Marine Analyst Service Handbook

Caterpillar
Service Training

January 2004 - 6th Edition

January 2004
LEBV4830-05

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.

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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.

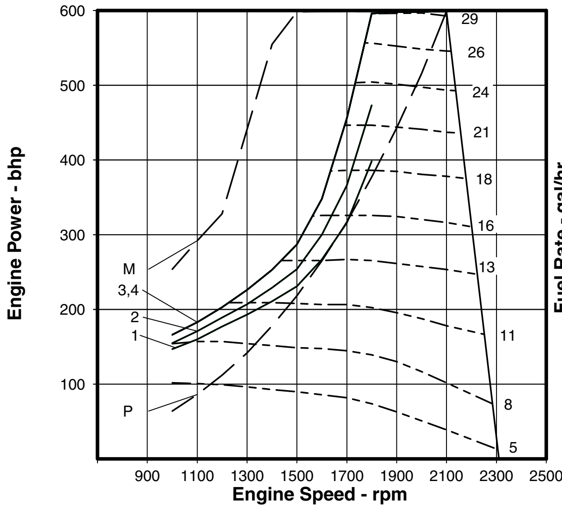
Useful output as described under DIN 6270 is defined as the output available to drive the load after suitable deductions are made for engine driven accessories. This is equivalent to the net rating. Caterpillar ratings indicate gross output. At the kW requirement to drive such accessories as charging 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

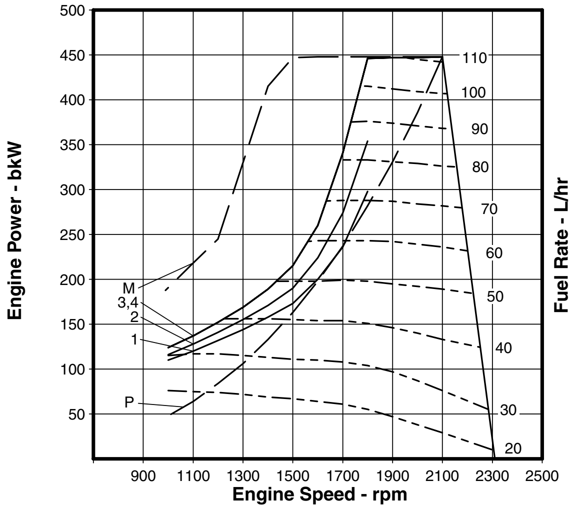
Engine Speed rpm	Engine Power bhp	Fuel Cons lb/ hp-hr	Fuel Rate gal/ hr	Boost Press in. Hg- Gauge	Air Flow cfm	Exh Temp F	Exh Flow cfm
2100	599	0.342	29.4	59.6	1446	648	3121
1900	599	0.339	29.0	56.2	1262	708	2909
1700	599	0.334	28.6	53.9	1124	799	2743
1500	598	0.336	28.7	48.2	930	966	2594
1300	441	0.352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

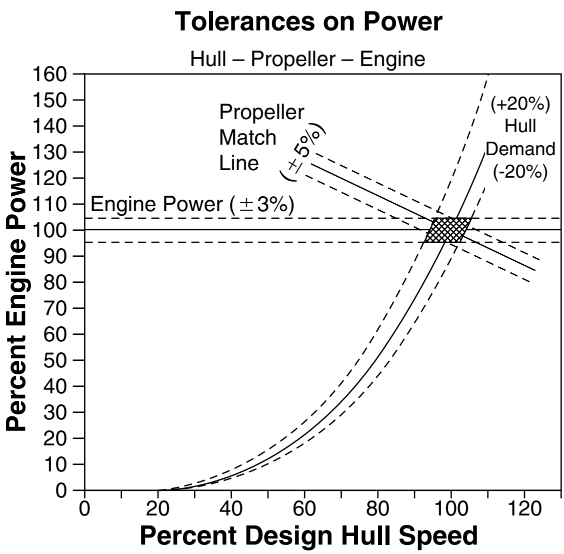


FIGURE 1.1

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.