Fuel savings for small fishing vessels

A manual

Cover photo:

FAO designed beach landing boat on the east coast of India fitted with a 10 hp diesel engine and liftable propulsion (the "BOB-drive"). FAO/O. Gulbrandsen.

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Preparation of this document

This manual is based on the FAO Fisheries Technical Paper No. 383, *Fuel and financial savings for operators of small fishing vessels* published in 1999, and on the Bay of Bengal Programme publication BOBP/WP/27, *Reducing the fuel costs of small fishing boats*, published in 1986 by FAO/SIDA. Due to the recent fuel crisis, a new emphasis has been placed on energy conservation in fisheries and on research programmes related to energy use in fisheries worldwide. Information from various sources has been included in the References and Additional Reading sections of this manual.

This manual is aimed at assisting small fishing vessel owners and operators together with boat designers and boatbuilders in reducing fuel consumption. It also serves as a guide for those involved with fuel savings for small vessels used in support of aquaculture activities.

Preparation of this manual was funded by the government of Norway and by the FAO Fisheries and Aquaculture Department and completed under the supervision of Ari Gudmundsson, Fishery Industry Officer (Vessels), Fishing Operations and Technology Service.

Abstract

The recent sharp increase in the price of fuel has had a major impact on the economics of operating fishing vessels. Fishing boat owners and operators struggle to meet this challenge and ask what measures can be taken to reduce the heavy burden of increased fuel cost. Litres of fuel required per tonne of fish landed varies widely depending on the fish specia and fishing method used. Fuel saving methods have to be tailored to each fishing method and fishery.

This manual aims to provide practical advice to fishing boat owners and crews, boatbuilders and boat designers and fisheries administrators on ways to reduce fuel costs. It focuses on small fishing boats measuring up to 16 m (50 ft) in length and operating at speeds of less than 10 knots. This covers the majority of the world's fishing boats. It also serves as a guide for those involved with fuel savings for small vessels used in support of aquaculture activities. The manual provides information to boat designers and boat builders on hull shape for low resistance and the selection of efficient propellers.

The first chapters of this manual deal with fuel saving measures that can be taken on existing boats without incurring major investment costs. The most effective measures include reducing boat service speed, keeping the hull and propeller free from underwater fouling and maintaining the boat engine. It also suggests that changing fishing methods can save fuel.

The final chapters of this manual provide information regarding the fuel savings that are possible by changing from a 2-stroke outboard engine to a diesel engine, installing a diesel engine, and using sail. Selecting economic engine power on the basis of the waterline length and the weight of the boat is discussed. Advice is given on the choice of gear reduction ratio and of propeller related to service speed, service power and propeller rpm. Data are provided to assist with the design of a new fuel-efficient boat and the selection of an optimum propeller.

The information contained in this manual is accompanied by many illustrations to make the main points more easily understood. Detailed background information is provided in the appendices. The appendices also contain blank tables that may be used to calculate potential fuel savings, cost of engine operation, the weight of a boat and the diameter and pitch of a propeller.

Gulbrandsen, O. 2012. *Fuel savings for small fishing vessels - a manual.* Rome, FAO. 57 pp.

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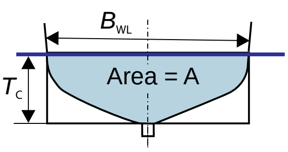
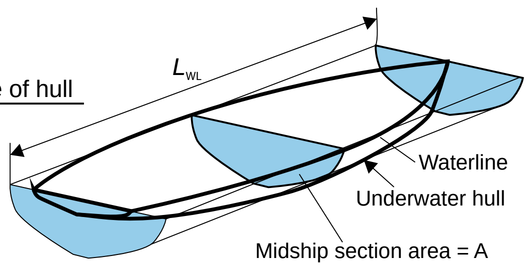
ABBREVIATIONS AND ACRONYMS

BOBP	Bay of Bengal Programme
cm	centimeter
CUNO	cubic number = length overall x beam x depth moulded (see Appendix 5)
DANIDA	Ministry of Foreign Affairs of Denmark
FAO	Food and Agriculture Organization
FRP	fibre reinforced plastic
ft	feet
GPS	global positioning system
hp	horsepower: 1 hp = 75 kgm/s = 0.735 kW; 1 kW = 1.36 hp
ISO	International Organization for Standardization
kg	kilogram
knot	1 nautical mile per hour
kW	kilowatt
kWh	kilowatt hour
lb	pound
LCA	life cycle energy analysis
m	metre
mm	millimetre
nm	nautical mile = 1 852 m
NPV	net present value
RM	righting moment
rpm	revolutions per minute
SIDA	Swedish International Development Cooperation Agency
TBT	Tribultyltin

$$\text{Midship section coefficient} = \frac{\text{Area A}}{B_{WL} \times T_c}$$



$$\text{Prismatic coefficient} = \frac{\text{Underwater volume of hull}}{\text{Area A} \times L_{WL}}$$



L_H = Length over all

L_{WL} = Length in waterline

B_{WL} = Beam in waterline

T_c = Draft midship

declared crankshaft power	continuous power at the engine output shaft without a reduction gear.
declared propeller shaft power	continuous power as given by the engine manufacturer according to ISO 8665 at the propeller shaft coupling, including a reduction gear.
light displacement	weight of a boat without a load.
propeller effective power	propeller shaft power x propeller efficiency.
service displacement	weight of the boat with a service load of crew, fishing gear, water, fuel, fish and ice. A service load is often taken as ½ of a maximum load.
service speed	average speed in knots of the boat at sea with average wind and wave condition.
tonne	tonne = 1 000 kg: close to 1 long ton = 1 016 kg.

INTRODUCTION

The fishing industry today is highly dependent on fuel energy for propulsion of the fishing boats and operation of the fishing gear. The recent rise in fuel prices has created problems for fishers in both developed and developing countries because the rise in operational costs cannot be offset by increasing the price of fish. In addition, there is a greater awareness of the effects that the use of combustion engines has on the climate.

The aim of this manual is to present the existing knowledge of fuel saving methods in a way that will be more understandable to fishers, boat owners, boat designers and fisheries administrators. Also, horsepower (hp) rather than kilowatt (kW) is used as a unit of measure for engine power because it is a more familiar unit.

This manual deals with small fishing vessels measuring up to 16 m (50 ft) in length. The reason for the emphasis on smaller boats is because the owners and operators of these boats have less access to assistance from naval architects, engine suppliers and others than do owners and operators of larger boats. However, the main principles of fuel saving such as reduced speed and use of low engine rpm and large diameter propeller are the same for large and small boats.

This manual aims to be as practical as possible by giving specific advice on the selection of engine power, hull shape and service speed. The wrong choice of propeller is a common cause of fuel wastage and this manual provides tables to facilitate choosing the right propeller diameter and pitch for engines up to 50 hp running at a speed of up to 8 knots.

The quantity of fuel required to catch and land one tonne of fish varies greatly with the fishing method used and the fish resource sought. The strength of the fish resource is of major importance concerning fuel use. Fishing a poor fish resource results in more fuel being used per tonne of fish landed. The main priority of a government, in collaboration with the fishers, is to manage the fishery in a sustainable way.

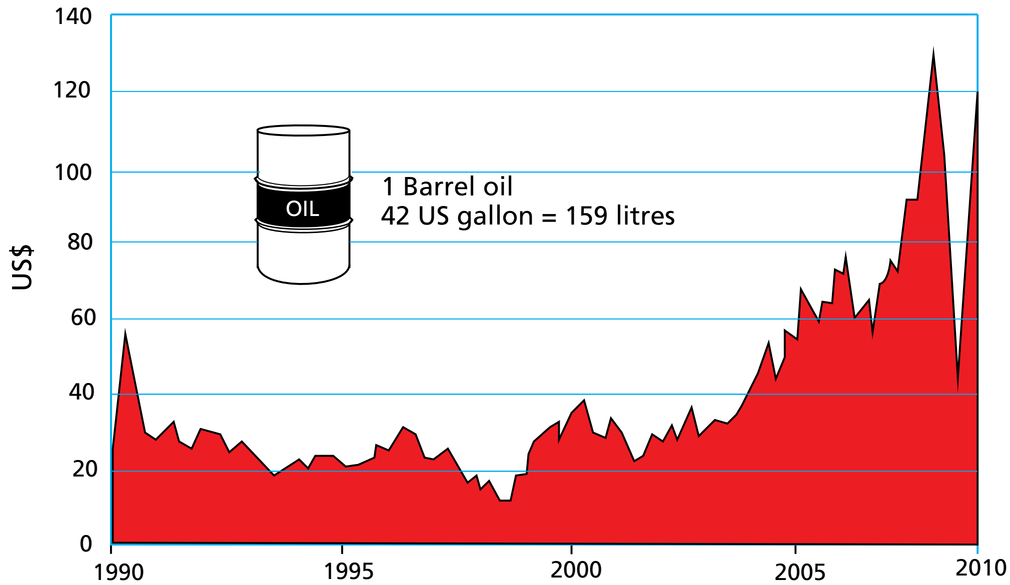
The relatively low investment cost of the 2-stroke outboard engine has made this engine popular among artisanal fishers in developing countries. With the increase in fuel prices, the operational cost of these engines is very high. Rather than subsidizing fuel, financial assistance schemes should aim to provide assistance to fishers for the purchase of inboard diesel engines.

Until recently, low fuel prices encouraged a trend towards increasing engine power in fishing boats all around the world, and especially in developed countries where, because of high salaries, fuel cost was a smaller portion of the total cost of operation. The choice of engine power is often based on irrational grounds such as the prestige and status of having a boat slightly faster than that of other fishers. 'Greed for speed' is found everywhere.

For most fishing vessels operating passive fishing gear such as gillnets and lines, there is no better way to save fuel than to reduce the service speed. Also, trawlers can reduce speed travelling to and from fishing grounds, although they require high engine power to drag the trawl. Fuel savings for trawlers must be achieved through modifications to the propeller and nozzle, trawl doors and the net or, alternatively, a changeover to such fishing methods as pair trawling or Danish seining.

This manual deals mainly with boats operating at a displacement speed of up to 10 knots. Increasing speed beyond 10 knots is justified only by increasing catches. For example, trolling for tuna requires speed to catch up to the fast moving tuna schools.

The potential for saving fuel is greatest when planning a new boat: the engine can be matched to the size and weight of the boat, a large diameter, low rpm propeller can be selected and the shape of the hull can be designed to give minimum resistance.



The world price of one barrel of crude oil

Diesel fuel, gasoline and kerosene are produced by refining crude oil. The prices of these fuels to the fishers will follow the prices of crude oil adjusted for taxes or subsidies.

The price of diesel fuel paid by fishers shows great variation around the world, from countries with high subsidies such as Saudi Arabia (US$0.15 per litre) to countries with high taxation such as Norway (US$1.50 per litre in November 2010).

During the 15 years between 1990 and 2005, fuel prices were low, which encouraged the use of high powered engines, trawling as the fishing method and the operation of distant-water fishing fleets for high value species such as tuna.

The price of fuel increased dramatically in 2008. It has since dropped but is currently on the rise again. Because of the increased demand for fuel in the developing countries and a lack of new oil fields, a rise in fuel costs is expected.

Rising fuel costs cannot always be offset by raising fish prices

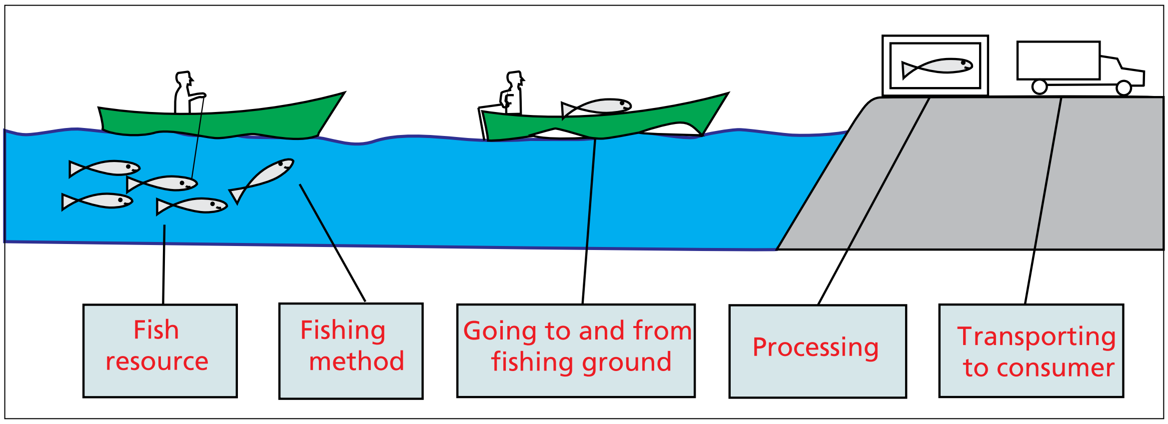
Now is the time to look into ways for saving fuel

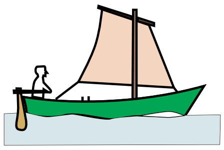
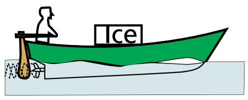
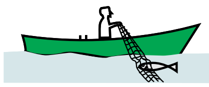
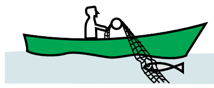
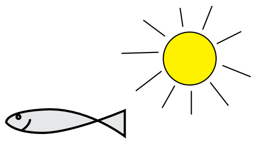
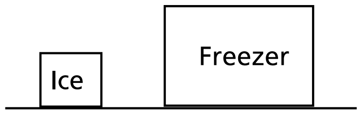
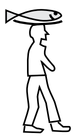
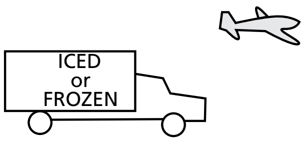
- Fuel savings will benefit the fisher.
- Fuel savings will benefit the consumer.
- Fuel savings will benefit the climate.

Climate change

Exhaust gases from power stations producing electricity by burning coal or oil and exhaust gases from the engines of cars, trucks, ships and fishing boats include greenhouse gases such as Co_2 and NO_x. Greenhouse gases have already caused an alarming rise in temperature. The rise in temperature will affect life in the sea and will cause sea levels to rise. Fishers living along the coasts will be among the first to be affected.

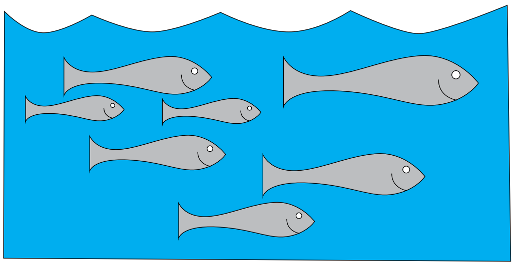
The amount of energy required to catch fish and bring them to the consumer depends on many things



	Pre-industrial methods Human and solar energy	Industrial methods Fuel energy 100–3000 litres of diesel per tonne
Going to and from fishing grounds	 Human power or wind	 Engine power
Hauling fishing gear	 Human power	 Mechanical hauler
Processing	 Sun drying, smoking and salting	 Icing or freezing
Transporting to consumers	 Human, animal power or boat	 Truck, train, boat or plane

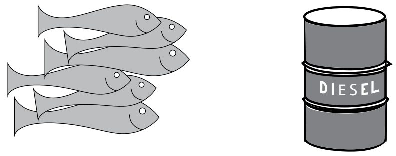
Because most of the energy used in fisheries today is in the form of liquid fuel, litres of diesel fuel will be used as a measure of energy consumption in this manual.

Sustainable fishing means preventing overfishing so that the fish resource will sustain high catches for generations

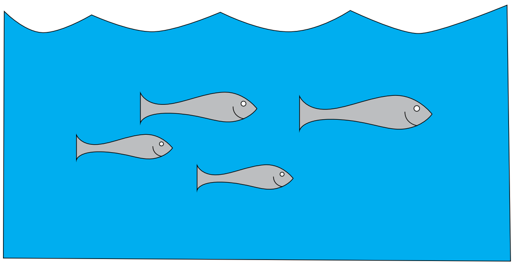


Good fish resource

The catch per trip is high.
Time is not lost and fuel is not consumed searching for fish.

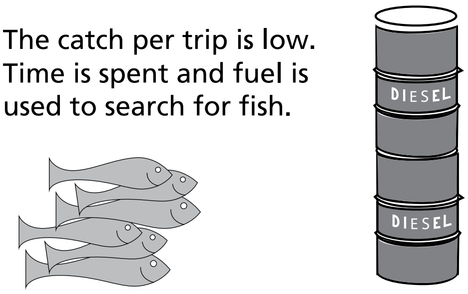


1 tonne of fish 200 litres of diesel



Poor fish resource

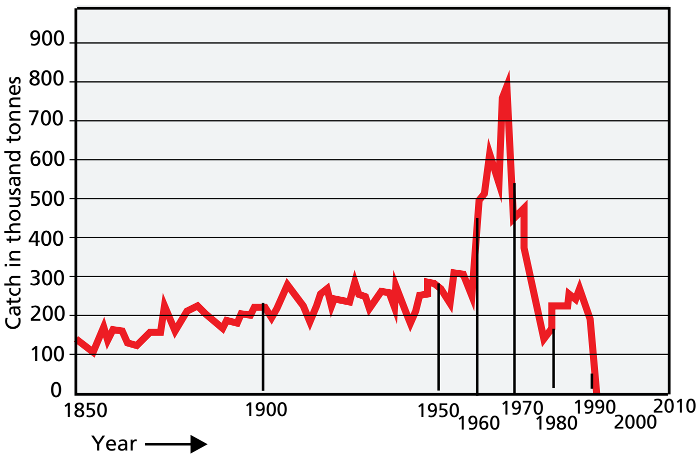
The catch per trip is low.
Time is spent and fuel is used to search for fish.



1 tonne of fish 400 litres of diesel

A case of overfishing and poor management

The fishing grounds off Newfoundland were among the richest cod fishing grounds in the world.



The fishing method was originally handlining and longlining from small rowing boats, which delivered the catch to a sailing mothership. In the 1960s, large factory trawlers with modern fish-finding equipment were introduced and the catches increased to around 800 000 tonnes. It was realized too late that the resource could not sustain this development and all fishing for cod had to be stopped. The fish resource has still not recovered 20 years late. (Hannesson, 2008).

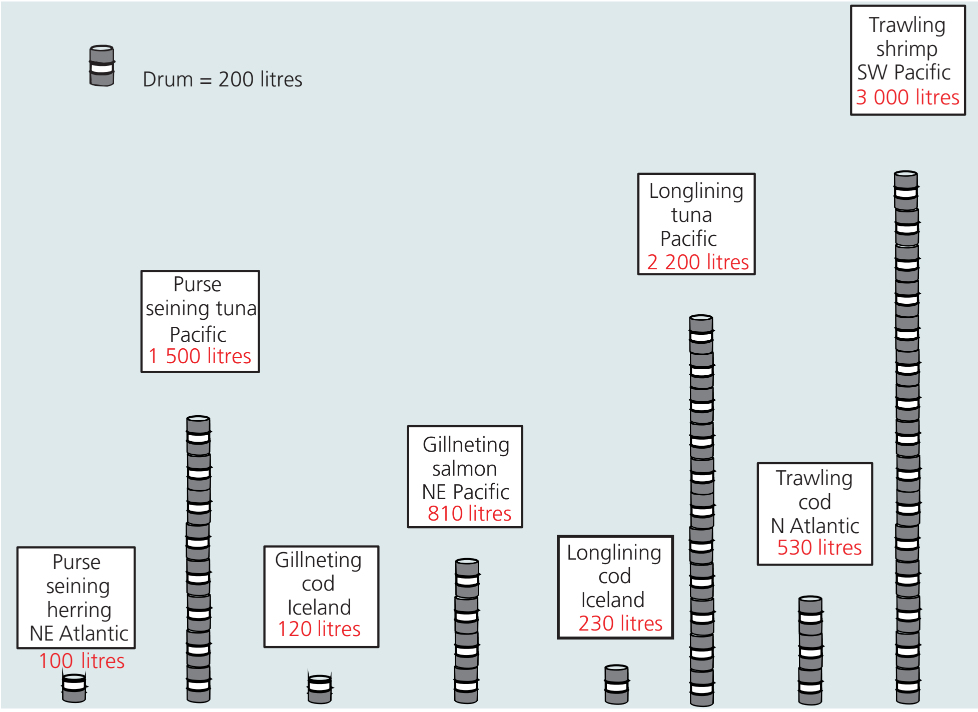
Preventing overfishing is in the fishers' own interest

Preventing overfishing can be accomplished in various ways through regulation:

- Designate a time of year when fishing is not allowed in order to protect fish when breeding.
- Regulate the type of fishing gear allowed. Set limitations on mesh size for gillnets and trawls.
- Regulate the quantity of fish allowed to be caught by each boat.
- Limit fishing in certain areas to a certain size of boat or to boats without engines.

