTTER OR BOUNCE – In engine valves, refers to a condition where the valve is not held tightly on its seat during the time the cam is not lifting it.

FLYBALL GOVERNOR (Flyweight Governor) – Conventional type of centrifugal governor commonly called a *mechanical governor.*

FLYWHEEL – A device for storing energy in order to minimize cyclical speed variations.

FLYWHEEL RING GEAR – A circular steel ring having gear teeth on the outer circumference.

FOAMING – Formation of a foam in an oil-refrigerant mixture due to rapid evaporation of refrigerant dissolved in the oil. This is most likely to occur when the compressor starts and the pressure is suddenly reduced.

FOOT-POUND (ft-lb) – The amount of work accomplished when a force of 1 lb produced a displacement of 1 ft.

FORCE – The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds (kilograms).

FORCE CONVECTION – Movement of fluid by mechanical force such as fans or pumps.

FORCE-FEED LUBRICATION – A lubricating system in which oil is pumped to the desired points at a controlled rate by means of positive displacement pumps.

FORECASTLE – (Foc'sle) The forward portion of the main deck, contains anchor windlass, etc.

FORGED – Shaped with a hammer or machine.

FOSSIL FUEL – Oil, coal, natural gas, or their by-products. Fuel that was formed in the earth in prehistoric times from remains of living-cell organisms.

FOUNDATION – The structure on which an engine is mounted. It performs one or more of the following functions: holds the engine in alignment with the driven machine, adds enough weight to the engine to minimize vibration, adds to rigidity of the bed plate.

FOUR-CYCLE ENGINE – Also known as Otto cycle, where an explosion occurs every other revolution of the crankshaft, a cycle being considered as ½ revolution of the crankshaft. These strokes are (1) intake stroke, (2) compression stroke, (3) power stroke, (4) exhaust stroke.

FOUR-STROKE ENGINE – Cycle of events which is completed in four strokes of the piston, or two crankshaft revolutions.

FRAME – The main structural member of an engine.

frame *Generator frame size*

FRC *Fuel Ratio Control*

FREEBOARD – The vertical distance from the waterline to the weather deck.

FREE ELECTRONS – Electrons which are in the outer orbit of the atom's nucleus.

FREE FLOW – Flow which encounters little resistance.

FREON – Trade name for a family of synthetic chemical refrigerants manufactured by DuPont, Inc.

FREQUENCY – The number of cycles completed within a one-second period, expressed as hertz.

FREQUENCY METER – A unit which monitors a generator set's output frequency.

FREQUENCY RELAY – This relay can be configured to operate when the monitored frequency is above or below a given setpoint.

FRICTION – The resistance to motion due to the contact of two surfaces, moving relatively to each other.

FRICTION HORSEPOWER (FHP) – A measure of the power lost to the engine through friction or rubbing of parts.

FS *Fuel Solenoid*

FSS *Floor Standing Switchgear*

ft-lb *foot-pound*

FTSFS *Full Torque Static Fuel Setting*

FUEL CELL – A device or an electrochemical engine with no moving parts that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly into electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes, thus producing electricity.

FUEL-FLOW OIL FILTER – All engine oil passes through this oil filter before entering the lubrication channels.

FUEL KNOCK – See *Detonation.*

FUEL LEVEL – On the EMS II module, a flashing red light and horn annunciate when a customer provided fuel level switch is activated. This information is provided to EMS II directly and then sent on the datalink. In the even that coolant level input is not provided, the input will be shorted on the terminal strip.

FUEL MIXTURE – A ratio of fuel and air.

FUEL PRESSURE – The fuel pressure supplied to the injection pumps of a diesel engine.

FUEL RATE (Diesel) – The mass of fuel burned by an engine in a specified time. Corrected fuel rate is the actual or observed fuel rate corrected for fuel density.

FUEL RATE (Spark Ignited) – The volume or fuel burned by an engine in a specified time at the pressure and temperature being supplied to the engine. Corrected fuel rate is the volume of fuel at standard conditions multiplied by the lower heating value of the fuel.

FUEL TRANSFER PUMP – A mechanical device used to transfer fuel from the tank to the injection pump.

FUEL VALVE – A valve admitting fuel to the combustion chamber. In a more general sense, this term may also apply to any manual or automatic valve controlling flow of fuel.

FULCRUM – The pivot point of a lever.

FULL-FLOATING PISTON PIN – A piston pin free to turn in the piston boss of the connecting-rod eye.

FULL LOAD – The maximum power an engine can develop when running at rated speed with the fuel system opened to its maximum specified condition.

GALLERY – Passageway inside a wall or casting.

GALLEY – The kitchen of a ship.

GALVANIC ACTION – When two dissimilar metals are immersed in certain solutions, particularly acid, electric current will flow from one to the other.

GAS – A substance which can be changed in volume and shape according to the temperature and pressure applied to it. For example, air is a gas which can be compressed into smaller volume and into any shape desired by pressure. It can also be expanded by the application of heat.

GASKET – A layer of material used between machined surfaces in order to seal against leakage.

GASSING – Hydrogen bubbles rising from the electrolyte when the battery is being charged.

GATE VALVE – A common type of manually operated valve in which a sliding gate is used to obstruct the flow of fluid.

GAUGE CONSTRUCTION – Shell is a cosmetic wrapper. Only advantage – no varnish clean-up of shell required.

GAUGE, LOW PRESSURE – Instrument for measuring pressures in range of 0 psig and 50 psig.

GAUGE, HIGH PRESSURE – Instrument for measuring pressures in range of 0 psig to 500 psig.

GAUGE PRESSURE – Pressure above atmospheric pressure.

GAUGE SNUBBER – A device installed in the fuel line to the pressure gauge used to dampen pressure surges and thus provide a steady reading. This helps protect the gauge.

GCCS *landfill Gas Collection and Control Systems*

GCM *Generator Control Module*

GEAR RATIO – The number of revolutions made by a driving gear as compared to the number of revolutions made by a driven gear of different size. For example, if one gear makes three revolutions while the other gear makes one revolution, the gear ratio would be 3 to 1.

GEAR-TYPE PUMP – A pump which uses the spaces between the adjacent teeth of gears for moving the liquid.

GENERATOR, ELECTRICAL – An electromagnetic device used to generate electricity.

GENERATOR, COOLING – A device used in absorption-type refrigeration systems to heat the absorbing liquid to drive off the refrigerant vapor for condensing to a liquid before entering the evaporator.

GENERATOR POWER SYSTEM (GPS) – EPG power system that uses energy off an electric generator.

GHOST (Ferrite Ghost) – A faint brand of ferrite.

GLAND – A device to prevent the leakage of gas or liquid past a joint.

GLAZE – As used to describe the surface of the cylinder, an extremely smooth or glossy surface such as a cylinder wall highly polished over a long period of time by the friction of the piston rings.

GLAZE BREAKER – A tool for removing the glossy surface finish in an engine cylinder.

GLOW PLUG – A heater plug for the combustion chamber. It has a coil of resistance wire heated by a low voltage current.

GMM *Generator Monitoring System*

gov *governor*

GOVERNOR – A device that maintains a constant engine speed under various load conditions. The governor must have provision for adjustment of speed (which controls generator frequency) and of the amount of speed droop from no load to full load.

GPD *Gallons Per Day*

gpm *gallons per minute*

GPS *Generator Power System*

GRA *Generator Rear Axial*

GRAIN – A unit of weight equal to one 7000th of a pound. It is used to indicate the amount of moisture in the air.

GRAIN SIZE – There are two type of grains in steel which affect the physical properties of steel; the austenite grain and the ferrite grain. The ferrite grain tends to remain stable in size at temperatures below the transformation range unless the steel is cold worked a critical amount, in which case the grains grow rapidly. When steel is heated above the transformation range, the newly formed austenite grain is small but tends to grow in size with increasing temperature and time at temperature. Grain size, as commonly used, is the size of the grain that is developed in the austenite at the final heat treating temperature and does not refer to the ferrite grain. Except for the austenitic steels, the austenite grain size does not exist at room temperature; but its pattern can be developed by special methods.

GRAVITY – The force which tends to draw all bodies toward the center of the earth. The weight of a body is the result of all gravitational forces on the body.

GRAVITY, SPECIFIC – The specific gravity of a solid or liquid is the ratio of the mass of the body to the mass of an equal volume or water at some standard temperature. At the present time a temperature of a 4° C (39° F) is commonly used by physicists, but the engineer uses 16° C (60° F). The specific gravity of a gas is usually expressed in terms of dry air at the same temperature and pressure as the gas.

GRH *Generator Rear Horizontal*

GRID – The electric utility companies' transmission and distribution system that links power plants to customers through high power transmission line service (110 kilovolt [kV] to 765kV); high voltage primary service for industrial applications and street rail and bus systems (23 kV to 138 kV); medium voltage primary service for commercial and industrial applications (4 kV to 35 kV); and secondary service for commercial and residential customers (120 V to 480 V). Grid can also refer to the layout of a gas distribution system of a city or town in which pipes are laid in both directions in the streets and connected at intersections.

GRID, BATTERY – The lead frame to which the active material is affixed.

GRID INTERCONNECTION – The intertie of a cogeneration plant to an electric utility's system to allow electricity flow in either direction.

GRINDING – Removing metal from an object by means of a revolving abrasive wheel, disk, or belt.

GRINDING COMPOUND – Abrasive for resurfacing valves, etc.

GROUND, BATTERY – The battery terminal that is connected to the engine of the framework.

GROUND FAULT PROTECTION – This function trips (opens) a circuit breaker or sounds an alarm in the event that there is an electrical fault between one or more of the phase conductors and ground (earth). This ground fault protection function may be incorporated into a circuit breaker.

GROUNDING BAR – A copper or aluminum bar that electrically joins all the metal sections of the switchgear. This bar is connected to the earth or ground connection when the system is installed. The grounding or earthing protects personnel.

GROWLER – A test instrument used for testing the armature of a starter of generator for open, short, and grounded circuits.

GRV *Generator Rear Vertical*

GSC *Genset Status Control*

GSC+ (S)YNCHRONIZING – General Status Control plus Synchronizing

GSE *Generator Set Engine*

HALF-MOON KEY – A fastening device in a shape somewhat similar to a semicircle. (See *Key.*)

HARDENABILITY – This relates to the ability of steel to harden deeply upon quenching and takes into consideration the size of the part and the method of quenching. In testing for hardenability, standards are established governing the method of quenching and the quenching medium which makes it possible to compare the hardenability of steels of various analysis and grain size.

HARDNESS – The ability of a metal to resist penetration. The principal methods of hardness determination are described under hardness testing and the correlation of these determinations with the other mechanical properties are described under physical properties.

HARDNESS TESTING – The determination of the ability of a metal to resist penetration; the hardness of the metal may be determined by several methods (i.e., Brinell, Rockwell, Superficial).

HARMONICS – Waveforms whose frequencies are multiples of the fundamental (60 Hz) wave. The combination of harmonics and fundamental waves causes a non-sinusoidal, periodic wave. Harmonics in power systems are the result of non-linear effects. Typically, harmonics are associated with rectifiers and inverters, arc furnaces, arc welders, and transformer magnetizing current. There are both voltage and current harmonics.

HATCH – An opening in the deck of a ship leading to the "hold". Any small door or opening.

HAWSER PIPE – Casting extending through deck and side of a ship for passage of an anchor chain, for storage in most cases.

HCR *High Compression Rating*

HD *Heavy Duty*

HEAD – The toilet facilities aboard a ship.

HEAD PRESSURE – Pressure which exists in the condensing side of a refrigerating system.

HEAD, STATIC – Pressure of fluid expressed in terms of height of column of the fluid, such as water or mercury.

HEAD, VELOCITY – In flowing fluid, heat of fluid equivalent to its velocity pressure.

HEAD-PRESSURE CONTROL – Pressure operating control which opens electrical circuit if high side pressure becomes excessive.

HEAT – Form of energy the addition of which causes substances to rise in temperature; energy associated with random motion of molecules.

HEAT BALANCE – Energy flow in a power generating system.

HEAT COIL – A heat transfer device which releases heat.

HEAT EXCHANGER – Device used to transfer heat from a warm or hot surface to a cold or cooler surface. Evaporators and condensers are heat exchangers.

HEAT, LATENT – Heat characterized by a change of state of the substance concerned, for a given pressure and always at a constant temperature for a pure substance, i.e., heat of vaporization or of fusion.

HEAT LOAD – Amount of heat, measured in Btu, which is removed during a period of 24 hours.

HEAT OF COMPRESSION – Mechanical energy or pressure transformed into energy of heat.

HEAT OF FUSION – The heat released in changing a substance from a liquid state to a solid state. The heat of fusion of ice is 144 Btu per pound.

HEAT PUMP – A name given to an air-conditioning system that is reversible so as to be able to remove heat from or add heat to a given space or material upon demand.

HEAT PUMP – AIR SOURCE – A device that transfers heat between two different air quantities, in either direction, upon demand.

HEAT PUMP – WATER SOURCE – A device that uses a water supply as a source of heat or for disposal of heat depending upon the operational demand.

HEAT RATE – A measure of generating station thermal efficiency, generally expressed in Btu (per net kilowatt-hour).

HEAT RECOVERY – The capture and utilization of heat energy which is normally wasted as a by-product of a diesel or gas engine.

HEAT, SENSIBLE – A term used in heating and cooling to indicate any portion of heat which changes only the temperature of the substances involved.

HEAT SINK – An aluminum plate or extrusion under the rectifier assembly which dissipates heat generated by the rectifier.

HEAT SOURCE – The material from which the refrigeration system extracts heat.

HEAT, SPECIFIC – The heat absorbed (or given up) by a unit mass of a substance when its temperature is increased (or decreased) by 1-degree Common Units: Btu per (pound) (Fahrenheit degree), calories per (gram) (Centigrade degree). For gases, both specific heat and constant pressure (cp) and specific heat at constant volume (cv) are frequently used. In air-conditioning, cp is usually used.

HEAT TRANSFER – Movement of heat from one body or substance to another. Heat may be transferred by radiation, conduction, convention, or a combination of these three methods.

HEAT TREATMENT – A combination of heating and cooling operations timed and applied to a metal in a solid state in a way that will produce desired properties.

HEATING VALUE – The amount of heat produced by burning 1 lb or fuel.

HELICAL GEAR – A gear wheel or a spiraling shape. (The teeth are cut across the face at an angle with the axis.)

HERMETICALLY SEALED UNIT – A sealed hermetic-type condensing unit is a mechanical condensing unit in which the compressor and compressor motor are enclosed in the same housing with no external shaft or shaft seal, the compressor motor operating in the refrigerant atmosphere. The compressor and compressor motor housing may be of either the fully welded or brazed type, or of the service-sealed type. In the fully welded or brazed type, the housing is permanently sealed and is not provided with means or access of servicing internal parts in the field. In the service-sealed type, the housing is provided with some means of access of servicing internal parts in the field.

HERMETIC MOTOR – Compressor drive motor sealed within same casing which contains compressor.

