

8 MECHANICAL

SPEED AND HORSEPOWER

INTRODUCTION

Although it is beyond the scope of this book to accurately estimate power needed to drive a boat at specific speeds, I will provide some simple rules of thumb and tables to get a reasonable approximation of power requirements. This should enable one to estimate what to expect from a boat being considered for purchase. Is it underpowered? Does it go as fast as it should given the installed engine size? If I repower with a bigger engine, what should I expect?

For a more comprehensive treatment of this subject, obtain the *Propeller Handbook* by Dave Gerr, which provides information on boat horsepower requirements along with substantial detail on propeller types, sizing, and selection (Dave Gerr, *Propeller Handbook*. Camden: International Marine, 2001)

As discussed in the chapter on boat design, a boat can operate at displacement, semi-displacement, and planing speeds. In each of these regimes the methods for determining power requirements are different. For example, at slow displacement speeds, friction on the wetted surface area will be the major form of resistance, whereas at higher displacement speeds, wave motion becomes the dominant force. At planing speeds, the boat is subject to a different form of resistance and air resistance also starts to become more significant. To keep things simple, in this book we only consider formulas for estimating horsepower at displacement speeds and at planing speeds.

HORSEPOWER AT DISPLACEMENT SPEEDS

The chapter at the beginning of this book entitled *Boat Types, Design, and Construction*, describes the speed to length ratio (SLR) on page 21 and the displacement to length ratio (DLR) on page 34. As mentioned in that section, at SLRs of up to around 1.34, the boat is considered to be in displacement mode, although this is not an absolute number.

In the *Propeller Handbook*, Gerr provides an equation relating the SLR to displacement and shaft horsepower for boats traveling at displacement speeds, which is restated here on the next page as equation 8-1.

$$SLR = \frac{10.665}{\left(\frac{D(\text{lbs})}{\text{SHP}(\text{hp})}\right)^{1/3}} = \frac{9.036}{\left(\frac{D(\text{kg})}{\text{SHP}(\text{kW})}\right)^{1/3}}$$

Where: SLR = Speed to length ratio
 D = Displacement
 SHP = Shaft horsepower

EQUATION 8-1: SLR Versus Displacement and Shaft Horsepower. See horsepower definitions on page 450 for explanation of shaft horsepower (Equation Courtesy Dave Gerr)

Table 8-1 evaluates equation 8-1 for typical SLR values.

SLR	lb/SHP	kg/kW	SLR	lb/SHP	kg/kW
0.90	1660	1010	1.30	550	340
0.95	1410	860	1.35	490	300
1.00	1210	740	1.40	440	270
1.05	1050	640	1.45	400	240
1.10	910	550	1.50	360	220
1.15	800	490	1.55	330	200
1.20	700	430	1.60	300	180
1.25	620	380	1.65	270	160

TABLE 8-1: Speed to Length Ratio Versus Displacement to Horsepower

Inspection of table 8-1 shows that to travel at SLR=1.35 (hull speed) a boat will need approximately 1 shaft horsepower for every 490 pounds of displacement (1 kilowatt for every 300 kilograms of displacement). Here's a rule of thumb:

A typical boat will require about 1 shaft horsepower per 500 pounds of displacement to drive it at hull speed. This works out to a little over 4 horsepower per displacement ton.

Take this for what it is—a gross estimate of horsepower requirement. For example, the displacement to length ratio (DLR) described in chapter 1 is also related to achievable SLRs at displacement speeds. Everything else being equal, a lower DLR will allow a higher speed than a higher DLR. In particular, the so-called hull speed will be higher for the lower DLR, which describes a longer more slender hull. Equation 8-1 provides estimates for boats with DLRs of around 300 to 350.

A boat with a DLR of just 150 could have a maximum SLR as high as 1.6, which shows that long thin boats can go faster than short fat ones (at displacement speeds).

Also keep in mind this is for calm seas. You will need additional power to drive into wind and waves.

If the speed to length equation 1-1 from chapter 1 page 21 is substituted into equation 8-1 then solved for shaft horsepower, we get equation 8-2.

$$\text{SHP}(\text{hp}) = \frac{D(\text{lb}) \times S(\text{kn})^3}{1213 \times \text{LWL}(\text{ft})^{3/2}}$$

$$\frac{D(\text{kg}) \times S(\text{kn})^3}{4385 \times \text{LWL}(\text{m})^{3/2}}$$

Where: SHP = Shaft horsepower

D = Displacement

S = Speed in knots

LWL = Length at waterline

EQUATION 8-2: Horsepower at Displacement Speeds From Displacement, Speed, and Length

With equation 8-2 and a scientific calculator you can solve for approximate shaft horsepower required for any displacement boat.

Table 8-2 on the next two pages evaluates equation 8-2 for various sample boat sizes and speeds. Note: The table does not take into account the effect of varying DLRs as described previously as it is only meant to give an approximate idea of power needed for various sizes of boats.

HORSEPOWER AT PLANING SPEEDS

At speeds higher than SLR 2.0, the boat can be considered to be planing. Approximate horsepower required at planing speeds can be calculated using the Crouch formula shown in equation 8-3 on page 448.

The value of C in the formula will be around 150 for an average planing boat. A high performance, lighter hull with little superstructure may have a C value of 200. A longer hull for a given displacement will tend to have a higher C value also.

Some observations:

1. The horsepower at planing speeds increases as the square of the speed whereas the horsepower at displacement speeds increases as the cube of the speed.
2. Length is not a variable in the Crouch formula like it is in the formula for displacement speeds. It follows that

LWL		Disp		Speed		Horsepower			
				S/L 1.0	S/L 1.34	S/L 1.0		S/L 1.34	
(ft)	(M)	(lb)	(Kg)	(kn)	(kn)	(hp)	(kW)	(hp)	(kW)
15	4.6	760	340	3.9	5.2	0.6	0.5	1.5	1.1
15	4.6	1130	510	3.9	5.2	0.9	0.7	2.2	1.7
15	4.6	1510	680	3.9	5.2	1.2	0.9	3.0	2.2
15	4.6	1890	860	3.9	5.2	1.6	1.2	3.7	2.8
15	4.6	2270	1030	3.9	5.2	1.9	1.4	4.5	3.4
15	4.6	2650	1200	3.9	5.2	2.2	1.6	5.3	3.9
15	4.6	3020	1370	3.9	5.2	2.5	1.9	6.0	4.5
15	4.6	3400	1540	3.9	5.2	2.8	2.1	6.7	5.0
15	4.6	3780	1710	3.9	5.2	3.1	2.3	7.5	5.6
18	5.5	1300	590	4.2	5.7	1.1	0.8	2.6	1.9
18	5.5	2000	910	4.2	5.7	1.6	1.2	4.0	3.0
18	5.5	2600	1180	4.2	5.7	2.1	1.6	5.2	3.8
18	5.5	3300	1500	4.2	5.7	2.7	2.0	6.5	4.9
18	5.5	3900	1770	4.2	5.7	3.2	2.4	7.7	5.8
18	5.5	4600	2090	4.2	5.7	3.8	2.8	9.1	6.8
18	5.5	5200	2360	4.2	5.7	4.3	3.2	10	7.7
18	5.5	5900	2680	4.2	5.7	4.9	3.6	12	8.7
18	5.5	6500	2950	4.2	5.7	5.4	4.0	13	9.6
22	6.7	2400	1100	4.7	6.3	2.0	1.5	4.8	3.6
22	6.7	3600	1600	4.7	6.3	3.0	2.2	7.1	5.2
22	6.7	4800	2200	4.7	6.3	4.0	3.0	9.5	7.2
22	6.7	6000	2700	4.7	6.3	4.9	3.7	12	8.8
22	6.7	7200	3300	4.7	6.3	5.9	4.5	14	11
22	6.7	8300	3800	4.7	6.3	6.8	5.1	16	12
22	6.7	9500	4300	4.7	6.3	7.8	5.8	19	14
22	6.7	10700	4900	4.7	6.3	8.8	6.6	21	16
22	6.7	11900	5400	4.7	6.3	9.8	7.3	24	18
26	7.9	3900	1800	5.1	6.8	3.2	2.4	7.7	5.9
26	7.9	5900	2700	5.1	6.8	4.9	3.7	12	8.8
26	7.9	7900	3600	5.1	6.8	6.5	4.9	16	12
26	7.9	9800	4400	5.1	6.8	8.1	6.0	19	14
26	7.9	11800	5400	5.1	6.8	9.7	7.3	23	18
26	7.9	13800	6300	5.1	6.8	11	8.5	27	21
26	7.9	15700	7100	5.1	6.8	13	9.6	31	23
26	7.9	17700	8000	5.1	6.8	15	11	35	26
26	7.9	19700	8900	5.1	6.8	16	12	39	29
32	9.8	7000	3200	5.7	7.6	5.8	4.3	14	10
32	9.8	11000	5000	5.7	7.6	9.1	6.8	22	16
32	9.8	15000	6800	5.7	7.6	12	9.2	30	22
32	9.8	18000	8200	5.7	7.6	15	11	36	27
32	9.8	22000	10000	5.7	7.6	18	14	44	33
32	9.8	26000	11800	5.7	7.6	21	16	52	38
32	9.8	29000	13200	5.7	7.6	24	18	58	43
32	9.8	33000	15000	5.7	7.6	27	20	65	49
32	9.8	37000	16800	5.7	7.6	31	23	73	55

TABLE 8-2(1): Horsepower at Displacement Speeds From Displacement and Speed to Length

LWL		Disp		Speed		Horsepower			
				S/L 1.0	S/L 1.34	S/L 1.0		S/L 1.34	
(ft)	(M)	(lb)	(Kg)	(kn)	(kn)	(hp)	(kW)	(hp)	(kW)
36	11.0	10000	4500	6.0	8.0	8.2	6.1	20	15
36	11.0	16000	7300	6.0	8.0	13	9.9	32	24
36	11.0	21000	9500	6.0	8.0	17	13	42	31
36	11.0	26000	11800	6.0	8.0	21	16	52	38
36	11.0	31000	14100	6.0	8.0	26	19	61	46
36	11.0	37000	16800	6.0	8.0	31	23	73	55
36	11.0	42000	19100	6.0	8.0	35	26	83	62
36	11.0	47000	21300	6.0	8.0	39	29	93	69
36	11.0	52000	23600	6.0	8.0	43	32	103	77
45	13.7	20000	9000	6.7	9.0	16	12	40	29
45	13.7	31000	14000	6.7	9.0	26	19	61	46
45	13.7	41000	19000	6.7	9.0	34	26	81	62
45	13.7	51000	23000	6.7	9.0	42	31	101	75
45	13.7	61000	28000	6.7	9.0	50	38	121	91
45	13.7	71000	32000	6.7	9.0	59	43	141	104
45	13.7	82000	37000	6.7	9.0	68	50	163	121
45	13.7	92000	42000	6.7	9.0	76	57	182	137
45	13.7	102000	46000	6.7	9.0	84	62	202	150
54	16.5	35000	16000	7.3	9.8	29	22	69	52
54	16.5	53000	24000	7.3	9.8	44	33	105	78
54	16.5	71000	32000	7.3	9.8	59	43	141	104
54	16.5	88000	40000	7.3	9.8	73	54	175	130
54	16.5	106000	48000	7.3	9.8	87	65	210	157
54	16.5	123000	56000	7.3	9.8	101	76	244	183
54	16.5	141000	64000	7.3	9.8	116	87	280	209
54	16.5	159000	72000	7.3	9.8	131	98	315	235
54	16.5	176000	80000	7.3	9.8	145	108	349	261
64	19.5	59000	27000	8.0	10.7	49	37	117	88
64	19.5	88000	40000	8.0	10.7	73	54	175	130
64	19.5	117000	53000	8.0	10.7	96	72	232	173
64	19.5	147000	67000	8.0	10.7	121	91	292	218
64	19.5	176000	80000	8.0	10.7	145	108	349	261
64	19.5	206000	93000	8.0	10.7	170	126	409	303
64	19.5	235000	107000	8.0	10.7	194	145	466	349
64	19.5	264000	120000	8.0	10.7	218	163	524	391
64	19.5	294000	133000	8.0	10.7	242	180	583	434
78	23.8	106000	48000	8.8	11.8	87	65	210	157
78	23.8	159000	72000	8.8	11.8	131	98	315	235
78	23.8	213000	97000	8.8	11.8	176	131	423	316
78	23.8	266000	121000	8.8	11.8	219	164	528	395
78	23.8	319000	145000	8.8	11.8	263	197	633	473
78	23.8	372000	169000	8.8	11.8	307	229	738	551
78	23.8	425000	193000	8.8	11.8	350	262	843	629
78	23.8	478000	217000	8.8	11.8	394	294	948	708
78	23.8	531000	241000	8.8	11.8	438	327	1053	786

TABLE 8-2(2): Horsepower at Displacement Speeds From Displacement and Speed to Length

$$\text{SHP}(\text{hp}) = \frac{D(\text{lb}) \times S(\text{kn})^2}{C^2}$$

$$\text{SHP}(\text{kW}) = \frac{D(\text{kg}) \times S(\text{kn})^2}{C^2 \times 0.60827}$$

Where: SHP = Shaft horsepower

D = Displacement

S = Speed in knots

C = Coefficient from 150 to 200

EQUATION 8-3: Horsepower at Planing Speeds From Displacement and Speed

displacement to length ratio is a greater factor at displacement speeds than at planing speeds.