Fuel efficiency = the fuel used to land 1 tonne of fish

The litres of diesel fuel needed to land 1 tonne = 1 000 kg of fish (live weight).



Source: Tyedemers, 2004; Arason, 2002.

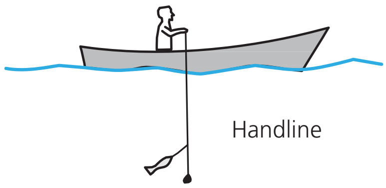
- Fuel consumption varies greatly and is related to the price the fish to be caught would fetch on the market. Fishing for resources such as shrimp and tuna, which command a high market price, encourages high fuel consumption. For example, to trawl for shrimp and tuna, which fetch high prices, longliners and purse seiners travel long distances from the base to the fishing area and use much fuel.
- Fishing for resources such as herring, which fetch low prices on the market, incurs low fuel consumption when the purse seining method is used.
- Fishing for resources such as cod, which fetch a medium price on the market, involves lower fuel consumption when static gear like gillnets and longlines are used rather than trawling gears.

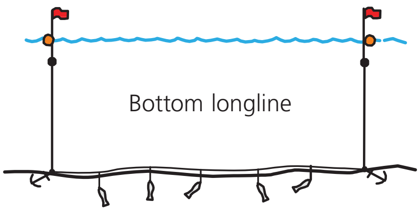
Fuel used in fishing boat operations = the main energy use in fisheries

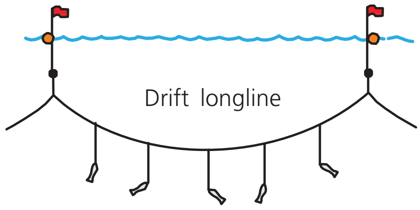
Life cycle energy analysis (LCA) shows that the energy used in building a boat is not significant compared with the fuel used in operating the boat. The use of light- weight materials such as aluminium, fibre reinforced plastic (FRP) and plywood in the construction of a boat can result in a slight energy saving during boat operation due to the lighter weight of the hull compared with the weight of a traditional hull of timber and steel construction (see Appendix 1).

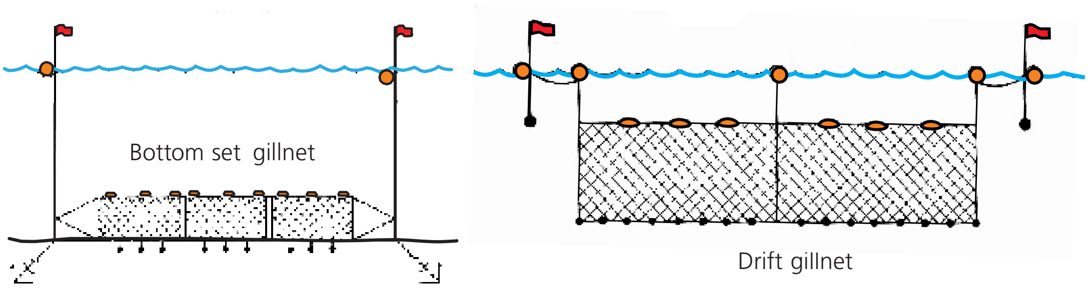
Air transport will greatly increase energy use

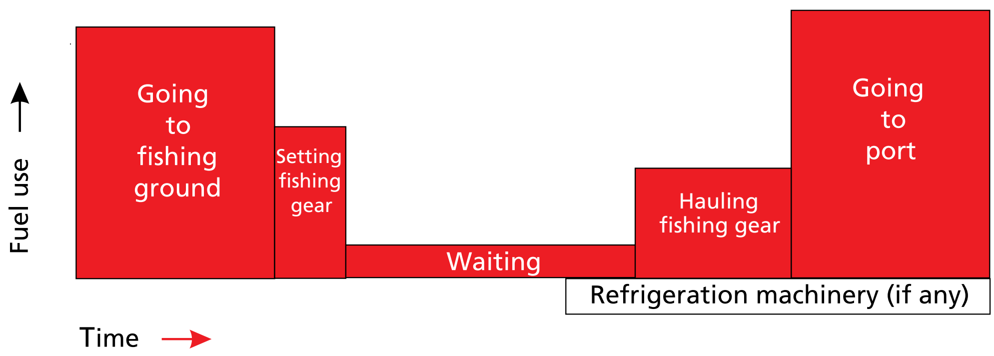
Air transport will greatly increase total energy use. Air transport of iced salmon from Norway to Japan uses energy equivalent to 3 600 litres of diesel fuel per tonne of fish, while transport of frozen salmon by container ship from Norway to Japan uses 390 litres per tonne of fish (Winther *et al.*, 2009).









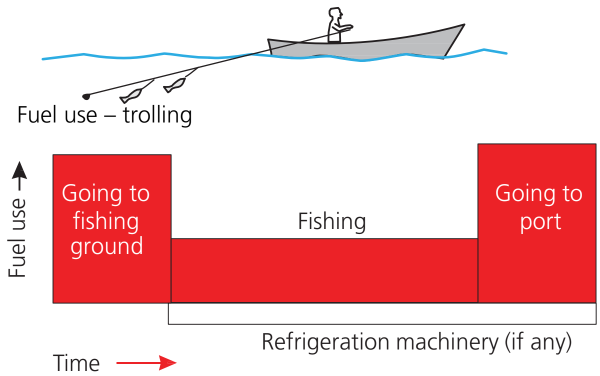


Fuel use – gillnetter or longliner

Most fuel is used to travel to and from fishing grounds. The setting and hauling of passive fishing gear can be done with human power or low engine power with mechanical or hydraulic haulers.

To save fuel

1. Reduce service speed.
2. Keep the hull free from fouling.
3. Use high gear reduction and an efficient propeller.
4. Changeover from a petrol outboard engine to a diesel engine.

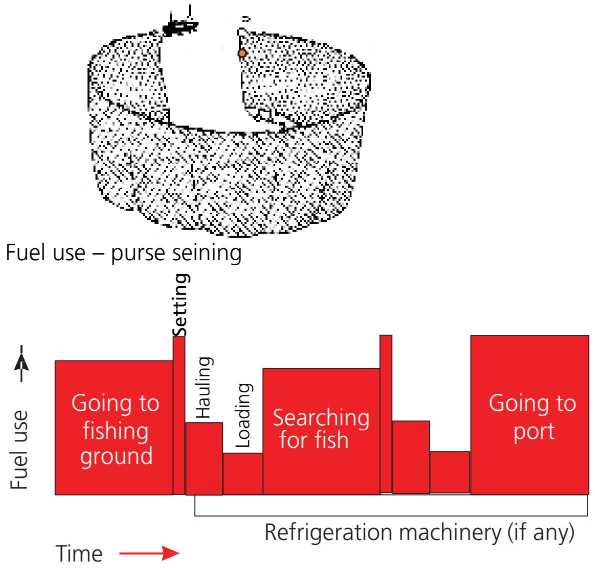


Trolling

Fuel is used both for travelling and for fishing.

To save fuel

1. Change over to a diesel engine.
2. Reduce service speed (except when fishing for tuna which require high speed).
3. Keep the hull free from fouling.
4. Install a high gear reduction and large diameter propeller.

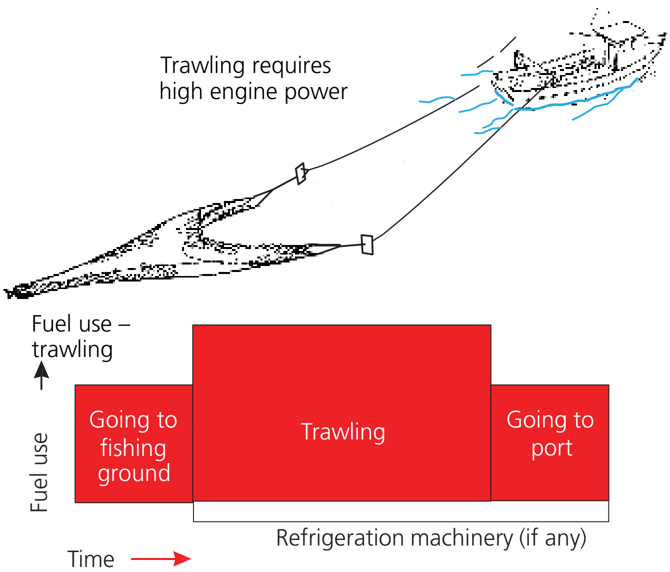


Purse seining

Most fuel is used going to and from fishing grounds and searching for fish.

To save fuel

1. Reduce service speed.
2. Install advanced fish-finding equipment.
3. Keep the hull free from fouling.
4. Install a high gear reduction and large diameter propeller.



Trawling

Most fuel is used to drag the trawl along the bottom (bottom trawling) or above the bottom (pelagic trawling). Reducing power going to and from fishing grounds saves fuel.

To save fuel

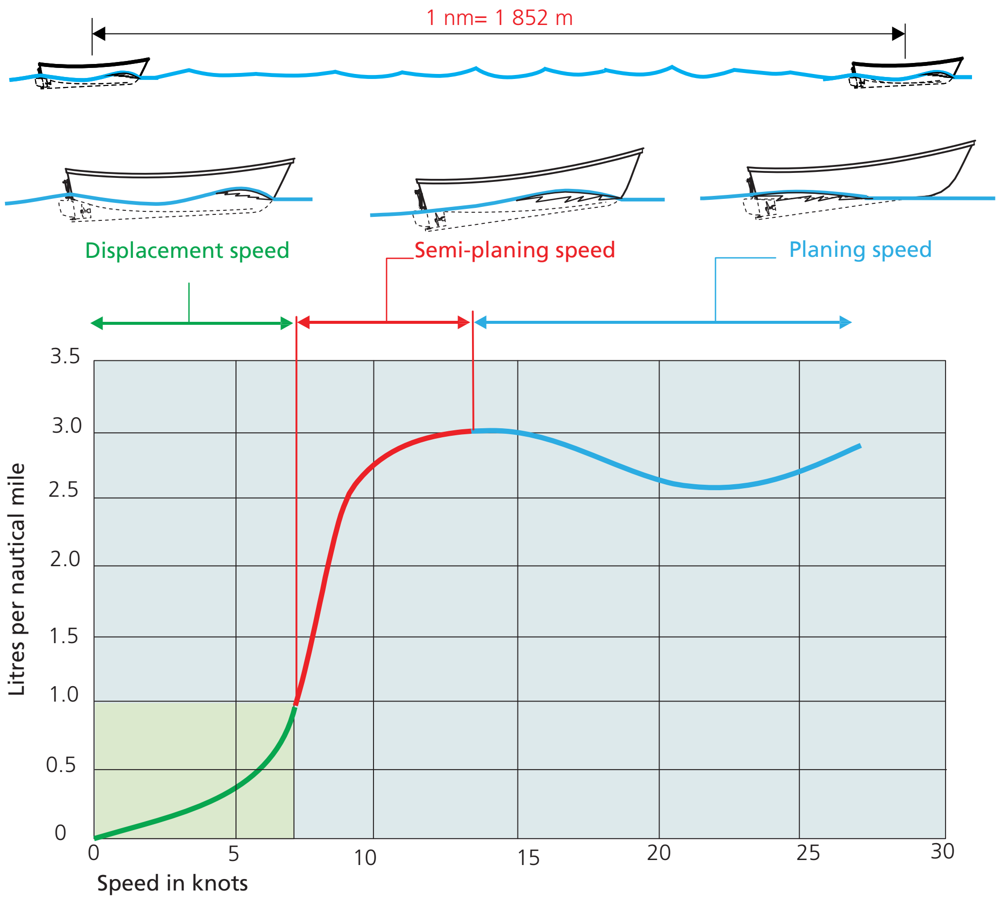
1. Modify the trawl and trawl boards.
2. Install the highest gear reduction available and a large diameter propeller with a propeller nozzle (depending on stern aperture).
3. Install advanced fish-finding equipment.
4. Consider a changeover in fishing method to pair trawling or Danish seining.

For most fishing methods, a major portion of the total fuel used is to go to and from fishing grounds

Exception: For most trawlers, a major portion of the fuel used is for pulling the trawl.

Speed at sea is measured in knots: 1 knot = 1 nautical mile (nm) per hour = 1 852 m per hour.

> Fuel efficiency is measured by the number of litres of fuel needed to travel 1 nm.



The diagram shows the measured fuel consumption per nm of a boat with the following characteristics:

Length overall = 10.35 m
Displacement = 6.3 tonnes
Installed power = 370 hp

The green area in the diagram shows the so-called displacement speed, the speed at which the boat operates at low fuel consumption per nm. At the semi-planing speed, fuel consumption increases rapidly. At the planing speed, the fuel consumption will first drop as the boat gets over 'the hump' and on to full planing and then will increase again. In this case, the best planing speed is 23 knots. Planing speed is justified only when the cost of time is high, the saved time can increase fishing time or when trolling for fast-moving fish schools like tuna.

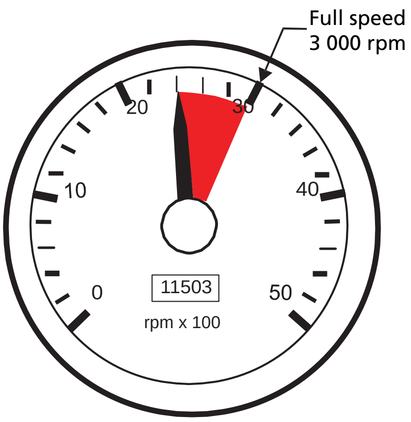
This manual deals only with displacement speed of boats up to 16 m in length.

This is a fuel flow measuring instrument.

Reducing speed is the easiest and most effective way to save fuel

Fuel consumption per nm is the best measure of fuel efficiency while travelling to and from the fishing ground.

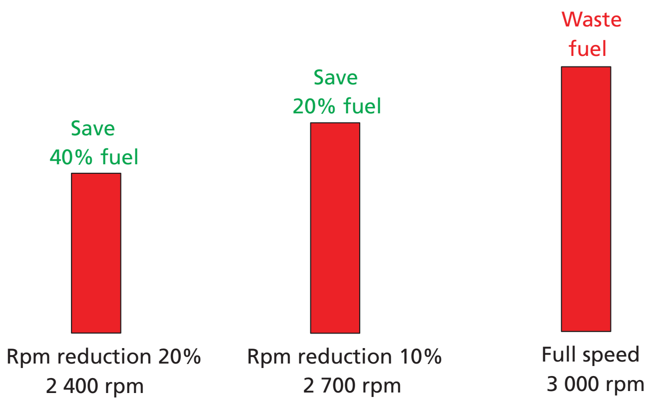
A fuel consumption instrument measures the fuel consumption in litres/hour or gallons/hour. Coupled to a GPS, it can show litres or gallons per nm. For a diesel engine it is necessary to measure both the fuel flow to the engine and the return fuel flow from the injectors to the tank.



A measuring instrument for fuel consumption is a very good investment

For a specific boat, one can use a 'home made' fuel consumption meter such as the one shown in Appendix 2 and calculate the fuel consumption per nm at different speeds by using a GPS. A table can then be made showing fuel consumption at different engine rpm.

The engine tachometer is the cheapest fuel saving instrument



However, reducing the engine rpm also reduces the speed of the boat. To find the real fuel saving, you must measure the speed of the boat and calculate the fuel consumption per nm:

The GPS will give the boat speed at various engine rpm.

$$\text{Litres/nm} = \frac{\text{fuel consumption per hour (litres/hour)}}{\text{boat speed in knots}}$$

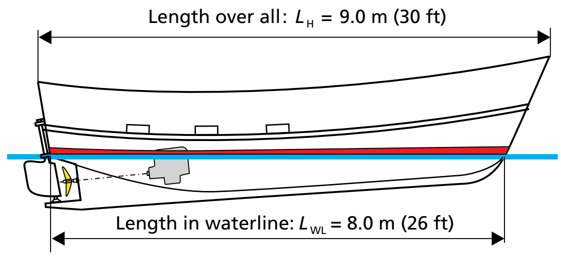
Fuel savings will depend on the size and type of boat and the power of the engine. By using the engine tachometer and a GPS, you can estimate how much fuel you save by reducing the engine rpm.

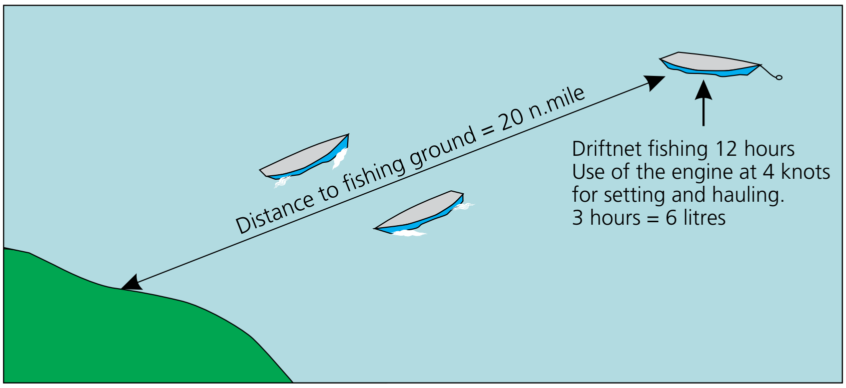
See Appendix 3 for a blank table to use for the calculation of fuel savings.

The following page gives an example.

SILVER FISH

Decked boat, length overall = 9 m (30 ft)
Service displacement: 5 000 kg = 5 tonnes (half load)
Engine: Declared shaft power = 31 hp (23 kW) continuous duty shaft power at 3000 rpm (ISO 8665)





Total distance per trip = 40 nm

1. Propeller shaft power

The declared power is 31 hp at 3000 rpm. This is measured at an air temperature of 20° Celsius and a humidity of 60%. The boat is operating in the tropics with high temperature and humidity and this will give an estimated 6% loss in power. The maximum actual power of the engine is: 0.94 x 31 = 29 hp at 3000 rpm.

As the engine rpm is reduced, the power of the engine follows the curve for the propeller power. The propeller power varies approximately as the rpm^3. At 3000 rpm the engine power = propeller power = 29 hp. If we reduce rpm by 10% to 2700 rpm, the engine power = propeller power = 0.73 x 29 hp = 21 hp. If we reduce engine rpm further by 20% to 2400 rpm, the engine power = propeller power = 0.51 x 29 = 15 hp.

By reducing the engine rpm 20% we have reduced the engine power by almost 50% and thereby reduced the fuel consumption by almost 50%.