HERMETIC SYSTEM – Refrigeration system which has a compressor driven by a motor contained in compressor dome or housing.

HERTZ (hz) – A unit of frequency equal to one cycle per second.

HEUI *Hydraulically actuated Electronically controlled Unit Injector*

Hg (Mercury) – Heavy silver-white metallic element; only metal that is liquid at ordinary room temperature.

HHV *High Heat Value*

HIGH COOLANT TEMPERATURE – On the EMS II module, a flashing red light and a horn will indicate the engine has started a high coolant temperature. If the ECM triggers an engine shutdown due to high coolant temperature, the light and horn will continue, and the system shutdown light will also begin flashing.

HIGH HEAT VALUE (HHV) – The total energy content of a fuel available by complete combustion and all products of combustion at 60° F and water in a vapor state. Equals to the High Heat Value less the latent heat of vaporization.

HIGH IDLE SETTING – The maximum speed at which an engine will run with the governor wide open at no load condition.

HIGH SIDE – Parts of a refrigerating system which are under condensing or high side pressure.

HIGH VOLTAGE – Any AC voltage above 15,000V.

HOLD – The interior of a ship below decks where cargo is stored.

HONE – A tool with an abrasive stone used for removing metal, such as correcting small irregularities or differences in diameter in a cylinder.

HORSEPOWER (hp) – A unit used to measure power of an engine. An electric motor develops one horsepower by lifting weight of 550 pounds through a distance of one foot in one second. It represents the product of force and rate of motion (See *Brake Horsepower and Indicated Horsepower.*)

HORSEPOWER-HOUR (hp-h) – A unit of energy equivalent to that expended in 1 hp applied for 1 hour. Equal to approximately 2545 Btu.

HOT SHORTNESS – Brittleness in metal when hot.

HOT SPOT – Refers to comparatively thin section or area of the wall between the inlet and exhaust manifold of an engine, the purpose being to allow the hot exhaust gases to heat the comparatively cool incoming mixture. Also used to designate local areas of the cooling system which have attained above average temperatures.

HOT WELL (expansion tank) – A system used when static head exceeds 17.4 m (57 ft), or a boost pump imposes excessive dynamic head.

HP *High Performance*

hp *Horsepower*

HULL – The outer walls of the ship, the outer skin of the ship that is exposed to the water.

HUMIDIFIER – Device used to add to and control the humidity in a confined space.

HUMIDISTAT – An electrical control which is operated by changing humidity.

HUMIDITY – Moisture; dampness. Relative humidity is a ratio of quantity of vapor present in air to the greatest amount possible at given temperature.

HUNTING – Alternate overspeeding and underspeeding of the engine caused by governor instability.

HV *High Voltage*

HWTS *High Water Temperature Switch*

HYBRID – An engine which combines the features of reciprocating and rotating engines.

HYDRAULIC GOVERNOR – A governor which used a control valve to allow oil pressure to work directly on the terminal shaft through a power piston.

HYDRAULICALLY ACTUATED ELECTRONICALLY CONTROLLED UNIT INJECTOR (HEUI) – A Cat system which manages precise injection of fuel in an engine to achieve optimal efficiency and performance.

HYDRAULICS – That branch of mechanics or engineering which deals with the action or use of liquids forced through tubes and orifices under pressure to operate various mechanisms.

HYDROCARBONS (HC) – Emissions consisting of unburned fuel or lubricating oil, which cause eye irritation and unpleasant odors. Measured in parts per million by volume.

$$\text{HC concentration (ppm)} = \frac{2067 \times \text{ HC mass emissions (g/hr)}}{\text{Exhaust mass flow (kg/hr)}}$$

HYDROGEN – One of the elements constituting fuel and lubricating oil.

HYDROMECHANICAL GOVERNOR – A governing system which used engine or it's own lubricating oil pressure to support the action of a mechanical control – any mechanical governor assisted by a hydraulic servo valve.

HYDROMETER – A test instrument for determining the specific gravities of liquids.

Hz *Hertz*

IAPCV *Injector Actuator Pressure Control Valve*

ID *Inside Diameter*

IDLE – To operate (an engine) without transmitting power.

IDLING – Refers to the engine operating at its slowest speed with a machine not in motion. An engine running without load.

IEC *International Electromechanical Commission*

IGNITION – The start of combustion.

IGNITION DELAY – The period between when fuel injection begins and when fuel actually starts to burn.

IGNITION LAG – The time between start of injection and ignition.

ihp *indicated horsepower*

IMMERSED – To be completely under the surface of a fluid.

IMPACT TESTING – Method to determinate the tendency of a metal toward brittleness. Samples are mounted and struck with a single pendulum-type blow of such force as to fracture the specimen. The energy required is measured in foot-pounds and is affected by the striking velocity, temperature, form, and size of sample. If the sample resists fracture in the test, it is described as tough; if it fractures easily, it is brittle or notch sensitive. See *Cohesive Strength.*

IMPORT/EXPORT CONTROL – Requires varying generator set power output with site load to keep the amount of power "imported" from or "exported" to the utility near constant. The generator sets operate in parallel with the utility, and their output is raised and lowered to match changes in the site load. This scheme requires a monitoring device at the point in the system to be kept near constant and is typically accomplished with a programmable logic controller (PLC).

in *inch*

INBOARD – Inside the ship; toward the center line.

INBOARD EXCITER – Exciter components are physically inborad of ball bearing. This design is okay where shaft deflection between bearing center and engine drive flange mounting is not a problem.

INCLUSION – Particles of impurities, usually oxides, sulphides, silicates, and such, which are mechanically held during solidification or which are formed by subsequent reaction of the solid metal. These impurities are called nonmetallic inclusions and may or may not be harmful depending on their type, size, distribution, and and the end product to be manufactured.

INDICATED HORSEPOWER (ihp) – An elevated engine power measurement which includes the entire amount of horsepower developed in the combustion chamber, before any is lost through friction or operation of satellite systems.

INDICATED THERMAL EFFICIENCY – The ratio of indicated horsepower to equivalent power input in the form of heat from fuel.

INDICATOR – An instrument for recording the variation of cylinder pressure during the cycle.

INDICATOR CARD – A graphic record of the cylinder pressures made by an indicator.

INDIRECTLY COOLED PISTON – A piston cooled mainly by the conduction of heat through the cylinder walls.

INDUCTION GENERATOR – A nonsynchronous AC generator similar in construction with an AC motor, and which is driven above synchronous speed by external sources of mechanical power.

INDUCTION HARDENING – A method of hardening the surface of a part electrically. A high frequency current, varying from a few thousand cycles to several million cycles per second, is passed through a coil that is held very close to the surface to be hardened. This induces eddy currents into the surface of the part which, together with hysteresis effect of the rapid reversal, heats the surface, and by conduction may through heat the part, if desired. Quenching may be done immediately in water, or in some cases the cold core of the steel itself may be the quenching medium. The surface finish is in no way affected by this method nor is the part distorted.

INDUCTION MOTOR – An AC motor which operates on the principle of rotating magnetic field. The rotor has no electrical connection, but receives electrical energy by transformer action from field windings.

INDUCTION SYSTEM – Those components of an engine involved in providing combustion air to an engine.

INDUCTOR – An apparatus formed by wrapping a number of turns of insulated wire around a form; used to introduce inductance into an electric circuit.

INDUSTRIAL AIR CONDITIONING – Air-conditioning for uses other than comfort.

INDUSTRIAL GRADE RELAY – An AC protective relay that is installed within the switchgear enclosure and cannot be easily removed for testing and calibration.

INERTIA – That property of matter which causes it to tend to remain at rest if already motionless or to continue in the same straight line of motion if already moving.

INHIBITOR – Any substance which retards or prevents such chemical reactions as corrosion or oxidation.

INJECTION PUMP – A high-variable pressure pump delivering fuel into the combustion chamber.

INJECTOR SYSTEM – the components necessary for delivering fuel to the combustion chamber in the correct quantity, at the correct time, and in a condition satisfactory for efficient burning.

INJECTOR – A device used to bring fuel into the combustion chamber.

INJECTOR ACTUATION PRESSURE CONTROL VALVE (IAPCV) – A component of the Cat HEUI fuel system that controls the pressure of the oil which actuates the unit injector.

INLET AIR PRESSURE – The dry air pressure supplied to the inlet of an engine. This is normally barometric pressure minus water vapor pressure minus inlet air restriction.

INLET AIR RESTRICTION – The pressure drop of the combustion air from atmospheric pressure to the compressor inlet of a supercharged engine or to the inlet manifold of a naturally aspirated engine.

INLET FUEL PRESSURE – The fuel pressure supplied to the fuel inlet of a diesel engine.

INLET FUEL PRESSURE (ABS) – The gas pressure supplied to the fuel inlet of a spark ignited engine.

INLET FUEL TEMPERATURE – The temperature of the fuel supplied to the fuel inlet of either a diesel or spark ignited engine.

INLET MANIFOLD PRESSURE – Absolute pressure in the inlet manifold of a spark ignited engine.

INLINE – A type of cylinder arrangement in an engine where the cylinders are aligned in a row.

INPUT SHAFT – The shaft carrying the driving gear, such as in a transmission by which the power is applied.

INSERT BEARING – A removable, precision-made bearing.

INSULATED CASE CIRCUIT BREAKER – A power circuit breaker that is provided in a preformed case, similar to a molded case breaker.

INSULATOR – Materials or substances that effectively block the movement of electrons. An example is glass.

INTAKE MANIFOLD – A connecting casting between the air filter or turbocharger and the port openings to the intake valves.

INTAKE VALVE – The valve which allows air to enter into the cylinder and seals against exit.

INTEGRAL – The whole, made up of parts.

INTERCOOLER – Heat exchanger for cooling the air between stages of compression.

INTERNAL RATE OF RETURN – Discount rate at which the present value of an investment is equal to the investment.

INTERNAL-COMBUSTION ENGINE – An engine that burns fuel within itself as a means of developing power.

INTERRUPTED QUENCHING – Refers to the use of two or more quenching media to obtain the final structure required. The part may be removed after a definite time in the original quenching medium and then finish cooled in another medium. Several methods have been developed. See *Austempering, Isothermal Quenching, Martempering.*

INTERRUPTIBLE – This refers to the practice of operating on-site power systems, at the request of a utility, to reduce electrical demand on the utility grid during periods of high consumption.

INTERRUPTIBLE LOADS – Loads which can be temporarily disconnected without damage or any apparent reduction in facility performance. Such loads may include electric motors, driving pumps and fans, or lighting circuits.

INTERRUPTIBLE POWER – Electric energy supplied by an electric utility subject to interruption by the electric utility under specified conditions.

INTERRUPTING CAPACITY – The magnitude of electrical current that a device can safely interrupt (open against), without failure of the component.

INTERRUPTING RATING – The maximum current allowed by the normal source protective device on a generator set, that the automatic transfer switch is capable of interrupting. It applies when line voltage falls below the preset value of the voltage sensing relay, and the standby source is present. The switch then could transfer before the normal service protective device clears the fault.

INVERTER – An electromechanical or electronic device for converting direct current into alternating current.

IR *Infrared*

IRREGULAR STRAIGHTENERS – Used to straighten hexagons, flats, and squares. Essentially consisting of two groups of rolls placed at right angles to each other. Each group of rolls consists of five or more rolls set in the same plane and adjusted to provide reciprocate bending of the steel in the same plane.

ISO *Independent System Operator, International Standards Organization*

ISOCHRONOUS – The condition of maintaining constant speed, regardless of load, at steady-state conditions, for constant electrical frequency output.

ISOCHRONOUS GOVERNOR – A governor having zero speed droop.

ISOCHRONOUS LOAD SHARING – A method of controlling the speed or paralleled generator sets so that all sets share the load equally, without any droop in frequency.

ISOLATORS – Materials used between the foundation of a generator set and its mounting surface.

ISOTHERMAL QUENCHING – A method of hardening steel by quenching from the austenitizing temperature into an agitated salt bath which is maintained at a constant temperature level above the point at which martensite is formed (usually 450° F or higher), holding in this for sufficient time to permit transformation, transferring the steel immediately to some medium maintained at some higher temperature level for tempering and cooling in air. The advantages of this method of interrupted quenching are a minimum of distortion and residual strains with higher hardness which can be tempered to produce the needed physical properties. Larger sections can be hardened by this method than by austempering.

JACKET – A covering used to isolate or insulate, especially engine heat.

JACKET WATER – Cooling water which circulates through the engine.

JACK STAFF – A flagpole at the bow of a vessel, from which the union jack maybe displayed.

JET COOLING – A method of passing cooling oil below the piston by means of a jet or nozzle.

JIT *Just-in-Time (Juran lingo)*

JOIMINY HARDENABILITY TEST – A test used to determine the hardenability of any grade of steel. It is based on the premise that (1) irrespective of their chemistry, steel bars of the same size lose heat at a predetermined number of degrees per second under fixed conditions and (2) that the structure and physical properties vary with the rate of cooling. See *Hardenability* and *Quenching.*

JOURNAL – The portion of a shaft, crank, etc., which turns in a bearing.

JW *Jacket Water*

JWAC *Jacket Water After-Cooling*

JWH *Jacket Water Heater*

kAIC *k Amps Interrupting Capacity*

KEEL – The principal structural member of a ship, extending from bow to stern and forming the backbone of the ship.

KELVIN SCALE (K) – A temperature scale having the same size divisions as those between Celsius degrees, but having the zero point at absolute zero.

KEY – A fastening device wherein two components each have a partially cut groove, and a single square is inserted in both to fasten them together such as between the shaft and hub to prevent circumferential movement.

KEYWAY OR KEYSEAT – The groove cut in a component to hold the key.

KILLED STEEL – A steel sufficiently deoxidized to prevent gas evolution during solidification. The top surface of the ingot freezes immediately and subsequent shrinkage produces a central pipe. A semikilled steel, having been less completely deoxidized, develops sufficient gas evolution internally in freezing to replace the pipe by a substantially equivalent volume of rather deep-seated blow holes.

KILOMETER (km) – A metric measurement of length equal to 0.6214 mi.

KILOVOLT (kV) – 1000 volts.

KILOWATT (kW) – 1000 watts. A term for rating electrical devices. Generator sets in the United States are usually rated in kW. Sometimes called active power, kW loads the generator set engine.

KILOWATT-HOUR (kW-h) – The most commonly used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour.

KINETIC ENERGY – The energy which an object has while in motion.

KNOCK – A general term used to describe various noises occurring in an engine; may be used to describe noises made by loose or worn mechanical parts, preignition, detonation, etc.

KNOT – A speed measurement of one nautical mile per hour, a nautical mile being about $1\frac{1}{7}$ land miles (6080 feet or $\frac{1}{60}$ of a degree at the equator.)