3. Horsepower requirements go up dramatically if you wish to drive a boat at planing speeds. Consider a 40-foot boat weighing 26,000 pounds (11800 kg). The approximate horsepower required to drive it is shown in table 8-3.

Speed (kn)	SLR	Horsepower	
		(hp)	(kW)
6	1.00	21	16
8	1.34	52	38
13	2.00	185	138
19	3.00	416	310
25	4.00	740	551
38	6.00	1664	1241
51	8.00	2958	2206

FIGURE 8-3: 40-Foot 26,000-Pound Boat at Various Speeds

Table 8-4 on the next page uses the formula to calculate horsepower at some representative speeds and displacements and for C values of 150 and 200.

ENGINES

INTRODUCTION

In this section, two- and four-stroke gasoline and diesel engines are discussed and compared with the intent of helping to match engines with boating applications. Additionally, the information is meant to assist normal preventative maintenance procedures and to help debug engine problems. Having a basic understanding of how the engine operates will help in reasoning through starting and running problems.

Displacement				Horsepower							
C=150	C=150	C=200	C=200	20 knots		30 knots		40 knots		50 knots	
(lb)	(Kg)	(lb)	(Kg)	(hp)	(kW)	(hp)	(kW)	(hp)	(kW)	(hp)	(kW)
1000	450	1800	800	18	13	40	30	71	50	110	80
1100	500	2000	890	20	15	44	30	78	60	120	90
1300	590	2300	1050	23	17	52	40	92	70	140	110
1400	640	2500	1140	25	19	56	40	100	70	160	120
1600	730	2800	1300	28	21	64	50	110	90	180	130
1800	820	3200	1460	32	24	72	50	130	100	200	150
2000	910	3600	1620	36	27	80	60	140	110	220	170
2200	1000	3900	1780	39	29	88	70	160	120	240	180
2500	1130	4400	2010	44	33	100	70	180	130	280	210
2800	1270	5000	2260	50	37	110	80	200	150	310	230
3100	1410	5500	2510	55	41	120	90	220	160	340	260
3500	1590	6200	2830	62	46	140	100	250	190	390	290
3900	1770	6900	3150	69	52	160	120	280	210	430	320
4400	2000	7800	3560	78	58	180	130	310	230	490	370
4900	2220	8700	3950	87	65	200	150	350	260	540	410
5500	2490	9800	4430	98	73	220	160	390	290	610	450
6200	2810	11000	5000	110	82	250	180	440	330	690	510
6900	3130	12000	5560	120	91	280	210	490	370	770	570
7800	3540	14000	6080	140	100	310	230	550	410	870	650
8700	3950	15000	7300	150	120	350	260	620	460	970	720
9800	4450	17000	7910	170	130	390	290	700	520	1100	810
11000	4990	20000	9120	200	150	440	330	780	580	1200	910
12000	5440	21000	9730	210	160	480	360	850	640	1300	990
14000	6350	25000	11600	250	190	560	420	1000	740	1600	1160
15000	6800	27000	12200	270	200	600	450	1100	790	1700	1240
17000	7710	30000	14000	300	230	680	510	1200	900	1900	1410
19000	8620	34000	15200	340	250	760	570	1400	1010	2100	1570
22000	9980	39000	17600	390	290	880	660	1600	1170	2400	1820
24000	10900	43000	19500	430	320	960	720	1700	1270	2700	1990
27000	12200	48000	21900	480	360	1100	800	1900	1430	3000	2230
30000	13600	53000	24300	530	400	1200	890	2100	1590	3300	2480
34000	15400	60000	27400	600	450	1400	1010	2400	1800	3800	2810
38000	17200	68000	30400	680	500	1500	1130	2700	2010	4200	3140
43000	19500	76000	34700	760	570	1700	1280	3100	2280	4800	3560
48000	21800	85000	38900	850	640	1900	1430	3400	2550	5300	3980
54000	24500	96000	43800	960	720	2200	1610	3800	2860	6000	4480
60000	27200	110000	48100	1100	790	2400	1790	4300	3180	6700	4970
68000	30800	120000	54700	1200	900	2700	2030	4800	3600	7600	5630
76000	34500	140000	61400	1400	1010	3000	2270	5400	4030	8400	6300
85000	38600	150000	68700	1500	1130	3400	2540	6000	4510	9400	7050
95000	43100	170000	76600	1700	1260	3800	2830	6800	5040	10600	7870
110000	49900	200000	88800	2000	1460	4400	3280	7800	5830	12200	9120
120000	54400	210000	96700	2100	1590	4800	3580	8500	6360	13300	9940
130000	59000	230000	104600	2300	1720	5200	3880	9200	6900	14400	10780
150000	68000	270000	121000	2700	1990	6000	4470	10700	7950	16700	12420

TABLE 8-4: Horsepower Required at Planing Speeds for Various Displacements and Speeds

Understanding how the engine works can also be very helpful when talking to an engine technician about problems with your boat.

Both gas and diesel are *internal combustion* engines that burn an air-fuel mixture inside the engine cylinders to provide motive power.

HORSEPOWER DEFINITIONS

There are several measures of horsepower, and it is important to understand the differences.

Horsepower is usually measured at the engine flywheel as *brake horsepower (BHP)* or at the propeller as *shaft horsepower (SHP)*. BHP is measured on an engine without any peripherals such as alternators. BHP is what is normally specified by the engine manufacturer. SHP will usually be about 96 to 97 percent of BHP.

Horsepower *ratings* are defined for different types of boat operation and different manufacturers often use different sets of ratings. Most use three ratings, while others use as many as five different ratings. Here we define the most common ratings.

Continuous duty horsepower refers to the power that can be maintained indefinitely without overheating or straining the engine and is usually at around 80 percent of maximum RPM. If available this is the power rating you should use when comparing boats. For a given engine, this rating specifies the lowest horsepower.

Medium duty rating where maximum RPM and horsepower are used less than 50 percent of the time.

High output where the engine is run at maximum less than one hour per eight hours of operation (10 to 15 percent of operating hours). This rating specifies the highest horsepower for a given engine.

For example, a specific engine might have ratings of:

- Continuous duty: 103 horsepower (77 kW)
- Medium duty: 115 horsepower (86 kW)
- High output: 126 horsepower (94 kW)

GASOLINE ENGINES

Gasoline powered engines are considered *spark ignition* internal combustion engines since they use an electrical spark (spark plug) to ignite a air-fuel mixture.

Inboard and Stern Drive Gasoline Engines

Inboard and stern drive (inboard/outboard) gasoline engines are typically an automobile engine block that has been adapted for marine use (*marinized*). Marinization includes modifying such items as pistons, valves, carburetor, fuel injection, spark protection, cooling systems, etc., for the marine environment. Because these engines are based on car engines, they only come in the same general horsepower range as car engines, ranging from about 80 to 400 horsepower, which limits their use to certain sizes and types of boats (more on this later). The only practical way to significantly increase gasoline engine power beyond this is to install two engines.

For purposes of comparison, commonly available marinized auto engine sizes are shown in table 8-5. Note: These numbers vary from one manufacturer to another and some of the entries in this table are averages of two or more engines.

Power			No. Cyls	Displ.		Wt		Ratios			
hp	kW	RPM		CID	L	Lbs	Kg	hp /cui	hp /lb	kW /L	kW /kg
135	101	4600	4	181	3.0	600	183	0.75	0.23	34	0.55
190	142	4600	6	262	4.3	800	244	0.73	0.24	33	0.58
220	164	4800	8	305	5.0	900	274	0.72	0.24	33	0.60
280	209	4400	8	350	5.7	900	274	0.80	0.31	37	0.76
320	239	4800	8	377	6.2	948	289	0.85	0.34	39	0.83
375	280	4400	8	496	8.1	1120	341	0.76	0.33	35	0.82

TABLE 8-5: Displacement and Power of Gasoline Inboard Engines

Note: *Displacement* refers to engine displacement and is defined later in this chapter.

Mercury MerCruiser, *Volvo Penta*, and *Crusader* are the primary makes of inboard and sterndrive gasoline engines available for sale in North America.

Outboard Engines

Outboard engines are designed specifically for marine use and range from very small (2 hp/1.5kW) to medium sized (250 hp/190 kW). These come in both two- and four-stroke (cycle) versions. Table 8-6 shows some representative outboard engine specifications.

Note: The weights can't be directly compared to the weights for inboard and diesel engines since outboards include the entire unit including propellers. Even so the power to dis-

placement ratios and the power to weight ratios are generally higher for the outboard engines. Also the power ratings are at the propeller shaft and not at the engine.

In table 8-6, observe how the two-stroke outboards have higher power to displacement and power to weight ratios than the four-stroke outboards.

Propshaft			No Cyls	Strokes	Fuel Del.	Displ.		Wt		Ratios			
HP	kW	RPM				CID	L	Lbs	kg	hp /cui	hp /lb	kW /L	kW /kg
2	1	5500	1	4	C	3.4	0.1	27	8	0.59	0.07	26	0.18
4	3	4500	1	4	C	8.4	0.1	55	17	0.48	0.07	22	0.18
8	6	5000	2	2	C	10	0.2	58	18	0.80	0.14	36	0.34
8	6	5000	2	4	C	14	0.2	98	30	0.59	0.08	27	0.20
15	11	5500	2	2	C	16	0.3	74	23	0.96	0.20	44	0.50
15	11	5000	2	4	C	21	0.4	101	31	0.70	0.15	32	0.36
30	22	5000	2	2	C	32	0.5	117	36	0.94	0.26	43	0.63
30	22	5800	3	4	C	36	0.6	212	65	0.82	0.14	37	0.35
50	37	5000	2	2	C	45	0.7	195	59	1.11	0.26	51	0.63
50	37	6200	3	4	I	50	0.8	240	73	1.01	0.21	46	0.51
115	86	5500	4	2	I	105	1.7	369	112	1.09	0.31	50	0.76
115	86	5500	4	4	I	137	2.3	496	151	0.84	0.23	38	0.57
150	112	5000	6	2	I	158	2.6	419	128	0.95	0.36	43	0.88
150	112	5500	4	4	I	144	2.4	478	146	1.04	0.31	48	0.77
225	168	5750	6	2	I	200	3.3	524	160	1.13	0.43	51	1.05
225	168	5500	6	4	I	212	3.5	588	179	1.06	0.38	48	0.94
250	186	5750	6	2	I	200	3.3	524	160	1.25	0.48	57	1.17

Fuel Del.: I=Injection, C=Carburetor

TABLE 8-6: Typical Outboard Engines Horsepower and Displacement

As with inboard engines, the only practical way to get more power from outboards is to install two (or even three) engines.

In North America, *Evinrude*, *Honda*, *Johnson*, *Mercury*, *Nissan*, *Suzuki*, *Tohatsu*, and *Yamaha* engines are the primary makes of outboard engines. Both Evinrude and Johnson are owned by Bombardier Corporation. Mercury is owned by Brunswick Corporation.

Specialized engines for jet drives also come in both two- and four-stroke versions. Two-stroke engines have been used in personal watercraft (PWC) applications but are increasingly being supplanted by four-stroke engines to reduce both noise and exhaust pollution.

Safety

Gasoline fumes are heavier than air and will concentrate in spaces that are enclosed on the bottom and sides (which, by the way, is a good description of a boat's bilge and engine room). This isn't an issue with automobiles since the engine compartment is open on the bottom and any fumes simply descend downward and then dissipate. Since gasoline fumes are explosive in certain concentrations, this presents a potentially dangerous situation for the boater.

Ignition systems and any other electrical gear for marine use that creates, or has the potential to create, sparks, must be enclosed to prevent sparks and gasoline fumes from coming into contact with one another. In addition, spark arrestors are required by law to be installed on engine air intakes of gasoline powered inboard and stern drive engines. U.S. and Canadian regulations also require both natural ventilation and exhaust blowers for enclosed engine and fuel tank compartments.

Although gasoline engines are regarded as unsafe by many boaters, they are quite safe if proper precautions are taken when refueling and starting the engines. When refueling, all openings into the boat are kept closed so gasoline fumes cannot flow into and down to the bilge and engine compartments. Portable fuel tanks are always removed from the boat and refilled on the dock.