2. Measurements

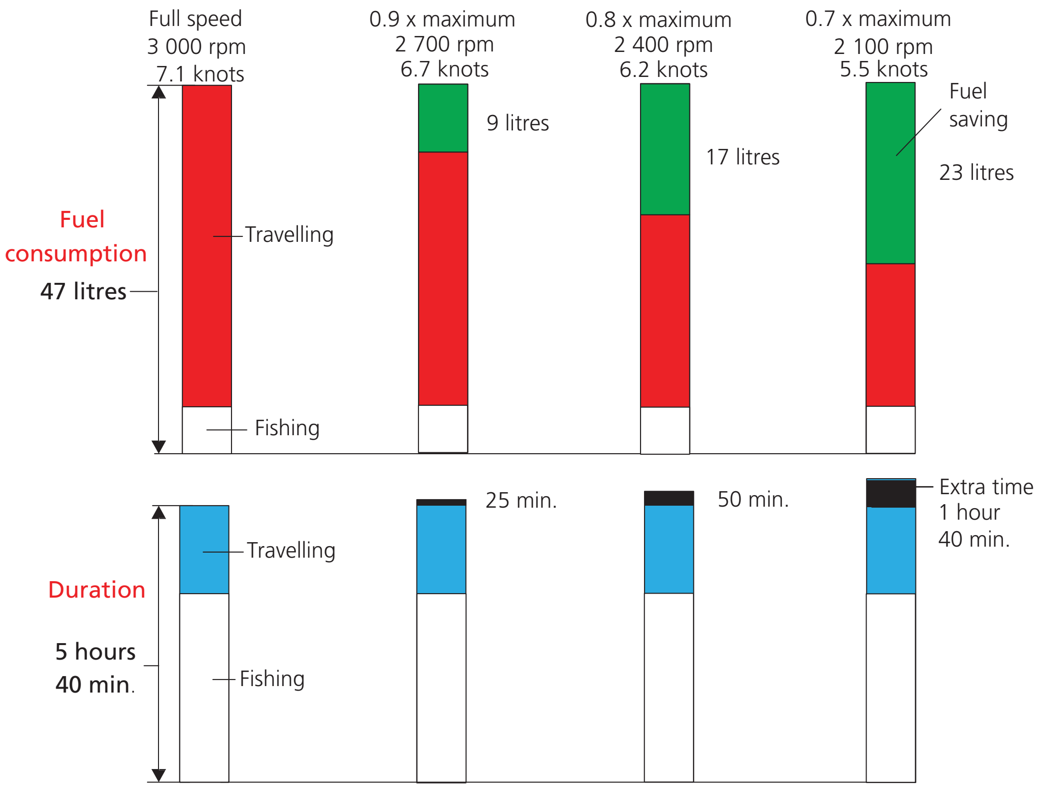
Measurements are made under typical service conditions with normal wind and waves and some fouling on the underwater hull. The boat is loaded with an average service load.

The engine rpm is recorded from the engine tachometer. The boat speed is measured with a GPS.

3. Calculation of fuel savings

The calculations are made with a pocket calculator and it is practical to use the table shown in Appendix.3. Fuel consumption per hp varies with engine model and engine rpm, but a fixed value of 0.25 litres per hp is used in this case.

The calculation of fuel savings is shown in Appendix 3



(See Appendix 3 for the calculation of fuel savings per fishing trip.)

The main question is:

Is the extra time per trip worth the savings in fuel?

The answer to this question will depend upon many factors:

- what the cost of fuel is in relation to the total cost of a fishing trip, including crew cost. When the fuel cost is a large portion of the total cost, there will be a strong motivation to save fuel and the answer to the above question would be yes. This is often the case in developing countries where wages and fish prices are low.
- whether extra fishing time at a 7.1 knot speed would produce extra catch, the proceeds from which the cost of the extra 17 litres of fuel needed would be paid.
- whether arriving in port one hour earlier would result in a better price for the fish, the proceeds from which the extra fuel would be paid?

Repowering with a smaller engine

In common with many fishing boats, the *SILVER FISH* has an engine that is too powerful to permit low fuel consumption. It is recommended that a boat with a waterline length of 8 m and a service displacement of 5 tonnes have a declared engine power of around 18 hp continuous duty and that the engine operate at 13 hp service power with a service speed of 6 knots (see Table 2, page 28). When the time comes to replace the engine, an engine of around 18 hp should be selected, using the largest available reduction in the gearbox and using a propeller that is designed to fit in the available space. This will save investment and fuel costs.

12 A BOAT’S WATERLINE LENGTH AND FUEL SAVING SPEED

Fuel consumption almost doubles when the speed of *SILVER FISH* is increased from 6 to 7 knots. Said in another way, the boat uses as much fuel going from 6 to 7 knots as it does going from 0 to 6 knots. Why? Engine power is needed to overcome the resistance of the water when the boat moves through the water. The resistance is mainly caused by the following factors.

Friction

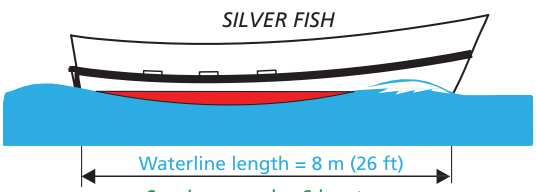
The boat moves, but the water is still. This causes friction between the hull surface and the water just as when you move your hand along the surface of a table. The underwater surface of the boat should be as smooth as possible to reduce friction. If it is rough like sandpaper, or with much fouling as shown on page 13, it will cause high friction resistance. When the boat speed increases from 6 to 7 knots, the friction resistance increases by about 35%.

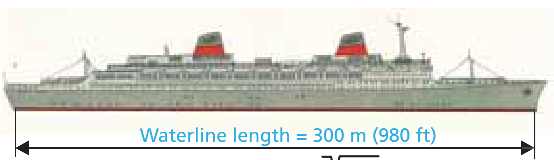
Wavemaking

A boat moving through the water creates waves. To create waves, power is needed. If you had been aboard the *SILVER FISH*, you would have seen clearly the large increase in the height of waves made when the boat speed increased from 6 to 7 knots. The resistance caused by making waves almost doubled (180%) when the boat speed increased from 6 to 7 knots. This is therefore the main explanation for the large increase in fuel consumption when increasing the speed from 6 to 7 knots.

Froude, a scientist in England, found that the wave resistance of a boat is related to the speed and the waterline length of the boat. The scientific law he formulated to express this relationship is called Froude’s law or the speed/length ratio:

$$\text{Water resistance} = \text{speed/length ratio} = \frac{\text{speed (knots)}}{\sqrt{\text{waterline length}}}$$





Maximum speed = $2.1 \times \sqrt{300} = 36$ knots

The “Silver Fish” waterline length = 8 m

$\sqrt{8} = 2.8$

At 6 knots, fuel saving speed = 6/2.8 = 2.1

At 7 knots, fuel saving speed = 7/2.8 = 2.5

The speed/length ratio for fuel saving speed

Waterline length measured in metres:

Speed (knots) = $2.1 \times \sqrt{\text{Waterline length (m)}}$

Waterline length measured in ft:

Speed (knots) = $1.20 \times \sqrt{\text{Waterline length (ft)}}$

Even the biggest and fastest passenger ships will not travel at a speed greater than the speed indicated using the speed/length ratio = 2.1.

Length in waterline		Service speed knots
m	ft	
5	16	4.7
6	20	5.1
7	23	5.6
8	26	6.0
9	30	6.3
10	33	6.6
11	36	7.0
12	39	7.3
13	43	7.6
14	46	7.9
15	49	8.1
16	52	8.4

TABLE 1:

Waterline length and service speed for low fuel consumption

Find the service speed of your boat for low fuel consumption.

Note:

Service speed is for average service condition of wind and waves and some fouling on the hull. In calm weather and with a clean underwater hull, the boat will travel at a higher speed.

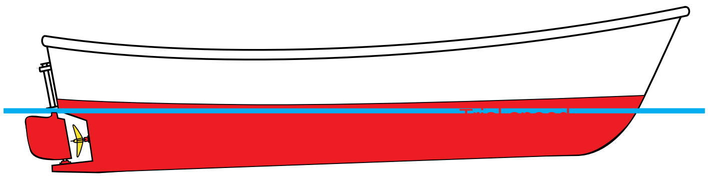
Hull fouling with slime, weeds and barnacles will slow down a boat

In the tropics, the increase in fuel consumption due to hull fouling can be 7% after only one month and 44% after half a year if antifouling paint is not used. To save fuel, the bottom of the boat must be kept free from fouling.

Small boats can be hauled out of the water and the bottom cleaned by scraping and scrubbing with a brush. Larger boats, which stay in the water for a long time, must have antifouling paint applied at regular intervals. Besides saving fuel, this procedure is especially important for wooden boats that can be attacked by wood-eating organisms such as toredo.

Copper is a poison to most marine organisms and is used in conventional, red antifouling paints. Note that this type of paint must not be used on aluminium boats. Antifouling paint containing Tribultyltin (TBT) should not be used because it is harmful to marine life. It is banned in many countries.

Self-polishing antifouling paints are a newly developed product. They become smoother over time and can give reasonable protection from fouling for up to two years. They are more expensive than the conventional antifouling paints but the fuel savings due to a smoother boat bottom and to the longer life of the paint protection can justify the extra cost.



Keep the propeller clean!

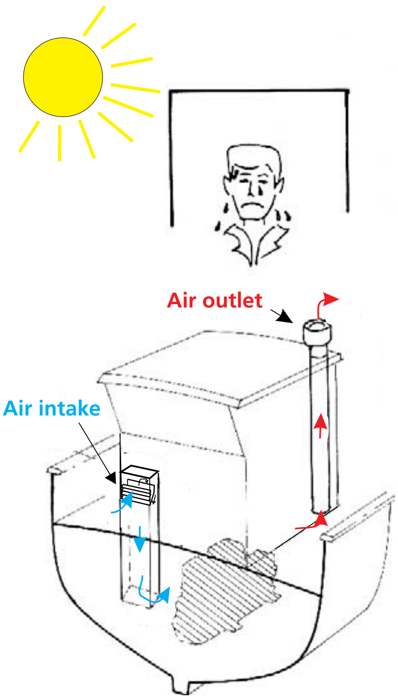
A propeller covered with marine growth will result in a considerable reduction in boat speed and an increase in fuel consumption.

Service the engine regularly

Oil: Follow engine manufacturers' recommendations regarding the change of oil and oil filters.

Fuel: Clean fuel is vital to keeping fuel pumps and injectors in good condition. Change fuel filters regularly and use a water separator.

Valves: Adjust valve clearances to the manufacturers' recommendations.



Make sure the engine has fresh air

Would you like to be working hard in a room without ventilation on a hot day?

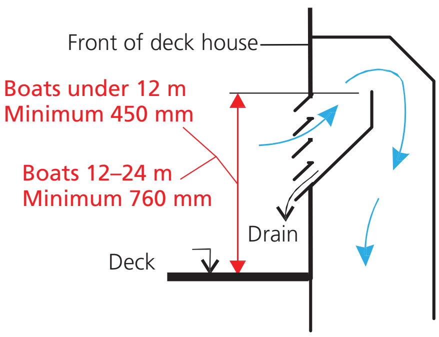
Your engine would not like it either. It needs plenty of fresh air for combustion. If the air in the engine room gets too hot, the engine will produce less power and waste fuel.

In a home, there is often a fan over the stove that sucks warm air out of the room. If warm air is drawn out, fresh air will automatically replace it if there are openings from the outside. The same principle must apply on a boat. How to get rid of hot air is the first question. The next question is how to supply fresh air from the outside.

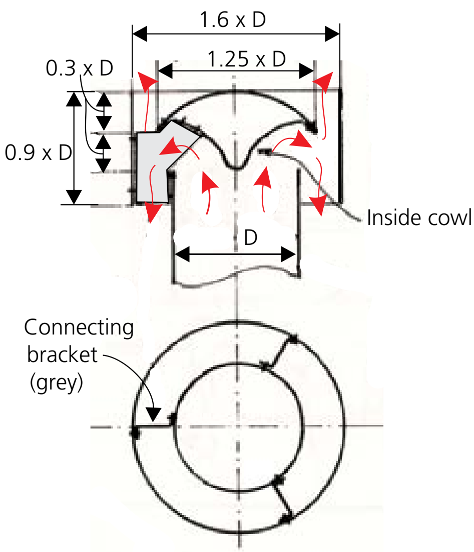
In the engine room, the air intake of the hot air duct should be located high up and away from the cool air inlet.

For larger engines, there must be an electric fan to suck the hot air out. Follow the engine manufacturers' instructions.

In tropical countries, the cross-sectional area of the air ducts should be 8 cm^2 per hp (10 cm^2 per kW) engine power. The air ducts can have different sectional shapes as long as the cross-sectional area is the same:

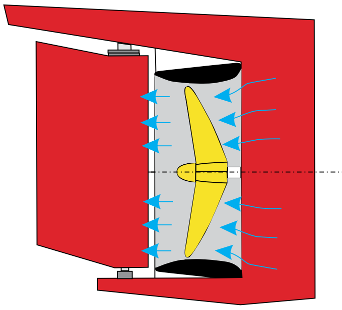


TYPICAL AIR INTAKE
with louvres



EFFICIENT AIR OUTLET COWL

A low rpm propeller and nozzle combination is optimum for trawling speed

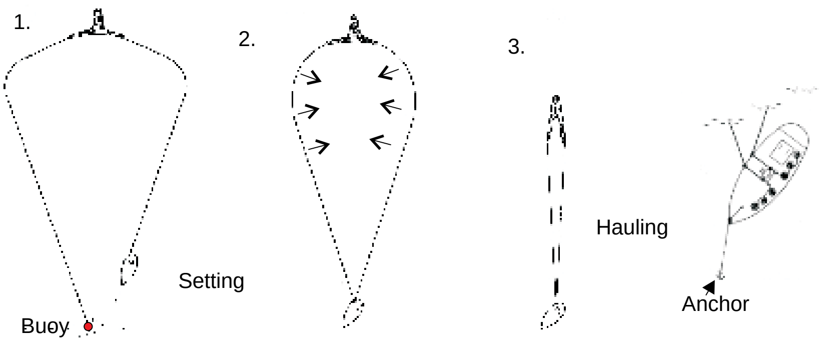


At a trawling speed of 3–4 knots, the best fuel efficiency is achieved with a propeller with low rpm (which means a gearbox with a large reduction) and a propeller-and-nozzle combination that is optimum for trawling speed. A correct nozzle and propeller can give a fuel savings of 20% at the normal trawling speed of 3–4 knots. There will normally be a slight reduction in service speed when travelling to and from the fishing ground.

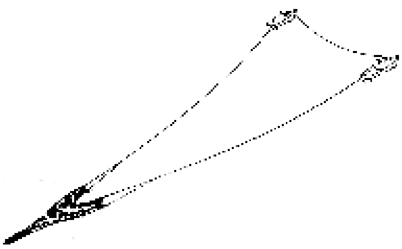
A modern design of trawl doors and net will reduce resistance

A large portion of the resistance of a trawl being dragged along the bottom is due to the resistance of the trawl doors required to spread the trawl. Modern design of the trawl doors will reduce resistance. A redesign of the trawl with thinner and stronger webbing and an increase in mesh size can give a substantial fuel savings.

Danish seining is a fuel saving fishing method



An alternative fuel saving fishing method is bottom seining or Danish seining. A buoy is thrown overboard and the first warp is paid out while the boat is steaming away from the buoy. The seine is set and then the second warp is paid out. The boat operator places an anchor and then the warps are hauled in with the use of an engine-driven deck winch. A much lower engine power is required for this fishing method than for trawling.



Pair trawling saves fuel

Pair trawling requires two boats of approximately the same size and with the same power. Pair trawling saves fuel because the two vessels can tow a larger trawl than a single boat and the resistance of the trawl doors is eliminated. A fuel saving of up to 40% with the same landings has been reported.

Multiday fishing saves fuel and increase catches

Staying in the fishing area for several days instead of going back and forth to the fishing area each day will save fuel and increase catches. Multiday fishing will, however, require a boat with an insulated fish hold where the catch can be kept on ice and with facilities for the crew.

Sri Lanka provides an example of a country where this fishing method has been developed: 50 years ago, only day fishing was done. Large-mesh driftnet fishing for tuna was introduced by FAO and boats started to make overnight fishing trips. Later, boats went out for two to three days. Today fishing boats from Sri Lanka operate over a large area of the Indian Ocean and make fishing trips of several weeks duration. The catch is preserved on ice.

A Portuguese schooner, laden with salt, food and fishing stores, on the way to the Newfoundland fishing grounds in 1958. Stacks of flat-bottomed dories fill the deck.

Mothership operations save fuel

Mothership operations can increase catches, maintain employment and save fuel. A mothership is large enough to carry a number of small fishing boats and has storage for the catch and facilities for the crew to rest.

Examples of this kind of operation are the earlier fisheries that operated on the rich cod and halibut grounds off the coasts of Newfoundland, Canada, and Greenland.

Sailing motherships from Portugal, Spain and the United States of America carried up to 60 men and a large number of small flat-bottomed boats called dories. The dories were launched in the morning and the dory crews fished with bottom longline and hand line during the day. In the evening, the dory crews returned to the mothership and off-loaded the catch, and the dories were hoisted back on board the mothership. The fish were cleaned and salted for preservation. Motherboats stayed on the fishing grounds for up to six months.

This type of mothership operation was carried out by Portuguese fishers up to 50 years ago, until rising crew cost and competition with trawlers made it uneconomical.

A bad day on the fishing grounds makes it impossible to launch the dories. The crew removes the rowing thwarts from the dories so the dories can be stacked up to eight high, one inside the other.

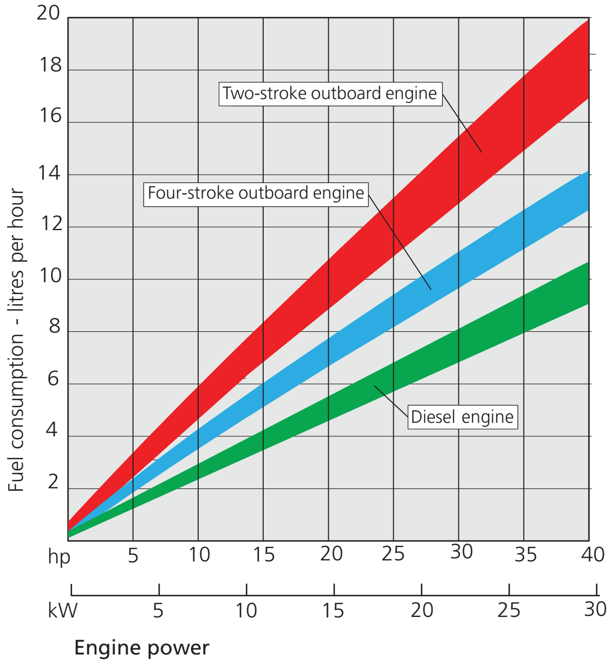
Source: A. Villiers, *Of Ships and Men,* 1962

The dories carried a crew of one or two men and were rowed and sailed. The fishing methods used were a 600 hook longline and a hand line. In the drawing to the left, the man in the bow is hauling the longline over a roller and the man in the stern is killing the large halibut before hauling it on board. The oars, mast and sail are stored in the boat. A mothership schooner is seen in the background. (Villiers, 1962).

Fuel consumption of outboard engines and diesel engines

The fuel consumption of the 2-stroke petrol or kerosene engine is about twice as high as for a diesel engine of the same power. High powered outboard engines used on heavy displacement boats have very high fuel consumption.

The advantages of the 2-stroke outboard engine are low cost, simple construction, light weight and portability, which facilitates service and repair. In addition, installation on boats is simple and the possibility of tilting the engine is an advantage when beach landing.



The 4-stroke outboard engine has lower fuel consumption than a 2-stroke engine but is more costly and complex.

The outboard engine operates at 5 000 rpm and with a gear reduction of around 2:1, the propeller rotates at 2 500 rpm. The high engine rpm means that the service life will be short, especially when the engine is run on kerosene fuel. The high propeller rpm gives low efficiency when used on displacement boats operating at speeds below 10 knots. The engines are mainly built for the pleasure boat market, which includes **light boats operating at speeds above 20 knots** and for relatively few operating hours per year.

Alternative diesel engines and their characteristics

The horizontal, single cylinder, water-cooled diesel engine is the most popular engine for fishing boats in Asia.

This type of engine is a multipurpose engine. It is used for pumps, power tillers, transport tractors and generators. It is relatively inexpensive and spare parts are normally available. The power ranges from 5 to 20 hp at up to 2 200 rpm. For good propulsion, a reduction of a minimum 2:1 to the propeller shaft is required.

The single cylinder air-cooled diesel engine is a multipurpose engine similar to the engine mentioned above and likewise is relatively inexpensive. Spare parts are normally available. The power normally ranges from 5 to 10 hp at up to 3 000 rpm. A reduction of a minimum 2:1 to the propeller shaft is required. Sometimes there is a gearbox bolted to the engine with this gear ratio.