KNURLING – A method of placing ridges in a surface, thereby forcing the areas between these ridges to rise.

kV•A – The abbreviation for Kilo-Volt-Amperes, a common term for rating electrical devices. A device's kV•A rating is equal to its rated output in amps multiplied by its rated operating voltage.

kVAR – The abbreviation for Kilo-Volt-Amperes Reactive. It is associated with the reactive power that flows in a power system. Reactive power does not load the set's engine but does limit the generator thermally.

kW *Kilowatt*

L *Liter*

LACQUER – A solution of solids in solvents which evaporate with great rapidity.

LADDERS – Any stairway aboard a ship.

LAG – To slow down or get behind; time interval, as in *ignition lag.*

LAND – The projecting part of a grooved surface; for example, that part of a piston on which the rings rest.

LAP – A surface defect appearing as a seam caused from folding over hot metal, fins, or sharp corners and then rolling or forging, but not welding them into the surface.

LAP (lapping) – A method of refinishing (grinding and polishing) the surface of a component.

LATENT HEAT – Heat energy absorbed in process of changing form of substance (melting, vaporization, fusion) without change in temperature or pressure.

LCD *Liquid Crystal Display*

LCR *Low Compression Rating*

LENGTH OVER ALL – The length of a ship from the forward most point of the stem to the after most point of the stern.

LETTER DRILLS – Drills on which the size is designated by a letter.

LFG *Landfill Gas*

LFGTE *Landfill Gas-To-Energy*

LH *Left Hand*

L-HEAD ENGINE – An engine design in which both valves are located on one side of the engine cylinder.

LHV *Low Heat Value*

LIFELINES – Light wire ropes supported on stanchions. They serve the same purpose as bulwarks.

LINE – A tube, pipe, or hose which is used as a conductor of fluid.

LINEAR – Moving in one direction only.

LINER – The sleeve forming the cylinder bore in which the piston reciprocates.

LINKAGE – A movable connection between two units.

LIQUID – Matter which has a definite volume but takes the shape of any container.

LIQUID ABSORBENT – A chemical in liquid form which has the property to “take on” or absorb moisture.

LIQUID CRYSTAL DISPLAY (LCD) – A device for alphanumeric displays using a pattern of tiny sealed capsules which contain a transparent liquid crystal that becomes opaque when an electric field is applied to it; the contrast between the transparent and opaque areas forms letters or numbers.

LIQUEFIED NATURAL GAS (LNG) – Natural gas that has been condensed to a liquid, typically by cryogenically cooling the gas to –327.2° F (below zero).

LIQUEFIED PETROLEUM GAS (LPG) – A mixture of gaseous hydrocarbons, mainly propane and butane that change into liquid form under moderate pressure.

LIST – Refers to athwartships balance. A ship with one side higher than the other side has a starboard list or port list. List is measured in degrees by an inclinometer, mounted on the bridge, exactly on the center line of the ship. Also called “Heeling”.

LITER (L) – A metric measurement of volume equal to 0.2642 gal (U.S.).

LIVE WIRE – A conductor which carries current.

LLDPE *Liner Low Density Polyethylene*

LOAD – The power that is being delivered by any power-producing device. The equipment that used the power from the power-producing device. (Also see *Cooling Load and Engine Load.*)

LOAD CURRENT – Amperage required by the load that is supplied by an electrical power source.

LOAD CURVE – A curve on a chart showing power (kilowatts) supplied, plotted against time of occurrence, and illustrating the varying magnitude of the load during the period covered.

LOAD FACTOR – The mathematical ratio of the actual load divided by the connected load.

LOAD FOLLOWING – Operation of equipment to match production to demand.

LOAD LINE – A center line indicating the points of contact where the load passes within the bearing.

LOAD MANAGEMENT – The utilization of generator sets in order to control the amount of electrical power purchased from a utility. This can be accomplished by switching specific loads from utility power to generator power, or operating generator(s) in parallel with the utility.

LOAD SENSE DEMAND – A paralleling system operating mode in which the system monitors the total kW output of the generator sets, and controls the number of operating sets as a function of the total load on the system. The purpose of load demand controls is to reduce fuel consumption and limit problems caused by light load operation of reciprocating diesel generator sets.

LOAD SHEDDING – The process by which the total load on a paralleling system is reduced, on overload of the system bus, so that the most critical loads continue to be provided with reliable electrical service. Overload is typically determined as a bus underfrequency condition.

LOAD-LINE ANGLE – The angle of a load line with respect to the shaft center or bearing radial centerline.

LOAD WATER LINE – Line of the surface of water on a ship when loaded to maximum allowance in salt water in the summertime.

LOBE – The projecting part, usually rounded, on a rotating shaft.

LOPS *Low (rev/min) Oil Pressure Switch*

LOW COOLANT TEMPERATURE – On the EMS II module, a flashing red light and horn annunciate when the coolant temperature falls below a value programmed within EMS II.

LOW HEAT VALUE (LHV) – The total heat produced by burning a given mass of fuel minus the latent heat of evaporation of water produced by the combustion process.

LOW VOLTAGE – Any AC voltage between 120V and 600V.

LP-GAS, LIQUEFIED PETROLEUM GAS – Made usable as a fuel for internal combustion engines by compressing volatile petroleum gases to liquid form. When so used, must be kept under pressure or at low temperature in order to remain in liquid form, until used by the engine.

LUBRICANT – A substance to decrease the effects of friction, commonly a petroleum product (grease, oil, etc.)

LUBRICATOR – A mechanical oiler which feeds oil at a controlled rate.

LUG – Condition when the engine is operating at or below its maximum torque speed, or slowing the speed of an engine by adding load.

LWLS *Low Water Level Switch*

MACHINABILITY – The factors involved in determining machinability are cutting speed and feed, resultant surface produced, and tool life. There are, however, many variables involved in each of these factors such as hardness, grain size, structure, inclusions, size and shape of tool, coolant, etc. The standard for machinability ratings is SAE 1112 (AISI B.1112) Bessemer screw stock rated as 100% although other materials may be used.

MAGNAFLUX – A method used to check components for cracks.

MAGNAFLUX TESTING – A method of inspection used to locate cracks, cavities or seams in steel bars at or very close to the surface. Special equipment has been developed for this test and several methods are used. In principle the part is magnetized and magnetic powder is applied, wet or dry. Flaws that are not otherwise visible will be indicted by the powder clinging to them. Due to many variables that may be present in this test, considerable experience is needed for uniform interpretation or results.

MAGNETIC FIELD – The affected area of the magnetic lines of force.

MAGNETIZING CURRENT – Transformers, motors and other electromagnetic devices containing iron in the magnetic circuit must be magnetized in order to operate. It is customary to speak of the lagging inductive current as a magnetizing current.

MAIN BEARING – A bearing supporting the crankshaft on its axis.

MAIN BREAKER – A circuit breaker at the input or output of the bus, through which all of the bus power must flow. The generator main breaker is the device that interrupts the set's power output. Main breakers provide overcurrent protection and a single disconnect point for all power in a switchboard or device.

MAINTENANCE COSTS – The cost of servicing and repair of equipment, including parts and labor.

MAINTENANCE POWER – Electric energy supplied by an electric utility during scheduled outages of the cogenerator.

MAKEUP WATER – The water required to replace the water lost from a cooling tower by evaporation, drift, and bleedoff.

MANDREL – A mounting device for a stone, cutter, saw, etc.

MANIFOLD – A pipe with one inlet and several outlets, used to collect and direct fluids and gases.

MANOMETER – A device for measuring a vacuum. It is a U-shaped tube partially filled with fluid. One end of the tube is open to the air and the other is connected to the chamber in which the vacuum is to be measured. A column of Mercury 30 in. high equals 14.7 lbs. per square in., which is atmospheric pressure at sea level. Readings are given in terms of inches of Mercury.

MANUAL CONTROL – A device which allows manual control of output voltage.

MANUAL VALVE – A valve which is opened, closed, or adjusted by hand.

MARINE DUTY – A generator with features to meet marine duty certification. PM, thermocouples in winding for heat sensing, green paint, and space heaters.

MARINE POWER SYSTEM (MPS) SOFTWARE – A Cat computer program which automatically sizes engines, gears, and propellers, based on desired vessel performance. A complete report is compiled for buyers to reference comparisons between various system configurations.

MARMON CLAMPS – Circular clamps used for air pipe connection. They include metal rings to aid in sealing.

MARTEMPERING – A method of hardening steel by quenching from the austenitizing temperature into some heat extracting medium (usually salt) which is maintained at some constant temperature level above the point at which martensite starts to transform (usually about 450° F), holding the steel in this medium until the temperature is uniform throughout, cooling in air for the formation of martensite and tempering by the conventional method. The advantages of this method of interrupted quenching are a minimum of distortion and residual strains. The size of the part can be considerably larger than for austempering.

MARTENSITE – A microconstituent or structure in quenched steel characterized by an acicular or needle-like pattern on the surface polished and etched. It has the maximum hardness of any of the decomposition products of austenite. It is a transition lattice formed by the partial transformation of austenite.

MASH *Machine Sales History, Marine Analyst Service Handbook*

MASS ELASTIC SYSTEM – Pistons, rods, crankshaft, flywheel, coupling, driven equipment, and associated shafting.

MATH *Maintenance & Technical Handbook*

MATTER – Any substance which occupies space and has weight. The three forms of matter are solids, liquids, and gases.

MBH *1000 Btu/hour*

MD *Medium Duty*

MEAN EFFECTIVE PRESSURE (mep) – The calculated combustion in pounds per square inch (average) during the power stroke, minus the pounds per square inch (average) of the remaining three strokes.

MEAN INDICATED PRESSURE (mip) – Net mean gas pressure acting on the piston to produce work.

MECHANICAL ADVANTAGE – The ratio of the resisting weight to the acting force. The distance through which the force is exerted divided by the distance the weight is raised.

MECHANICAL EFFICIENCY – (1) The ratio of brake horsepower to indicated horsepower, or ratio of brake mean effective pressure to mean indicated pressure. (2) An engine's rating which indicates how much of the potential horsepower is wasted through friction within the moving parts of the engine.

MECHANICAL GOVERNOR – A simple type of governor using flyweights for speed sensing and throttle control.

MECHANICAL INJECTION – Mechanical force pressurizing the metered fuel and causing injection.

MECHANICAL PROPERTIES – Those properties that reveal the reaction, elastic and inelastic, of a material to an applied force or that involve the relationship between stress and strain; for example, Young's modulus, tensile strength, fatigue limit. These properties have often been designated as physical properties, but the term mechanical properties is much to be preferred. See *Physical Properties.*

MECHANICALLY OPERATED VALVE – A valve which is opened and closed at regular points in a cycle of events by mechanical means.

MEDART – Equipment developed for straightening cold drawn bars measuring from about ½" to 2 ⅞" in diameter. These straighteners have one concave and one straight roll which revolve the bar as it passes between them. Much of the sizing of the bar and the brightness of the finish is accomplished in this operation.

MEDIUM VOLTAGE – Any AC voltage between 1000 and 15,000 VAC.

MEGAWATT (MW) – One million watts.

MEGAWATT HOUR (MWh) – One thousand kilowatt-hours, or an amount of electricity that would supply the monthly power needs of a typical home having an electric hot water system.

MEP *Mean Effective Pressure*

MEPS *Marine Engine Power Systems*

METAL FATIGUE – When metal crystallizes and is in jeopardy of breaking because of vibration, twisting, bending, etc.

METERING FUEL PUMP – A fuel pump delivering a controlled amount of fuel per cycle.

METHYL CHLORIDE (R-40) – A chemical once commonly used as a refrigerant. The chemical formula is CH_3Cl. Cylinder color code is orange. The boiling point at atmospheric pressure is –10.4° F.

METRIC SIZE – Size of a component, part, etc., in metric units of measurement (e.g., meters, centimeters).

MG *Million megagrams*

MHA *Material Handling Arrangement*

MICROMETER (M) – One one-millionth of a meter or 0.000039 in.

MICROMETER (mike) – A precision measuring tool that is accurate to within one one-thousandth of an inch or one one-hundredth of a millimeter.

MILLIMETER (mm) – One one-thousandth of a meter or 0.039370 in.

MILLING MACHINE – A machine used to remove metal, cut splices, gears, etc., by the rotation of its cutter or abrasive wheel.

MINIMUM GENERATION – Generally, the required minimum generation level of a utility system's thermal units. Specifically, the lowest level of operation of oil-fired and gas-fired units at which they can be currently available to meet peak load needs.

MIP *Mean Indicated Pressure, Membrane Interface Probe*

MISFIRING – When the pressure of combustion of one or more cylinders is lower than the remaining cylinders, one or more cylinders have an earlier or later ignition than the others.

MIXED CYCLE – Where fuel burns partly at constant volume and partly at constant pressure. Sometimes applied to the actual combustion cycle in most high-speed internal combustion engines.

MIXTURE CONTROL – A screw or adjustable valve to regulate the air/fuel provided by a carburetor.

mm *millimeter*

MMS *Marine Monitoring System*

MODULUS OF ELASTICITY – The ratio, within the limit of elasticity, of the stress to the corresponding strain. The stress in pounds per square inch is divided by the elongation in fractions of an inch for each inch of the original gauge length of the specimen.

MOLDED CASE CIRCUIT BREAKER – Automatically interrupts the current flowing through it when the current exceeds the trip rating of the breaker. Molded case refers to the use of molded plastic as the medium of electrical insulation for enclosing the mechanisms, and for separating conducting surfaces from one another and from grounded metal parts.

MONOCHLORODIFLUOROMETHANE – A refrigerant better known as Freon 12 or W-22. The chemical formula is $CHClF_2$. Cylinder color code is green.

MONOCOQUE CONSTRUCTION – Integral construction of stator assembly where outside shell provides a major portion of construction strength.

MOTOR – An actuator which converts fluid power or electric energy to rotary mechanical force and motion. This term should be used in connection with an electric motor and should not be used when referring to the *engine* of a machine.

MOTOR INRUSH CURRENT – The current required to start an electric motor at rest. This current is equal to the current that would be drawn by the motor if the rotor were not allowed to turn.

mph *miles per hour*

MPS *Marine Power System*

MPU *Magnetic Pick-Up*

MR *Medium Range, Mid-Range*

MT *Multi-Torque*

MUFFLER – A chamber attached to the end of the exhaust pipe which allows the exhaust gases to expand and cool. It is usually fitted with baffles or porous plates and serves to subdue much of the noise created by the exhaust.

MUI *Mechanical Unit Injector*

MULTIFUEL – A term used to describe an engine which can burn a variety of different fuels.

MULTIMEGAWATT – Many million watts.

MULTIPLE RATING ENGINE – An engine which has a variable full load fuel setting to provide more than one full load power.

MULTIVISCOSITY OIL – An oil meeting SAE requirements.

MW *Megawatt*

MWh *Megawatt hour*

NA *Naturally Aspirated*

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA) – A non-profit U.S. trade association of manufacturers of electrical apparatus and supplies. This organization facilitates understanding between manufacturers and users of electrical products.

NATURAL CONVECTION – Movement of a fluid caused by temperature differences (density changes).

NATURAL GAS – Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane and other gases.

NATURALLY ASPIRATED – A term applied to an engine which has no method of compressing air supplied to the inlet manifold.