Once refueling is complete and before any engine startup, the engine room exhaust fans are run for at least two minutes, preferably more like five minutes. Before starting up, sniff for fumes in the engine room or compartment. Gasoline fume detectors are available for less than \$200 and give extra protection and piece of mind.

Four-Cycle Gas Engine

The four-cycle (or four-stroke) gasoline engine is used in automobiles and also in boats with inboard and stern drive power trains. Note that the terms cycle and stroke are pretty much synonymous in that a cycle is essentially one up stroke or one downstroke of the piston. In a four-cycle engine the power stroke is one stroke of every four strokes.

The two figures on the next page show a four-stroke gasoline engine working through its four cycles.

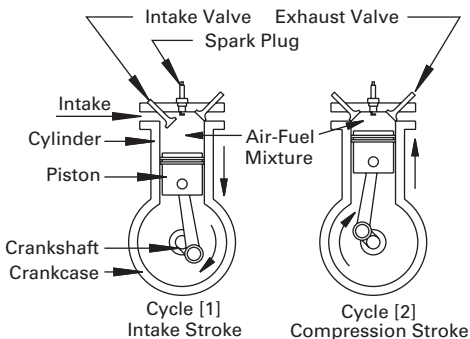


FIGURE 8-1: Four-Cycle Intake and Compression Cycles.

The four-stroke cycle begins with the intake stroke (1). The piston moves down from *top dead center* (TDC) with the intake valve open. As the piston moves downward, the air-fuel mixture is drawn into the cylinder. The compression stroke (2) then compresses the or air-fuel mixture. The ratio of the uncompressed mix to the compressed mix is known as the compression ratio and ranges from about 8:1 to 10:1. Higher ratios are found in higher performance engines.

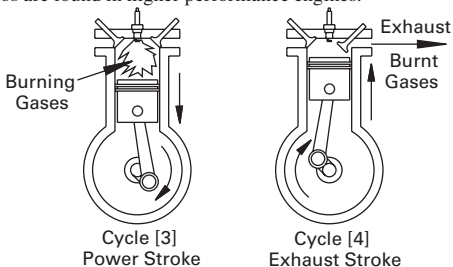


FIGURE 8-2: Four-Cycle Power and Exhaust Cycle

The third cycle (3) is the power stroke down. When the cylinder is just past TDC the spark plug ignites the compressed air-fuel mixture and the resulting controlled explosion

pushes the piston down. When the piston reaches the bottom of the power stroke, the exhaust valve opens and then the burnt gases are expelled by the piston moving up (4). When the piston reaches the top again, the four cycles have been completed and the entire process is then repeated. Note that the crankshaft has completed two complete revolutions (720 degrees) to complete the four cycles.

The air-fuel mixture is provided by either a *carburetor* or a *fuel-injection* system. In a carburetor, air passes through a venturi, which lowers the air pressure such that fuel can be drawn into the intake air stream. Note: A venturi is a tube that narrows in the center which causes gases to flow faster which in turn results in lowered pressure at the center of the tube. A fuel injector actually *injects* a measured amount of fuel into the intake air stream (kind of like a hypodermic needle). Injection systems are becoming more prevalent because they allow more precise metering of the amount of fuel injected and they are more suitable for use with computerized engine control systems, with the net result being less emissions and more power. (There is a more complete discussion of fuel injection in the diesel engine topic later.)

The mechanism for opening and closing the valves at the correct times is the camshafts, which may be either overhead at the top of the engine near the valves, or down in the crankcase. Overhead cams are driven by timing belts or chains from the crankshaft, and the crankcase style cams are usually driven by gears from the crankshaft. Push rods through the engine block from the crankcase cams up to rocker arms operate the valves. Overhead cams have been found to be lighter and more efficient, and today are the preferred method of operating the valves in gasoline engines.

A four-cycle engine lubricates the cylinders with oil from the crankcase and pumps oil to the top of the engine to lubricate the valves.

Two-Cycle Gas Engine

The two-cycle (or two-stroke) gasoline engine has traditionally been used in most outboards and also in PWCs and some jet boats. In a two-cycle engine the power stroke is one stroke out of two strokes.

The four-cycle engine accomplishes one function per stroke, while the two-cycle engine accomplishes two functions per stroke in a rather ingenious way. The following four schematics show how a two-stroke gasoline engine accomplishes all the functions of a four-cycle engine in just two cycles.

The first schematic (figure 8-3), shows how both intake and compression are combined. Intake of air-fuel mixture into the cylinder is completed at the bottom of the downstroke by the piston uncovering the inlet port so that the pressurized air-fuel mix is expelled from the crankcase below the piston up into the cylinder above the piston 8-3(A). The air-fuel mix moving into the cylinder also forces the last of the exhaust gases out of the exhaust port.

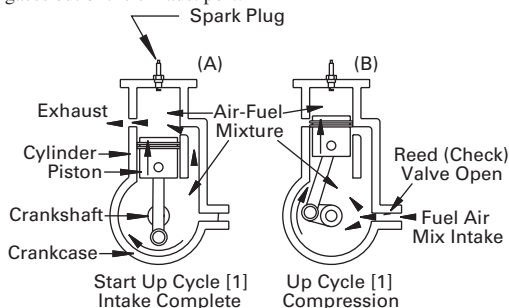


FIGURE 8-3: Two-Stroke Intake and Compression Cycle

In figure 8-3(B) we see both the input and exhaust ports are covered by the piston moving up, which causes the mixture to be compressed. At the same time, the next charge of air-fuel mix is being drawn into the crankcase through the Reed valve (a one-way check valve) by the vacuum induced by the upward moving piston.

In figure 8-4(A), the piston has reached the top and is just starting down, the mix is fully compressed, and the spark plug fires and the mixture is ignited. The ignition forces the piston downward providing power to the crankshaft.

As the piston passes the exhaust port, as in 8-4(B) the pressurized burnt gases escape through the open exhaust port as shown. Also as the piston moves downward, the Reed valve is closed by the pressure and the air-fuel mix in the crankcase is compressed in preparation for charging the upper cylinder.

On the way down, the cylinder inlet port is uncovered, and the pressurized air-fuel mix moves up from the crankcase. When the cylinder reaches bottom the two cycles have been

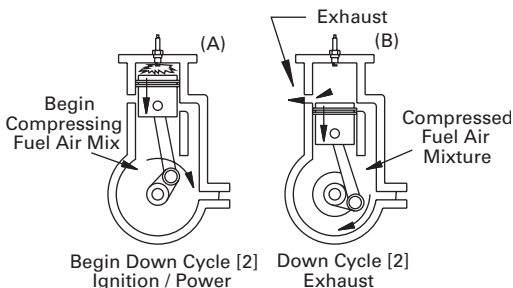


FIGURE 8-4: Two-Stroke Ignition and Exhaust Cycle

completed and the whole process repeats itself. In the two-cycle engine the complete power cycle is accomplished with one up and one downstroke and the crankshaft has turned through just one complete turn (360 degrees).

The crankcase is part of the air-fuel intake system so the oil bath can't be used like it is in the four-cycle engine. The usual method of lubricating the two-cycle engine is to mix the fuel with the lubricating oil in the gas tank so that the mix actually lubricates the moving parts as it passes through the engine. The ratio of the fuel oil mix is about 1 part oil to 40 parts gasoline. As you might expect, the oil gets burned along with the gasoline, which results in more atmospheric emissions than gasoline alone.

Direct injection systems have been developed to try to reduce the emissions from two-cycle engines while increasing power output. In a direct injection system, fuel injectors inject a precisely controlled amount of fuel just before ignition, and oil is injected into the crankcase rather than being mixed with the fuel. This results in oil consumption being reduced to about 1 part oil to 80 parts gasoline.

Compare Four-Cycle Gas Engines With Two-Cycle Gas Engines

The two-cycle engine is much simpler than a four-cycle engine since there are no valves that require a complex mechanical system to operate properly. As a result the two-stroke is cheaper to build, easier to maintain, is lighter and has a higher power to weight ratio than the four-stroke. For this reason, two-cycle engines are used extensively in

hand held power tools and in outboard engines where lighter weight is an important factor. Unfortunately, the two-stroke is an inherently dirtier burning engine. Imperfectly or incompletely burned air-fuel mixture escapes in the exhaust, and as mentioned previously, the oil is being exhausted also.

As a result, much government legislation is being enacted regarding the permitted uses and operating locations of two-cycle engines. California has banned two-cycle engines from some lakes, and laws are being considered regarding the use of two-cycle engines in lawn and garden equipment. Some outboard engine manufacturers have responded by developing direct fuel-injection systems to dramatically reduce two-stroke emissions while others have converted their entire line of engines to four-strokes. Some are producing both. Where this will all end up is anyone's guess, although we can be sure the environmental regulations will get tougher as time goes on.

Four-cycle engines are just the opposite. They are more complex, more expensive to build, heavier, and have a lower power to weight ratio. But, they are inherently cleaner burning. Although the power to weight ratio of a four-stroke is less, the fuel efficiency is better so you get more miles to the gallon. Also, two-stroke oil isn't cheap so this will also add to your cruising cost. Last but not least, oil distribution in the four-stroke is far better resulting in a longer lasting engine, although this is somewhat offset by the greater complexity which increases the odds of something breaking.

DIESEL ENGINES

Introduction to Diesel Engines

The diesel engine is a *compression ignition* internal combustion engine, meaning that ignition of the air-fuel mixture is by means of compression to high pressure and temperature. This process is based on the thermodynamic principle that compressing a gas causes its temperature to rise. In the case of the diesel engine the compression has to be enough to raise the gas temperatures enough to initiate ignition. Compression ratios for diesel engines range from about 15:1 to 25:1, although some have been built with even higher ratios.

Diesel engines are used in inboard and stern drive applications and come in a much wider range of size and power than the four-cycle gasoline engines available for these applications. Many diesel engines used in boats are marinized versions of car or truck engines while others are designed specifically for marine use from the start.

The major makers of marine diesel engines are *Alaska Diesel (Lugger), American Diesel, Caterpillar, Cummins, Detroit Diesel, John Deere, Volvo Penta, Perkins, and Yanmar.*

Table 8-7 lists specifications for some randomly selected engines from various manufacturers. The RPM given is the RPM for the rated horsepower.

Power			No.Cyls	Aspirate	Displ.		Wt		Ratios			
hp	kW	RPM			CID	L	Lbs	Kg	hp /cui	hp /lb	kW /L	kW /kg
8	6	3400	1	N	19	0.3	167	51	0.41	0.05	19	0.12
10	7	3600	2	N	28	0.5	247	75	0.36	0.04	17	0.10
10	7	3200	2	N	28	0.5	247	75	0.36	0.04	17	0.10
55	41	3000	4	N	134	2.2	558	170	0.41	0.10	19	0.24
63	47	2600	4	N	183	3.0	579	176	0.34	0.11	16	0.27
70	52	2500	4	N	212	3.5	787	240	0.33	0.09	15	0.22
75	56	2400	4	N	276	4.5	961	293	0.27	0.08	12	0.19
101	75	2200	4	N	425	7.0	1710	521	0.24	0.06	11	0.14
105	78	2200	6	N	414	6.8	1194	364	0.25	0.09	12	0.22
140	104	2200	6	T	414	6.8	1194	364	0.34	0.12	15	0.29
158	118	3100	4	T	211	3.5	805	245	0.75	0.20	34	0.48
208	155	2300	6	T	414	6.8	1399	426	0.50	0.15	23	0.36
230	172	3900	6	T	219	3.6	534	163	1.05	0.43	48	1.05
254	189	2400	6	T	442	7.2	1812	552	0.57	0.14	26	0.34
325	242	2100	6	T	674	11.0	2400	732	0.48	0.14	22	0.33
375	280	1900	6	T	766	12.5	2695	821	0.49	0.14	22	0.34
415	309	2750	6	T	452	7.4	1815	553	0.92	0.23	42	0.56
480	358	2600	6	T	444	7.3	2304	702	1.08	0.21	49	0.51
510	380	1800	12	T	1649	27.0	6257	1907	0.31	0.08	14	0.20
615	459	2100	6	T	740	12.1	1400	427	0.83	0.44	38	1.07
700	522	1800	6	T	1413	23.2	5525	1684	0.50	0.13	22	0.31
825	615	2300	6	T	855	14.0	4240	1292	0.96	0.19	44	0.48
1000	746	1800	8	T	2105	34.5	11500	3505	0.48	0.09	22	0.21

Aspirate: N=Natural, T = Turbocharge

TABLE 8-7: Typical Diesel Engine Specifications

Notice the large variation of the RPM, horsepower to displacement (hp/cui) and horsepower to engine weight (hp/lb) for the different engines. These ratios have implications relating to engine longevity that will directly affect matching the engine to the boating application. In general a slower turning engine with lower power to displacement and lower power to weight ratios will be the longer lasting engine. The faster turning higher ratio engines are performance engines

that would be used in planing craft where weight is a prime consideration.