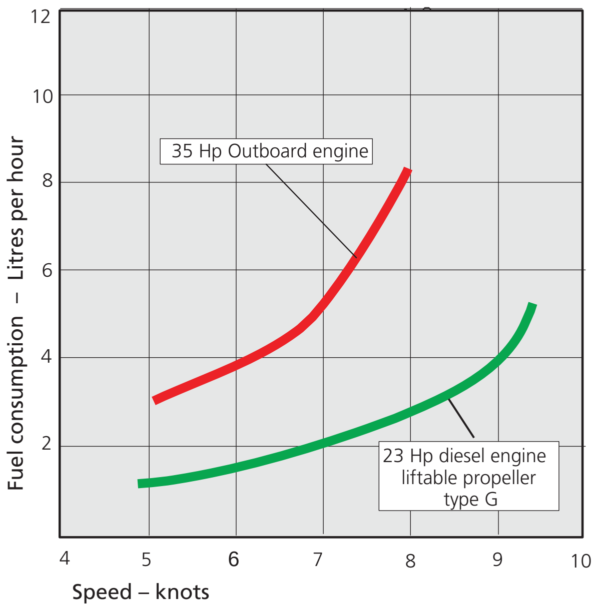
The multicylinder marine diesel engine is similar to a car or truck engine, with freshwater cooling and a heat exchanger. The gearbox reduction ratios are from 2:1 to 5:1. The power ranges from 10 to 500 hp. The availability of spare parts can be a problem if few engines are in use. This type of special marine engine is initially more expensive than the above alternative types of engines.

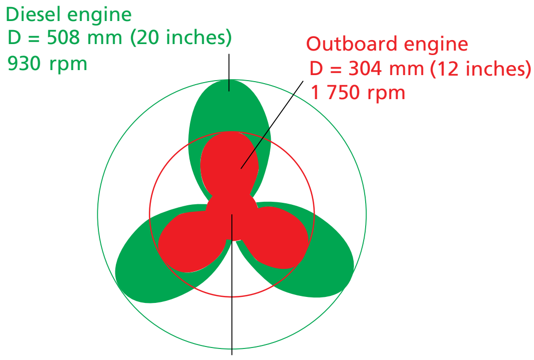
The canoes in Ghana are mostly operated from beaches with surf. The outboard engine of 25 to 40 hp is fitted on the side. Steering is done with a steering oar.

The canoes in Ghana are up to 19 m (60 ft) long. The bottom part is carved out of a single tree. The topsides are planked.

A canoe with an outboard engine was later fitted with a diesel engine installation

In 1985, the project for Integrated Development of Artisanal Fisheries in West Africa (FAO/ DANIDA/NORWAY) conducted a trial for engine efficiency with a Ghana canoe measuring 14 m (46 ft) in length and having a load displacement of 3.1 tonnes. The canoe was fitted with a 35 hp outboard engine and later converted to a diesel engine installation of the liftable propeller and rudder type, similar to the BOB drive shown on pages 20 and 21 but with a fixed engine and a liftable propeller and rudder. The diesel engine developed a maximum 23 hp at 3 000 rpm with a 3:1 reduction to the propeller shaft. The results from the trials are shown in the diagram below.





Relative size of propellers

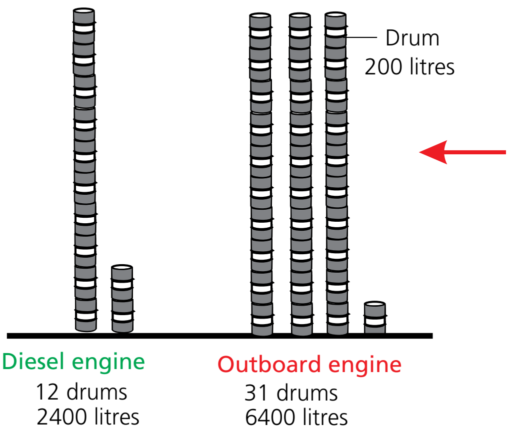
The diesel engine had a fuel savings of 62% over the outboard engine

At a speed of 8 knots, the diesel engine installation had a fuel consumption of 3 litres per hour and the outboard engine had a fuel consumption of 8 litres per hour. The diesel engine installation had a fuel savings of 62% over the outboard engine. The saving was due to the lower fuel consumption of a diesel engine versus a 2-stroke outboard engine running on petrol. It was also due to the improved propeller efficiency of the slower turning propeller of the diesel engine, which ran at 930 rpm versus 1 750 rpm for the outboard engine.

How long would it take for the savings from lower fuel costs to offset the diesel engine's higher purchase price?

The diesel engine is much more costly to buy but is less costly to operate. To answer the above question, a cost analysis must be made using information on the capital cost of the diesel and outboard engine, depending on their service life, and interest rate on bank loans. Information is also needed on the approximate maintenance cost. Most important is data on fuel consumption on an average fishing trip, the number of fishing trips per year and the cost of fuel per litre.

The analysis below of costs per year of operating a diesel versus an outboard engine considers the capital, fuel and installation costs. Appendix 4 shows a simple cost analysis based on cost figures in 2008 in Ghana.



Capital cost
Outboard engine: US$5 000
Diesel engine: US$9 000
Yearly fuel cost
Assuming speed = 8 knots, engine running 4 hours per trip, 200 fishing trips per year and US$0.80/litre for both petrol and diesel fuel
Yearly total cost
Outboard engine: US$8 040
Diesel engine: US$5 670

Saving per year with a diesel engine: US$8 040 – US$5 670 = US$2 370
The additional cost of a diesel engine installation: US$9 000 – US$5 000 = US$4 000
Time needed to repay the additional cost of a diesel engine:

$$\frac{\text{Additional cost}}{\text{Savings per year}} = \frac{\text{US\$4 000}}{\text{US\$2 370}} = 1.7 \text{ years} = 20 \text{ months}$$

Conclusion: At a market price of US$0.80 per litre (2008) for both petrol and diesel fuel, the additional cost of a diesel engine installation would be repaid in a relatively short time.

Incentives to replace inefficient engines rather than fuel subsidies are needed

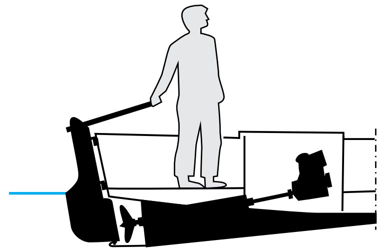
In 2008, fishers could buy both diesel fuel and petrol at a subsidized price of US$0.50 per litre. At this price, the government subsidized a fishers using a fuel wasting 2-stroke outboard engine with US$1 900 yearly, while a fisher using the more economical diesel engine received a subsidy of only US$700. A subsidy on fuel was, therefore, an encouragement to waste fuel. At the subsidized price, it would take more than three years to repay the high cost of a diesel engine.

Loan schemes to finance the higher cost of diesel engines are needed

Capital for the purchase of a diesel engine is scarce in most developing countries. Often investment in the cheapest alternative to a diesel engine is made regardless of how the cheaper engine affects long-term profitability. To replace a 2-stroke outboard engine with a diesel engine is usually possible only if there is a loan scheme that is tailored to finance the higher cost of the diesel engine and that takes into account the difficulties in recovering loans from fishers spread along a coastline. The government can provide incentives to fishers for the purchase of diesel engines and provide training in the installation and maintenance of diesel engines.

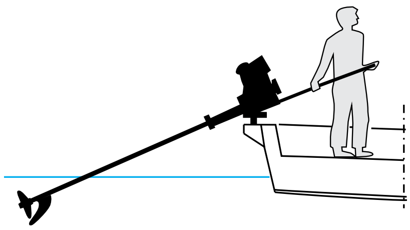
It is also important to conduct a thorough trial of a new engine installation over a period of more than a year to ensure that the engine is working properly.

A review of alternative engine installations can be found in Gulbrandsen and Ravikumar (1998).



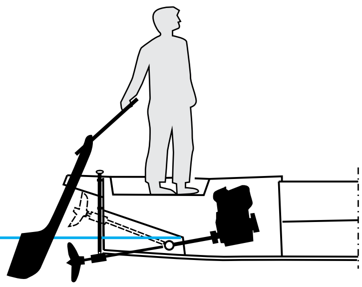
The conventional fixed installation

This is the preferred type of diesel engine installation when there are no restrictions on draft. The skeg protecting the propeller will cause a deep draft and relatively slow rudder response, which makes the installation unsuitable for beach landing with heavy surf.



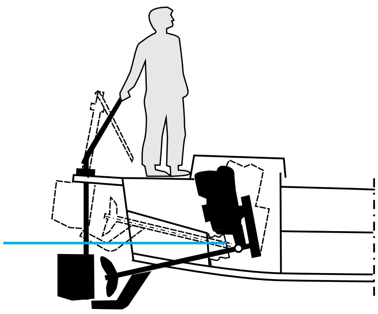
The longtail installation

The diesel engine is fixed so that it can both pivot and turn. It is either directly coupled to the propeller shaft or has a 2:1 reduction in a fixed gear, a chain drive or a V-belt drive. This type of installation permits the removal of the whole unit. This installation is suitable for beach landing, but heavy surf increases the risk of persons being hit by the rotating propeller. See the following page for more details on the longtail engine.



An installation with liftable propeller with external universal joint

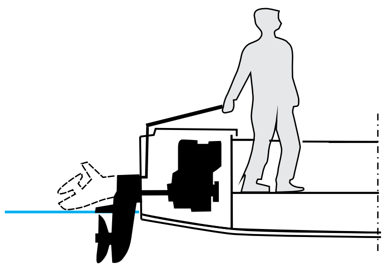
This installation is common in Japan on boats that operate from beaches with no surf. The engine is fixed and there is a conventional shaft line with stuffing box and bearing to the inside of a tunnel. A universal joint made of stainless steel or bronze permits lifting of the propeller. This is done with a liftable vertical strut that carries the outer bearing. The rudder is lifted separately and makes this installation less suitable for beach landing with heavy surf, which requires that the propeller and rudder be raised quickly.



An installation with liftable propeller with rubber bellows

This installation, also referred to as the BOB-drive, was developed by the FAO Bay of Bengal project on the east coast of India. It is based on the "longtail" principle, with the engine and the propeller shaft coupled together. A neoprene rubber bellows assures water-tightness and permits the tilting of the engine and propeller by lifting the rudder.

The diesel engine is permanently coupled to the propeller shaft through a 2:1 belt drive, but a neutral is achieved by lifting the propeller out of the water. See the following page for more detail on liftable propeller installations.



The Z-drive

The engine is fixed in the boat and coupled to the Z-drive with double flexible couplings. The Z-drive is mechanically complex and fairly expensive.

The longtail engine is popular

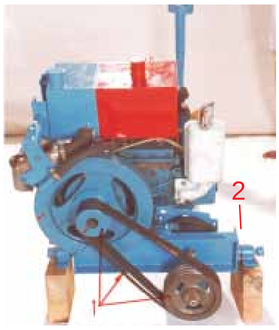
The longtail diesel engine installation is popular in many countries because of its low cost, ease of installation and portability. On the east coast of India, thousands of air-cooled 9 hp diesel engines running at 3 000 rpm are fitted with a reduction gearbox with a 2:1 ratio. When used for landing through the surf, as shown in this photo, there is a problem with safety. Persons can be hit and even killed by the rotating propeller when the boat is thrown sideways by a breaking wave. In addition, the vibration of the diesel engine is transmitted to the arms of the fisher and can cause health problems in arms and shoulders.

The propeller shaft of the longtail installation is often at an angle of up to 20^{o} with the water surface as shown in this photo. This means that there will be some loss of propeller efficiency.

A 8 hp/3 000 rpm air-cooled diesel engine with a 2:1 belt drive to the propeller shaft.

1. Neoprene rubber bellows
2. Bellows plate fixed to the bulkhead
3. Propeller
4. Removable skeg
5. Free movement of the rudder pivot

The "BOB drive"



A 9 hp/2 200 rpm water-cooled diesel engine (keel cooling).

1. A 2:1 belt drive to the propeller shaft
2. The pivots for the engine chassis fixed to the engine bearers

By lifting the rudder shaft, the whole installation is tilted and the propeller and rudder raised when landing on the beach.

Sails are used by fishers in many countries for inshore fishing


India


Tuvalu

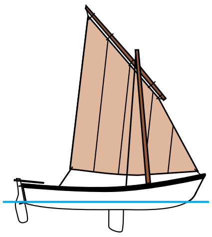

Kiribati

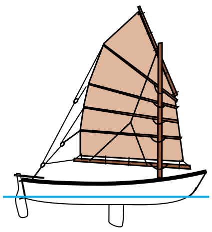

Indonesia

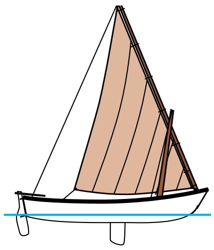

Madagascar

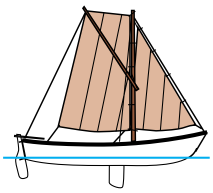

Sri Lanka

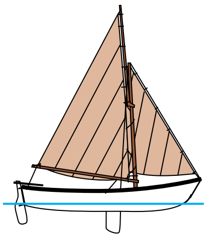
Many different sail rigs are suitable for small craft

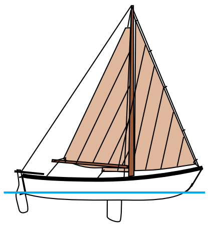

Dipping lug
This is a simple and effective rig with a short mast.

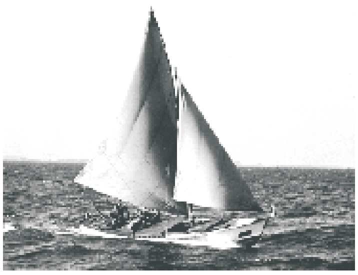

Chinese lug
The main advantage of this rig is the ease of reducing the sail area.


Lateen rig
This is the most common rig in the Indian Ocean. The long yard is a disadvantage.


Sprit rig
This is a common working boat rig. A good sail area is set on a short mast.


Gunter rig
This rig has a high efficiency and can be made from locally available materials, such as young trees for mast and bamboo for the yard and boom.


Bermudan rig
This is a common rig on sailing pleasure boats. The rig requires a specially made long mast with stays and is more costly than the other alternative rigs.


Gunter rig was the winner in the sail trials

Sail trials were conducted in Chennai (Madras), India

Trials with all the above-mentioned sailing rigs were made with two identical 8.5 m (28 ft) FRP beach-landing boats. The boats were fitted with a retractable dagger board to prevent side drift. Measurements of speed and wind direction were taken and the boats were sailed in competition with each other. The trials showed that the Gunter rig was the most efficient – even better than the Bermudan rig – and much less costly.

The sprit rig and the lug rig performed well and better than the lateen rig. For combined low cost and ease of handling, the lug sail was considered best as an emergency sailing rig and for use with favourable wind. (Palmer, 1990.)

The lug sail is a low cost sail rig for safety in case of engine breakdown and for saving fuel

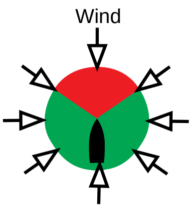
The Bay of Bengal Programme (BOBP) developed the 8.5 m beach landing boat (IND-20) for the east coast of India. The service displacement of this boat is 2 tonnes. The boat has a 9 hp diesel engine with liftable propeller and rudder. The dipping lug sail is 18 m^2 (190 ft^2) and affords fuel saving as well as important safety in case of engine breakdown. The boat has a slot for a centreboard, which is fitted off centre so that it does not interfere with the net hold.

The main fishing methods used on a boat with this rig are driftnetting and longlining. However, because most fishers lack sail training with this rig, they continue to use their traditional lateen sailing rig. The disadvantage of the lateen rig is the long yard, which takes up deck space when not in use.

> The introduction of a new sail rig different from the traditional rig will fail unless a thorough sail training programme is established.

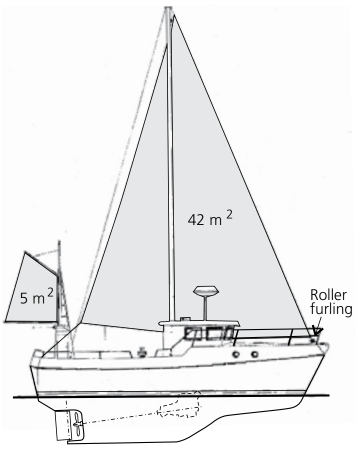
Sails have limitations

There is considerable interest in more extensive use of sail to save fuel. However, it is important to know the limitations of sail:



- Sail boats cannot sail straight against the wind. In the figure to the left, the red area is where the wind resistance of the sailing rig will increase the fuel consumption when using an engine.
- Mast and rigging of a sail boat will often interfere with the operation of fishing gear.
- Except for small boats, which can use the weight of the crew as ballast, and for multihull boats, larger monohull boats need ballast for stability and the extra weight results in increased fuel consumption when using an engine.

Sailing trials were conducted in Norway



Trials were held in Norway with a new type of fuel-efficient small-scale fishing boat (Amble, 1985)

Length overall	10 m (33 ft)
Waterline length	9 m (29.5 ft)
Beam	3.16 m (10 ft)
Displacement service	8.5 tonnes
Ballast weight	1.7 tonnes
Engine	30 hp/1 900 rpm
Gear reduction	5:1
Propeller	Controllable pitch, 2-blade
	Diameter = 0.85 m (33 inches)

Mainsail, roller furling = 42 m^2 (450 ft^2)

Mizzen for steadying when hauling fishing gear = 5 m^2 (53 ft^2)

The boat consumed 50% less fuel than similar fishing boats. The main reason for this was the high gear reduction and a large diameter, slow turning (380 rpm) propeller, together with a hull shape which was similar to that of a sailing boat.

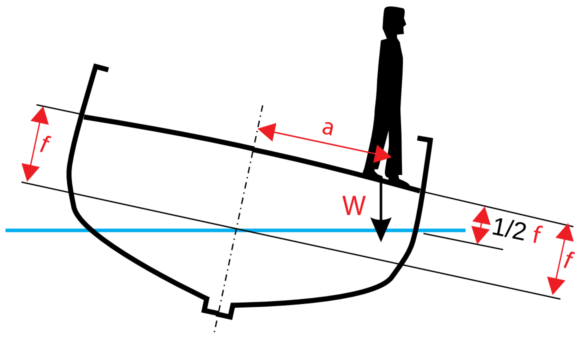
Sailing trials proved that a further 10–15% fuel savings could be achieved by using sail. However, there were some problems with the sail interfering with the radar when tacking.

Commercial sailing boats are few

At numerous conferences, the subject of sail propulsion for commercial craft has been discussed (see Additional reading, page 42). Unfortunately, there is not much evidence that in practice commercial boats use sail. With the increasing cost of fuel, there is a renewed interest in the use of the sail rig in countries with high fuel prices relative to the price of fish.

Conclusions from the sailing trials

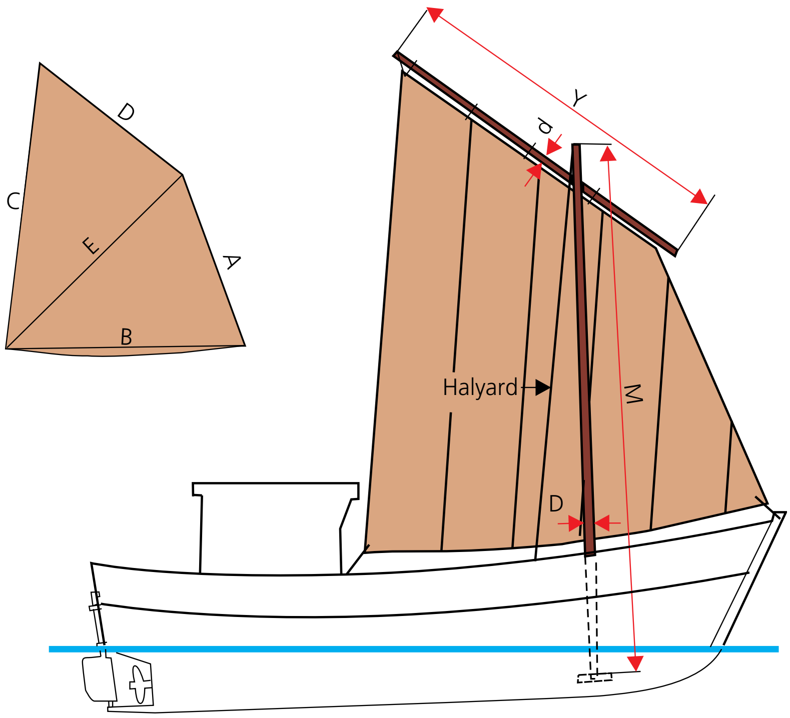
Greatest potential for fuel saving is having a low power engine, a large gear reduction, a large propeller and a hull shaped for low resistance. Sails are important for safety when the engine breaks down at sea. A simple and low cost sailing rig which do not interfere with the fishing operation is sufficient and can give some fuel savings with the wind from the side or astern. High cost modern sailing rigs for beating against the wind is not required.