NEEDLE BEARING – A roller-type bearing in which the rollers are smaller in diameter than in length proportional to the race.

NEGATIVE TERMINAL – A terminal from which the current flows back to its source.

NEMA 1 ENCLOSURE – This enclosure designation is for indoor use only when dirt, dust, and water are not a consideration. Personnel protection is the primary purpose of this type of enclosure.

NEOPRENE – A synthetic rubber highly resistant to oil, light, heat, and oxidation.

NETWORK – A system of transmission or distribution lines so cross-connected and operated as to permit multiple power supply to any principal point on it.

NEUTRON – A neutral charged particle of an atom.

NEW MATERIAL RELEASE – Announces new or different items of interest that would be of value to dealers and sales representatives.

NEWTON'S THIRD LAW – For every action there is an equal, opposite reaction.

NITROGEN OXIDE (NO) – The combination of nitrogen and oxygen that occurs during the combustion process.

NOMINAL – The specified or target value of an engine performance characteristic. The nominal value is usually accompanied by tolerances defining the acceptable range of the characteristic relative to the nominal.

NONFERROUS METALS – Any metals not containing iron.

NON-INTERRUPTIBLE LOADS – Loads which cannot tolerate even a momentary power outage without causing damage or severe functional loss to a facility. A computer is a non-interruptible load, as any power lapse could result in loss of vital data or computer-controlled action.

NONLINEAR LOADS – Any load for which the relationship between voltage and current is not a linear function. Some common nonlinear loads are fluorescent lighting, SCR motor starters, and UPS systems. Nonlinear loads cause abnormal conductor heating and voltage distortion.

NOT IN AUTO (EPG only) – On the EMS II module, a flashing red light annunciates when the engine control switch is not in auto. The engine control switch information will be available on the datalink.

NOTCHING – A method of producing stator laminations by indexing and punching stator slots one at a time.

NOx [combination of nitric oxide (NO) and nitrogen dioxide (NO_2)] – A harmful chemical present in combustion air formed by decomposition and recombination of molecular oxygen and nitrogen. Measured in parts per million by volume.

$$\text{NOx Concentration (ppm)} = \frac{629 \times \text{NOx mass emissions (g/hr)}}{\text{Exhaust mass flow (kg/hr)}}$$

NOx RACT – Reasonable Available Control Technology being applied to NOx on existing stationary sources in nonattainment areas.

NOZZLE – The component containing the fuel valve and having one or more orifices through which fuel is injected.

NUMBER DRILLS – Drills on which the size is designated by a number.

OA *Outside Air*

OCTANE – Measurement which indicates the tendency of a fuel to detonate or knock.

OD *Outside Diameter*

OEM *Original Equipment Manufacturer*

OFF-PEAK – Time periods when power demand are below average. For electric utilities, generally nights and weekends; for gas utilities, summer months.

OHM (W) – A unit used to measure the opposition or resistance to flow of electric current in a circuit.

OHMMETER – An instrument for measuring the resistance in a circuit or unit in ohms.

OHM'S LAW – The number of amperes flowing in a circuit is equal to the number of volts divided by the number of ohms.

OIL COOLER – A heat exchanger for lowering the temperature of oil.

OIL FILTER – A device for removing impurities from oil.

OIL GALLERY – A pipe-drilled or cast passage in the cylinder-head block and crankcase that is used to carry oil from the supply to an area requiring lubrication or cooling.

OIL PRESSURE – The engine oil pressure at full load at a specified location on the engine.

OIL PUMP – A mechanical device to pump oil (under pressure) into the various oil galleries.

OIL PUMPING – An engine condition wherein excessive oil passes by the piston rings and is burned during combustion.

OIL, REFRIGERATION – Specifically prepared oil used in refrigerator mechanism circulates to same extent with refrigerant. The oil must be dry (entirely free of moisture), otherwise, moisture will condense out and freeze in the refrigerant control and may cause refrigerant mechanism to fail. An oil classified as a refrigerant oil must be free of moisture and other contaminants.

OIL SEAL – A mechanical device used to prevent oil leakage, usually past a shaft.

OIL SEPARATOR – Device used to remove oil from gaseous refrigerant.

OIL SLINGER – A special frame disk fastened to a revolving shaft. When the shaft rotates and oil contacts the disk, it is thrown outward away from the seal, and thus reduces the force on the seal.

OIL-BATH AIR CLEANER – An air filter that utilizes a reservoir of oil to remove the impurities from the air before it enters the intake manifold or the compressor of the turbine.

OPEN CIRCUIT – A circuit in which a wire is broken or disconnected.

OPEN-TYPE SYSTEM – A refrigerating system which uses a belt-driven compressor or a coupling-driven compressor.

OPPOSED – A type of cylinder arrangement in an engine where the cylinders are placed opposite one another.

OPPOSED PISTON ENGINE – An engine having two pistons operating in opposite ends of the same cylinder, compressing air between them.

OPSS *Oil Pressure Step Switch (ESS)*

ORDERLY TURBULENCE – Air motion which is controlled as to direction or velocity.

ORIFICE – Accurate size openings for controlling fluid flow.

OS *Overspeed (ESS)*

OSCILLATE – To swing back and forth like a pendulum; to vibrate.

OSCILLOSCOPE – A device for recording wave forms on a fluorescent screen, proportional to the input voltage.

OSHA *Occupational Safety and Health Administration*

OTTO CYCLE – Also called four-stroke cycle. Named after the man who adopted the principle of four cycles of operation for each explosion in an engine cylinder. They are (1) intake stroke, (2) compression stroke, (3) power stroke, (4) exhaust stroke.

OUTBOARD EXCITER – Exciter components are physically located outboard of the ball bearing. This design is used to keep shaft deflection between the bearing center and the engine drive flange mounting to a minimum.

OUTAGE (Electric Utility) – An interruption of electric service that is temporary (minutes or hours) and affects a relatively small area (buildings or city blocks).

OUTPUT SHAFT – The shaft which delivers the power.

OVERCRANK (EPG only) – On the EMS II module, a flashing red light and a horn annunciate when an overcrank has occurred. The ECM will determine when an overcrank has occurred and will provide the information on the datalink.

OVERCURRENT RELAY – Operates when the monitored current exceeds the relay setpoint. Overcurrent protection usually consists of an instantaneous setting and a timed setting. Low voltage circuit breakers usually include a trip unit that incorporates these functions.

OVERHEAD CAMSHAFT – A camshaft which is mounted above the cylinder head.

OVERHEADS – The ceilings aboard a ship.

OVERRUNNING CLUTCH – A clutch mechanism that transmits power in one direction only.

OVERRUNNING-CLUTCH STARTER DRIVE – A mechanical device that locks in one direction but turns freely in the opposite direction.

OVERSPEED – Engine running higher than the operational speed range. A dangerous engine condition where the combustion system is receiving more fuel than the engine load demands. On the EMS II module, a flashing red light and a horn annunciate when an engine overspeed has occurred. The ECM will determine when an engine overspeed has occurred and will shut down the engine by shutting off the fuel to the engine and tripping the air shutoffs (if provided).

OVERSPEED GOVERNOR – A governor that shuts off the fuel or stops the engine only when excessive speed is reached.

OVERSQUARE ENGINE – An engine that has a larger bore diameter than the length of its stroke.

OVERVOLTAGE RELAY – Operates when the monitored voltage exceeds the relay setpoint. If monitoring a generator set the generator set's circuit breaker is typically tripped open and the generator set is shut down.

OXIDATION – That process by which oxygen unites with some other substance causing rust or corrosion.

PACKING GLAND – The seal used to keep sea water from entering the ship through the stern tube from around the prop shaft.

PAPER AIR CLEANER – An air filter with a special paper element through which the air is drawn.

PAR *Performance Analysis Report*

PARALLEL CIRCUIT – An electric circuit with two or more branch circuits. It is wired to allow current to flow through all branches at the same time.

PARALLELING – Two or more AC generator sets (or one generator set and the utility) supplying power to a common load. Connection of the power sources is made so that the sources electrically function as a single source of power. Parallel operation requires that the two sources of electrical power match in voltage, frequency, and number of phases.

PARTICLE EMISSIONS – Emitted substances including soot (unburned carbon), soluble organic fraction (SOF), and sulfates.

PASCAL'S LAW – Pressure applied anywhere to a body of confined fluid is transmitted undiminished to every portion of the surface of the containing vessel.

PASSAGEWAYS – Aisle ways through the ship for personnel to walk, also referred to as corridors.

PAYBACK PERIOD – The time required to completely recover the original capital investment.

PC *Personal Computer, Pre-Combustion Chamber*

PCNA *Pre-chambered Naturally Aspirated*

PCT *Pre-chambered Turbocharged*

PCTA *Pre-chambered Turbocharged Aftercooled*

PEAK DEMAND – The maximum electrical power (kilowatt) demand for a given facility for a given time.

PEAK LOAD – The highest electrical demand within a particular period of time. Daily electric peaks on weekdays occur in late afternoon and early evening. Annual peaks occur on hot summer days.

PEAK LOAD POWER PLANT – A power generating station that is normally used to produce extra electricity during peak load times.

PEAK SHARING – Power customers directly assisting utilities by generating electricity during times of peak demand on the utility system.

PEAK SHAVING – The process by which loads in a facility are reduced for a short time to limit maximum electrical demand in a facility and to avoid a portion of the demand charges from the local utility. This is typically accomplished by turning off low priority loads, transferring specific loads to generator power, or generating electrical power in parallel with the utility.

PEAK-TO-PEAK VOLTAGE – Measurement of voltage from the maximum value of one polarity to the maximum of the opposite polarity.

PEAK VOLTAGE – Measurement of voltage at the maximum points of the waveform.

PEAKING UNIT – A power generator used by a utility to produce extra electricity during peak load times.

PEARLITE – The lamellar aggregate of ferrite and carbide resulting from the direct transformation of austenite at Arl. It is recommended that this word be reserved for the microstructures consisting of thin plates of lamellae; that is, those that may have a pearly luster in white light.

PEEC *Programmable Electronic Engine Control*

PEEN – The thin end of a hammer head (opposite to the face).

PEENING – Flattening the end of a rivet, etc., using the force of a hammer.

PENETRATING OIL – A special oil that aids the removal of rusted parts.

PERFORATE – To make full of holes.

PERIPHERY – The external boundary or circumference.

PERMISSIVE PARALLELING – A feature of manual and automatic paralleling switchboards that prevents out-of-phase manual paralleling. A synchronizing check relay prevents the electrical closing of the electrically operated circuit breaker if the incoming set is outside of the frequency or phase angle limits required for proper paralleling to a bus.

PERSONALITY MODULE (PM) – The apparatus which houses the software in a Cat electronic engine's ECM.

PETROLEUM – An oil-liquid mixture made up of numerous hydrocarbons chiefly of the paraffin series.

PHASE – The relationship in time between two waveforms of the same frequency. For practical use, refer to single- and three-phase.

PHASE ROTATION – (Or phase sequence) describes the order (A-B-C, R-S-T, or U-V-W) of the phase voltages at the output terminals of a three-phase generator. The generator phase rotation must match the facility phase rotation.

PHASE SELECTOR SWITCH – Allows one meter to supply power to the voltage regulator and main exciter.

PHOSPHOR-BRONZE – A bearing material composed of tin, lead, and copper.

PHYSICAL CHANGE – A change which does not alter the composition of the molecules of a substance.

PHYSICAL PROPERTIES – It has been established that fully hardened steels have the same mechanical properties when tempered to the same hardness, regardless of composition. Any one of several compositions having the desired hardenability would produce the same results. Since service stresses determine tensile strength requirements, a knowledge of this factor will permit the determination of the other properties of hardness, tempering temperature, elongation, reduction of area and yield. See *Mechanical Properties.*

PICKLING – A treatment given hot rolled rods prior to cold drawing. Its purpose is to remove hot rolled scale and other foreign matter from the rod; and this is commonly done by immersing in a hot acid, generally a sulfuric acid solution. The rolls are then rinsed in cold water, followed most generally by lime coating by dipping in a vat of lime emulsion, and are then heated to dry the lime and remove acid embrittlement.

PILOT SHAFT – A shaft position in or through a hole of a component as a means of aligning the components.

PILOT VALVE – A valve used to control the operation of another valve.

PINION – A small gear having the teeth formed in the hub.

PINTLE-TYPE NOZZLE – A closed-type nozzle having a projection on the end of the fuel valve which extends into the orifice when the valve is closed.

PIPE – In diesel applications, that type of fluid line, the dimensions of which are designated by nominal (approximate) inside diameter.

PIPE (Steel Defect) – A cavity formed in metal (especially ingots) during the solidification of the last portion of liquid metal. Contraction of the metal causes the cavity pipe.

PISTON – A cylindrical part closed at one end which is connected to the crankshaft by the connecting rod. The force of the expansion in the cylinder is exerted against the closed end of the piston, causing the connecting rod to move the crankshaft.

PISTON BOSS – The reinforced area around the piston-pin bore.

PISTON COLLAPSE – A condition describing a collapse or a reduction in diameter of the piston skirt due to heat or stress.

PISTON DISPLACEMENT – The volume of air moved or displaced by a piston when moved from BDC to TDC.

PISTON HEAD – The portion of the piston above the top ring.

PISTON LANDS – That space of the piston between the ring grooves.

PISTON PIN (wrist pin) – A cylindrical alloy pin that passes through the piston bore and is used to connect the connecting rod to the piston.

PISTON RING – A split ring of the expansion type placed in a groove of the piston to seal the space between the piston and the wall.

PISTON RING END CAP – The clearance between the ends of the ring (when installed in the cylinder).

PISTON RING EXPANDER – A spring placed behind the piston ring in the groove to increase the pressure of the ring against the cylinder wall.

PISTON RING GAP – The clearance between the ends of the piston ring.

PISTON RING GROOVE – The grooves cut in between the sides of the ring and the ring lands.

PISTON SKIRT – The portion of the piston which is below the piston bore.

PISTON SPEED – The total distance traveled by each piston in 1 minute. The formula is:

$$\text{Piston speed} = \frac{(\text{stroke (ft)} \times \text{rpm} \times 2) \text{ or } (\text{stroke (in)} \times \text{rpm})}{6}$$

PIVOT – The pin or shaft on which a component moves.

PLATE (battery) – A flat, square, rigid body of lead peroxide or porous lead.

PLAY – The movement or slack between two components.

PLENUM CHAMBER – Chamber or container for moving air or other gas under a slight positive pressure.

PLC *Programmable Logic Controller*

PLUNGER PUMP – A pump which displaces fluid by means of a plunger.

PM *Personality Module, Preventive Maintenance*

PMS *Problem Monitoring System*

PNEUMATICS – That branch of physics pertaining to the pressure and flow of gases.

POLAR TIMING DIAGRAM – A graphic method of illustrating the events of an engine cycle with respect to crankshaft rotation.

POLARITY – Refers to the grounded battery terminal or to an electric circuit or to the north and south pole of a magnet.

POLARIZING – To develop polarization of the pole shoes in respect to battery polarity.