Four-Cycle Diesel Engine

The basic operating principle of the four-cycle engine is similar to the gasoline four-cycle engine except for a few fundamental differences. The similarity is that the four cycles are the same, these being intake, compression, ignition (power), and exhaust. The differences are the use of compression instead of spark ignition, direct fuel injection (explained below), and much higher operating temperatures and pressures.

Figure 8-5 and 8-6 show the four cycles of the diesel engine.

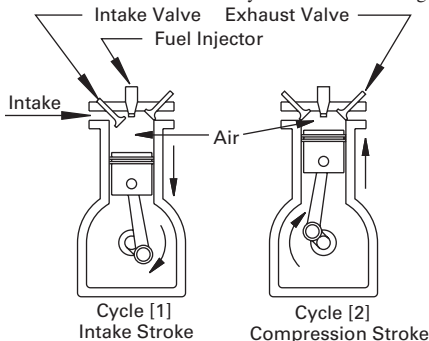


FIGURE 8-5: Diesel Engine Intake and Compression Cycle

The intake stroke (1) draws pure air in rather than a air-fuel mixture like a gas engine. The compression stroke (2) compresses the air to a much higher pressure and temperature than the gas engine does. At 15:1 to 25:1 compression ratios, pressures of over 500 psi (3450 kPa) and temperatures of 1000 degrees Fahrenheit (540 degrees C) can be achieved.

With the piston near the top, the injector injects fuel into the high temperature air and ignition occurs. The combustion induced high pressure pushes the piston down in the power stroke (3), the same as in the gas engine. The exhaust stroke (4) will then exhaust the burnt gases through the exhaust valve.

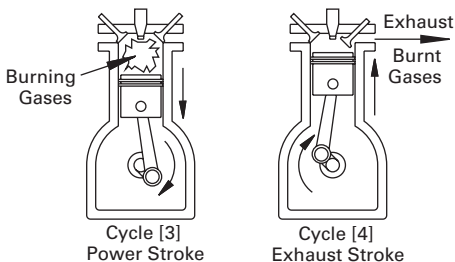


FIGURE 8-6: Diesel Engine Power and Exhaust Cycle

Two-Cycle Diesel Engine

The two-cycle diesel engine was popularized by Detroit Diesel and saw widespread use in the past. These are no longer being produced for use in pleasure craft although some might still be found in older boats. Since these are discontinued, I won't spend more than a paragraph on them here.

They are similar to the two-cycle gas engine with the same functions of intake, compression, power, and exhaust being combined into two strokes. They differ, however, in their means of getting fuel and air into the engine. Instead of an air-fuel mixture being forced up from the crankcase, the air is blown in the open port by a low boost blower, and the fuel is injected at the appropriate time just like in a four-cycle diesel. Lubrication takes place by pumping oil through the engine as in the four-cycle system.

Advantages are similar to those for the two-cycle gasoline engine and so are the disadvantages of higher emissions and less fuel economy. The higher emissions are the main reasons these engines have fallen out of favor.

Diesel Fuel Injection

If the engine fails to operate, odds are 90 percent that it's a problem in the fuel-injection system. If you're going to fix the problem yourself, it is important to understand how the injection system functions.

The fuel-injection system basically consists of a *low pressure pump*, a *high pressure pump*, and the *injectors*. There is also a *return line* to scavenge unused fuel from the injectors and return it to the fuel tanks.

The low pressure pump transfers fuel from the fuel tank to the high pressure pump. The high pressure pump may be located on the engine with high pressure supply lines running to the individual injectors, or it may be integrated with the injector in a **direct injector** or an **electronic fuel injector**. The first two injector systems are mechanically powered from the engine using gears, lifters and rocker arms whereas the electronic injector is driven electrically under control of an **electronic control module (ECM)**. An ECM is basically a microcomputer that can be programmed to control many engine functions to optimize operation under various operating conditions. Electronic fuel injector systems are becoming more prevalent since they allow more precise control of the injection process, which, in turn, results in less emissions and better engine performance.

The injector itself has either a **nozzle** with multiple holes, or a **pintle** with a single hole, through which finely atomized fuel is delivered to the cylinder. A **nozzle valve** held shut by an injector spring keeps the holes sealed until fuel is needed. The high pressure pump activates just before the piston reaches top dead center, and when the pressure is high enough to overcome the spring, the injector will release and inject the fuel into the cylinder.

The high pressure pump and the injectors have very fine tolerances so that even the smallest particle of dirt can disable them. If air is present in the fuel they won't function. Water in the fuel can vaporize in the high heat and stop operation also. Bacteria that like to grow in diesel fuel will clog the system and cause it to fail.

For this reason, the wise boat owner will be fanatical about buying only clean, contaminant-free fuel, and installing and maintaining filters and fuel cleaning and polishing systems. If the fuel is clean and the engine has been properly maintained then, aside from overheating, it's highly unlikely you'll ever experience an engine failure.

Diesel Air Supply and Turbocharging

Traditionally, diesel engines used natural aspiration to supply air to the cylinder. This simply means that the piston moving down on the intake stroke creates a vacuum that draws air in at atmospheric pressure. This engine is said to be a **naturally aspirated** engine.

In a naturally aspirated engine there is a limit to the amount of fuel that can be injected and burned in a cylinder of specific displacement and configuration, the limiting factor

being the amount of air available to burn all the fuel. To increase the horsepower of a naturally aspirated engine, we must increase the displacement, which, in turn, increases the size and weight of the engine.

An alternative is to boost the intake air pressure above normal atmospheric pressure to force more air into the cylinder, which allows the injection and burning of more fuel, which in turn increases the horsepower produced by the engine. The **turbocharger** accomplishes this task without adding much weight to the engine, and in fact, this is what turbocharging is all about. In planing boats, getting more horsepower without increasing weight is a critical design consideration.

Turbocharging can also improve overall efficiency (i.e., miles per gallon) and with improved burning, lower emissions. For these reasons, turbocharged engines are increasing their market share and may be your only choice in the not too distant future.

The turbocharger is basically a blower that has a turbine at one end that is powered by exhaust gases from the engine, connected by a shaft to a turbine at the other end that boosts intake air pressure. The result is more air and fuel burn in the cylinder to produce more power. The amount of increased pressure above atmospheric pressure is known as **boost**.

This sounds quite simple but unfortunately it gets more complex pretty quickly:

1. Burning more fuel and air means more heat and pressure, which places more load on an engine that may not have been designed to take it. There is no question that turbocharging reduces engine life.
2. The turbocharger will actually impede engine performance at slower speeds since there will not be enough exhaust gas to drive it effectively. This means turbocharging is not a good idea if you plan to run frequently at below cruising speeds.
3. The turbine runs at speeds up to 100,000 RPM and more. This is a very high speed, and it means another high maintenance item has been added that is subject to failure if everything is not just right because of its precise tolerances.
4. When a gas is compressed it heats up, which, in turn, expands it—exactly the opposite of what we want to happen in the turbocharger. In a sense, the turbo is working against itself. In addition, the exhaust gases used to

drive it are adding even more heat, which compounds the problem.

5. To counteract the heating problem and cool the air going to the turbocharger, an *intercooler* is commonly used, particularly in larger engines. The intercooler is a heat exchanger (much like a radiator) that uses raw (sea) water to cool the air.

ENGINE COOLING AND EXHAUST SYSTEMS

Cooling Systems

The engine cooling and exhaust systems are similar for both gasoline and diesel engines however diesel engines require more cooling capacity because of their higher operating temperatures. Gasoline engines are much more tolerant of overheating than diesel engines. Failure of the cooling system in a diesel can lead to an overheat condition and total engine failure in less than a minute, so monitoring and shutdown systems must be meticulously maintained.

Raw Water Cooling

Raw water cooling refers to the practice of circulating seawater directly through the engine block to cool the engine. Since salt water is quite corrosive, this is usually an undesirable way to cool the engine unless the boat is used exclusively in fresh water. The resulting corrosion will tend to reduce circulation and ultimately lead to the engine running hotter, which ultimately reduces engine life.

Outboard engines, most gasoline stern drives, and some gasoline inboards use raw water cooling. Generally, diesel installations don't use raw water cooling systems.

A raw water cooled boat that is hauled out of saltwater after each use needs to be flushed with fresh water each time. For boats that are left in the (salt) water, raw water cooling is just not recommended, since there is no practical way to flush the engines with fresh water. Outboard engines are designed to drain all the water after each use, which should help, but a good flushing is still recommended after each use in saltwater.

The most common type of raw water pump, uses a rubber vane type impeller. The raw water is circulated continuously by the raw water pump with a thermostat controlling the actual flow through the engine. When the thermostat is closed the water bypasses the engine and is discharged into the hot engine exhaust gases to cool them. When the thermostat is

open, the raw water passes through the engine and is then also discharged into the exhaust.

In climates where freezing temperatures are expected, the raw water system must be completely drained of all water, usually from several points on the engine block and the cooling system.

Closed Circuit Cooling with Heat Exchanger

In the closed circuit cooling system, the raw water circulates through a heat exchanger that cools a water-antifreeze mix, which is then circulated in a closed circuit through the engine. The raw water is continuously circulating and is discharged into the exhaust the same as with the raw water system (if the boat has a wet exhaust system).

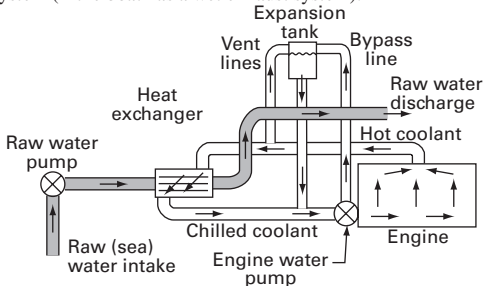


FIGURE 8-7: Closed Circuit Engine Cooling

The **heat exchanger** usually consists of a number of parallel tubes around which the closed circuit mixture circulates. The raw water passes through the inside of the tubes where the heat exchange actually takes place.

A thermostat regulates closed circuit coolant flow through the engine block as needed. Freezing temperatures are not such an issue as they are with the raw water system since the water-antifreeze mixture doesn't freeze. There still may be concerns with water in the raw water side of the system, particularly in the pump.

In general, the closed circuit cooling system is going to be both more expensive and more work to maintain than the raw water system, since there are more parts involved. However, this is more than offset by the harmful effects of circulating saltwater through the engine.

Closed Circuit Cooling With Keel Coolers

With a keel cooling system, the coolant in the closed circuit is run through a *keel cooler*, which is essentially a flat heat exchanger mounted on the outside of the hull. In this case, the cooling is by direct contact with the surrounding seawater.

Keel cooling is often favored for ocean crossing vessels because its simplicity contributes to reliability.

Keel cooling makes the most sense if combined with a dry exhaust system (described next). If a wet exhaust system is used, raw water must still be pumped into the boat, which negates one of the main advantages of using the keel cooler (eliminating the raw water pump).

Compare Closed Circuit and Keel Cooling

Advantages of heat exchanger versus keel cooling:

- Components inside the boat are not subject to damage from impact.
- Critical parts are inside the hull where they can be inspected and maintained.
- The system remains efficient when the boat is not underway.

Disadvantages of heat exchanger versus keel cooling:

- The heat exchanger system has more components subject to failure. The raw water pump is particularly prone to failure.
- There is a greater chance of a leak or break in a hose or other component, allowing seawater to flow into the hull.

Advantages of keel cooler versus heat exchanger:

- No raw water pump is needed, which eliminates a common failure point. This is considered the primary advantage of keel cooling.
- Substantially less maintenance than raw water cooling with a heat exchanger.

Disadvantages of keel cooler versus heat exchanger:

- The keel cooler is on the outside where it is subject to damage from impact. Also it is subject to fouling, which can reduce its efficiency.
- It can increase hull resistance to forward motion.
- It loses efficiency when the boat is not making way since there is no flow of seawater over the tubes.

Exhaust Systems

Exhaust systems are generally classified as either wet or dry exhaust systems.

The *dry exhaust* system discharges the hot exhaust gases directly, first through a muffler, then up vertically through the boat to a smoke stack. These gases are very hot, typically on the order of 1000 degrees Fahrenheit (540 degrees Celsius).

The *wet exhaust* system relies on the discharge of raw cooling water, used to cool the engine, into the exhaust to cool the engine exhaust gases to below 200 degrees Fahrenheit (93 degrees Celsius), where they can be discharged from the boat through noninsulated hoses and pipes.