The stability of a decked boat should be checked before fitting a sail

Before fitting a sail on a fishing boat, it is necessary to assess the boat's stability. Too large a sail can cause the boat to capsize. The following test will give an indication of the maximum sail area to be fitted. This sail area can be carried up to a wind speed of 15 knots (7.5 m/s).

1. Measure the minimum freeboard f midship with no load in the fish hold.
2. Make a mark on the side at ½ f.
3. Get a number of people to stand alongside the rail midship until the boat is inclined to the ½ f mark.
4. Get a scale and weigh the people. Total = W (kg).
5. Measure the distance a (m).
6. Calculate the righting moment (RM):



RM = W x a (kgm)

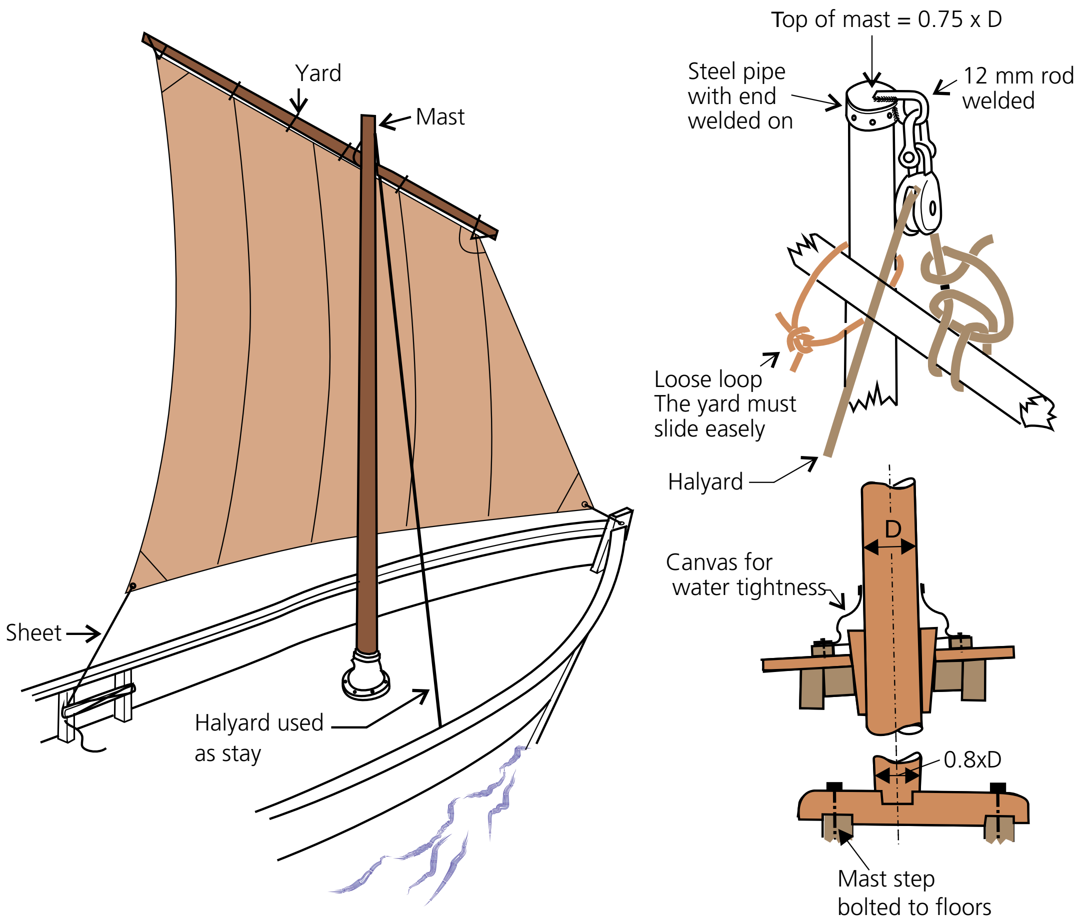
RM kgm	Sail area m^2
310	15
470	20
650	25
880	30

The mast is made from the wood of a suitable tree. It is tapered to 0.7 x D at the top

Sail area m^2	Sail dimension (m)				
	A	B	C	D	E
15	3.4	4.5	5.5	3.3	4.8
20	4.0	5.2	6.3	3.8	5.5
25	4.4	5.8	7.1	4.4	6.1
30	4.8	6.4	7.8	4.9	6.5

Sail area m^2	Mast		Yard		Haylard		Sheet	
	D mm	M m	d mm	Y m	Diam mm	Length m	Diam mm	Length m
15	105	6.4	60	3.6	10	13	10	12
20	120	7.0	65	4.1	12	15	10	14
25	130	7.7	70	4.7	12	16	10	15
30	140	8.4	75	5.2	12	16	12	17

The rigging uses the halyard as a stay



When the sail is not in use, there are no mast stays to interfere with fishing.

Outrigger canoes are especially suitable for use with sail

The 7.1 m (23 ft) single outrigger canoe KIR-8 is of a FAO design based on the traditional type of canoe. The service displacement is 600 kg. This canoe has a Gunter sail rig with a total sail area of 15 m^2. It is fitted with a 2–4 hp outboard engine for use on days with no wind. The main fishing methods used on this canoe are handlining and trolling for tuna.

The 7.8 m (25.5 ft) double outrigger canoe SOI-2A was designed by FAO for use in the Solomon Islands. The service displacement is 900 kg. The canoe has a Gunter sail rig with a total sail area of 19 m^2. It Is fitted with a 4 hp outboard engine, giving a speed of 6.5 knots in calm water. The fishing methods used on this canoe are handlining and trolling for tuna.

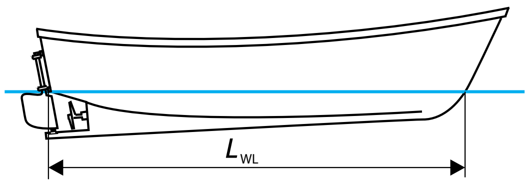
"Greed for speed" is found everywhere

The choice of an engine is often based on irrational feelings. Engine speed bestows status. When changing engines, most fishers like to put a bigger engine in their boat and to go a little faster than the other fishers. There is a clear trend towards escalating engine power on fishing boats. The engines used today are much bigger than those used when motorization started. The expenditure for bigger engines could be justified with an increase in fish prices and cheaper fuel.

Today, the competition among fishers to have the fastest boat has led to a gross over powering of boats. With the present high price of fuel, the losers in this game are the fishers themselves.

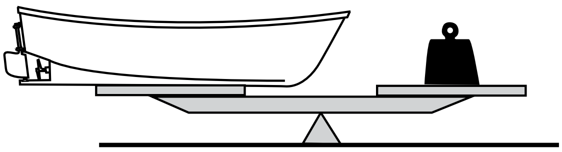
The recommendations in this manual aim to help fishers achieve low fuel consumption, while maintaining the same catch levels. This will in most cases lead to the installation of smaller engines than used previously. A change in mental attitude from going always bigger to going smaller is required. Many fishers will find this difficult in spite of all the rational arguments for lower fuel consumption.

The engine power of a boat operating at displacement speed depends on many factors



1. Length of waterline L_{WL}

Table 1 on page 12 shows the recommended fuel saving service speed for boats of different waterline lengths.



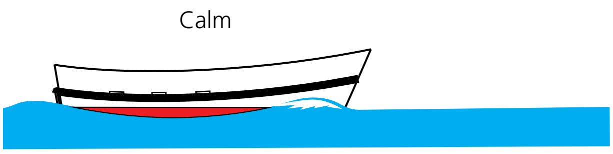
2. Weight of the boat with load service displacement

The service displacement is the weight of the boat with an average load, usually a half-filled fish hold, expressed in tonnes:

1 tonne = 1 000 kg

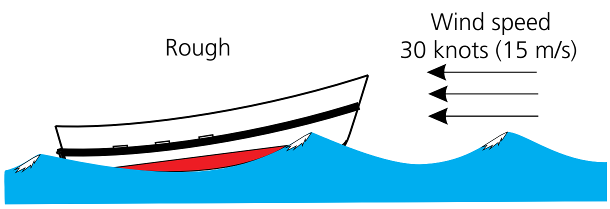
This is close to 1 long ton = 1 016 kg.

For the calculation of service displacement see Appendix 5.



3. Weather

A calm sea and no wind will require less power than a rough sea with strong wind. The boat engine must be powerful enough to allow steering and be able to advance at reduced speed under rough conditions.



Service condition

The average weather condition will be somewhere between calm and rough. In addition, there might be some fouling on the underwater hull. The boat should be able to maintain service speed under average weather conditions.

The *SILVER FISH* (page 10) provides an example of the power needed under various conditions

Calm weather

With a waterline length of 8 m and a service displacement of 5 tonnes, only a 7 hp engine is required to reach a speed of 6 knots in calm weather with no waves and no wind, and with a clean underwater hull.

Rough weather

The added wave resistance is at a maximum when the waves are about the same length as the boat. The wind resistance is calculated using the frontal area of the boat meeting a wind of 30 knots (15 m/s). Note below that the added power needed in rough conditions varies from 10 hp running at 5 knots to 15 hp running at 7.5 knots. The calculation for added resistance in rough weather follows the method shown in Larsson and Eliasson (1994).

Service condition

A normal service condition does not refer to calm weather and a clean hull, nor does it refer to rough weather with 30 knot winds and big waves, and a fouled hull. It can be argued as to where between these two extremes the service condition lies, but it has been assumed to be on average midway between calm weather and rough weather.

The graph below shows the calculation for the power needed for the Silver Fish fishing boat in calm, rough and in service conditions. For a fuel saving speed of 6 knots, a service power of 13 hp is required. This is almost double the power required in calm water and weather conditions. In rough weather, the boat would be able to progress at a speed close to 5 knots with a service power of 13 hp.

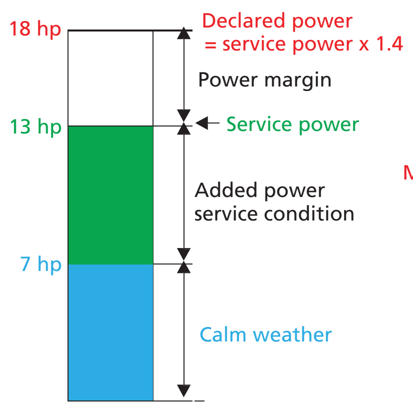
Margin for declared engine power

Declared engine power is indicated in the leaflet giving information about the engine. Details about this power are given below. Declared power should be for continuous duty. It is the power the engine can produce for many days without overloading itself. In the tropics where temperatures and humidity are high, the engine will produce around 6% less power than the power indicated in the leaflet. To avoid overloading the engine, a power margin above service power is needed. The power margin is estimated at 40% of service power. For the Silver Fish boat, this corresponds to 5 hp.

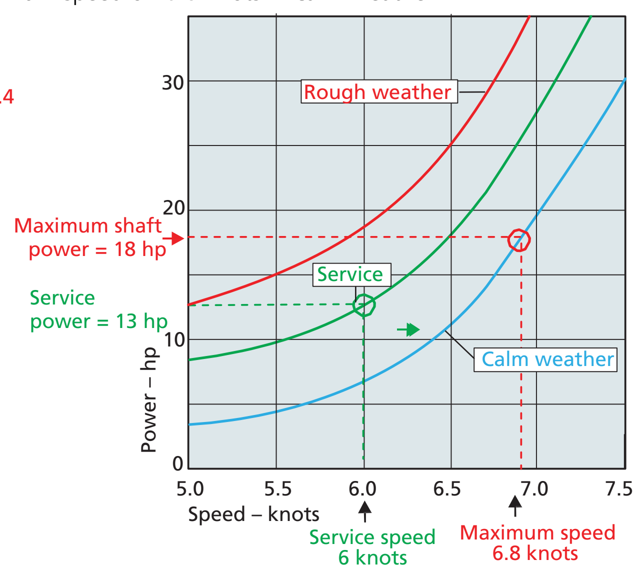
Declared engine power

The service engine power for the Silver Fish fishing boat is 13 hp. The minimum declared power of the engine should be:

13 hp x 1.4 = 18 hp. This gives an engine power/weight of boat = 18/5 = 3.6 hp/tonne.
With this power, the engine will give a maximum speed of 6.8 knots in calm weather.



Silver Fish
Power at a service speed of 6 knots



The recommended service power and maximum engine power for various waterline lengths and service displacement is shown on the following page.

The engine power and speed of fishing boats (not trawling) are based on boat waterline length and service displacement (½ load)

For trawlers, the engine power is determined by the size of the trawl and the trawling speed. For an estimation of service displacement see Appendix 5.
It is assumed that the boats have a good shape and proportions as shown on pages 35–37.
Service power: Propeller shaft power to reach *service speed* in average weather conditions with waves and wind, and with some hull fouling.
Declared propeller shaft power: Continuous duty engine power declared by the manufacturer according to the ISO 8665 standard. If the crankshaft power is given, obtain propeller shaft power by multiplying the crankshaft power by 0.96.
Declared power = 1.4 x *service power* giving a sufficient power margin and assuming 6% power loss due to high humidity and temperature in tropical conditions. For temperate conditions, the declared power can be reduced by 6%.
Service speed: Fuel-efficient speed = 2.1 x $\sqrt{\text{length in waterline (m)}}$ knots (Table 1, page 12).
Maximum speed: Speed with maximum power, no wind or waves, and a clean underwater hull. Approximate maximum speed = 2.4 x $\sqrt{\text{length in waterline (m)}}$ knots
The propeller is to be designed for *service power* and *service speed*. It is assumed that the propeller efficiency is around 50%. See Appendix 7 for information on propellers at various engine powers and propeller rpm.

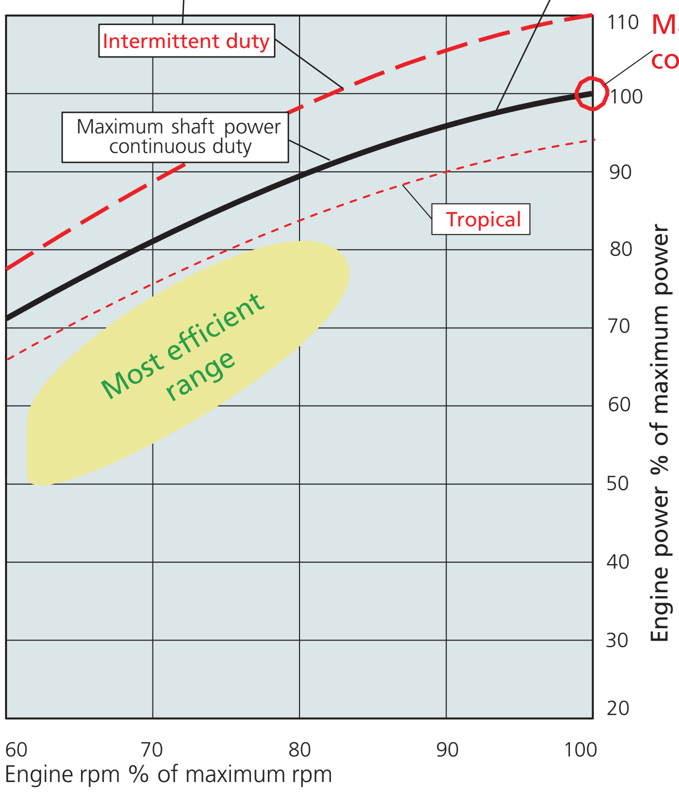
TABLE 2
The power and speed needed for boats of various waterline lengths

Length in waterline L_{wl}		Service displacement	Service power	Declared continuous shaft power	Service speed	Max. speed
m	ft	t	hp	hp	Knots	Knots
5	16.4	0.5	2	3	4.7	5.4
		1.0	2.5	4		
		1.5	3	5		
6	19.5	1	3	5	5.1	5.9
		2	5	7		
		3	6	8		
7	23	2	6	8	5.6	6.3
		3	7	10		
		4	8.5	12		
		5	10	14		
8	26	3	9	13	6.0	6.8
		4	10	14		
		5	13	18		
		6	15	21		
9	30	4	13	18	6.3	7.2
		6	16	22		
		8	18	25		
		10	21	29		
10	33	6	18	25	6.6	7.6
		8	21	29		
		10	24	34		
		12	27	38		
12	39	10	32	45	7.3	8.3
		15	40	56		
		20	47	66		
		25	56	78		
14	46	15	49	69	7.9	9.0
		20	59	83		
		30	75	105		
		40	91	127		
16	52	20	72	101	8.4	9.6
		30	92	129		
		40	107	150		
		50	124	174		

The engine manufacturer's leaflet contains useful information

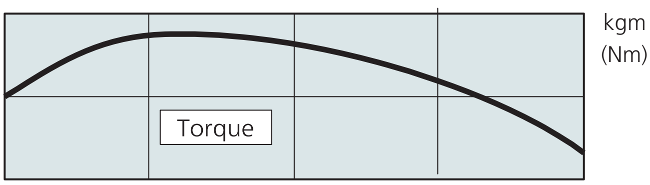
Do not consider the intermittent duty rating. The engine can only produce this power for a short time.

Continuous duty should be propeller shaft power according to an international standard such as ISO 8665. If information on crankshaft power is given, reduce the power by 4% due to a loss that occurs in the gearbox. Continuous duty means that the engine can produce this power for days without incurring damage. This is the power curve to consider!

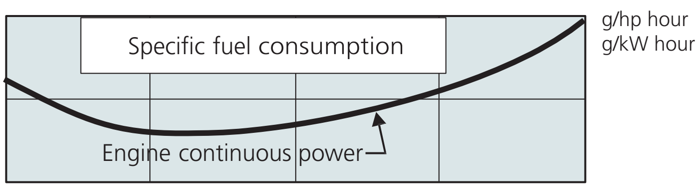


In the tropics with high temperatures and humidity, the engine will not give full power. A 6% derating is advised. You will not find a tropical power curve in the leaflet.

A Mussel diagram gives the specific fuel consumption at different engine powers and rpm and is the best indicator of the most efficient range of engine operation. Unfortunately it is rarely available from the engine manufacturers and you must rely on the torque and specific fuel consumption curves to get an approximation of the most efficient range.



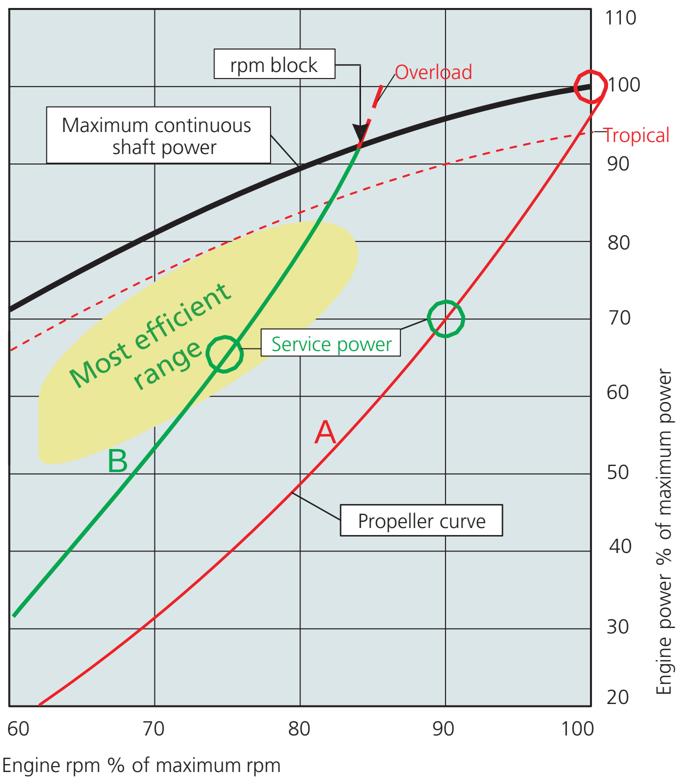
Torque is what turns the propeller. Notice that the torque is at maximum at around 70% of maximum rpm and drops off at higher rpm.