POLE (magnet) – The pole from which the lines of force emanate (thereafter entering the south pole).

PORT – The left side of a ship, when facing the front of the ship.

PORT BRIDGE – The portion of a cylinder or liner between two exhaust or scavenging ports.

PORT SCAVENGING – Introducing scavenging air through ports in the cylinder wall when they are uncovered by the power piston near the end of the power stroke.

PORTS – Openings in the cylinder block and cylinder head for the passage of oil and coolant. (Also exhaust-intake connection and valve openings.)

POSITIVE TERMINAL – The terminal which has a deficiency of electrons.

POTENTIAL ENERGY – The energy possessed by a substance because of its position, its condition, or its chemical composition.

POTENTIAL TRANSFORMER (PT) – An instrument used to reduce the voltage to be measured by a known ratio to a level suitable for the meter movement.

POUNDS PER SQUARE INCH (PSI) – A unit of measurement for pressure.

POUR POINT – The lowest temperature at which an oil will flow.

POWER – The rate of doing work. Power is the actual or observed power corrected to standard conditions of atmospheric pressure, inlet air temperature, and fuel density.

POWER, APPARENT – A quantity of power proportional to the mathematical product of the volts and amperes of a circuit. This product is generally designated in kilovoltamperes (kV•A), and is comprised of both real and reactive power.

POWER CONDITIONER – A device which removes undesirable transients and distortion from a power source.

POWER FACTOR – A correction factor used to figure the actual power being consumed. It is defined as the ratio of the actual power to the apparent power (current/voltage):

$$\text{Power Factor} = \frac{\text{Actual Power (watts)}}{\text{Apparent Power (kV}\bullet\text{A)}}$$

POWER FACTOR METER – Indicates the ratio between true power (kW) and apparent power (kV•A).

POWER FACTOR/VAR CONTROLLER – A device to maintain constant generator set reactive power output while operating in parallel with a utility or other large source. The controller interfaces with the generator automatic voltage regulator and can usually be set to maintain a constant power factor or constant kVAR outlet.

POWER POOL – Two or more interconnected electric systems planned and operated to supply power in the most reliable and economical manner for their combined load requirements and maintenance program.

POWER, REAL – The energy or work-producing part of “apparent power.” It is the rate of supply of energy, measured commercially in kilowatts.

POWER TAKE-OFF (PTO) – Accessory engine drive which is used to power auxiliary equipment.

ppm *parts per million*

PRCM *Programmable Relay Control Module*

PRECISION INSERT BEARING – A precision type of bearing consisting of an upper and lower shell and a replaceable wear surface.

PRE-COMBUSTION CHAMBER – A portion of the combustion chamber connected to the cylinder through a narrow port. Fuel is injected into and is partly burned in the pre-combustion chamber. Heat released by the burning causes the CO in the pre-combustion chamber to be ejected into the cylinder with considerable turbulence.

PRE-IGNITION – Ignition occurring earlier than intended. For example, the explosive mixture being fired in a cylinder as by a flake of incandescent carbon before the electric spark occurs.

PRE-LOADING – Adjusting taper roller bearings so that the rollers are under mild pressure.

PRE-ROTATION VANES (PRVs) – Vanes which are located at the compressor inlet. These vanes can be rotated through the use of an actuator to vary the load.

PRESS-FIT – Also known as a force-fit or drive-fit. This term is used when the shaft is slightly larger than the hole and must be forced into place.

PRESS-FIT PRESSURE – Force exerted per unit of area. (See *Drive-fit.*)

PRESSURE – An energy impact on a unit area; force or thrust exerted on a surface.

PRESSURE CAP – A special radiator cap with a pressure-relief and vacuum valve.

PRESSURE DIFFERENTIAL – The difference in pressure between any two points of a system or a component.

PRESSURE DROP – The pressure difference at two ends of a circuit, part of a circuit, or the two sides of a filter, or the pressure difference between the high side and low side in a refrigerator mechanism.

PRESSURE LUBRICATION – A lubricating system in which oil at a controlled pressure is brought to the desired point.

PRESSURE REGULATOR, EVAPORATOR – An automatic pressure regulating valve. Mounted in suction line between evaporator outlet and compressor inlet. Its purpose is to maintain a pre-determined pressure and temperature in the evaporator.

PRESSURE TIME (PT) CURVE – A visual representation of the pressure within the combustion chamber during an engine's working cycle.

PRESSURE-RELIEF VALVE – A valve that limits the maximum system pressure.

PRIMARY DISTRIBUTION FEEDER – An electric line supplying power to a distribution circuit, usually considered to be that portion of the primary conductors between the substation or point of supply and the center of distribution.

PRIME MOVER – The engine, turbine, water wheel, or similar machine which drives an electric generator.

PRIME POWER – An application where the generator set(s) must supply power on a continuous basis and for long periods of time between shutdowns. No utility service is present in typical prime power applications.

PRINTED CIRCUIT – An electric circuit where the conductor is pressed or printed in or on an insulating material (panel) and at the same time is connected to the resistor, diodes, condenser, etc.

PROBABILITY OF ON-SITE POWER ECONOMIC TEST (PROSPECT) – A Cat menu-driven personal computer software package which quickly analyzes peak shaving economic feasibility and return on investment.

PRODUCT INFORMATION – A book designed to educate dealers on a product or product line, and serve as a resource guide to aid in the sales process. It is comprehensive, yet quickly read, with a bulleted text format. Product features, benefits, and diagrams; servicing information; maintenance schedules; performance and competitive data; schematics; and other material may be included.

PRODUCT NEWS – A publication used to update dealers on the development and availability of a new product, product update, product change, or feature. In addition to a basic description of the new item, among the contents may be specifications, detailed feature breakdown, performance data, schematics, pricing and shipping information, product contacts, and any other pertinent statistics.

PROGNOSTICS – Predict failure or potential problems before occurrence.

PROGRESSIVE – Normally refers to a compound die where all slots are gang punched at one time.

PROOF STRESS – The load per unit area which a material is capable of withstanding without resulting in a permanent deformation of more than a specified amount per unit of cage length after complete release of load; i.e., the stress that will produce a very small permanent deformation, generally specified as 0.01% of the original gauge length. Because this is difficult to determine by the alternate loading and releasing which is generally prescribed, the offset method is frequently employed.

PROPELLER – The device used to propel the ship through the water.

PROPELLER GUARDS – Steel braces at the stern, directly above the propellers. They prevent the propellers from striking a dock, pier or other ship.

PROTON – The positively charged particle in the nucleus of an atom.

PRUSSIAN BLUE – A blue pigment, obtainable in tubes, which is used to find high spots in a bearing.

PS – PFERDESTARKE (horsepower) – German designation for metric horsepower.

PSA *Power Systems Associates*

PSD *Power Systems Distributor*

psi *pounds per square inch*

psig *pounds per square inch gauge*

PSYCHROMETRIC CHART – A chart that shows the relationship between the temperature, pressure, and moisture content of the air.

PT *Pressure Time, Potential Transformer*

PTO *Power Take-Off*

PUC *Public Utility Commission*

PULL DOWN – An expression indicating action of removing refrigerant from all or a part of a refrigerating system.

PULSATE – To move with rhythmical impulse.

PULSE WIDTH MODULATION (PWM) – A signal consisting of variable width pulses at fixed intervals, whose ratio of “TIME ON” versus total “TIME OFF” can be varied. (Also referred to as “duty cycle.”)

PULVERIZE – To reduce or become reduced to powder or dust.

PUMP – A device for moving fluids.

PUMP DOWN – The act of using a compressor or a pump to reduce the pressure in a container or a system.

PUMP SCAVENGING – Using a piston-type pump to pump scavenging air.

PUMPING LOSS – The power consumed by replacing exhaust gas in the cylinder with fresh air.

PUNCH PRESS – A method of straightening which employs a punch press, “V” block supports, a dial gauge, and a straightedge. The bar to be straightened in placed on “V” blocks under the punch and rotated against a dial gauge or straightedge. The punch is then used to straighten the bar by deflecting the bar in the direction indicated by the gauge or straightedge. Neither the size nor finish is affected by this operation.

PURGING – Releasing compressed gas to the atmosphere through some part of parts for the purpose of removing contaminants from the part or parts.

PUSH FIT – The part of the bearing that can be slid into place by hand if it is square with its mounting.

PUSH ROD – A connecting link in an operating mechanism, such as the rod interposed between the valve lifter and rocker arm on an overhead valve engine.

PVC *Polyvinyl Chloride*

PWM *Pulse Width Modulated*

PYROMETER – A temperature indicator used for indicating exhaust temperature.

QUALIFIED FACILITY – A cogeneration facility which has been granted a “qualified” status by the FERC. To obtain the qualified status a facility must meet the ownership requirements (i.e., less than 50% electric utility ownership) and operating efficiency standards as outlined in the Public Utility Regulatory Policies Act of 1978 (PURPA).

QUALIFYING FACILITY – A cogenerator or small power producer which, under federal law, has the right to sell its excess power output to the public utility.

QUARTERDECK – The deck on which you go aboard a ship.

QUENCHING – The rapid cooling by immersion in liquids or gases or by contact with metal. The operation of hardening steel consists of slowly and uniformly heating to the proper austenitizing temperature above the upper critical (AC3), holding for sufficient time for through heating, and then quickly cooling by plunging the part into the quenching medium.

QUICKSILVER – Metallic mercury.

R-11, TRICHLOROMONOFLUOROMETHANE – Low pressure, synthetic chemical refrigerant which is also used as a cleaning fluid.

R-113, TRICHLOROTRIFLUOROETHANE – Synthetic chemical refrigerant.

R-12, DICHLORODIFLUOROMETHANE – A popular refrigerant known as Freon 12.

R-134a – A commercially available, environmentally friendly hydrofluorocarbon (HFC) refrigerant for use as a long-term replacement for R-12 in new equipment and for retrofitting medium temperature CFC-12 systems.

R-160, ETHYL CHLORIDE – Refrigerant which is seldom used at the present time.

R-170, ETHANE – Low temperature application refrigerant.

R-22, MONOCHLORODIFLUOROMETHANE – Synthetic chemical refrigerant.

R-290, PROPANE – Low temperature application refrigerant.

R-40, METHYL CHLORIDE – Refrigerant which was used extensively in the 1920s and 1930s.

R-500 – Refrigerant which is azeotropic mixture of R-12 and R-152A.

R-502 – Refrigerant which is azeotropic mixture of R-22 and R-115.

R-503 – Refrigerant which is azeotropic mixture of R-23 and R-13.

R-504 – Refrigerant which is azeotropic mixture of R-32 and R-115.

R-600, BUTANE – Low temperature application refrigerant, also used as a fuel.

R-611, METHYL FORMATE – Low pressure refrigerant.

R-717, AMMONIA – Popular refrigerant for industrial refrigerating systems; also a popular absorption system refrigerant.

R-764, SULPHUR DIOXIDE – Low pressure refrigerant used extensively in the 1920s and 1930s. Not in use at present; chemical is often used as an industrial bleaching agent.

RACE (bearing) – A finished inner and outer surface in which balls or rollers operate.

RACEWAY – The surface of the groove or path which supports the balls or rollers of a bearing roll.

RACK SHUTOFF – An engine protection measure involving a hydraulic fuel rack actuator installed on an engine's injection pump housing. When activated, the piston of the actuator moves the rack to the fuel "off" position.

RADIAL – A type of cylinder arrangement in an engine where the cylinders are placed radially like wheel spokes.

RADIAL CLEARANCE (radial displacement) – The clearance within the bearing and between the balls and races, perpendicular to the shaft.

RADIAL LOAD – A "round-the-shaft" load; that is, one that is perpendicular to the shaft through the bearing.

RADIATOR – A heat exchanger in which cooling water gives up heat to the air without coming into direct contact with it.

RADIATOR COOLING – A type of cooling system used on generator sets which involves a fan forcing air through an engine's radiator, lowering the temperature of the coolant.

RADIUS – The distance from the center of a circle to its outer edge or the straight line extending from the center of the edge of a circle.

RANDOM WOUND – The type of winding style which refers to flexible bundles of main stator winding with round wire.

RATE SCHEDULE – Price list showing how the utility will bill a class of customers.

RATED – The advertised value of an engine when full load is removed, expressed as a percentage of full load speed.

RATED HORSEPOWER – Value used by the engine manufacturer to rate the power of his engine, allowing for safe loads, etc.

RATIO – The relation or proportion of one number or quantity to another.

REACTIVE DROOP COMPENSATION – One method used in paralleled generator sets to enable them to share reactive power supplied to a load. This system causes a drop in the internal voltage of a set when reactive currents flow from that generator. Typically, at full load, 0.8 PF, the output voltage of a set is reduced by 4% from that at no load when reactive droop compensation is used.

REACTIVE POWER – Power that flows back and forth between the inductive windings of the generator and the inductive windings of motors, transformers, etc., which are part of the electrical load. This power does no useful work in the electrical load nor does it present load to the engine. It does apply load to the generator and limits the capacity of the generator.

REAM – To finish a hole accurately with a rotating fluted tool.

REBORE – To bore a cylinder to a size slightly larger than the original.

RECIPROCATING ACTION (motion) – A back-and-forth (alternating) movement.

RECIPROCATING ENGINE – A type of engine where pistons with pressurized gas move back and forth (reciprocate) within the cylinders.

RECTIFIER – A device which exhibits a very high resistance to the flow of current in one direction and a very low resistance to flow in the opposite direction. Rectifiers are used to change AC voltages to DC before applying it to the generator field.

REDUCTION OF AREA – The difference between the original cross sectional area and that of the smallest area at the point of rupture. It is usually stated as a percentage of the original area, also called "contraction of area."

RECTIFIER ASSEMBLY – An electronic device which rectifies AC current (produced by exciter rotor winding) to DC current and applies it to the revolving field winding.

REFRIGERANT – Substance used in refrigerating mechanism to absorb heat in evaporator coil by change or state from a liquid to a gas, and to release its heat in a condenser as the substance returns from the gaseous state back to a liquid state.

REFRIGERANT CHARGE – Quantity of refrigerant in a system.

REFRIGERATING EFFECT – The amount of heat in Btu/h or Cal/hr the system is capable of transferring.

REFRIGERATION – The process of transferring heat from one place to another by the change in state of a liquid.

REFRIGERATION SYSTEM – A system composed of parts necessary to accomplish heat transfer by the change in state of the refrigerant.

REFRIGERANT-ABSORPTION – Refrigerating effect produced by the change in pressure in the system produced by the changes in the ability of a substance to retain a liquid dependent upon the temperature of the substance.

REFRIGERATION-MECHANICAL – Refrigerating effect produced by the changes in pressure in the system produced by mechanical action of a compressor.

REGULATOR – An electronic device which senses AC current, compares current to a set value, rectifies AC to DC and applies it to the exciter stator winding in order to maintain constant output voltage in the main stator winding. *(*See *VR1, 2, 3, 4)*

REGULATOR, ELECTRICAL – An electromagnetic or electronic device used to control generator voltage.