Dry Exhaust

Dry exhaust systems are used on most commercial boats and are found on some recreational boats (e.g., Nordhavn) that are designed specifically for crossing oceans. As a general rule, dry exhaust systems won't be found on recreational boats of less than 40 feet (12 m).

Relative to a wet exhaust system, the dry exhaust system is basically simpler in design since it has no moving parts. As a result, it requires considerably less maintenance and is much less prone to catastrophic failure. By catastrophic failure I mean failure that can stop the engine and damage it—to the extent that it needs to be rebuilt or replaced—or setting the boat on fire. Proper design and installation of the dry exhaust system is critical since failure will generally result in a boat fire. If it is designed and installed correctly, however, the probability of fire caused by a dry exhaust is near zero.

A dry exhaust system is quite often installed along with keel cooling systems, thus completely eliminating the need for any raw water pumps in critical systems.

Because of the high temperatures involved, the use of thick insulation and special materials such as stainless steel are required to isolate the hot stack from the parts of the boat through which it passes. In addition a large muffler is required to minimize exhaust noise. All this takes up much more interior room in the boat both in the engine room and right up through the center of the boat. On a boat of less than 40 feet (12 m), the space taken is prohibitive, but on a boat over 50 feet (15 m), it may be acceptable.

Disadvantages of dry exhaust relative to wet exhaust:

- As mentioned previously, it uses substantially more space.
- It is more expensive because of the need to use components that withstand the high temperature.
- It requires a smoke stack, which can't be lowered to clear overhead obstructions such as bridges.

- It can emit carbon and ash particulates that settle back on to the boat, particularly when starting.
- It radiates more heat into the boat.

Advantages of dry exhaust:

- There is less maintenance; it generally just requires periodic inspection.
- It is less likely to fail. This is the major reason dry exhaust is installed in boats that will be crossing oceans, or passagemakers.

Wet Exhaust

Wet exhaust systems are found on virtually all boats under 40 feet (12 m) and most recreational boats over 40 feet. All outboards and gasoline engines use wet exhaust systems.

The raw cooling water is the discharge from the heat exchanger in the case of a closed circuit cooling system, or the discharge from the engine block in a raw water cooling system. In the case of a keel cooling system, the raw water will be drawn directly from the sea. In all these cases the water circulation depends on a raw water pump.

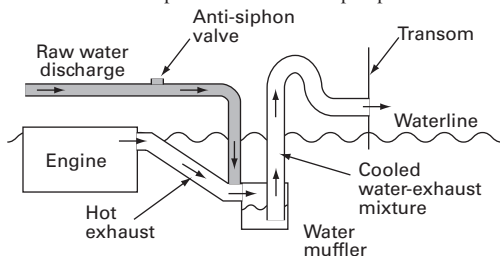


FIGURE 8-8: Wet Exhaust System Schematic

The hot exhaust discharge pipe must be capable of withstanding the high temperature exhaust (1000 degrees Fahrenheit/540 degrees Celsius) gases; however, once the exhaust gases mix with the discharge water, they are cooled to temperatures less than 200 degrees Fahrenheit (93 degrees Celsius), which allows the use of rubber and fiberglass piping to route the cooled mixture from the muffler out through the transom.

The gooseneck in the cooled exhaust discharge line is to prevent seawater from flowing back down into the engine

through the exhaust system. The anti-siphon device is designed to prevent siphoning of water back through the exhaust system. The heights and sizing of the various components must be correct and within certain limits or the system will not function correctly, so the design of a wet exhaust system should be left to a professional.

The water-exhaust mix is a heated blend of acidic exhaust gases and saltwater. This is a very corrosive combination, so the components from the water injection point onward corrode rather quickly. A five-year life is about all one might expect for some of these components.

Close and frequent monitoring and inspection of this system is an absolute necessity since failure can cause devastating results. There are plenty of anecdotal estimates by diesel engine technicians suggesting that *wet exhaust cooling system failures ultimately are responsible for 40 to 75 percent of all engine failures.*

Sensors can be placed in strategic places to monitor the system and warn of failure. Flow sensors can be placed in the raw water line, and temperature sensors can be placed in the cooled exhaust pipe. High temperature probes can be placed in the hot exhaust pipe. All of these combined with gauges and alarms, and lots of attention to preventative maintenance, will negate most of the disadvantages of the wet exhaust system.

Disadvantages of wet exhaust:

- If the raw water pump (impeller) fails, then without cooling water the high temperature exhaust gases enter the muffler and components made of rubber and fiberglass. Within less than a minute, there's going to be a fire in the engine room if you don't stop the engine in time.
- If the anti-siphon valve or vent fails, water can be siphoned back into the engine. Water in the cylinders may not total the engine if the situation is corrected quickly, but if left for a longer period a rebuild or new engine will likely be required.
- When the engine is shut down, salt-laden gases can back into the high temperature exhaust pipe causing more rapid than usual corrosion. Failure here will allow hot exhaust gases into the engine room and most likely result in a fire.
- The relative complexity and the severe penalty for failure imply relatively high maintenance costs.

Advantages of wet exhaust:

- Wet exhaust systems are cheaper to build since high temperature materials and insulation are not required throughout.
- They use much less space.
- The water muffler is much smaller and does a better job of reducing exhaust noise.
- They are quite safe if the correct precautions and maintenance are carried out. That's a big if, since most boaters tend to neglect this critical area even more than they neglect maintaining their engine.
- When the wet exhaust system is functioning correctly, there is probably less chance of fire than with dry exhaust.

GASOLINE AND DIESEL ENGINE COMPARISON AND SELECTION

Horsepower

From the engine specification tables (8-5, 8-6 and 8-7) starting on page 451, we see that inboard gasoline engines range from about 135 to 375 horsepower, outboards from 2 to 250 horsepower, and diesels from 8 to 1000 (and larger) horsepower. One major factor in comparison will simply be size: If more than 750 (375 x 2 engines) horsepower is required, then the diesel is all that's available.

Safety

As we are all aware, gasoline fumes are dangerous since they are explosive. Consequently, this is a significant consideration, although with proper maintenance and operating procedures in place, this shouldn't be a major factor in engine selection. Keep in mind that diesel fuel, although not normally explosive, is definitely a fuel and it can burn fiercely. The flash point of diesel fuel is in the range of 140 degrees Fahrenheit (60 degrees C), which is the temperature where explosive vapors are given off, so diesel explosions can occur too, they're just much less likely.

Expense

Diesel engines are expensive to buy and maintain. The largest gasoline engine runs about \$8000 and is roughly equivalent to a \$20,000 diesel engine. And, if anything goes wrong with the diesel, the cost of parts will be typically be twice as much as a gasoline engine. Offsetting this is the fact that the diesel uses less fuel. Diesel fuel was generally about 50 cents cheaper per gallon than gasoline up to 2005 but now

it costs more than gasoline. It is going to take several years to make up the difference in engine cost of \$12,000.

Operating Life

Diesels have achieved a reputation for operating up to 20,000 hours without major overhauls and this is often compared to a typical gasoline engine operating life of around 2000 hours. These high engine operating hours are achieved by working boats that operate high hours per year operating day in and day out. These are engines that produce low horsepower relative to engine displacement and weight.

Horsepower to engine displacement ratios for these long lived engines typically run at less than 0.3 horsepower/cubic inch (23 kW/L). Horsepower to weight ratios would run less than 0.1 horsepower/pound (0.3 kW/kg).

By way of comparison, a typical gasoline engine produces approximately 0.75 horsepower/cubic inch (34 kW/L) and 0.3 hp/lb (0.75 kW/kg). One major reason for this difference is that diesel engines run at much higher temperatures and pressures than gasoline engines, and therefore must be built much heavier if they are going to last as long. To get an extraordinarily long life, they must be even heavier.

In general the lower the ratios of horsepower to engine displacement and weight, the longer the engine can be expected to operate.

Unfortunately, many recreational boats aren't getting any more hours with diesels than with gasoline engines for several reasons:

- Many of the new turbocharged high performance diesels are achieving horsepower to engine displacement ratios of over 1.0 horsepower/cui, which is even higher than that of gasoline engines. Look back at table 8-7 to see some examples. These engines are designed this way for high-speed planing boats as a matter of necessity, since light weight and high horsepower are the critical factors in planing boat performance.
- To achieve this high performance they also operate at much higher RPMs—in the 3500 to 4000 range.
- Diesel engines are suited to continuous running at around 80 percent of full power and running at idle speeds for extended periods of time lessens engine life especially with turbocharged engines, this being primarily because of carbon build up in the cylinders. Regrettably, a lot of recreational boat diesel engines are run in just this way.

- Diesel engines are not suited to infrequent use. Diesel fuel is somewhat acidic and the byproducts will corrode internal engine surfaces when they are left unused for extended periods.

Keep in mind, a 2000-hour operating life is not necessarily a bad thing. An average weekend boater might use his boat six hours per weekend for 25 weekends for a net 150 hours per year. At this rate, if the gasoline or high performance engine is properly maintained you'll get 2000/150 or 13 years out of it.

If you are passagemaking, putting on thousands of hours per year with a low horsepower to weight engine, you can expect to get 20,000 engine hours just like the workboats. This is assuming you do the proper preventative maintenance.

Which Engine for Which Boat?

Small diesels are generally the best choice for auxiliary engines for cruising sailboats, if only because they are located deep in the unventilated bilge area where gasoline fumes can be particularly dangerous. On a cruising sailboat, this engine may be used for extended operating periods, which is where the diesels have the edge. Reliability is an important factor too.

The smallest boats, up to about 17 feet (5 m) are generally going to be outboard powered since these are the only engines small enough for these boats. This includes small sailboats. Outboards are also found on boats up to around 32 feet (10 m) long and 15,000 pounds (6800 kg) displacement. These larger, outboard-driven boats will usually be some kind of sport fisherman, which is a planing boat where light engine weight is important. Fishermen tend to like outboards because they can mount a second smaller outboard for trolling on the same transom.

Gasoline inboard and stern drive engines span the range from about 16 feet (5 m) to 40 feet (12 m). At the higher end, performance will likely be limited to semi-displacement speeds.

Diesels can be found in power boats from around 25 feet (8 m) and up. A diesel in a planing boat will be a higher performance engine, which involves accepting a lower engine life. A diesel for a displacement boat should be a heavier, slower turning (1800 to 2400 RPM) engine.

The question of gas versus diesel only arises for boats in the range of from about 25 feet (8 m) to 40 feet (12 m) in length. If the boat is only going to run 150 hours or less, then the gas

engine makes sense because it's much cheaper to buy, and it's more suited to infrequent use. Extended use at idle or slow speeds also points to a gas engine.

Extended cruising, such as doing the "great loop" around the East Coast, suggests the use of a diesel, although gasoline would work. The great loop is about 6000 miles and requires 1000 engine hours to complete at 6 knots.

If you're passagemaking, then diesel is the only way to go, both for range and reliability.

SURVEYING USED ENGINES

Many buyers, when buying a used boat, have a boat survey done and assume that the boat survey includes the engines. Normally a boat surveyor is not an engine surveyor and when buying a used boat, particularly larger boats (over, say, 28 feet or 9 meters), an engine survey is highly recommended since the nonprofessional will find it difficult to evaluate the internal condition of the engines. Even a professional can't always find all the problems.

You probably will find that most owners haven't bothered to keep detailed maintenance logs, so when you do find a meticulously kept log, this is a good indication the owner also took meticulous care of the engines. In addition, well-kept logs will help pinpoint developing problems. It follows that any owner should keep a good maintenance log as it not only enhances the value of the boat when it comes time to sell it, but it is invaluable in analyzing and troubleshooting engine and mechanical problems. A sample maintenance log is included at the end of this chapter.

The most obvious thing to look for in the engine room is just plain old cleanliness. A filthy engine room is a pretty obvious indication that the owner didn't like being in the "holy place" and hasn't taken care of it.

Even without a survey there are some basic things the prospective owner can check. The normal pretrip fluid level checks, visual checks of belts and filters, etc., are obviously minimum checks. Some sample mechanical checklists are included at the end of this chapter.

Here are some simple checks to make. The engine should be cold (as in not run since yesterday) before starting these checks

- When the dipstick is pulled, smell for diesel or gas in the oil. Observe the condition of the oil. Is it dirty black or clear?