Specific fuel consumption relates to the engine continuous power curve. This is an important curve. It shows where the engine burns the fuel most efficiently. For minimum fuel consumption, you should operate your engine near the lower part of the curve, around 70% of the maximum rpm.
Note that when the torque is at its maximum, the specific fuel consumption is at a minimum.

Be aware: Some manufacturers do not show the specific fuel consumption curve related to the power curve but show the specific fuel consumption of the propeller curve. This curve will not show you where the engine burns the fuel most efficiently.

Propellers affect the amount of fuel consumed



Propeller B

Propeller **B** has a larger diameter and pitch than propeller **A**. The propeller curve passes closer to the area of minimum specific fuel consumption. With the same power as propeller **A**, there would be a fuel saving of 6–7% with propeller **B**. With the same gear reduction as propeller **A**, the larger and slower running propeller **B** will have around 5–6% lower fuel consumption because of better propeller efficiency. Total fuel saving compared with propeller **A** is around 12–15%.

For service condition, propeller **B** takes out 65% power at 75% rpm. It will give the same effective propeller power as does propeller **A** taking out 70% power.

The service life of the engine with propeller **B** should be longer than the service live of the engine with propeller **A** because engine rpm is lower.

Propeller A

The red curve in the diagram above is the propeller curve often shown by the engine manufacturer for propeller A, giving 100% power at 100% rpm. With propeller A, the engine will not be overloaded because the engine is blocked at 100% rpm by the governor.

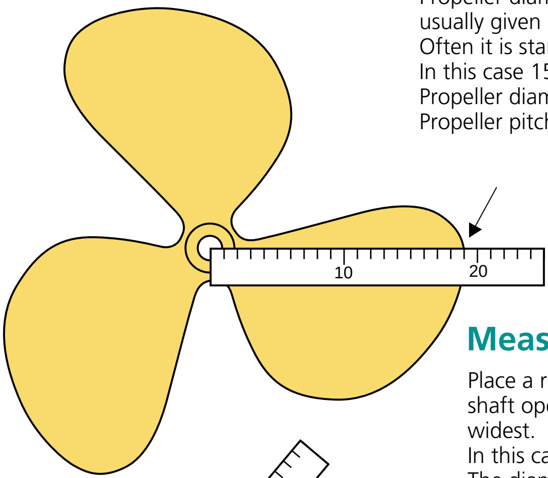
With the power margin mentioned above, the service power should be taken at 90% rpm, giving a service power of around 70% of maximum declared power.

The propeller curve does not pass through the area of minimum specific fuel consumption.

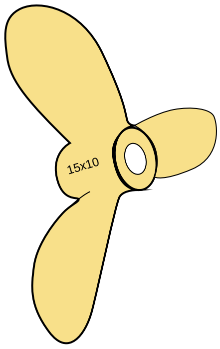
WARNING

Propeller B will overload the engine if there is no stop of the rpm. An rpm stop at about 0.85 x maximum rpm is essential to protect the engine from damage.

Place the propeller on a table with the flat face (aft face) up.



Propeller diameter and pitch are usually given in inches.
Often it is stamped on the propeller
In this case 15x10 means:
Propeller diameter = 15 in
Propeller pitch = 10 in



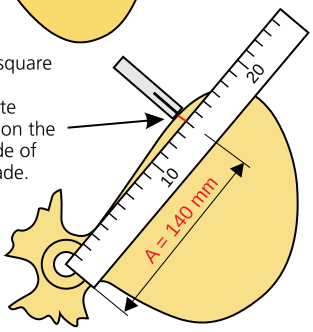
Measuring the propeller diameter

Place a ruler with the edge exactly in the centre of the shaft opening and to the place where the propeller is widest.
In this case the radius = 190 mm
The diameter = 2 x 190 = 380 mm

$$\frac{380}{25.4} = 15 \text{ in}$$

Using an inch scale, measure the radius and multiply by 2.

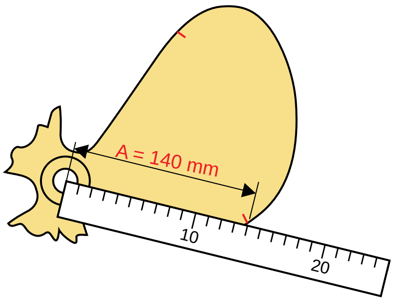
Use a square to get accurate marks on the low side of the blade.



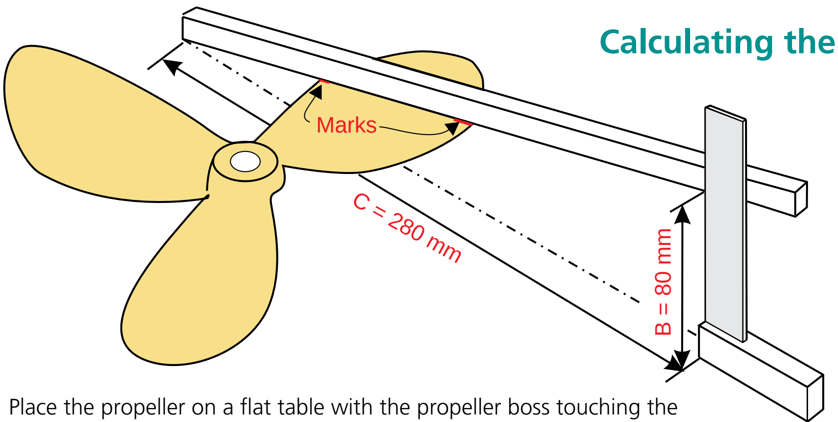
Markings for measuring the pitch

The propeller pitch is a measure for how far the propeller advances forward when making one turn assuming it was screwed in thick butter.

1. Place a scale with the 0 in the centre of the shaft opening. Measure the distance to approximately the widest part of the blade. Choose a round figure, in this case 140 mm. Make a mark at the edge of the propeller with a felt pen.
2. Do the same on the other edge of the blade and make a mark at 140 mm.



Calculating the pitch



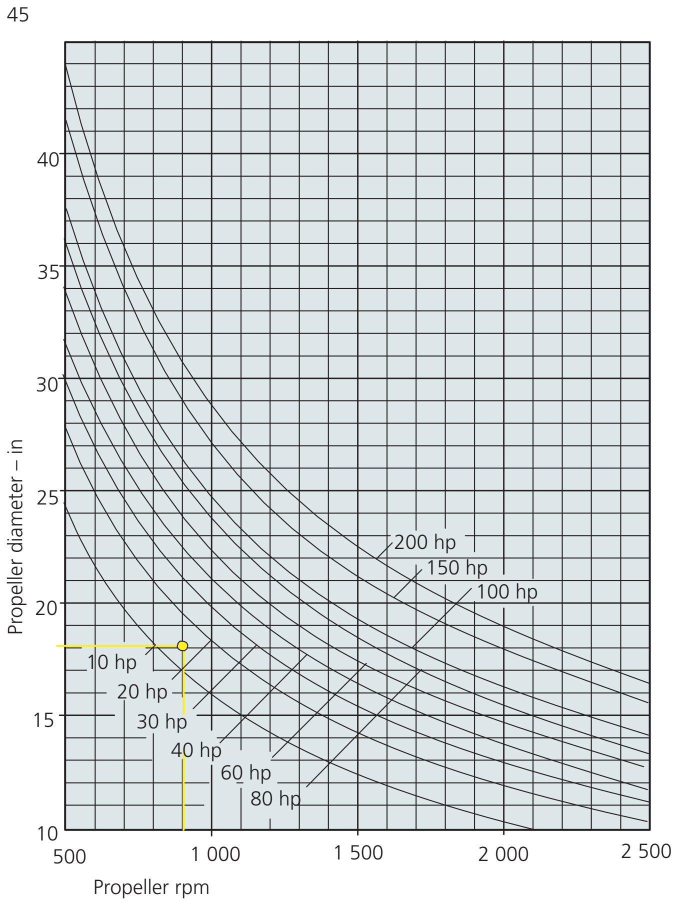
If the measures A, B and C are in inches, the formula for the pitch is:

$$\text{PITCH} = \frac{A \times B \times 6.3}{C}$$

Place the propeller on a flat table with the propeller boss touching the table, not the blades. Place a piece of wood with a straight edge along the two marks on the propeller and so that the corner of the stick touches the table. Place a square at any point along the ruler and measure the distances B and C. Calculate the pitch:

$$\text{PITCH} = \frac{A \times B}{4 \times C} = \frac{140 \times 80}{4 \times 280} = 10 \text{ in}$$

NOTE: A, B and C must be in mm



This diagram is useful for estimating the propeller diameter

At the boat design stage, it can be useful to make an estimate of the propeller diameter. The diagram to the left can be used for that purpose.

The diagram can indicate the amount of space needed for the propeller in the after body, depending on the gear ratio that determines the propeller rpm.

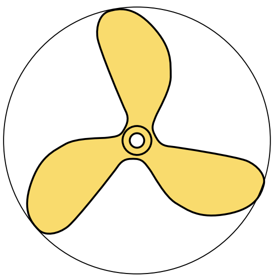
At a later stage, however, it is important to make a proper calculation of the propeller diameter and pitch as shown in Appendices 6 and 7.

In the diagram, an example is given using:

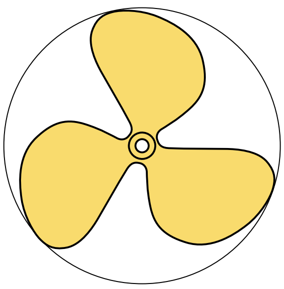
Service power = 13 hp
Propeller rpm = 900

1. On the bottom line of the diagram, find the point for 900 rpm.
2. Go vertically up until you meet the curved line for 13 hp.
3. Go horizontally out to find the propeller diameter = 18 in.

A lower propeller rpm = a larger diameter propeller = better efficiency.



Blade area ratio = 0.30



Blade area ratio = 0.50

Selecting the number of blades

Most propellers used on fishing boats with service speed under 10 knots are 3-bladed propellers. This is the most economical solution.

A 4-bladed propeller is used when there is a problem with vibration in the hull caused by the propeller or when the boat is used for trawling with a high load on the propeller, which could cause cavitation (the propeller surface on the blade tips is damaged).

Selecting the blade area ratio

The blade area ratio is:

$$\frac{\text{Area of the blades when seen as shown}}{\text{Area of a circle with the same diameter as the propeller}}$$

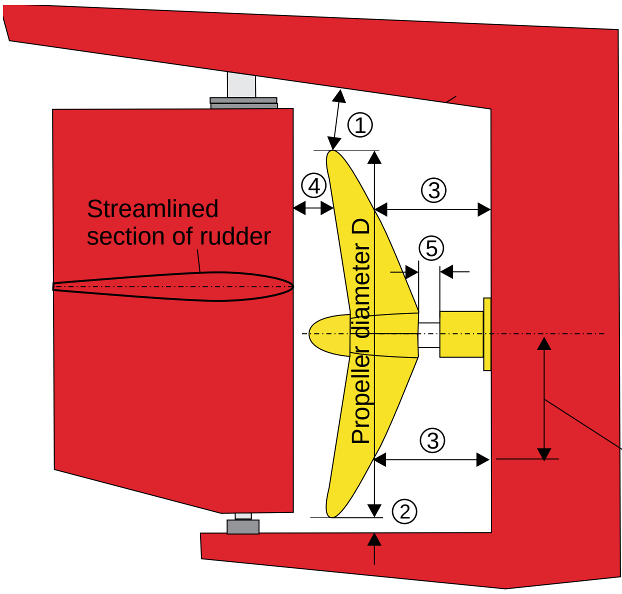
For fishing boats not used for trawling, blade area ratiosare between 0.30 to 0.50.

Trawlers will use blade area ratio from 0.50 and higherto avoid cavitation.

The shape of the skeg and propeller clearance from the skeg affect propeller efficiency

The shape of the skeg in this photo will cause a very turbulent flow of water into the propeller. The clearances of the propeller to the skeg and the hull are very small. There is no fairing of the skeg. These factors together will cause poor propeller efficiency.

There is a sharp knuckle between the hull and the half tunnel that will cause a turbulent flow of water into the propeller. The skeg in front of the propeller is very wide.



Minimum propeller clearances

D = propeller diameter

① 0.17 x D

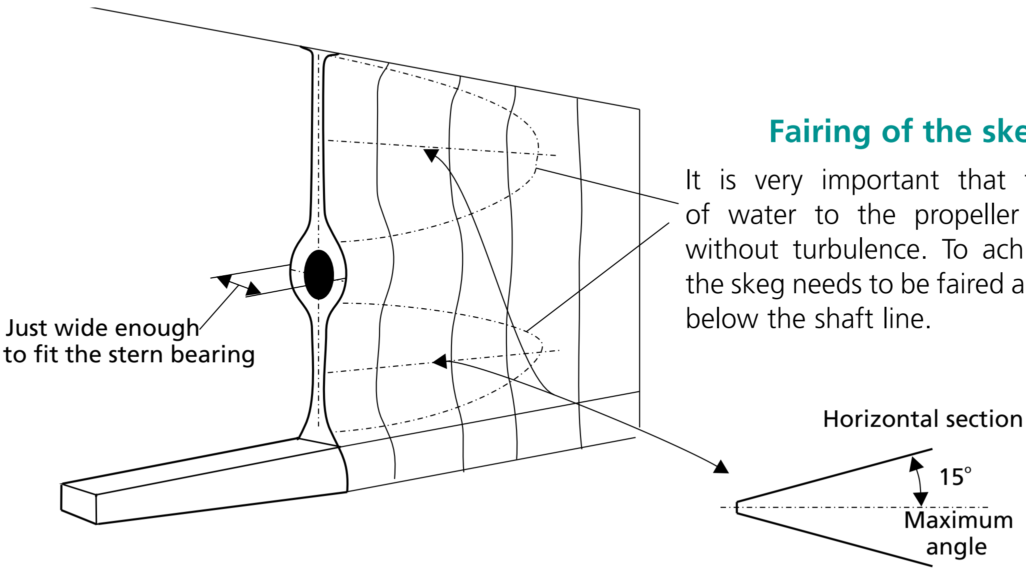
② 0.05 x D

③ 0.27 x D

④ 0.1 x D

⑤ Maximum bare shaft length: 2 x shaft diameter

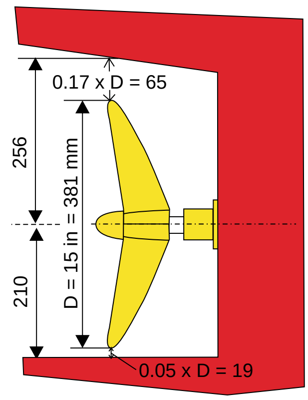
Measured at 0.7 x propeller radius



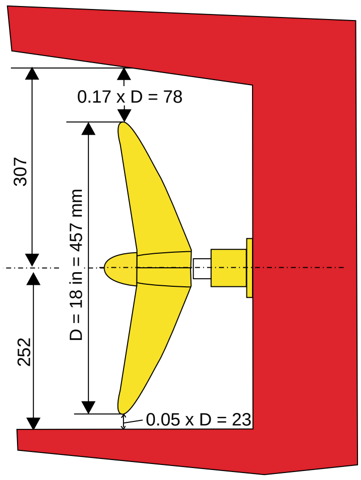
Fairing of the skeg

It is very important that the flow of water to the propeller is clean without turbulence. To achieve this, the skeg needs to be faired above and below the shaft line.

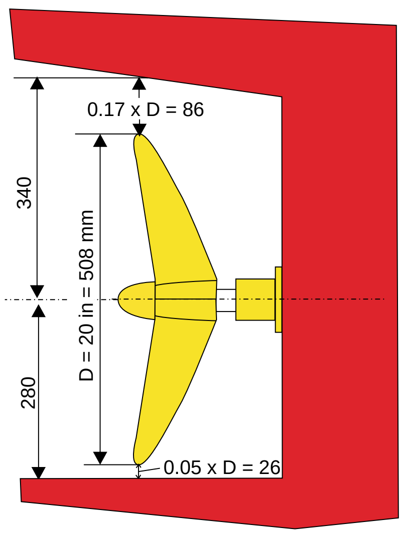
ALTERNATIVE 1



ALTERNATIVE 2



ALTERNATIVE 3



The example of 3 alternative propeller sizes on the *SILVER FISH* (page 10) illustrates how fuel savings can vary

The *SILVER FISH* has a waterline length of 8 m and a service displacement of 5 tonnes.

According to Table 2 on page 28, an engine of 18 hp declared continuous duty is sufficient to give this boat a service speed of 6 knots with a service power of 13 hp. An engine developing 18 hp continuous duty at 3 000 rpm is selected.

Appendix 6 shows the calculation for three propeller alternatives. All three propellers will give the same effective propeller power = 6.1 hp. This is the power that drives the boat at 6 knots.

For an explanation of the differences between propellers A and B, see page 30.

Propeller minimum clearances are according to those on page 33.

Alternative 1

Gear reduction = 2:1 and propeller A

Engine hp = 13
Engine rpm = 2 700 Propeller rpm = 1 350
Effective propeller hp = 6.1
Fuel saving = 0

Alternative 2

Gear reduction = 3:1 and propeller A

Engine hp = 11.3
Engine rpm = 2 700
Propeller rpm = 900
Effective propeller hp = 6.1

Fuel saving: $\frac{(13 - 11.3) \times 100}{13} = 13\%$

Alternative 3

Gear reduction = 3:1 and propeller B

Engine power = 10.9 hp
Engine rpm = 2 250 rpm
Propeller rpm = 750 rpm
Effective propeller power = 6.1 hp

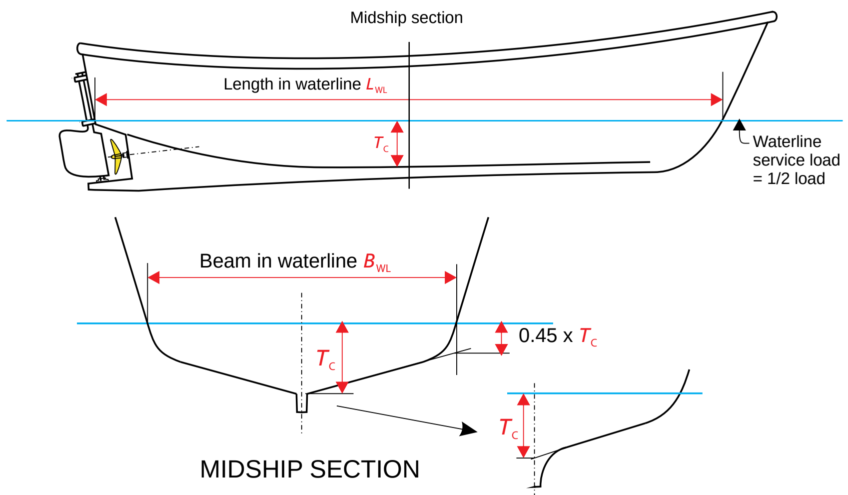
Fuel saving: $\frac{(13 - 10.9) \times 100}{13} = 16\%$

Because the engine is operating closer to the optimum range for low specific fuel consumption, there is a further fuel saving of around 6%.
Total fuel saving = 22%

Building a new boat?
Be sure you have enough space for an efficient propeller!

Based on the service displacement, the power and the main dimensions of a fuel efficient boat can be selected from the table below. Depending on the building cost, increasing the length, while keeping the same beam and depth, can give further fuel savings.