RELATIVE HUMIDITY – Ratio of the amount of water vapor present in air to the greatest amount possible at the same temperature.

RELAY – An electromagnetic switch which utilizes variation in the strength of an electric circuit to affect the operation of another circuit.

RELIEF VALVE – An automatic valve which is held shut by a spring of correct strength. Excess pressure opens the valve and releases some of the gas or liquid. This valve is for protecting filters, air tanks, etc. from dangerous pressures.

REMAN *Remanufactured*

REMANUFACTURED EXTENDED COVERAGE – A Caterpillar program which protects buyers from repair expenditures beyond the standard warranty period on remanufactured truck engines.

RESIDUAL FUEL – A fuel resembling tar and containing abrasive and corrosive substances. It is composed of the remaining elements from crude oil after the crude has been refined into diesel fuel, gasoline, or lubricating oil.

RESISTANCE, ELECTRICAL – The opposition offered by a body when current passes through it.

RESISTOR – A device placed in a circuit to lower the voltage, to reduce the current, or to stabilize the voltage.

RESPONSE CHECK – A measure of the engines' ability to develop increasing torque at constant speed.

RESPONSE CHECK IDLE SPEED – The engine speed specified for the cooldown portion of the response check.

RESPONSE CHECK SPEED – The constant engine speed at which the engine is loaded to determine the time to develop a specified torque.

RESPONSE TIME – A measure of the time required for an engine to develop a specified torque or power.

RETARD (injection timing) – To set the timing so that injection occurs later than TDC or fewer degrees before TDC.

REVERSE FLUSH – To pump water or a cleaning agent through the cooling system in the opposite direction to normal flow.

REVERSE POWER RELAY – A device which is sensitive to the current flow direction. Reverse currents trip the relay, activating auxiliary switches that control the circuit breaker and/or alarm devices.

REVERSE ROTATION – An engine condition caused by a transmission shift from forward to reverse, or vice versa, when sufficient engine torque is not available at idle speed to overcome propeller and driveline inertia. It causes the engine to stall or reverse itself.

REVERSE VAR RELAY – Detects VAR flow into generator set (leading power factor). This condition occurs in a paralleled generator set if the system is not adjusted properly or a failure has occurred in the excitation system.

REVOLUTIONS PER MINUTE (RPM) – The number of revolutions an engine's crankshaft makes in one minute.

RFI *Radio Frequency Interference*

RH *Right Hand*

RHEOSTAT – A device to regulate current flow by varying the resistance in the circuit.

RIMMED STEEL – An incompletely deoxidized steel normally containing less than 0.25% carbon and having the following characteristics: (a) During solidification an evolution of gas occurs sufficient to maintain a liquid ingot top ("open" steel) until a side and bottom rim of substantial thickness has formed. If the rimming action is intentionally stopped shortly after the mold is filled, the product is termed capped steel. (b) After complete solidification, the ingot consists of two distinct zones: a rim somewhat purer than when poured and a core containing scattered blowholes with a minimum amount of pipe and having an average metalloid content somewhat higher than when poured and markedly higher in the upper portion of the ingot.

RING GROOVE – A groove machined in the piston to receive the piston ring.

RING JOB – The service work on the piston and cylinder including the installation of new piston rings.

RISERS – Bus bars that connect circuit beakers to the system bus.

RIVET – A soft-metal pin having a head at one end.

ROCKER ARM – A first-class lever used to transmit the motion of the pushrod to the valve stem.

ROCKER ARM SHAFT – The shaft on which the rocker arms pivot.

ROCKWELL HARDNESS – A measurement of the degree of surface hardness of a given object by pressing a steel ball or diamond cone into a sample and using scales which indicate differences between depths penetrated by major and minor loads.

ROD – Refers to a connecting rod.

ROLLER BEARING – An antifriction bearing using straight (cupped or tapered) rollers spaced in an inner and outer ring.

ROLLER TAPPETS (Roller Lifters) – Refers to valve lifters having a roller at one end which is in contact with the camshaft and is used to reduce friction.

ROOTS BLOWER – An air pump or blower similar in principle to a gear-type pump.

ROPE BRAKE – A friction brake used for engine testing.

ROTARY BLOWER – Any blower in which the pumping element follows rotary motion, centrifugal blowers being the exception.

ROTARY COMPRESSOR – Mechanism which pumps fluid by using rotating motion.

ROTARY MOTION – A circular movement, such as the rotation of a crankshaft.

ROTATING ENGINE OR TURBINE – An engine which sends pressurized gas through a wheel, forcing it to turn.

ROTATION OF ENGINE – The direction of rotation of the engine flywheel as viewed from the rear of an engine, usually expressed as clockwise or counterclockwise. The rotation of an engine is normally counterclockwise.

ROUGING STONE (hone) – A coarse honing stone.

RPM *Revolutions per minute*

RUDDER – A vertically hinged plate mounted at the rear of a vessel used for directing or altering its course.

RUNBACKS – Bus extensions from the circuit breaker that provided a location for connection of the cables coming from a generator set.

RUNNING-FIT – A machine fit with sufficient clearance to provide for expansion and lubrication.

S *Single turbocharger*

SAE *Society of Automotive Engineers*

SAE HORSEPOWER (Rated Horsepower) – Formula to determine power: bore diameter 2 × number of cylinders/2.5 = hp

SAE VISCOSITY NUMBERS – Simplified viscosity ratings of oil based on Saybolt viscosity.

SAFETY FACTOR – Providing strength beyond that needed as an extra margin of insurance against parts failure.

SAND BLAST (Glass Blast) – A cleaning method using an air gun to force the sand at low pressure (about 150 psi) against the surface to be cleaned.

SATURATION – A condition existing when a substance contains the maximum of another substance for that temperature and pressure.

SC *Speed Control*

SCA *Supplemental Coolant Additives*

SCAB – A rough projection on a casting caused by the mold breaking or being washed by the molten metal or occurring where the skin from a blowhole has partly burned away and is not welded.

SCALE – A flaky deposit occurring on steel or iron. Ordinarily used to describe the accumulation of minerals and metals accumulating in an engine cooling system.

SCAVENGING – The displacement of exhaust gas from the cylinder by fresh air.

SCAVENGING AIR – The air which is pumped into a cylinder to displace exhaust gas.

SCAVENGING BLOWER – A device for pumping scavenging air.

SCAVENGING PUMP – A piston-type pump delivering scavenging air to an engine.

SCHEDULED OIL SAMPLING (S•O•S) – A Cat service which offers insight into engine wear through periodic analysis of oil samples.

SCORE – A scratch, ridge or groove marring a finished surface.

SCRAPER RING – An oil control ring.

SCREW – Another name for the propeller.

SCREW EXTRACTOR – A device used to remove broken bolts, screws, etc. from holes.

S-CURVE – The curve that results from plotting the time for austenite transformation against the temperature at which the transformation takes place. These curves were originally developed by Davenport & Bain and reported in their paper entitled “Transformation of Austenite and Constant Subcritical Temperatures.”

SE (Excitation Type) – A self-excited generator where residual magnetism found in the revolving field lamination initiates current flow in the main stator winding.

SEALED BEARING – A bearing which is lubricated and sealed at the factory and which cannot be lubricated during service.

SEALED UNIT – (See *Hermetic System*) A motor-compressor assembly in which motor and compressor operate inside a sealed dome or housing.

SEAM – A crack on the surface of metal which has been closed but not welded, usually produced by blowholes which have become oxidized. If very fine, a seam may be called a hair crack or hair seam.

SEAT – A surface, usually machined, upon which another part rests or seats. For example, the surface upon which a valve face rests.

SEAT (Rings) – Rings fitted or seated properly against the cylinder wall.

SECOND LAW OF THERMODYNAMICS – Heat will flow only from material at certain temperature to material at lower temperature.

SECONDARY DISTRIBUTION SYSTEM – A low-voltage alternating-current system which connects the secondaries of distribution transformers to the customer's services.

SEDIMENT – Solid impurities in a liquid.

SEGREGATION – Steel is a mixture of compounds and elements which, when cooled from the molten state, solidify at different temperatures. Segregation is the resulting concentration of the various ingredients in different parts of the ingot with the maximum concentration generally found at the base of the pipe.

SELECTIVE ENERGY SYSTEM – The name previously used to describe a form of cogeneration in which part, but not all of the site's electrical needs were met with on-site generation with additional electricity purchased from a utility as needed.

SELF EXCITED (SE) – Excitation Type – Generator where residual magnetism found in the revolving field lamination initiates current flow in the main stator winding.

SEMICONDUCTOR – An element which is neither a good conductor nor a good insulator.

SEMIFLOATING PISTON PIN – A piston pin which is clamped either in the connecting rod or piston bosses.

SENSIBLE HEAT – Heat which causes a change in temperature of a substance.

SEPARATE CIRCUIT AFTERCOOLED (SCAC) – Removal of the aftercooler from the jacket water circuit, and provision of cooling from an independent source. It is necessary on all turbocharged engines and high temperature jacket water systems used in heat recovery applications.

SEPARATE CIRCUIT AFTERCOOLER – A heat exchanger for cooling combustion air cooled by a source of water external to the engine.

SEPARATOR, BATTERY – A porous insulation material placed between the positive and negative plates.

SEPARATOR, OIL – A device used to separate refrigerant oil from refrigerant gas and return the oil to the crankcase of the compressor.

SERIES BOOST – An additional electronic device added into the generator power system which provides a power source for approximately 10 seconds after a short occurs to allow protective trip devices to function correctly.

SERIES CIRCUIT – An electric circuit wired so that the current must pass through one unit before it can pass through the other.

SERIES-PARALLEL CIRCUIT – A circuit with three or more resistance units in a combination of a series and a parallel circuit.

SERVICE AREA – Territory in which a utility system is required or has the right to supply electric service to ultimate customers.

SERVICEABLE HERMETIC – Hermetic unit housing containing motor and compressor assembled by use of bolts or threads.

SHAFT – The shaft that connects the reduction gear, marine transmission, to the propeller

SHAFT ALLEY – A watertight casing covering propeller shaft, large enough to walk in, extending from the engine room to after peak bulkhead, to provide access and protection to shaft in way of after cargo holds.

SHAFT HORSEPOWER – Power delivered at the engine crankshaft. This term is commonly used instead of *brake horsepower* to express output of large marine engines.

SHELL-TYPE CONDENSER – Cylinder or receiver which contains condensing water coils or tubes.

SHELL-AND-TUBE FLOODED EVAPORATOR – Device which flows water through tubes built into cylindrical evaporator or vice-versa.

SHIM – A thin, flat piece of brass or steel used to increase the distance between two components.

SHORT CIRCUIT – A circuit whose resistance is reduced in power owing to one or more coil layers contacting one another.

SHRINK-FIT – A fit between two components made by heating the outer component so that it will expand and fit over the inner component. As the outer component cools, it shrinks and thereby fits tight to the inner component.

SHROUD – The enclosure around the fan, engine, etc., which guides the airflow.

SHUNT – A parallel circuit where one resistance unit has its own ground.

SHUNT TRIP – Feature modification allows for tripping the beakers with an electrical signal from a remote location.

SHUNT WINDING – A resistance coil with its own ground.

SHUTOFF VALVE – A valve which opens and thereby stops the flow of a liquid, air, or gas.

SI *Spark Ignited*

SIGNIFICANT FIGURES – The number of digits in a number defining the precision of the number.

SILENCER – A device for reducing the noise of intake or exhaust.

SILICA GEL – Chemical compound used as a drier, which has the ability to absorb moisture when heated. Moisture is released and the compound may be reused.

SILICON-CONTROLLED RECTIFIER (SCR) – A device that passes current in one direction only, like an ordinary rectifier, but includes a switch to control the current flow.

SINGLE ELEMENT (SE) – Number of elements in an assembly, especially filters.

SINGLE PHASE – An AC system having one voltage of given frequency.

SINGLE VOLTAGE – Term used to denote 4-lead unit – 480V or 600V.

SINGLE-ACTING CYLINDER – An actuating cylinder in which one stroke is produced by pressurized fluid, and the other stroke is produced by some other force, such as gravity or spring tension.

SLIDING-FIT – Where sufficient clearance has been allowed between the shaft and journal to allow free running without overheating.

SLIP-IN-BEARING – A liner made to precise measurements which can be used for replacement without additional fitting.

SLOBBER – Unburned lubricating oil or fuel discharged into the exhaust system along with exhaust gasses.

SLOT CELL – Passage into which magwire is inserted. Either in stator lamination or revolving field lamination.

SLOT FILL – Calculated and actual percentage area of the wire. Compared to the available slot area in the lamination minus the slot and coil insulation.

SLOT LINERS – Insulation between top and bottom magwire coil in slot passage.

SLOT SEPARATOR – The insulation between top and bottom magwire coil in the slot passage.

SLUDGE – A composition of oxidized petroleum products along with an emulsion formed by the mixture of oil and water. This forms a pasty substance and clogs oil lines and passages and interferes with engine lubrication.

SMALL BRUSHLESS – The existing line of small generators; 360, 440, and 580 frames; where customer line lead connection and regulator assembly is covered with a top-mounted, front-covered terminal box.

SMALL POWER-PRODUCTION FACILITY – As defined in the Public Utility Regulatory Policies Act (PURPA), a facility that produces energy solely by using as a primary energy source, biomass, waste, renewable resources, or any combination thereof, and has a power production capacity that, together with any other facilities located at the same site (as determined by the Commission), is not greater than 80 megawatts.

SNAP RING – A fastening device in the form of a split ring that is snapped into a groove in a shaft or in a groove in a bore.

SNUBBERS – Material used to absorb energy produced by a sudden change in motion.

SODIUM VALVE – A valve designed to allow the stem and head to be partially filled with metallic sodium.

SOLAR CELL – A photovoltaic cell that can convert light directly into electricity. A typical solar cell uses semiconductors made from silicon.

SOLENOID – An electrically magnetic device used to do work.

SOLID INJECTION – The system used in diesel engines where fuel as a fluid is injected into the cylinder rather than a mixture of fuel and air.

SOLID WATER SYSTEM – A type of high temperature heat recovery system. Also known as ebullient system.

SOLVENT – A solution which dissolves some other material. For example, water is a solvent for sugar.

SORBITE – A late stage in the tempering of martensite when the carbide particles have grown so that the structure has a distinctly granular appearance. Further and higher tempering causes globular carbides to appear clearly.

S•O•S *Scheduled Oil Sampling*

SOUND ATTENUATED (SA) – A term used to describe a generator set enclosure which has been specially designed to reduce the amount and severity of escaping noise.

SOUND POWER LEVEL – The total sound power being radiated from a source, such as a generator set. The magnitude of the sound is independent of the distance from the source.

SPACE HEATERS – Heating elements mounted in the unit to keep windings warm during shutdown periods which eliminate condensation on the electric components.

SPARK IGNITED ENGINE – For purposes of this specification, Spark Ignited Engine is synonymous with Gaseous Fueled Engine.