- Check the coolant for contaminants and/or rust. Check the antifreeze level with a hydrometer.
- Squeeze the hoses. They should be firm, not soft and not hardened.
- Look everywhere for signs of corrosion. Look for signs of painting over corrosion.
- Look for oil (or fuel) leaks
- If possible run a compression test on each cylinder.
- Start the cold engine. Listen carefully for any strange or irregular sounds.
- Watch and record oil pressure as the engine warms up. It should remain steady and not fluctuate once the engine is warmed up.
- Look for smoke both when the engine is cold and when it's warming up. Note the color of the smoke. Smoke when cold is not unusual if it's not excessive.
- Get the boat out to sea so it can be run at cruising speed for at least an hour or two. During that time the engine should be taken to maximum throttle for at least a few minutes. Now check again for temperature, pressure, smoke, vibrations, and strange noises.
- Check the dipsticks again. See if the oil feels gritty between the fingers. It probably won't, but if it does there's something seriously wrong—something is abrading or wearing off inside the engine. A far better idea is to have a sample of the oil analyzed for contaminants, although if the oil has recently been changed this might not show problems.

ENGINE MAINTENANCE AND TROUBLESHOOTING

Maintenance

With any marine engine, it is essential that the manufacturer's preventative maintenance schedules be followed. This is true for gasoline engines and it is absolutely critical for diesel engines.

Certain checks should always be carried out before starting the engine. These should be in your engine manual. Samples of periodic checklists are at the end of this chapter. Pay particular attention to the cooling system and the exhaust system. Always be on the alert for leaks in these systems. Any leaks should be fixed immediately. Every cooler should be inspected and cleaned at least once per year even if it's not required in the engine maintenance schedule.

Alarm systems need to be checked frequently. These need to be in working order if there is a failure in the cooling or exhaust systems. As mentioned previously, if you don't have exhaust temperature gauges and alarms installed, get them installed sooner rather than later. The alarm system must include loud sound alarms as well as lights. Adhere to the manufacturer's recommendations for oil weight and quality, and follow the oil and filter change schedule. Install vacuum gauges on fuel filters to indicate when filters need to be changed.

Introduction to Troubleshooting

Make it a habit to always put on safety goggles or glasses when in the engine room. If they are prescription eyeglasses, make sure they are the kind with side protection as well.

In this topic we only consider engine starting problems without going into a great deal of detail. The purpose is primarily to introduce a generalized approach to troubleshooting engine problems.

I caution you not to rely on this book for troubleshooting engine problems; you should have the shop manual for your engine onboard. Normally this will be supplied with a new boat, but with a used boat it may be long gone. If it is gone, then get one, as it will save you a lot of trouble in the long run. It will describe in great detail how you go about fixing problems with your engine and will tell you what all those gizmos attached to it are. The manual will also contain detailed preventative maintenance schedules, fluid specifications and capacities, and a wealth of other information specific to your engine.

A set of tools should be onboard any boat with an engine. Larger boats and boats that travel offshore should have a more comprehensive set of tools and spares. A suggested set of tools is listed at the end of this chapter.

Troubleshooting Both Gasoline and Diesel Engines

Engine won't turn over at all when starting

Before doing anything, put on your safety goggles.

Check that the ignition is turned on and the battery selector is switched to on. Keep in mind that starting problems are almost always electrical.

The most obvious and probable cause is dead batteries or bad battery connections (corroded battery terminals).

- Use a battery acid tester to check the specific gravity of the electrolyte. This is the easiest way to determine charge.
- A clicking noise (from the starter solenoid) is a good indicator of dead batteries, although if you don't get the clicking sound that just might mean the batteries are totally dead or the terminals are very badly corroded.
- With a volt-ohmmeter (every boat should have one onboard), check the voltage across the battery terminals before starting. This should read over 12 volts; if it's less, then the battery is almost certainly the problem. If it's over 12 volts the battery still could be the culprit.
- Measure the voltage as you try to start. If the voltage drops way down (below 9 volts), when the starter is engaged, then the battery needs charging.

If the batteries are good then the problem may be the ignition switch, a bad starter motor, a seized engine, or possibly water in one or more cylinders.

- Check voltage to the starter motor terminals with the starter button pressed. No voltage indicates a problem in the starting circuit.
- If you have a booster battery (that you know is good), you can try connecting it directly to the starter motor to see if that will turn the engine over. Use heavy duty jumper cables.
- With a large wrench on the crankshaft, try turning the engine in its normal direction of rotation (clockwise from front) by hand. If you can turn it over then the engine is not seized and does not have water in the cylinders. The problem is most likely to be the starter motor if you're sure the starter circuit and batteries are okay. Note that you may not be able to turn the engine over by hand, particularly with a large engine.
- If you were able to turn it part way and then it stops, that's a pretty good indication that you have water in the cylinder(s).
- If you can't turn it over by hand and you don't have your shop manual for further advice, then perhaps it's time to turn this over to professionals.
- If you are a real do-it-yourself type, then the next step is to relieve the compression by removing the injectors or spark plugs and then turning the motor with the wrench again. If you still can't turn it, then either the engine is seized or you need to start lifting weights. If there was water in the

cylinder(s), then it will probably come out the spark plug or injector holes.

- If there's water in the cylinder, you might be able to siphon it with a small tube and work it out by continuing to turn the engine over with the wrench (don't use the starter). If the water has been in the cylinder(s) for a long time then the cylinders and valves will be rusted and the engine will have to be overhauled. Even if it's recent, you should probably get a professional to check things out and remove any remaining water.
- If you insist on doing this yourself or you're stuck at sea, then you must be sure that all water is out of the oil circulation system. If water has gone any further than the cylinder it will travel down past the pistons into the crankcase so check the crankcase for water. If water is present in the oil, then a complete oil change is required before starting the engine—although the oil should be changed as soon as possible regardless. Change the oil again after running the engine at operating temperature for a few minutes. Continue to check for water over the next few days. If all the water isn't removed, the engine is going to fail in the near future.
- Make at least two full turns of the crankshaft to be sure the engine turns freely through all four cycles.

Troubleshooting Gasoline Engines

Engine turns over but won't start

Before doing anything, put on your safety goggles.

- Never crank an engine more than 10 to 20 seconds, and wait two minutes before cranking again to prevent the starter motor from overheating.
- If the engine usually starts quickly but now won't start with continued cranking, don't keep cranking.
- Before continuing, be sure that the area is well ventilated to remove gasoline fumes, since some of the tests may produce sparks.
- In the marine environment, corrosion of electrical components, loose connections, and broken wires are commonplace and most problems like this are likely to be electrical.
- If the engine has been getting harder and harder to start over time, then that raises the probability that the problem may be in the fuel system but the ignition system is still the most likely culprit.
- Look for the obvious things first, such as loose ignition wires, detached tubes or hoses, fuel leaks, clogged air

filter, etc. Check fuses. (You did check that there is gas in the fuel tank, didn't you?)

- If the engine has a distributor, remove the ignition coil wire from the distributor cap and hold it a little more than 1/8 inch (3 mm) from a good ground. Turn the engine over and look for a good spark. If there's no spark then the coil or the ignition coil wire are likely to be the problem. Work backwards, first to the coil, and then check for power to the coil. This is about as far as you can go without the shop manual.
- If there is a spark, then remove the spark plug wires one by one, and do the same test at each spark plug to see if there's a spark.
- If there is a good spark at the plugs then remove the plugs one by one. Inspect each one for carbon or oil build up.
- If the spark plugs are very dirty, replace them. In an emergency, clean off any deposits.
- With the plug removed, reattach the spark plug wire and hold it against a good ground while cranking the engine. If all the spark plugs are clean and produce a good spark then the ignition is most likely okay. There still may a timing problem but that's beyond our discussion here; for that you'll want the shop manual.
- If the electrical system checks out then the air and fuel delivery systems are the remaining suspects.
- Fuel should be fresh. Old, stale, or contaminated fuel is the primary cause of fuel system problems.
- Check all fuel filters to make sure they are not clogged. Look for contaminants in the filters.
- Carbureted engines: Check to see that fuel is getting to the carburetor. *With the ignition turned off* and the spark arrestor removed, if you move the throttle back and forth, you might be able to see a stream of fuel being pumped into the barrel. If no fuel is getting to the carburetor then the fuel pump is likely at fault. Use the shop manual for troubleshooting the fuel pump.
- Fuel-injected engines: *Do not try to see if the fuel is being injected by looking down the barrel while cranking the engine. Flames can explode out of the barrel when the spark arrestor is removed causing serious injury.* You can often tell if a fuel pump is running by feeling it. It should run for a brief time when the ignition is first turned on, and it should run when cranking the engine.

Diesel Engine Troubleshooting

Engine turns over but won't start

Before doing anything, put on your safety goggles.

- Never crank an engine more than 10 to 15 seconds, and wait two minutes before cranking again to prevent the starter motor from overheating.
- If there is air and fuel being delivered to the cylinder and compression is good, a diesel should start. Some lower compression engines will require glow plugs to initiate combustion, particularly in cold weather.
- Remember, most diesel engine problems can be traced to fuel problems. Even the smallest of contaminants can clog the injection nozzles. Water in the fuel will also stop the injectors from operating. Air will most likely stop injection also.
- The easiest thing to check is air intake. Are there any obstructions to airflow such as a clogged air filter?
- Next check for fuel delivery to the injector. Loosen the fuel delivery line one by one, at each injector. Crank the engine and watch for good fuel delivery. Watch for bubbles in the fuel, which indicate the presence of air in the lines. If you just changed a filter that may have introduced the air. Crank the engine until the bubbles are cleared. If air is found in one injector, repeat the process at each injector until all are cleared.
- If the bubbles persist then air is leaking into the fuel supply somewhere before the high pressure pump. Check to see that the low pressure pump is working. If it is, the leak is likely before the low pressure pump. Look for leaks at all filters, connections, gaskets, etc. Make sure the pickup in the fuel tank is actually immersed completely in fuel.
- If there is no air in the fuel and fuel is being delivered to the injectors then remove the injectors one by one, reattach them to their delivery line, and check to see that they actually spray fuel from the pintle or nozzle. *Be careful here; the fuel is sprayed at extremely high pressures and can easily penetrate skin. Again: Make sure you are wearing safety goggles!*
- If the injectors are at fault, you might be able to clean them, but most likely they will have to go into the diesel shop.
- If the engine is getting both fuel and air, then the remaining check is the glow plugs, if they are present. Remove them one by one and hold the body against a good ground while cranking the engine. They should glow red hot.

- If the injectors are injecting, and there is plenty of air, inadequate compression is likely the problem. You will not be able to be able to do much about that.
- *The use of starting fluid in diesel engines is strongly discouraged. It can ignite on the upstroke and cause serious damage to the engine. It will probably void your warranty too.* The factory manual may have something to say on this subject.

PROPELLERS

INTRODUCTION

Accurately selecting and sizing a propeller for your boat is beyond the scope of this book, but you should be able to at least determine if you are over-propped or under-propped with the information contained herein.

It's necessary to first develop some definitions and terminology.

PROPELLER TERMINOLOGY

A *right-hand* propeller rotates clockwise as viewed from aft (facing forward). A *left-hand* propeller rotates counter-clockwise as viewed from aft.

Propellers are usually specified by their diameter and pitch, for example 14x21, where 14 is the diameter in inches and 21 is the pitch in inches, but there is a lot more to propeller design than just these two items (although these two are the most important).

The *diameter* is simply the diameter in inches of a circle that circumscribes the outside edges (tips) of the propeller. As diameter increases, the amount of horsepower needed to drive the propeller increases.

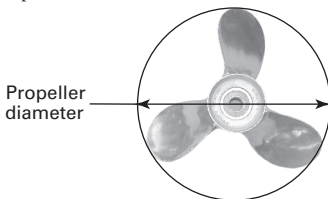


FIGURE 8-9: Propeller Diameter

Pitch is the distance in inches the propeller would move forward through a solid in one complete revolution.

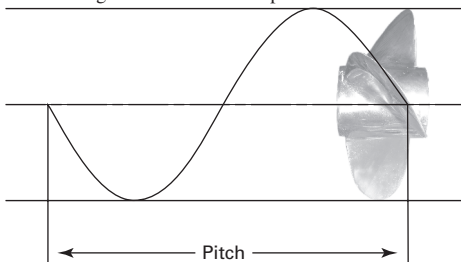


FIGURE 8-10: Propeller Pitch

The **pitch ratio** is the ratio of pitch to diameter. As the pitch increases the horsepower required increases.

$$PR = \frac{P}{D}$$

Where: PR = Pitch ratio
P = Pitch
D = Diameter

EQUATION 8-4: Propeller Pitch Ratio

In water the propeller actually moves forward a distance less than the pitch and the difference between the pitch and the actual distance moved is defined as the **slip**. **Slip percent** is the slip divided by the pitch = (slip/pitch) x 100.

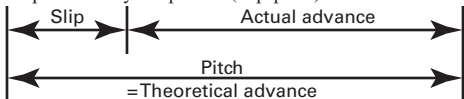


FIGURE 8-11: Propeller Slip

The **hub** is the cylinder at the center of the propeller with a hole bored to allow installing on the propeller shaft.