Service displacement ½ load	Declared propeller shaft power	Service speed	Max. speed	Length waterline L_{wl}	Beam waterline B_{wl}	Draft canoe body T_c
tonne	hp	knots	knots	m (ft)	m (ft)	m (ft)
0.5	2	4.0	4.6	3.7 (12)	1.4 (4.6)	0.23 (0.7)
0.75	3	4.4	5.0	4.3 (14)	1.6 (5.2)	0.26 (0.9)
1	4	4.6	5.2	4.7 (15)	1.7 (5.6)	0.30 (1.0)
1.5	5	4.9	5.6	5.4 (18)	2.0 (6.4)	0.34 (1.1)
2	6	5.1	5.8	5.9 (19)	2.1 (6.9)	0.38 (1.3)
3	9	5.4	6.3	6.8 (22)	2.3 (7.7)	0.46 (1.5)
4	13	5.6	6.5	7.4 (24)	2.5 (8.3)	0.51 (1.7)
5	16	6.0	6.8	8.0 (26)	2.7 (8.8)	0.56 (1.8)
6	19	6.1	7.0	8.5 (28)	2.7 (9.0)	0.62 (2.0)
8	26	6.4	7.4	9.4 (31)	2.9 (9.6)	0.70 (2.3)
10	33	6.6	7.6	10.1 (33)	3.1 (10.2)	0.77 (2.5)
12	40	6.9	7.9	10.7 (35)	3.3 (10.8)	0.82 (2.7)
14	48	7.1	8.1	11.3 (37)	3.4 (11.2)	0.88 (2.9)
16	55	7.2	8.2	11.8 (39)	3.5 (11.5)	0.93 (3.0)
18	62	7.3	8.4	12.2 (40)	3.6 (11.8)	0.98 (3.2)
20	69	7.5	8.6	12.7 (42)	3.7 (12.0)	1.03 (3.4)
25	88	7.7	8.9	13.6 (45)	3.9 (12.8)	1.13 (3.7)
30	108	8.0	9.1	14.5 (48)	4.1 (13.4)	1.22 (4.0)
35	127	8.2	9.4	15.2 (50)	4.2 (13.9)	1.30 (4.3)
40	147	8.4	9.6	15.9 (52)	4.4 (14.5)	1.36 (4.5)
45	166	8.5	9.7	16.5 (54)	4.5 (14.9)	1.44 (4.7)
50	187	8.7	9.9	17.1 (56)	4.7 (15.4)	1.49 (4.9)



The table is based on the following assumptions:

$$\frac{L_{WL}}{\text{Displacement}^{1/3}} = 4.75$$

$$\frac{L_{WL}}{B_{WL}} = 2.7 - 3.4 \text{ for boats below } L_{WL} = 12 \text{ m}$$
$$= 3.4 - 3.7 \text{ for boats } L_{WL} = 12 - 18 \text{ m}$$

Midship section coefficent: $C_M = 0.72$

Prismatic coefficient: $C_P = 0.58$

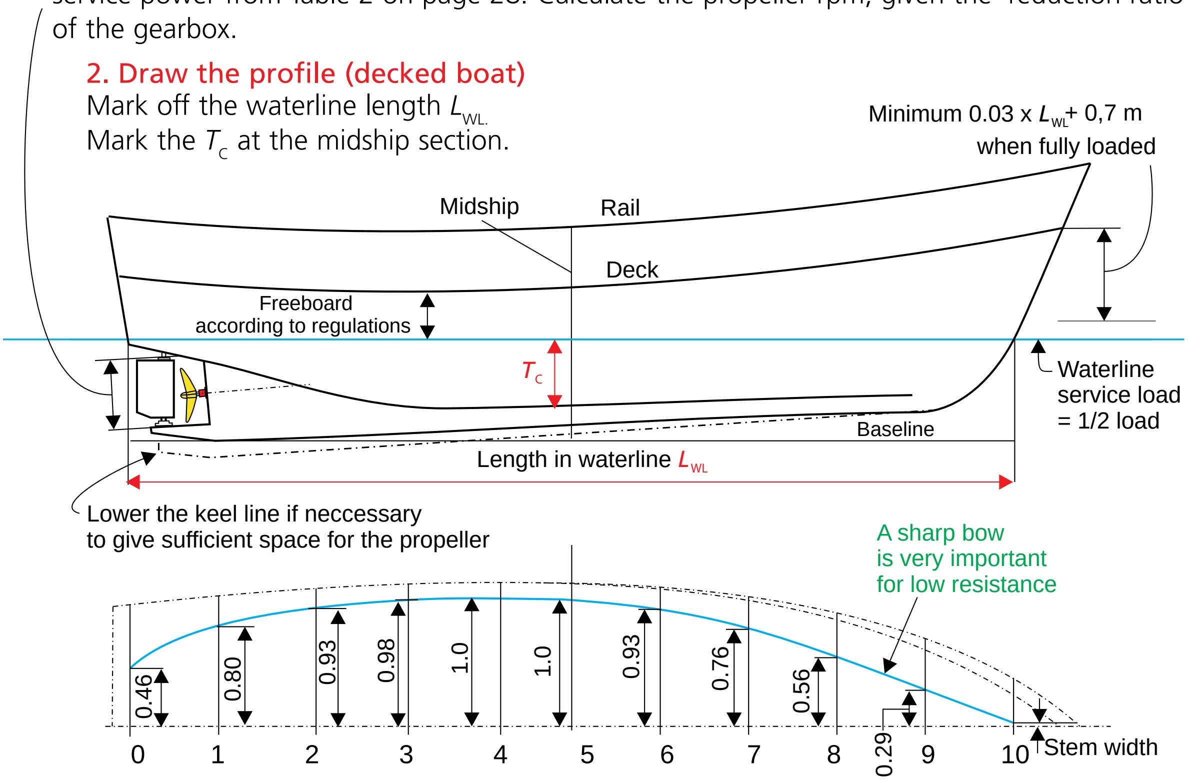
$$T_c = \frac{2.4 \times \text{Displacement}}{L_{WL} \times B_{WL}}$$

1. Calculate the diameter of the propeller and the space required for the propeller

See pages 32 and 33. Decide whether you want to use propeller A (90% of maximum engine rpm) or the bigger and more efficient propeller B (75% of maximum engine rpm). Use the service power from Table 2 on page 28. Calculate the propeller rpm, given the reduction ratio of the gearbox.

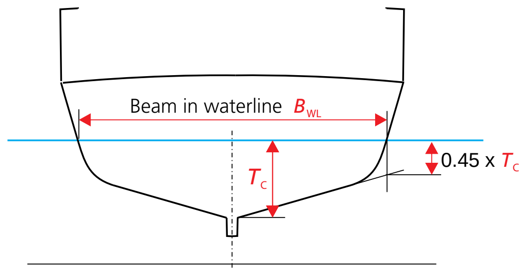
2. Draw the profile (decked boat)

Mark off the waterline length L_{WL}.
Mark the T_C at the midship section.

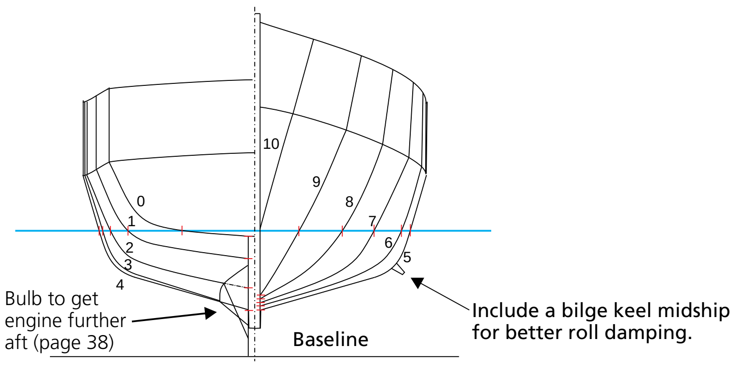


3. Draw the waterline

Divide the length of the waterline in ten parts and multiply ½ the waterline width B_{WL} by the coefficients above. This will produce a sharp bow, which is essential for low resistance.



MIDSHIP SECTION

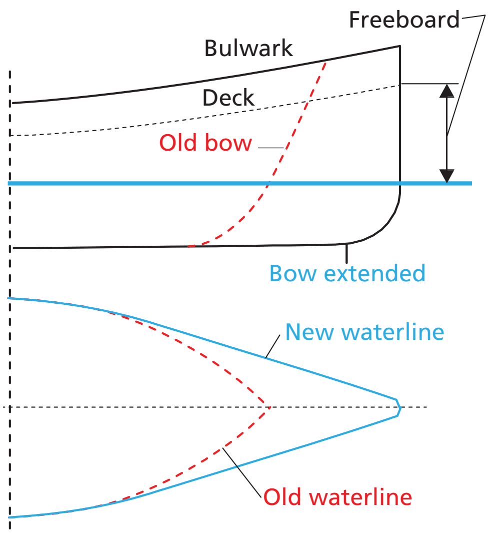


4. Draw the midship section

Mark off the waterline width B_{WL} and the T_C
Mark a point at 0.45 x T_C as shown and draw the bottom line. Round off the corner for a round bottom boat or leave corner as a chine for a V-bottom boat. A V-bottom boat will have a higher resistance but better roll damping.

5. Sketch the sections and fair the lines

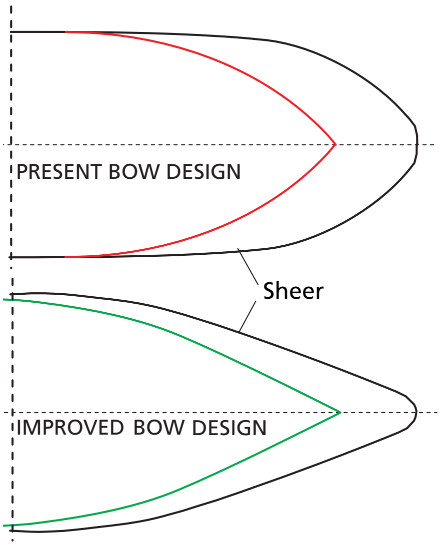
Mark the waterline widths and the rabbet height for each station and sketch in the sections. Avoid too much flare in the forebody because too much flare will slow down the boat in a head sea.



A sharp bow is essential for low fuel consumption

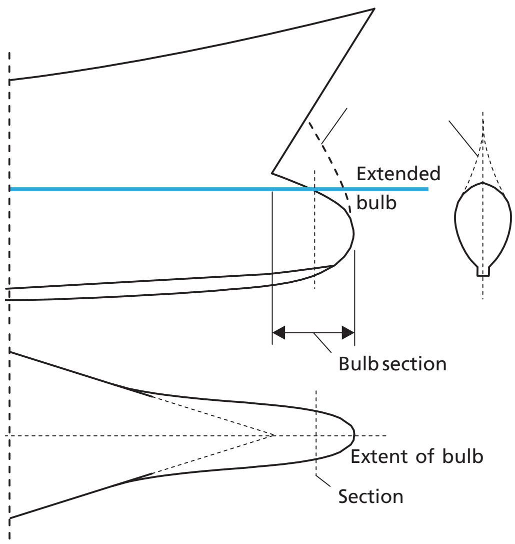
The Oliefiskprosjektet project (Nordforsk, 1984) found that by extending the bow as shown in the figure to the left, a fuel saving of 15% to 25% was achieved, depending on boat speed. Higher speed resulted in greater savings. Trials also showed that the new extended bow was better in waves. The old blunt bow when going into a wave threw spray forward and sideways, which the wind then blew onboard, making the boat wet.

The new bow sliced better through the waves, and did not throw up a big bow wave. However, with a slim bow, it is necessary to have a high freeboard up to the forward deck, minimum = 0.03 x L_{WL} + 0.7 m in the loaded condition.



Calisal and McGreer (1993) made a resistance study of fishing vessels in British Columbia, Canada, that had a great beam in relation to the length.

The two figures to the left show the present design of the bow and the design changes required to reduce resistance. The sharpening of the bow is essential to reducing resistance. The sharpening should be not only at the waterline but also extend up to the sheer. Other improvements in design to reduce resistance include a change from a single chine to a double chine.



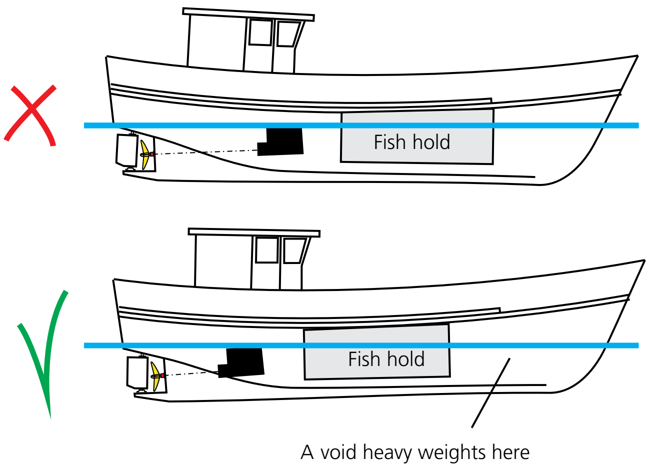
Carefully designed bulbs reduce resistance

Forward bulbs can reduce resistance by 5 to10% but must be designed carefully to be effective.

They are suitable for FRP, steel and aluminium boats greater than 12 m in length at the service speed shown in Table 2 on page 28. For wooden boats, the same effect as that produced by a bulb can be had by lengthening and sharpening the bow as shown here.

Bulbs will normally reduce the pitching in waves and this can have a positive effect on propeller efficiency.

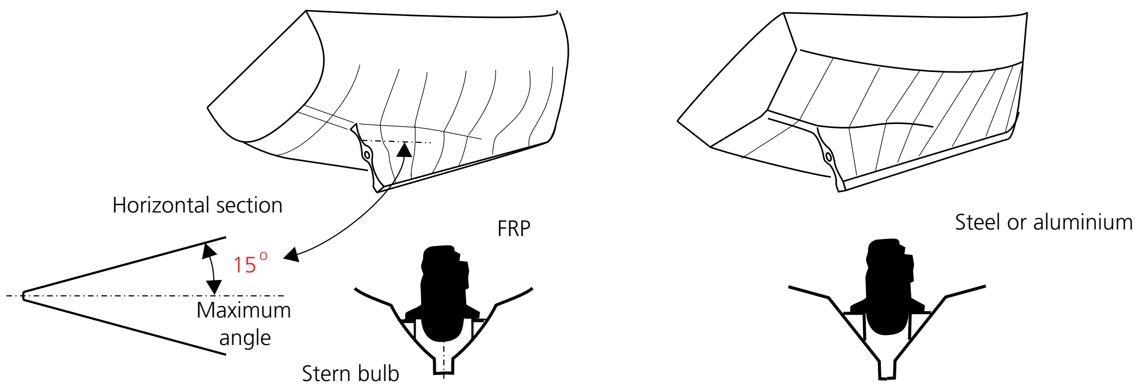
Bulbs are vulnerable to damage by grounding or collision and should, therefore, be separated from the rest of the boat by a watertight bulkhead.

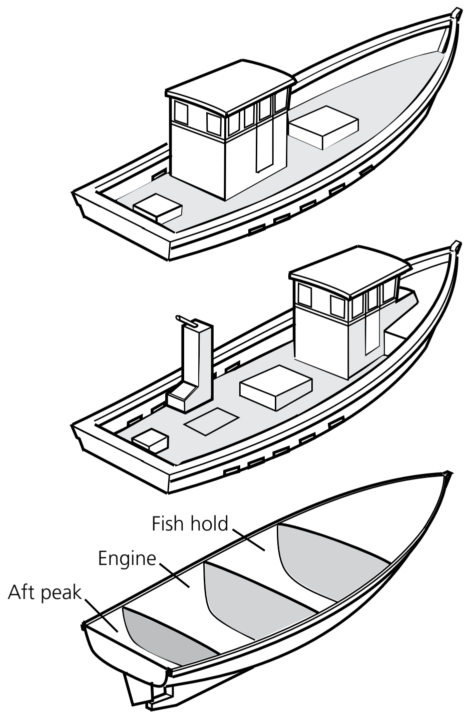


The position of the fish hold

With the conventional shape of the aft body, the position of the engine forces the fish hold to be placed too far forward. A sharp stem is essential for reducing power but with the fish hold forward, the boat will have a forward trim which increases resistance and can be dangerous in heavy weather because of difficult steering and low freeboard forward.

To position the fish hold further aft, it is necessary to move the engine further aft. A modification of the afterbody makes this possible.





The position of the wheelhouse forward or aft

If the engine is moved aft, it is possible to have a deck arrangement with a wheelhouse either aft or forward.

With the wheelhouse forward, the access to the engine room is through a hatch with coaming, usually on the port side. The engine can be removed through a bolted watertight hatch which is at the same level as the deck.

Outrigger craft and multihull boats require less power than monohull boats for semi-displacement speed

The most popular fishing boat in Sri Lanka is the 5.8 m (19 ft) FRP boat shown in the photo on the left. Initially these boats were powered with a 6 hp kerosene outboard engine, later increased to 8 then12 hp and currently, even 25 hp. Trials were made during the BOBP to compare the performance of a modernized, traditional, single outrigger canoe measuring 8 m (26 ft) in length with that of a 5.8 m FRP boat, both using the same engine and having the same load of 400 kg. The 5.8 m boat was operated beyond the displacement speed range and the longer and narrow hull of the outrigger canoe gave a fuel saving of 25 to 28%. The outrigger canoe was also tested with an 8 hp diesel engine, which further reduced the fuel consumption to 0.20 litre per nm, a fuel saving of 54% compared with the fuel consumption of the 5.8 m boat.

Type vessel	Maximum speed Outboard engine		Fuel consumption litre/nm	
	8 hp	12 hp	8 hp	12 hp
5.8 m boat	6.3 knots	7.3 knots	0.54	0.75
8.0 m canoe	9.4 knots	11.5 knots	0.40	0.56

Fuel savings with the outrigger canoe
8 hp engine = 28% and with the 12 hp engine = 25%

FAO designed the KIR-4 single outrigger canoe for use in Kiribati. It measures 7.2 m (24 ft) in length and has a 9.9 hp outboard engine, using a trial speed of 11 knots and with a load of three men and fishing gear. Fuel consumption was 0.57 litre/nm. This canoe is used for trolling for tuna and hand lining for reef fish.

FAO designed the INS-2 double outrigger canoe for use in Indonesia. It measures 8 m (26 ft) in length and has an inboard diesel engine of 4.5 hp, using a trial speed of 7 knots with a load of two men and 150 kg. Fuel consumption was 0.15 litre/nm. A similar canoe, the INS-3, with length increased to 9.7 m (32 ft), was fitted with a 6.5 hp diesel engine.

FAO designed the 8.9 m (29 ft) catamaran (Alia) for use in Western Samoa. Trolling for tuna requires semi-planing speed. The trial speed with a 25 hp outboard engine was 13 knots with a load of four men and fishing gear. Several hundred of this type of craft have been built in aluminium. This catamaran is mainly used for trolling for tuna, vertical longlining for tuna and bottom fishing for snappers and groupers. Trials with a 40 hp engine showed an increase in speed to 16 knots but the fuel consumption per nm increased by 50%, from 0.92 litre/nm to 1.4 litre/nm.

Top priority
Management plans for a sustainable fishery

Overfishing leads to more time and fuel being expended to chase fewer fish.
The government must, through management plans and in collaboration with the fishers, maintain the fish resource for future generations.

The government can provide incentives to replace fuel inefficient engines

Fuel for fishing boats is subsidized in many countries. There is no doubt that removing subsidies will reduce fuel consumption, but this has to be done gradually so that the fishers can adjust. Incentives should be directed at fuel saving technologies. The 2-stroke outboard engine has very poor fuel efficiency. Rather than subsidizing fuel, it would be better if the government provided incentives to replace these engines with diesel engines after running trials in a pilot project using alternative ways of installing the inboard diesel engine.

The government can create fuel saving teams to promote the use of fuel meters and warp tension meters

Within the Fisheries Department there should be a fuel saving team with a good knowledge of fuel saving methods, such as those presented in this manual. This team, equipped with an advanced fuel consumption measuring instrument, would show the fishers aboard their boats the usefulness of this instrument for tracking on a monitor in the wheelhouse a boat's fuel consumption. Nothing is more effective than for fishers to see for themselves the potential there is of saving fuel by reducing engine power. The team would also have a warp tension meter to measure the towing force on trawlers. In New Zealand (Billington, 1988), fishers have responded positively to the installation of these meters. Most of them were surprised to see on the fuel meter the effect of changing engine rpm and they consequently modified their travelling speed or towing mode. Many of them installed fuel measuring instruments onboard. Fuel savings of up to 30% were achieved.