SPARK TESTING – An inspection method for quickly determining the approximate analysis of steel. It is intended primarily for the separation of mixed steel and, when properly conducted, is a fast, accurate, and economical method of separation. It consists in holding the sample against a high speed grinding wheel and noting the character and color of spark, which is compared with samples of known analysis.

SPECIFIC FUEL CONSUMPTION – The fuel rate divided by the power. Corrected specific fuel consumption is the value obtained when the corrected fuel rate is divided by corrected power.

SPECIFIC GRAVITY – The ratio of the weight of a given volume of any substance to that of the same volume of water.

SPECIFIC HEAT – Ratio of quantity of heat required to raise the temperature of a body one degree to that required to raise the temperature of an equal mass of water one degree.

SPECIFICATION SHEET – A technical overview of a particular engine or engine-related product. Sales features, engine specifications, performance data and curves, dimensions and weight, standard and accessory equipment, and rating definitions and conditions are among the standard contents.

SPLINE – A long keyway. The land between two grooves.

SPLIT SYSTEM – Refrigeration or air-conditioning installation which places condensing unit outside or remote from evaporator. Also applicable to heat pump installations.

SPOOL VALVE – A hydraulic directional control valve in which the direction of the fluid is controlled by means of a grooved cylindrical shaft (spool).

SPOT WELD – To attach in spots by localized fusion of the metal parts with the aid of an electric current.

SPUR GEAR – A toothed wheel having external radial teeth.

sq ft *square foot*

sq in *square inch.*

SQUISH AREA – The area confined by the cylinder head and flat surface of the piston when on compression stroke.

SR *Slave Relay*

STA *Series Turbocharged-Aftercooled*

STABILITY – The resistance of a fluid to permanent change such as that caused by chemical reaction, temperature changes,etc.

STABILIZED – The steady or cyclic condition of an engine performance characteristic which remains unchanged with time while the engine is running under a given steady state condition.

STANDARD ATMOSPHERE – Condition when air is at 14.7 psia pressure, at 68° F temperature.

STANDARD CONDITIONS – Used as a basis for air-conditioning calculations. Temperature of 68° F, pressure of 29.92 in Hg and relative humidity of 30 percent.

STANDBY CAPACITY – The capacity that is designed to be used when part or all of the prime source of power is interrupted.

STANDBY POWER – Output available with varying load for the duration of the interruption of the normal source power. Fuel stop power in accordance with ISO3046/1, AS2789, DIN6271, and BS5541.

STANDBY RATE – The utility charge for standby electricity.

STARBOARD – The right side of a ship, when facing the front of the ship.

STARTING AIR – Compressed air used for starting an engine.

STARTING-AIR VALVE – A valve which admits compressed starting air to the cylinder.

STATIC ELECTRICITY – Electricity at rest; pertaining to stationary charges.

STATIC FUEL SYSTEM SETTING – A setting of a fuel system, either mechanical or electronic, made in an attempt to obtain the desired fuel rate at a particular engine operating point. Settings are normally made to provide either full load fuel rate or the fuel rate at torque check rpm. They are identified respectively as Full Load Static Fuel Setting (FLSFS) or Full Torque Static Fuel Setting (FTSFS).

STATIC HEAD – The maximum height the coolant water is raised.

STATIC PRESSURE – The pressure exerted against the inside of a duct in all directions. Roughly defined as *bursting pressure*.

STATOR – The fixed or stationary portion of a generator.

STAYBOLT – A stress bolt running diagonally upward from the bedplate to the opposite side of the frame.

STD *Standard*

STEADY FLOW – A flow in which the velocity components at any point in the fluid do not vary with time.

STEM – The point of the hull at the bow, where port and starboard sides meet, extending from keel to forecastle deck.

STERN – The back part of a ship, where the two sides meet. To move in that direction is to go aft.

STERN STRUT – A device used to help support the propeller and propeller shaft.

STERN TUBE – The part of the ship where the prop shaft goes through the hull of the ship.

STETHOSCOPE – A device for conveying the sound of a body (engine noise) to the technician.

STRAIGHTENING – Cold finished bars may require straightening following cold drawing, turning, or furnace treatment in order to meet the standard established for the particular type or grade being produced. These bars may be straightened by several different types of equipment designed to deflect the bar so that equalizing stresses are set up in the bar which keep it straight. See *Irregular Straighteners,* and *Medart, Punch Press.*

STREAMLINE FLOW – A nonturbulent flow, essentially fixed in pattern.

STRESS – The force or strain to which a material is subjected.

STRESS RELIEF – A method of relieving the internal stress set up in metal by forming or cooling operations. It consists in heating to a temperature of approximately 1050° F for a sufficient length of time to through heat the part, and cooling in air.

STROBOSCOPE (timing light) – An instrument used to observe the periodic motion of injection visible only at certain points of its path.

STROKE – A single movement (usually repeated continuously) of a piston within a cylinder from one end of its range to the other; constitutes a half revolution of an engine.

STROKE-TO-BORE RATIO – The length of the stroke divided by the diameter of the bore.

STRUCTURAL SHAPES – The general term applied to the rolled, flanged sections having at least one dimension of their cross section 3 inches or greater.

STUD – A rod with threads cut on both ends, such as a cylinder stud which screws into the cylinder block on one end and has a nut placed on the other end to hold the cylinder head in place.

STUD PULLER – A device used to remove or to install stud bolts.

STUFFING BOX – A chamber having a manual adjustment device for sealing.

SUBCOOLING – Cooling of liquid refrigerant below its condensing temperature.

SUCTION – Suction exists in a vessel when the pressure is lower than the atmospheric pressure, also see *Vacuum*.

SUCTION LINE – Tube or pipe used to carry refrigerant gas from evaporator to compressor.

SUCTION VALVE – Often used interchangeably with *intake valve*.

SULFUR – An undesirable element found in petroleum in amounts varying from a slight trace to 4 or 5 percent.

SULFUR DIOXIDE (SO_2) – An engine emission made up of the oxidized portion of sulfur in fuel.

SUMP – A receptacle into which liquid drains.

SUMP PUMP – A pump which removes liquid from the sump tank.

SUPERCHARGER – A blower or pump which forces air into the cylinders at higher-than atmospheric pressure. The increased pressure forces more air into the cylinder, thus enabling more fuel to be burned and more power produced.

SUPERFICIAL HARDNESS – Measure of the degree of surface hardness with a more sensitive depth measuring system than is used with regular Rockwell machines. It is recommended for use on thin strip or sheet material, nitrided or lightly carburized pieces.

SUPERSTRUCTURE – The part of the ship above the main deck.

SUPPLEMENTAL THERMAL – The heat required when recovered engine heat is insufficient to meet thermal demands.

SUPPLEMENTARY FIRING – The injection of fuel into the recovered heat stream (such as turbine exhaust) to raise the energy content (heat of the stream).

SUPPLEMENTARY POWER – Electric energy supplied by an electric utility in addition to that which the facility generates itself.

SUPPLY LINE – A line that conveys fluid from the reservoir to the pump.

SURGE – A momentary rise and fall of pressure or speed in a system or engine.

SWITCHGEAR – The equipment between a generator and the lines of distribution that switches the electrical load to and from a generator, protects the generator from short circuits, monitors generator output, provides the means to parallel two or more units onto the system, and controls the operation of the engine.

SYNCHRONIZATION – The act of matching a generator set's frequency and phase with that of the system bus, before paralleling the set.

SYNCHRONIZE – To make two or more events or operations occur at the proper time with respect to each other.

SYNCHRONIZER – An electronic device that monitors the phase relationship between two voltage sources and provides a correction signal to an engine governor, to force the generator set to synchronize with a system bus.

SYNCHRONIZING CHECK RELAY – A device used in conjunction with both types of circuit beakers to assure that the incoming unit is within specified voltage and frequency limits before paralleling is accomplished.

SYNCHRONIZING LIGHTS – Lamps connected across a circuit breaker of a generator set. The lights indicate when the voltage wave forms of the incoming and operating power sources coincide and paralleling can be completed. When the lights fade from light to dark, and they are at their darkest, the two sources are synchronized and paralleling can be accomplished.

SYNCHRONOUS – Recurring operation at exactly the same time. The speed at which a rotating AC electrical machine would rotate if there were no slip. Example: Four-pole, 60 Hz generator has a synchronous speed of 1800 rpm.

SYNCHROSCOPE – A meter that indicates the relative phase angle between an incoming set voltage and the bus voltage. The synchroscope pointer indicates whether the set is faster or slower than the bus and allows the operator to adjust the frequency (speed) accordingly before manually paralleling to the bus.

SYNTHETIC MATERIAL – A complex chemical compound which is artificially formed by the combining of two or more compounds or elements.

SYSTEM SHUTDOWN – On the EMS II module, a flashing red light and a horn annunciate if the ECM initiates a system controlled emergency shutdown of if there is an active system fault.This may be an overspeed, low oil pressure, or high coolant temperature shutdown.

SYSTEM VOLTAGE – On the EMS II module, a flashing red light and a horn annunciate when the DC system falls below 20 volts.

T *Turbocharged*

TA *Turbocharged-Aftercooled*

TACHOMETER – An instrument indicating rotating speeds. Tachometers are sometimes used to indicate crankshaft rpm.

TAP – A cutting tool used to cut threads in a bore. (See *Chamfer*.)

TAP AND DIE SET – A set of cutting tools used to cut internal and external threads.

TAPERED ROLLER BEARING – See *Roller Bearing.*

TAPPET – The adjusting device for varying the clearance between the valve stem and the cam. May be built into the valve lifter in an engine or may be installed in the rocker arm on an overhead valve engine.

TAPPET NOISE – The noise caused by the excessive clearance between the valve stem and the rocker arm.

TC *Top Center*

TDR *Time Delay Relay (ESS)*

TEMPER – The condition of a metal with regard to harness achieved through heating and then suddenly cooling.

TEMPER BRITTLENESS – The term applied to the brittleness or low impact resistance that may occur in medium carbon and many alloy steels that are slowly cooled from the tempering temperature. It may be corrected by water quenching after tempering. Molybdenum in amounts of 25% to 50% tend to retard the formation of temper brittleness.

TEMPERATURE OF COMPRESSION – The temperature of the compressed air charge in a power cylinder at the end of the compression stroke before combustion begins.

TEMPORARY HARDNESS – Dissolved substances which precipitate out when water is heated.

TENSILE STRENGTH – The maximum load in pounds per square inch that the sample will carry before breaking under a slowly applied gradually increasing load. In the stress/strain diagram, this is the highest point on the curve and is probably the most used steel specification.

TENSION – Stress applied on material or body.

TERMINAL – The connecting point (post) of a conductor.

T-HEAD ENGINE – An engine design wherein the inlet valves are placed on one side of the cylinder and the exhaust valves are placed on the other.

THEORY – A scientific explanation tested by observations and experiments.

THERMAL CAPACITY – The maximum amount of heat that a system can produce.

THERMAL EFFICIENCY – A gallon of fuel contains a certain amount of potential energy in the form of heat when burned in the combustion chamber. Some of this heat is lost and some is converted into power. The thermal efficiency is the ratio of work accomplished to the total quantity of heat in the fuel. (See also *Brake Thermal Efficiency* and *Indicated Thermal Efficiency*.)

THERMAL EXPANSION – The increase of volume of a substance caused by temperature change.

THERMAL GROWTH – The tendency for materials to expand when exposed to heat. Exhaust piping of a generator set undergoes this phenomenon.

THERMOCOUPLE – The part of a pyrometer which consists of two dissimilar metal wires welded together at the inner end and held in a protective housing.

THERMODYNAMICS –

1st law of: Energy can neither be created nor destroyed – it can only be changed from one form to another.

2nd law of: To cause heat energy to travel, a temperature (heat intensity) difference must be created and maintained.

THERMOMETER – An instrument for measuring temperature.

THERMOSTAT – A temperature-responsive mechanism used for controlling heating systems, cooling systems, etc. (such as between the cylinder block and the radiator) usually with the object of maintaining certain temperatures without further personal attention.

THIMBLES – Separate the exhaust pipe from walls or ceiling to provide mechanical and thermal isolation.

THREE PHASE – An AC system having three voltages of the same frequency but displaced in phase by 120 degrees relative to another.

THROTTLING – Reducing the engine speed (flow of fuel).

THROW – The distance from the center of the crankshaft main bearing to the center of the connecting rod journal.

THRU-BOLT – Term usually applied to the stress rod passing through the engine frame to carry combustion stresses.

THRUST BEARING (Washer) – A bearing or washer of bronze or steel which restrains endwise motion of a turning shaft, or withstands axial loads instead of radial loads as in common bearings.

THRUST LOAD – A load which pushes or reacts through the bearing in a direction parallel to the shaft.

THYRISTOR CONTROL – A method of powering a DC motor by an AC generator.

TIF *Technical Information File*

TIME-OF-USE RATES – Electricity prices that vary depending on the time periods in which the energy is consumed. In a time-of-use structure, higher prices are charged during utility peak-load times.

TIMING (Diesel) – The angular position of the crankshaft relative to top dead center at the start of injection.

TIMING GEARS – Gears attached to the crankshaft, camshaft, idler shaft, or injection pump to provide a means to drive the camshaft and injection pump and to regulate the speed and performance.

TIMING MARKS – The marks located on the vibration damper, flywheel, and throughout an engine to check injection and valve opening timing.

TIMING (Spark Ignited) – The angular position of the crankshaft relative to top dead center at the time the spark plugs are energized.

TMI *Technical Marketing Information*

TOLERANCE – A permissible variation between the two extremes of a specification of dimensions. Used in the precision fitting of mechanical parts.

TON – 12,000 Btu/Hour.

TON OF REFRIGERATION – Refrigerating effect equal to the melting of one ton of ice in 24 hours. This may be expressed as follows: 288,000 Btu/24 hr, 12,000 Btu/1 hr, 200 Btu/min, 3.52 kW.

TOP CENTER (TC) – The position of the crankshaft at the time the piston is at its highest position.

TOP-DOWN – Must meet the most stringent law, but, based on environmental, energy, and economic considerations could step down to a less stringent law

TOPPING-CYCLE – A cogeneration facility in which the energy input to the facility is first used to produce useful power, with the heat recovered from power production then used for other purposes.

TORQUE – A measure of the tendency of a force to cause rotation, often used in engine specifications. Equal to the force multiplied by the perpendicular distance between the line of action of the force and the center of rotation.

TORQUE AT TC RPM – The steady state torque developed by an engine at the torque check speed.

TORQUE CHECK SPEED – The speed at which an engine is run to check the low speed performance characteristics.

TORQUE CURVE OR LUG CURVE – A performance map created for a diesel engine, using high idle setting and rack setting values.

TORQUE SHAPING – A way to optimize engine response through control of horsepower at a given engine speed.

TORQUE WRENCH – A special wrench with a built-in indicator to measure the applied turning force.

TORSIONAL STUDY – An analysis used to predict operating characteristics of the vibrating system of an engine, which includes pistons, rods, the crankshaft, the flywheel, coupling, the driven equipment, and associated shafting.