The **leading edge** is the front edge of the blade that is cutting through the water. The **trailing edge** is the back edge of the blade where water leaves the blade. The **blade face** (also termed the **suction side**) is the surface that faces forward (to the front of the boat). The **blade back** (also termed **pressure**

side or *pitch side*) is the surface that faces aft. The *blade root* is where the blade meets the hub. The *blade tip* is the outside edge of the blade furthest from the center of the hub. When the propeller rotates, the blade tip circumscribes the circle that defines the propeller diameter.

Cup is a curve aft in the trailing edge of the blade. A cup acts to reduce slip and has the effect of increasing effective pitch.

A *pitch line* is a line on the blade back from the leading edge to the trailing edge, which is a constant distance (radius) from the shaft centerline. Pitch lines may be drawn at any distance (radius) from the shaft centerline. The *pitch angle* or *blade angle* is the angle between a pitch line and a plane perpendicular to the shaft.

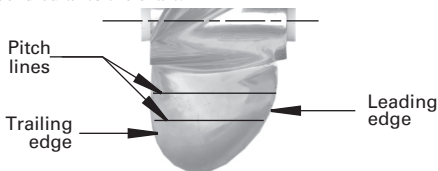


FIGURE 8-12: Propeller Pitch Lines

To maintain a *constant* or *fixed-pitch*, the pitch angle must decrease as the pitch line moves outward from the hub. Figure 8-13 illustrates graphically the helical paths followed by a point at the hub and a point at the tip. Note how the pitch angle at the hub and tip are aligned to follow those paths.

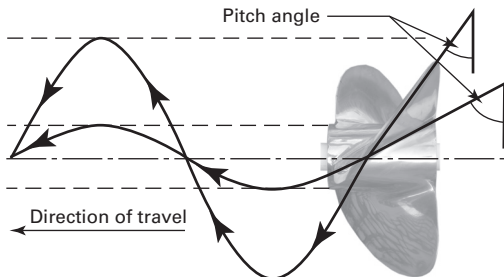


FIGURE 8-13: Propeller Pitch Angle (Blade Angle)

The pitch can be related to the pitch angle with an equation as follows.

$$P = \frac{\text{Tan}(A)}{2 \times \pi \times R}$$

Where: P = Pitch

A = Pitch or face angle

R = Radius (distance from the centerline to the pitch line)

EQUATION 8-5: Pitch Versus Pitch Angle

Most propellers are fixed pitch but there are other types, these being:

- **Variable-pitch**, where the pitch varies with the radius.
- **Progressive-pitch**, where the pitch varies from the leading edge to the trailing edge.
- **Controllable-pitch**, where the pitch angle can be changed mechanically. Controllable pitch propellers are often (erroneously) referred to as variable pitch propellers.

The **disk area** is the area of the circle circumscribing the propeller blade tips.

Disk area is the shaded area in the circle



FIGURE 8-14: Propeller Disk Area

The formula for calculating disk area is:

$$DA = \pi \times r^2 = \frac{\pi \times D^2}{4}$$

Where: DA = Disk area

π = Pi = 3.1415

r = Radius of propeller

D = Diameter of propeller

EQUATION 8-6: Calculation of Disk Area

Developed or expanded area (Ad) is the actual area of all the blades combined. If a blade could be removed and flattened out it would occupy the developed area for that one blade. The developed area for the propeller is the developed area of a single blade times the number of blades. You can determine area of a propeller blade by using some paper cross ruled

with one-quarter inch squares. Place the paper flat on a blade and trim it to fit the blade. Count the number of quarter-inch squares and divide the count by 16 to get the developed blade area in square inches.

If a light is placed in line with the shaft a good distance away, the area of the shadow projected by the blades is termed the *projected area*.

Developed area ratio (DAR) is simply the developed area divided by the disk area.

$$\text{DAR} = \frac{A_d}{A_D}$$

Where: DAR = Developed area ratio
 Ad = Developed or expanded area
 DA = Disk area

EQUATION 8-7: Developed Area Ratio (DAR).

Cavitation can occur if the DAR of a propeller is too low. On the forward or suction side of the blade a vacuum is created as the blade rotates. If there is too much vacuum created, the water vaporizes (boils) and forms bubbles of water vapor. This phenomenon is known as *cavitation*. The small bubbles pop as they collapse back into liquid form which can cause pitting of the blades. Some high speed propellers are designed specifically to operate as *cavitating propellers* (sometimes called *supercavitating propellers*).

Ventilation is when surface air or exhaust gases are drawn into the propeller which can cause loss of power and also allow the engine to over speed. Ventilation is quite often confused with cavitation, although they are distinctly different phenomena.

The propeller blade can slope forward or aft. A blade sloping aft has *positive rake* and a blade sloping forward has *negative rake*.

If the blade centerline curves away from the direction of rotation, it is said to be *skewed*.

PROPELLER SELECTION AND SIZING

Maximum or Design RPM

The propeller is sized based on the engine operating at design RPM at wide open throttle. In other words, with the throttle wide open (WOT); the engine should turn at the design specified RPM, if the propeller is correctly sized.

If the engine RPM at WOT is higher than design RPM then the boat is **underpropped**, with a propeller that has too small a pitch or diameter. If the engine cannot reach design RPM then the boat is **overpropped**, with a propeller that has too much pitch or diameter.

Operating an underpropped boat is analogous to operating a car in a lower gear. Operating an overpropped boat is analogous to operating a car in too high a gear.

Boaters will often deliberately underprop their boat to “get out of the hole” more quickly when towing water skiers. This is okay, but if this is done, care must be taken never to exceed design RPM. Underpropping yields additional acceleration but will result in a loss of top speed.

The boat should *never* be overpropped, since doing so results in the engine always operating under additional strain, adversely affecting engine life. Overpropping will not get more top speed since the engine can never get to design RPM and develop maximum horsepower. *Along with wet exhaust problems, improper propeller sizing ranks right up there as one of the major causes of premature engine failure.*

A general rule of thumb is that increasing pitch by 1 inch (2.5 cm) will result in a drop of 100 to 200 RPM.

Figure 8-15 shows a typical engine power curve. The curve labeled engine power shows the horsepower produced by the engine versus engine speed. The curve immediately below it, labeled shaft power shows the SHP delivered at the propeller after losses through the gearing. The propeller power curve shows the horsepower used by a typical propeller at various engine speeds.

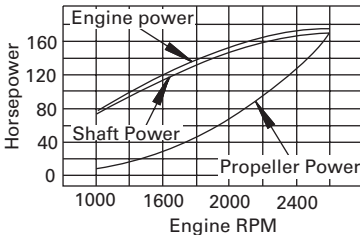


FIGURE 8-15: Typical Engine Power Curve

Unfortunately, the propeller power curve doesn't match the engine power curve and at lower RPMs the propeller draws less power than the engine is able to produce. There is no cure for this; it's just the way it is. The propeller is selected so that the propeller curve meets the shaft power curve at the engine's maximum rated horsepower and RPM. In this way, we can deliver the most power to the propeller when it is needed. Normally, the engine will be run around 80 percent of maximum RPM, so the engine will have reserve power available and will operate under much less strain. Also, the excess engine power is available for additional uses such as driving alternators or hydraulic systems.

Overpropping moves the propeller curve upward on the graph so that the intersection with the shaft power curve moves to the left and down, with the result that maximum horsepower and RPM achievable have been reduced.

Sizing the Propeller

Propeller sizing is beyond the scope of this little book and in general is a subject best left to the pros.

If you are getting different opinions on your propeller or are an avid do-it-yourselfer, get the *Propeller Handbook* by Dave Gerr, mentioned earlier in this chapter. It is the best text on the subject for the layman, and it explains in detail both the Crouch method and the more precise Bp- δ (Bp-delta) method. The Bp- δ method is the way to go if you want accuracy so get that book if you have reason to do these calculations yourself.

There are some computer programs on the market as well, and the propeller manufacturers have online forms you can fill out on their websites.

If you are thinking about repropping then you should have a (reputable) professional or naval architect perform the calculations.

SAMPLE LOGS AND CHECKLISTS

MAINTENANCE LOGS

Figure 8-16 is a sample boat maintenance log. It's too small to be useable but it should provide a model for setting up your own. A full size Excel spreadsheet of this and other forms are available for download at <http://www.anchorcovepublishing.com>.

ally remember for sure whether you changed the oil filter last fall?

- Keeping it will act as your conscience; having to omit a log entry because you didn't do the scheduled work will, hopefully, tend to make you feel guilty (and therefore maybe get the work done).
- A detailed log will really help when it comes time to sell the boat. This will prove to the buyer that this boat was conscientiously and meticulously maintained.
- If you are actually doing all the scheduled maintenance work, the time it takes to make the entries is miniscule compared to the time it takes to do the work.

TOOLS AND SPARES

Any boat needs to have a minimum set of tools and spare parts. Here is a list of some of the more common tools that should be kept onboard permanently, grouped approximately by boat length. This list should be viewed as a minimum required list, since there will be many additional specialized tools for specific hardware and equipment on a particular boat.

Many of these tools are available in stainless steel from marine supply stores and are not much more expensive than good tools from your local hardware store. A complete set of tools like those recommended here is not particularly expensive, and with tools, unlike lot of consumer goods, quality is generally correlated with price. A cheap tool that breaks might end being the most expensive tool you ever bought when you need it to do an emergency repair at sea.

A list of suggested electrical tools is given separately in the electrical chapter.

Example Onboard Toolkit

Tool	< 25ft 8m	< 40ft 12m	> 40ft 12m	Off- shore
#1 phillips screwdriver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
#2 phillips screwdriver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
#3 phillips screwdriver			<input type="checkbox"/>	<input type="checkbox"/>
#4 phillips screwdriver				<input type="checkbox"/>
#1 phillips stubby screwdriver		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
#2 phillips stubby screwdriver		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
#3 phillips stubby screwdriver			<input type="checkbox"/>	<input type="checkbox"/>
3/16" slotted screwdriver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1/4" slotted screwdriver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Tool	< 25ft 8m	< 40ft 12m	> 40ft 12m	Off- shore
5/16" slotted screwdriver			<input type="checkbox"/>	<input type="checkbox"/>
3/8" slotted screwdriver				<input type="checkbox"/>
3/16" slotted stubby screwdriver		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1/4" slotted stubby screwdriver		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5/16" slotted stubby screwdriver			<input type="checkbox"/>	<input type="checkbox"/>
8" slip-joint pliers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10" groove-joint (waterpump) pliers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6-1/2" needlenose pliers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6-1/2" diagonal (side-cut) pliers		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7" linemans pliers		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
snap-ring (inside) pliers			<input type="checkbox"/>	<input type="checkbox"/>
snap-ring (outside) pliers			<input type="checkbox"/>	<input type="checkbox"/>
6" adjustable (crescent) wrench	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8" adjustable (crescent) wrench		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10" adjustable (crescent) wrench			<input type="checkbox"/>	<input type="checkbox"/>
12" adjustable (crescent) wrench				<input type="checkbox"/>
15" adjustable (crescent) wrench				<input type="checkbox"/>
6" vise grip long nose wrench	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7" vise grip wrench		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10" vise grip wrench			<input type="checkbox"/>	<input type="checkbox"/>
14" pipe wrench			<input type="checkbox"/>	<input type="checkbox"/>
18" pipe wrench				<input type="checkbox"/>
5/16"-3/4" combination (box/open) wrench		<input type="checkbox"/>		
5/16"-1" combination (box/open) wrench			<input type="checkbox"/>	<input type="checkbox"/>
10-19mm combination (box/open) wrench		<input type="checkbox"/>		
10-26mm combination (box/open) wrench			<input type="checkbox"/>	<input type="checkbox"/>
3/8" drive ratchet wrench		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1/2" drive ratchet wrench			<input type="checkbox"/>	<input type="checkbox"/>
5/16"-3/4" american (imperial) socket set		<input type="checkbox"/>	<input type="checkbox"/>	
5/16"-1" american (imperial) socket set				<input type="checkbox"/>
10-19mm metric socket set		<input type="checkbox"/>	<input type="checkbox"/>	
10-26mm metric socket set				<input type="checkbox"/>
spark plug sockets for your engines		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1/16"-3/8" allen wrench set			<input type="checkbox"/>	<input type="checkbox"/>
1.5-10mm allen wrench set			<input type="checkbox"/>	<input type="checkbox"/>
oil filter wrench		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Tool	< 25ft 8m	< 40ft 12m	> 40ft 12m	Off- shore
fuel filter wrench		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
claw hammer	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
ballpeen hammer			<input type="checkbox"/>	<input type="checkbox"/>
utility (drywall) knife	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6" standard knife	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25' steel measuring tape	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
hacksaw		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
scissors	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
tin snips			<input type="checkbox"/>	<input type="checkbox"/>
pulley puller			<input type="checkbox"/>	<input type="checkbox"/>
propeller puller			<input type="checkbox"/>	<input type="checkbox"/>
battery connector puller			<input type="checkbox"/>	<input type="checkbox"/>
>12 V cordless drill			<input type="checkbox"/>	<input type="checkbox"/>
1/16"-1/2" drill bits			<input type="checkbox"/>	
1/16"-1" drill bits				<input type="checkbox"/>
vise				<input type="checkbox"/>
clamps				<input type="checkbox"/>
level				<input type="checkbox"/>
woodworking chisels				<input type="checkbox"/>
cold chisels				<input type="checkbox"/>
duct tape	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
feeler gauge set				<input type="checkbox"/>
files				<input type="checkbox"/>
sandpaper, wet or dry 140 - 400 grit			<input type="checkbox"/>	<input type="checkbox"/>
emery cloth		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
tap & die set				<input type="checkbox"/>
tapered punches				<input type="checkbox"/>
straight punches				<input type="checkbox"/>
WD-40		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
hand cleaner		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
silicon seal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
fiberglass patch kit			<input type="checkbox"/>	<input type="checkbox"/>
magnetic part retriever		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
plastic wire ties			<input type="checkbox"/>	<input type="checkbox"/>