TORSIONAL VIBRATION – The vibration caused by twisting and untwisting a shaft.

TOTAL ENERGY SYSTEMS – The name previously used to refer to a form of cogeneration in which all electrical and thermal energy needs were met by on-site systems. A total energy system was usually completely isolated from or completely served by the electrical utility system for back-up. Generally a user was not served simultaneously by the electric utility grid and the cogenerator.

TRANSDUCER – A device for converting a variable physical parameter to a proportional electrical signal. The inputs can be temperature, pressure, position, voltage, current, or any other physical parameter. Outputs are typically 4-20 ma, 0-10 volts or some other signal easily accommodated by instruments and controlling devices.

TRANSFER PUMP – A mechanical device for moving fuel from one tank to another or bringing fuel from the tank to the injection pump.

TRANSFER SWITCH – An electrical device for switching loads between alternate power sources. An automatic transfer switch monitors the condition at the sources and signals for starting of the emergency system if the preferred source fails. When the emergency source is available the load is switched. Upon return of the normal source the load is retransferred to normal power and the start signal is removed.

TRANSFORMER – A device used to convert from one voltage level to another with very little loss of power.

TRANSMISSION – The act or process of transporting electric energy in bulk from a source or sources of supply to other principal parts of the system or to other utility systems.

TRAP – A receptacle often installed at the lowest point in generator set exhaust piping to drain moisture that could reach and damage the system's silencer.

TRG *Time Requirement Guide*

TRICHLOROTRIFLUOROETHANE – Complete name of refrigerant R-113. Group 1 refrigerant in rather common use. Chemical compounds which make up this refrigerant are chlorine, fluorine, and ethane.

TRIM – The relationship between the fore and aft draft. A ship properly balanced fore and aft is in trim, other-wise she is down by the head or down by the stern.

TRIP UNIT – A device within a low voltage circuit breaker that provides overcurrent protection.

TROOSTITE – A microconstituent of hardened and tempered steel which etches rapidly and therefore usually appears dark. It consists of a very fine aggregate of ferrite and cementite and is normally not resolved under the microscope.

TROPICALIZATION – Thoroughly insulating rotor and stator with epoxy to provide high insulating and mechanical properties under severe moisture and temperate conditions.

TROUBLESHOOTING – A process of diagnosing or locating the source of the trouble or troubles from observation and testing. Also see *Diagnosis*.

TT *Twin Turbocharged*

TTA *Twin Turbocharged-Aftercooled*

TUBE CUTTER – A tube cutting tool having a sharp disk which is rotated around the tube.

TUBING – That type of fluid line whose dimensions are designated by actual measured outside diameter.

TUBE-UP – The act of checking, testing, measuring, repairing, and adjusting the engine components in order to bring the engine to peak efficiency.

TURBINE – An engine or motor having a drive shaft driven either by steam, water, air, gas, etc., against curved vanes of a wheel or set of wheels, or by the reaction of fluid passing out through nozzles located around the wheel(s).

TURBINE GENERATOR – A device that uses steam, heated gases, water flow, or wind to cause spinning motion that activates electromagnetic forces and generates electricity.

TURBOCHARGER – A type of charger driven by a turbine powered by exhaust gases.

TURBOCHARGING – Increasing the intake air charge to a reciprocating engine by using a turbine driven by the energy of the engine's exhaust.

TURBULENCE – A disturbed, irregular motion of fluids or gases.

TURBULENCE CHAMBER – A combustion chamber connected to the cylinder through a throat. Fuel is injected across the chamber and turbulence is produced in the chamber by the air entering during compression.

TURNING AND POLISHING – Whereas cold drawing reduces the cross sectional area by subjecting the bar to compressive and elongating forces, turning and polishing accomplishes the same by turning $1/16$ to $3/16$ inches from the diameter, depending on the bar size, usually following by polishing and straightening in a combination straightening and polishing machine.

TWIST DRILL – See *Drill.*

TWO-CYCLE ENGINE – An engine design permitting a power stroke once for each revolution of the crankshaft.

TWO-STAGE COMBUSTION – Combustion occurring in two distinct steps such as in a precombustion chamber engine.

TWO-STROKE CYCLE – The cycle of events which is complete in two strokes of the piston or one crankshaft revolution.

"U" FACTOR – The amount of heat energy in Btu/h that will be absorbed by one square foot of surface for each degree of mean temperature difference through the surface material.

UNDERVOLTAGE RELAY – Operates when the monitored voltage is below the relay setpoint. It can be used to detect a failure in a power system or to indicate that a generator set is ready to be connected to a load on initial start-up.

UNIFLOW SCAVENGING – Scavenging method in which air enters one end of the cylinder and exhaust leaves the opposite end.

UNINTERRUPTED POWER SUPPLY (UPS) – A power supply which maintains regulated power during a shortage to under- or overvoltage or no voltage.

UNIT INJECTOR – A combined fuel injection pump and fuel nozzle.

UPDRAFT – A carburetor type in which the mixture flows upward to the engine.

UPS *Uninterrupted Power System*

U.S. GALLON [GAL (U.S.)] – United States gallon (231 in^3).

UTILITY – A commercial power source that supplies electrical power to specific facilities from a large power grid.

UTILITY GRADE RELAY – Refers to a draw-out relay.

UTILIZATION FACTOR – The ratio of the maximum demand of a system (or part of a system) to its rated capacity.

VACUUM – A perfect vacuum has not been created as this would involve an absolute lack of pressure. The term is ordinarily used to describe a partial vacuum; that is, a pressure less than atmospheric pressure – in other words a suction.

VACUUM FLUORESCENT (VF) – A type of visual display, often used on system control/ monitoring panels, which provides excellent visibility in a variety of lighting conditions.

VACUUM GAUGE – A gauge used to measure the amount of vacuum existing in a chamber or line.

VACUUM PUMP – Special high efficiency compressor used for creating high vacuums for testing or drying purposes.

VALVE – Any device or arrangement used to open or close an opening to permit or restrict the flow of a liquid, gas, or vapor.

VALVE CLEARANCE – The air gap allowed between the end of the valve stem and the valve lifter or rocker arm to compensate for expansion due to heat.

VALVE DURATION – The time (measured in degrees of engine crankshaft rotation) that a valve remains open.

VALVE EXPANSION – Type of refrigerant control which maintains pressure difference between high side and low side pressure in a refrigerating mechanism. Valve is caused to operate by pressure in low or suction side. Often referred to as an Automatic Expansion Valve or AEV.

VALVE FACE – That part of a valve which mates with and rests upon a seating surface.

VALVE FLOAT – A condition where the valves are forced open because of valve-spring vibration or vibration speed.

VALVE GRINDING – Also called valve lapping. A process of lapping or mating the valve seat and valve face usually performed with the aid of an abrasive.

VALVE GUIDE – A hollow-sized shaft pressed into the cylinder head to keep the valve in proper alignment.

VALVE HEAD – The portion of the valve upon which the valve face is machined.

VALVE KEEPER (valve retainer) – A device designed to lock the valve spring retainer to the valve stem.

VALVE LASH – Clearance set into the valve mechanism to assure that when hot, the valve will not be held open.

VALVE LIFT – The distance a valve moves from the fully closed to the fully open position.

VALVE LIFTER – A push rod or plunger placed between the cam and the valve on an engine. It is often adjustable to vary the length of the unit. (Also see *Cam Follower.*)

VALVE MARGIN – The distance between the edge of the valve and the edge of the face.

VALVE OIL SEAL – A sealing device to prevent excess oil from entering the area between the stem and the valve guide.

VALVE OVERLAP – The period of crankshaft rotation during which both the intake and exhaust valves are open. It is measured in degrees.

VALVE ROTATOR – A mechanical device locked to the end of the valve stem which forces the valve to rotate about 5° with each rocker-arm action.

VALVE SEAT – The surface on which the valve face rests when closed.

VALVE SEAT INSERT – A hardened steel ring inserted in the cylinder head to increase the wear resistance of the valve seat.

VALVE SPRING – A spring attached to a valve to return it to the seat after it has been released from the lifting or opening means.

VALVE STEM – That portion of a valve which rests within a guide.

VALVE STEM GUIDE – A bushing or hole in which the valve stem is placed which allows lateral motion only.

VALVE, SUCTION – Valve in refrigeration compressor which allows vaporized refrigerant to enter cylinder from suction line and prevents its return.

VALVE TIMING – The positioning of the camshaft (gear) to the crankshaft (gear) to ensure proper valve opening and closing.

VALVE-IN-HEAD ENGINE – Same as Overhead Valve Engine.

VALVE-SEAT INSERT – A hardened steel ring inserted in the cylinder head to increase the wear resistance of the valve seat.

VANES – Any plate, blade, or the like attached to an axis and moved by or in air or a liquid.

VAPOR – Word usually used to denote vaporized refrigerant rather than the word gas.

VAPOR LOCK – A condition wherein the fuel boils in the fuel system, forming bubbles which retard or stop the flow of fuel to the carburetor.

VAPORIZATION – The process of converting a liquid into vapor.

VAPORIZER – A device for transforming or helping to transform a liquid into vapor; often includes the application of heat.

VDC *DC to DC Voltage Converter (75 to 24 Vdc)*

VEE – A type of cylinder arrangement in an engine where the cylinders form the shape of the letter "V".

VENTURI – A specially shaped tube with a small or constricted area used to increase velocity and reduce pressure.

VI *Viscosity Index*

VIBRATION DAMPER – A device to reduce the torsional or twisting vibration which occurs along the length of the crankshaft used in multicylinder engines; also known as a harmonic balancer.

VISCOSITY – The property of an oil by virtue of which it offers resistance to flow.

VISCOSITY INDEX (VI) – Oil decreases in viscosity as temperature changes. The measure of this rate of change of viscosity with temperature is called the viscosity *index* of the oil.

VOLATILE – Evaporating readily at average temperature on exposure with air.

VOLATILITY – The tendency for a fluid to evaporate rapidly or pass off in the form of vapor. For example, gasoline is more volatile than kerosene as it evaporates at a lower temperature.

VOLT (V) – A unit of electromotive force that will move a current of one ampere through a resistance of 1 ft.

VOLTAGE – Electric potential or potential difference expressed in volts.

VOLTAGE ADJUST POTENTIOMETER – Controls generator voltage output through the generator voltage regulator.

VOLTAGE DIP – The momentary drop of generator output voltage that occurs whenever a load is added to the system. There is momentary increase in output voltage whenever a load is removed from the system. This is called "Voltage Rise". "Voltage Rise" is seldom of concern with an adequate voltage regulator.

VOLTAGE DROOP – Gradual fall of voltage with increase in electrical load.

VOLTAGE DROP – Voltage loss due to added resistance caused by undersized wire, poor connection, etc.

VOLTAGE FLICKER – Term commonly used to describe a significant fluctuation of voltage.

VOLTAGE REGULATOR – A circuit which senses the generator output voltage and automatically adjusts the field coil current to maintain the desired output.

VOLTMETER – A test instrument for measuring the voltage or voltage drop in an electric circuit.

VOLTS-PER-HERTZ REGULATION – Providing fast recovery under block loading conditions, maintaining close voltage control over the normal load range, and producing rapid response of an engine/generator set by matching generator output to engine performance.

VOLUME – The amount space within a given confined area.

VOLUMETRIC EFFICIENCY – The difference between the volume of air drawn in on the intake stroke and the air mechanically entering the cylinder.

VOP *Valve Opening Pressure*

VORTEX – A whirling movement of a mass of liquid or air.

VR3 – This new regulator replaces both VR1 and VR2 conversion of existing product line complete through 580 frame. VR3 meets all Cat premium custom specs.

VR4 – This new generator is used for alternate energy applications. Premium custom specs do not apply.

WATER BRAKE – A device for engine testing in which the power is dissipated by churning water.

WATER JACKET – The enclosure directing the flow of cooling water around the parts to be cooled.

WATER LOOP – The test cell water piping is plumbed to allow flow and temperature control to the evaporator, measured in tons.

WATER-COOLED CONDENSER – Condensing unit which is cooled through use of water.

WATERLINE – The line where the hull meets the sur-face of the water.

WATER-STEAM CIRCUIT – Piping to direct the flow of steam.

WATER VAPOR PRESSURE – The partial pressure of the water vapor in the combustion air being supplied to an engine.

WATT – The unit of measure for electrical power.

WATT-HOUR DEMAND METER – Similar to a watt-hour meter except that it also provides an indication of the highest kW load level achieved during operation.

WATT-HOUR METER – A recording device that totals the average power (kW) passing through it in a period of time. The reading is kilowatt hours – a measure of the total energy consumed by the load.

WATTMETER – Simultaneously measures voltage current and power factor, and automatically multiplies the results to measure true power.

WAVEFORM – The graphic representation of a voltage plotted against time.

WEAR TESTING – Wear is due to several unrelated actions such as cutting, abrasion, corrosion, galling, and fatigue. In wear testing, first the type of wear developed in service is determined, then suitable laboratory equipment is developed for the test, duplicating service conditions.

WEATHER PROTECTIVE (WP) – A type of enclosure often used for generator sets to prevent damage from natural elements.

WET BULB – Device used in the measurement of relative humidity. Evaporation of moisture lowers temperature of wet bulb compared to dry bulb temperature in the same area.

WET SLEEVE – A cylinder sleeve which is about 70 percent exposed to the coolant.

WHEEL – Another name for the “screw” or “propeller”.

WHEEL HOUSE – The area of the ship which has the controls for the rudders. This control can be a “ship’s wheel” or a “tiller”. This may or may not be the same area as the “Bridge”.

WHEELING – The use of the transmission facilities of one system to transmit power for another system.

WHITE SMOKE – The emission caused by vaporized but unburned fuel passing through an engine; usually occurs during startup of a cold engine.

WITHSTAND RATING – The maximum current of an automatic transfer switch on a generator set a fault condition when the switch is closed and on normal service. The ATS is required to withstand the energy let through the normal service protective device while that device interrupts the fault.

WRIST PIN – The journal for the bearing in the small end of an engine connecting rod which also passes through piston walls. Also known as a piston pin.

WYE CONNECTION – A means of connecting generator windings with the option of using the neutral connection.

Y2 *Year 2000*

YIELD POINT – The load per unit of original cross section at which, in soft steel, a marked increase in deformation occurs without increase in load. In other steels and in nonferrous metals, yield point is the stress corresponding to some definite and arbitrary total deformation, permanent deformation or slope of the stress deformation; this is more properly termed the yield strength. See *Yield Strength*.

YIELD STRENGTH – Stress corresponding to some fixed permanent deformation such as 1% or 2% offset from the modulus slope. Not to be confused with yield point which, for steel, may occur over a wide range of elongation. It is the result of an effort to obtain the equivalent of the yield point by a standard means that provide reliable, easily reproducible determination. In general, the determination may be made by the offset method or by the use of the extensometer or other appropriate measuring device.

YOKE – A link which connects two points.

ZENER DIODE – A diode that allows current to flow in reverse bias at the designed voltage.

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