Example Spare Parts List

Item	
Engines	
Engine oil	<input type="checkbox"/>
Oil filters	<input type="checkbox"/>

Item	
Transmission fluid	<input type="checkbox"/>
Fuel filters	<input type="checkbox"/>
Cooling pump impellers	<input type="checkbox"/>
Cooling pump gaskets	<input type="checkbox"/>
Gasket cement	<input type="checkbox"/>
Engine thermostats	<input type="checkbox"/>
Engine belts	<input type="checkbox"/>
Spare injectors & nozzles	<input type="checkbox"/>
Electrical	
Spare alternator	<input type="checkbox"/>
Alternator parts	<input type="checkbox"/>
Spare voltage regulator	<input type="checkbox"/>
Brushes for Motors & Generators	<input type="checkbox"/>
Fuses — spares for all	<input type="checkbox"/>
Bulbs — spares for all	<input type="checkbox"/>
Miscellaneous Other	
Greases	<input type="checkbox"/>
Silicone grease	<input type="checkbox"/>
Lithium grease	<input type="checkbox"/>
Grease gun	<input type="checkbox"/>
WD-40	<input type="checkbox"/>
Silicone spray	<input type="checkbox"/>
Spare zincs	<input type="checkbox"/>
Spare hoses	<input type="checkbox"/>
Wooden plugs	<input type="checkbox"/>
Hose clamps for all hoses	<input type="checkbox"/>
Assortment stainless nuts, bolts, screws	<input type="checkbox"/>

Maintenance Checklists

These lists are provided only as samples. The boat owner should make his own preventative maintenance schedule based on the engine and other manuals provided with the boat.

These sample checklists associate 50 hours with a month regardless of the maintenance task, which is not what is actually encountered. For example, the manufacturer may recommend the engine oil be changed every 100 hours or every six months, but the pump impeller checked every 300 hours or six months.

All inspection should be noted as carried out in the maintenance log. All fluid additions or changes should be logged. Any repairs and/or parts installed should be logged.

Before Starting / Daily

Check these items at least once per day or on the first engine start of the day. For each engine including the generator.

Check oil level (if any added log hours and amount)	<input type="checkbox"/>
Check hydraulic fluid	<input type="checkbox"/>
Check coolant level (if any added log hours and amount)	<input type="checkbox"/>
Check transmission oil (if any added log hours and amount)	<input type="checkbox"/>
Check secondary fuel filter	<input type="checkbox"/>
Check primary fuel filter	<input type="checkbox"/>
Check any other fuel filters	<input type="checkbox"/>
Check sea strainers	<input type="checkbox"/>
Check for any fluid leaks	<input type="checkbox"/>
Check stuffing boxes	<input type="checkbox"/>
Belts visual check (powder, floppiness) —log changes	<input type="checkbox"/>
Bilge water level	<input type="checkbox"/>
Visual inspection all around engine	<input type="checkbox"/>
Visual inspection engine room	<input type="checkbox"/>

Periodic Checks While Underway**Bridge**

Check these items every 1 or 2 hours and enter readings in a log. You might opt to keep a separate day log for these entries rather than keeping them in your primary maintenance log. When the engine is new or recently repaired or overhauled, do this even more frequently, like twice an hour.

Engine Temperature (check and log temperature)	<input type="checkbox"/>
Oil Pressure (check and log pressure)	<input type="checkbox"/>
Exhaust temperature (check and log temperature)	<input type="checkbox"/>
Any other critical gauges (check and log)	<input type="checkbox"/>

Engine Room

This is just a quick visual looking for anything unusual. Set a schedule such as every 1 or 2 hours. Enter in the log that the check was made.

Smoke	<input type="checkbox"/>
Belts visual check (powder, floppiness) —log changes	<input type="checkbox"/>
Bilge water level	<input type="checkbox"/>
Check for any fluid leaks	<input type="checkbox"/>
Unusual noises	<input type="checkbox"/>
Vacuum gauges	<input type="checkbox"/>

25 Hours or Weekly

Carry out these every 25 hours or every week, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Close visual inspection of wet exhaust system when cold	<input type="checkbox"/>
Check wet exhaust for leaks underway	<input type="checkbox"/>
Check all fuel lines for leaks	<input type="checkbox"/>
Check oil lines for leaks	<input type="checkbox"/>
Check raw water lines for leaks	<input type="checkbox"/>
Check fresh water cooling lines for leaks	<input type="checkbox"/>
Check for leaks anywhere else you can think of	<input type="checkbox"/>
If engines have not been run for a week, run them for 5 to 10 minutes at 1600 to 1800 RPM	<input type="checkbox"/>

50 Hours or Monthly

Carry out these every 50 hours or every month, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Remove and test all engine alarm lights	<input type="checkbox"/>
Test engine audible alarms	<input type="checkbox"/>
Check hoses for hardening or softening or other damage	<input type="checkbox"/>
Propeller shaft coupling check	<input type="checkbox"/>
Check battery electrolyte level	<input type="checkbox"/>

150 Hours / 3 months

Carry out these every 150 hours or every 3 months, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Inspect anti-siphon on raw water discharge to exhaust	<input type="checkbox"/>
Engine zinc inspect	<input type="checkbox"/>
Operate all sea cocks	<input type="checkbox"/>

300 Hours / 6 months

Carry out these every 300 hours or every 6 months, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Change engine oil	<input type="checkbox"/>
Change engine oil filter	<input type="checkbox"/>
Change primary fuel filter element	<input type="checkbox"/>
Replace air cleaner	<input type="checkbox"/>
Remove cover and inspect raw water impeller	<input type="checkbox"/>
Remove cover and inspect fresh water pump	<input type="checkbox"/>

600 Hours / 1 Year

Carry out these every 600 hours or every year, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Check belt tension and wear	<input type="checkbox"/>
Check valve clearances —adjust if necessary	<input type="checkbox"/>
Clean crankcase vent tube	<input type="checkbox"/>
Change secondary fuel filter element	<input type="checkbox"/>
Check injectors	<input type="checkbox"/>
Replace raw water impeller	<input type="checkbox"/>
Flush fresh water cooling circuit and change coolant	<input type="checkbox"/>
Engine alarm system test (probably requires a professional)	<input type="checkbox"/>

1200 Hours / 2 Years

Carry out these every 1200 hours or every 2 years, whichever comes first. Note: This list is not for use. It is a sample to provide a starting point for a checklist customized to your boat. Maintenance intervals recommended by your engine builder should be used rather than the intervals shown here.

Wet exhaust system, disassemble, inspect	<input type="checkbox"/>
Fuel cooler disassemble, inspect, clean	<input type="checkbox"/>
Heat exchanger disassemble, inspect, clean	<input type="checkbox"/>
Intercooler disassemble, inspect, clean	<input type="checkbox"/>
Oil cooler disassemble, inspect, clean	<input type="checkbox"/>
Transmission cooler, disassemble, inspect, clean	<input type="checkbox"/>
Check fuel injection pump	<input type="checkbox"/>

Winterize or Long-Term Layup

These are basic tasks that should be carried as a part of winterizing or before a long-term layup. This is by no means a complete list. Consider doing many of the things you normally do in the spring when recommissioning.

Engine

Gasoline —if possible drain and run carburetor dry. If not use stabilizer

Change engine oil before long term layup — don't wait until spring

Change transmission oil before long term layup — don't wait until spring

Flush and change coolant (antifreeze) in the freshwater circuit -don't wait until spring

Drain the raw water circuit completely

Remove, inspect, clean, gap, spark plugs

Spray oil into air intake while cranking the engine. Don't start the engine while doing this. Gasoline engines can remove spark plugs and squirt oil directly into cylinders

Grease all grease fittings and parts

Cover engine openings including exhaust

Shaft and Propeller

Remove, clean, inspect, propeller (repair if necessary)

Inspect shaft for excessive play, check for stuffing box leaks

Other Systems

Add fuel stabilizer if not draining fuel

Drain entire fresh water system including water heater. Use propylene glycol if antifreeze is used

Drain and flush blackwater system.

Test the bilge pumps especially if the boat is staying in the water

Electrical / Electronics

Remove electronics —they will winter better in your house than in the salt air. Less likelihood of theft too

Fully charge batteries. Batteries must be topped up once per month while laid up or be on continuous maintenance charge

Recommission after Long-Term Layup

These are tasks that should be carried as a part of recommissioning after a long-term layup. This is by no means a complete list. Consider doing many of these things when laying up for the winter.

Engine

Uncover all the engine openings covered at layup	<input type="checkbox"/>
Change engine oil if you didn't do it before layup like you should have	<input type="checkbox"/>
Change transmission oil if not done before layup	<input type="checkbox"/>
Change coolant (antifreeze) in the freshwater circuit if not done before layup	<input type="checkbox"/>
Clean carburetor, adjust linkages	<input type="checkbox"/>
Change air filter	<input type="checkbox"/>
Remove spark plugs, inspect and clean	<input type="checkbox"/>
Raw water pump remove cover. Remove, inspect, light grease raw water impeller. Consider replacing with a new one, regardless of condition, it's cheap insurance	<input type="checkbox"/>
Check and clean raw water intake strainers	<input type="checkbox"/>
Remove cover and inspect fresh water pump	<input type="checkbox"/>
Check fuel lines for cracks, leaks, wear, etc.	<input type="checkbox"/>
Check, clean or replace fuel filters	<input type="checkbox"/>
Check all hoses for condition. Replace if soft, worn, cracked or otherwise damaged	<input type="checkbox"/>
Inspect all belts, replace if necessary	<input type="checkbox"/>
Inspect exhaust system closely (particularly wet exhaust)	<input type="checkbox"/>
Grease any grease fittings	<input type="checkbox"/>
Control cables and pulleys, inspect, adjust, lubricate	<input type="checkbox"/>
Check propeller shaft coupling	<input type="checkbox"/>

Other Systems

Check the log to see what might have been missed when laying up. Carry out the omitted tasks.	<input type="checkbox"/>
Steering cables and pulleys, inspect, adjust and lubricate	<input type="checkbox"/>
Steering hydraulics, inspect, test, top up fluid	<input type="checkbox"/>
Check for worn hoses and clamps	<input type="checkbox"/>
Check bilge and engine room exhaust blower	<input type="checkbox"/>
Check bilge pump screens	<input type="checkbox"/>
Check operation of all bilge pumps, lift floats to test	<input type="checkbox"/>
Check all openings and intakes for spider, insect, or animal nests.	<input type="checkbox"/>
Inspect all through-hulls	<input type="checkbox"/>
Operate all seacocks	<input type="checkbox"/>
Drain antifreeze, inspect water tanks and system	<input type="checkbox"/>
Test operate heads	<input type="checkbox"/>
Test run all mechanical equipment	<input type="checkbox"/>

Recommission after Long-Term Layup

Recommission after Long-Term Layup	
Safety	
Check inventory of safety equipment	<input type="checkbox"/>
Fire extinguishers, check expiration and charge	<input type="checkbox"/>
Test sound signaling equipment	<input type="checkbox"/>
Flares, check expiration, replace if necessary	<input type="checkbox"/>
Test gasoline fume detectors	<input type="checkbox"/>
Test carbon monoxide detectors	<input type="checkbox"/>
Electrical	
Batteries fully charged	<input type="checkbox"/>
Check battery electrolyte level, top-up	<input type="checkbox"/>
Terminal posts clean and greased	<input type="checkbox"/>
Inspect all electrical connections and wiring	<input type="checkbox"/>
Charging system check	<input type="checkbox"/>
Test run all electrical systems	<input type="checkbox"/>
Test run all electronics	<input type="checkbox"/>