The government can ensure that proven fuel saving technologies are extended through large schemes

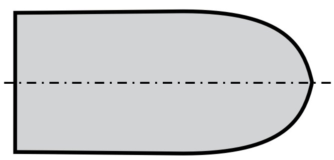
FAO has extensive experience in demonstrating more fuel-efficient boats and engines in developing countries. However, in many cases, there has been no follow-up after initial pilot demonstrations.

To succeed in introducing fuel-efficient technologies, it is important that there be a certain momentum in order to achieve an impact. After a pilot demonstration, proven technologies need to be extended through well-organized and financed larger schemes.

A new technology should not be introduced without a thorough trial period.

Beware that rules and regulations based on boat length will lead to abnormally shaped boats with high fuel consumption

Many countries use the overall length of a boat as a limit with regard to safety regulations or access to certain fisheries. The result is that fishers increase the beam and the depth rather than length of their boats in order to get as large a fish-hold capacity as possible. The result is short and beamy boats, as shown in the figure to the left, and presently built in Norway. A boat of this type will have extremely high fuel consumption and perform poorly in waves.



The best criterion for boat size is cubic number (CUNO) or gross tonnage based on the cubic number. The boat owner can then choose a length and a beam for good fuel economy.

Amble, A. 1985. Sail-assisted performance of a 33 foot fishing vessel. Results of full scale trials. *Journal of Wind Engineering and Industrial Aero Dynamics,* 19: 149–156. The Netherlands.

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Calisal, S.M. & McGreer, D. 1993. A resistance study on a systematic series of low L/B vessels. *Marine Technology,* 30(4): 286 – 296.

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Mithraratne, N., Vale, B. & Vale, R. 2007. *Sustainable living: The role of the whole life costs and values.* Oxford, UK, Elsevier. 211 pp.

Nordforsk. 1984. *Oliefiskprosjektet.* Nordic Cooperative Organization for Applied Research. Denmark.

Palmer, C. 1990. Rig and hull performance. *Wooden Boat Magazine,* 92: 76–89. USA.

Tyedemers, P. 2004. Fisheries and energy use. *Encyclopedia of Energy, 2*. The Netherlands, Elsevier.

Villiers, A. 1962. *Of ships and men.* London, Newnes.

Winther, U. Ziegler, F., Skontorp Hognes, E., Emanuelsson, A., Sund, V. & Ellingsen, H. 2009. *Carbon footprint and energy use of Norwegian seafood products.* SINTEF Fisheries and Aquaculture. Norway.

Extensive bibliographies on fuel savings can be found in the following publications:

Donat, H. 1979. *Practical points on boat engines.* Nautical Publishing Co. Ltd.

Ellingsen, H. & Lønseth, Moten. 2005. *Energireduserende tiltak innen norsk fiskeri.* SINTEF Fiskeri og havbruk. Norway. (Available at www.fiskerifond.no/files/projects/attach/331013.pdf)

Endal, A. 1988. *Energy fishing – challenge and opportunities.* Paper presented at the World Symposium on Fishing Gear and Fishing Vessel Design. Marine Institute, St John's, Newfoundland, Canada.

Gulbrandsen, O. & Savins, M. 1987. *Artisanal fishing craft of the Pacific Islands.* FAO/UNDP Regional Fishery Support Programme. Document 89/4. Fiji. 36 pp.

MacAlister Elliott & Partners Ltd. 1988. *Sails as an aid to fishing.* UK, Overseas Development Administration.

Schau, E.M., Ellingsen, H., Endal, A. & Aanondesen, S. A. 2009. Energy consumption in the Norwegian Fisheries. *Journal of Cleaner Production,* 17: 325–334. The Netherlands, Elsevier.

Vos-Efting, S. et al. 2006. *A life cycle based eco design consideration for the Rainbow Runner.* HISWA Symposium. The Netherlands.

White, G. 1959. *Propeller determination. Problems in Small Boat Design.* USA, Sheridan House.

Woodward, J., Beck, R.F., Scher, R. & Cary, C. 1975. *Feasibility of Sailing Ships for the American Merchant Marine.* Department of Naval Architecture and Marine Engineering. Report No. 168. Ann Arbor, Michigan, USA, University of Michigan Press.

Proceedings from the following conferences contain much information regarding energy use and fuel savings for operators of fishing boats:

Fishing Industry Energy Conference. 1981. Sponsored by The National Marine Fisheries Service and The Society of Naval Architects and Marine Engineers. Seattle, Washington, USA.

Innov'sail. 2008. International Conference on Innovation in High Performance Sailing Yachts. Royal Institution of Naval Architects. London, UK.

International Conference on Sail-assisted Commercial Fishing Vessels: Proceedings. 1983. Florida Sea Grant College, USA.

Symposium on Wind Propulsion of Commercial Ships. 1980. Royal Institution of Naval Architects. London, UK.

World Symposium on Fishing Gear and Fishing Vessel Design. 1988. Marine Institute, St. John's, Newfoundland, Canada.

A calculation of energy use over the service life of a boat will indicate the relative importance of the choices of materials used in boat construction and operation

The energy used for the construction of a boat is based on a calculation using the weight of hulls of planked wooden construction and single skin FRP construction, as per Appendix 5 for a 9 m boat with a cubic number = 24 m^3 (*SILVER FISH*, page 10). The energy content embodied in the construction materials is expressed in joules (J), megajoules (MJ) or gigajoules (GJ), the international unit for energy (Mithraratne, Vale and Vale, 2007).

The joules are then converted to the equivalent energy in diesel fuel:

1 litre diesel fuel = 36.4 MJ = 10.1 kWh.

Example:

1. Energy used in building a boat

A detailed analysis of the energy and weight embodied in the materials, engine and equipment required for the building of a wooden and a FRP boat gives the following result:

The FRP boat embodies three times the amount of energy compared with the wooden boat, but the FRP boat will have a 0.9 tonne lower service displacement.

	Wood boat	FRP boat
Weight of boat (lightship)	3.1 tonnes	2.2 tonnes
Service load	2.0 tonnes	2.0 tonnes
Service displacement	**5.1 tonnes**	**4.2 tonnes**
Energy in construction materials, engine, equipment	35 GJ	100 GJ
Equivalent energy in diesel fuel	**900 litres**	**2 800 litres**

Energy is used in the production of the diesel engine but some of this energy is recovered when the engine is scrapped.

2. Energy used during fishing operations

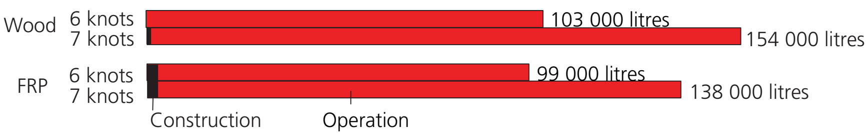
In the example of a LCA presented here, the fishers who use the wooden and FRP boats do driftnet fishing at a distance of 20 nm from the shore. The fuel consumption of the engines of each boat, run at 4 knots for setting and hauling for 3 hours = 6 litres. The catch is kept on ice and the ice amounts to 500 kg per trip. The ice is produced by electricity at the rate of 50 kWh per tonne. The energy used when converted to an equivalent energy in diesel fuel = 3 litres.

	Diesel fuel in litres per trip			
	6 knots		7 knots	
Operation	**Wood**	**FRP**	**Wood**	**FRP**
Travelling 40 nm	25	23	42	36
Fishing	6	6	6	6
Preserving catch – ice	3	3	3	3
Total litres of diesel per trip	**34**	**32**	**51**	**45**

Some energy will be required for the maintenance of the boat, including antifouling paint, replacement of gillnets and the scrapping of the boat at the end of the service life but the energy content of these activities is of minor significance compared with energy used in fuel consumption.

3. Total energy used during the life cycle (litres of diesel fuel)

Assuming 200 trips per year and a 15-year service life of each boat, the energy used is:



- **Service speed is very important.** In the above example, a reduction from 7 to 6 knots will reduce the total energy cost by around 30% (passive fishing gear).
- The amount of energy embodied in the materials used for building a boat is not significant.
- Lightweight hull materials such as FRP, aluminium and plywood will in this example reduce total energy use by 4% at an economic speed of 6 knots.

EXAMPLE: The time it takes to consume 0.5 litres of fuel = 186 seconds. Speed = 7.8 knots

Fuel consumption

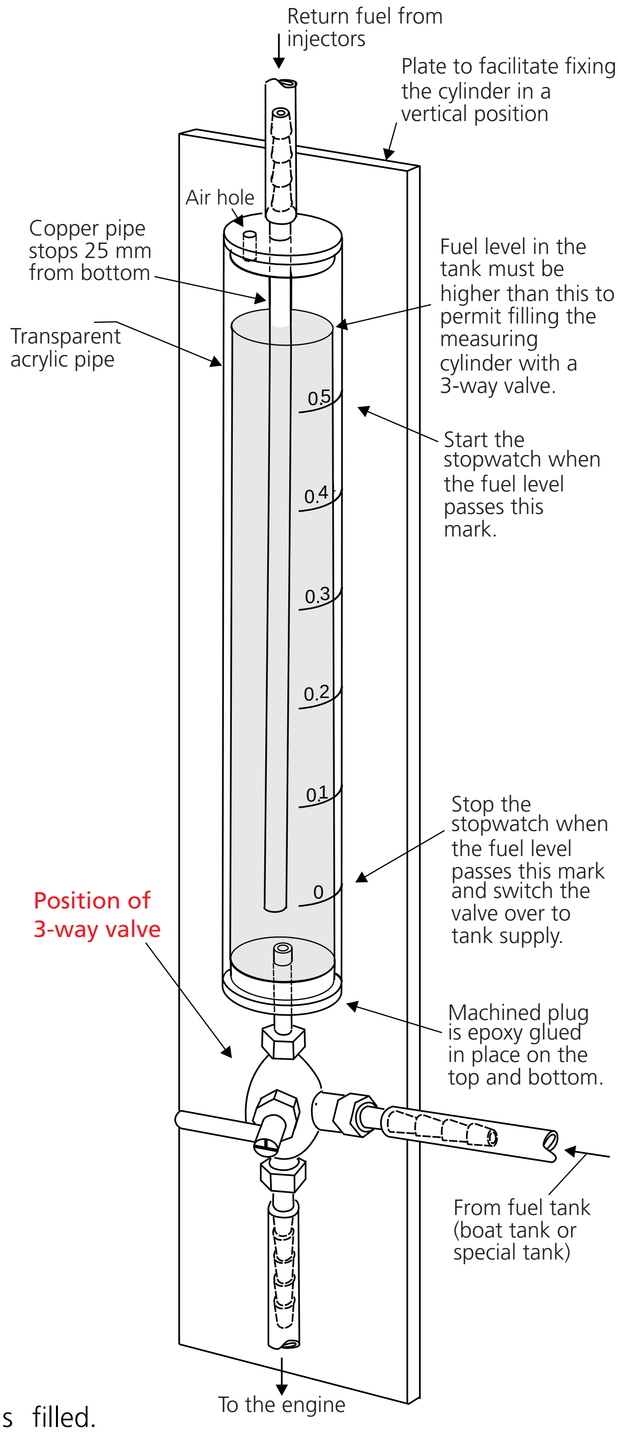
$$\textbf{Litres/hour} = \frac{0.5 \times 3\,600}{186} = \mathbf{9.7}$$

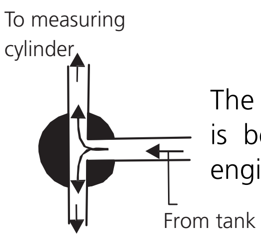
$$\textbf{Litres/nm} = \frac{9.7}{7.8} = \mathbf{1.24}$$

The pipe diameter and length should be appropriate for the engine power. Example: For engines up to 50 hp, use diameter = 40 mm and length = 0.6 m, which is sufficient for 0.5 litres. For bigger engines increase pipe diameter and length.

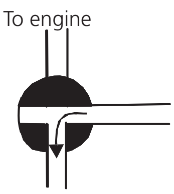
To mark for quantity, first pour some water into the cylinder to cover the outlet pipe + 30 mm.

Make a mark. Place the return fuel pipe in the cylinder. Carefully measure 0.5 litres into a measuring glass. Pour the fuel into the cylinder and mark the top level. Then divide the filled volume in equal parts by marking each 0.1 litres of fuel as shown in the figure. Use the total 0.5 litres when measuring 30–50 hp. For lower power, you can use from 0.1 to 0.4 litres measuring volume. Adjust so that measuring time is more than two minutes.

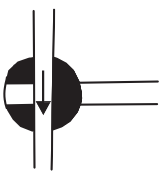




The measuring cylinder is being filled while the engine is running.



The measuring cylinder is filled. The engine is fueled from the tank.



The engine is fueled from the measuring cylinder. The connection to the tank is closed.

(The drawing aims to show the principle: it is not to scale.)

Boat: SILVER FISH

Length over all	9,0 m
Length in waterline	8,0 m
Service displacement (if known)	5 tonnes
Engine declared power, hp continuous duty	31 hp
Engine maximum rpm, continuous duty	3000 rpm

			Maximum	0.9 x maximum rpm	0.8 x maximum rpm	0.7 x maximum rpm
①	Maximum propeller shaft power hp		29			
②	Engine rpm		3000	2700	2400	2100
③	Service speed	knots	7.1	6.7	6.2	5.5
④	Propeller shaft powerfraction		1.0	0.73	0.51	0.34
⑤	Propeller shaft power ①x④	hp	29	21	15	10
⑥	Fuel consumption ⑤x 0.25	litres/hour	7,3	5,3	3,8	2,5
⑦	Fuel consumption per nautical mile ⑥/③	litres/nm	1,03	0,79	0,61	0,45
⑧	Distance to fishing ground and back again	nm	40	40	40	40
⑨	Fuel, travelling per trip ⑦x⑧	litres	41	32	24	18
⑩	Fuel, fishing per trip	litres	6	6	6	6
⑪	Total fuel per trip ⑨+ ⑩	litres	47	38	30	24
⑫	Fuel saving ⑪max - ⑪reduced	litres	0	9	17	23
⑬	Travelling time per trip ⑧/③	hours	5,6	6,0	6,5	7,3
⑭	Fishing time per trip	hours	12	12	12	12
⑮	Total time per trip ⑬+⑭		17,6	18	18,5	19,3
⑯	Extra time per trip ⑪-⑪max	hours	0	0,4	0,9	1,7
⑰	Number of trips per year		200	200	200	200
⑱	Fuel saving per year ⑫x⑰	litres	0	1800	3400	4600

Boat:

Length over all	
Length in waterline	
Service displacement (if known)	
Engine declared power, hp continuous duty	
Engine maximum rpm, continuous duty	

			Maximum	0.9 x maximum rpm	0.8 x maximum rpm	0.7 x maximum rpm
①	Maximum propeller shaft power hp					
②	Engine rpm					
③	Service speed	knots				
④	Propeller shaft powerfraction		1.0	0.73	0.51	0.34
⑤	Propeller shaft power ①x④	hp				
⑥	Fuel consumption ⑤x 0.25	litres/hour				
⑦	Fuel consumption per nautical mile ⑥/③	litres/nm				
⑧	Distance to fishing ground and back again	nm				
⑨	Fuel, travelling per trip ⑦x⑧	litres				
⑩	Fuel, fishing per trip	litres				
⑪	Total fuel per trip ⑨+ ⑩	litres				
⑫	Fuel saving ⑪max -⑪reduced	litres				
⑬	Travelling time per trip ⑧/③	hours				
⑭	Fishing time per trip	hours				
⑮	Total time per trip ⑬+⑭					
⑯	Extra time per trip ⑪-⑪max	hours				
⑰	Number of trips per year					
⑱	Fuel saving per year ⑫x⑰	litres				

Example: A comparison of the cost of an outboard engine and a diesel engine used on a canoe in Ghana.

Note: This is a relatively simple analysis which will provide an indication only of total cost per year. A "net present value" (NPV) analysis is more accurate but more complex.

			35 hp Outboard engine	23 hp Diesel engine
①	Installed cost	US$	5000	9000
②	Service life	years	3	6
③	Depreciation per year ① / ②	US$	1666	1500
④	Interest on capital at 15 %	US$	750	1350
⑤	CAPITAL COST PER YEAR ③ + ④	US$	2420	2850
⑥	REPAIR PER YEAR 0.1 x ①	US$	500	900
⑦	Engine running time per fishing trip	hours	4	4
⑧	Fuel consumption per hour	litres	8	3
⑨	Fuel per fishing trip ⑦ + ⑧	litres	32	12
⑩	Cost of fuel per litre	US$	0.80	0.80
⑪	Cost of fuel per fishing trip ⑨ x ⑩	US$	25,60	9,60
⑫	Number of fishing trips per year		200	200
⑬	COST OF FUEL PER YEAR ⑪ x ⑫	US$	5120	1920
⑭	TOTAL COST PER YEAR ⑤ + ⑥ + ⑬	US$	8040	5670

WORKSHEET FOR CALCULATIONS

Note: This is a relatively simple analysis which will provide an indication only of total cost per year. A "net present value" (NPV) analysis is more accurate but more complex.

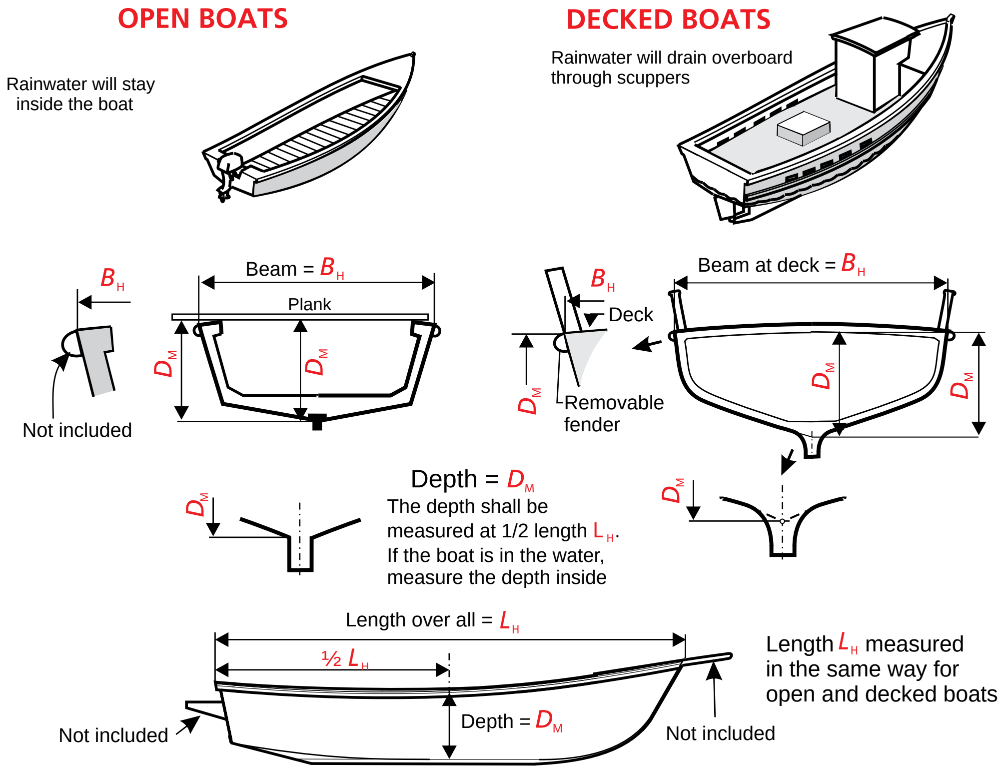
①	Installed cost		
②	Service life years		
③	Depreciation per year ① / ②		
④	Interest on capital at %		
⑤	CAPITAL COST PER YEAR ③ + ④		
⑥	REPAIR PER YEAR 0.1 x ①		
⑦	Engine running time per fishing trip hours		
⑧	Fuel consumption per hour litres		
⑨	Fuel per fishing trip ⑦ + ⑧ litres		
⑩	Cost of fuel per litre		
⑪	Cost of fuel per fishing trip ⑨ x ⑩		
⑫	Number of fishing trips per year		
⑬	COST OF FUEL PER YEAR ⑪ x ⑫		
⑭	TOTAL COST PER YEAR ⑤ + ⑥ + ⑬		

Weight = displacement

1 tonne weight = 1 000 kg = 1 tonne displacement (1 long ton = 1.016 metric tonnes)

An estimation of the weight of the boat with no load can be made on the basis of the CUBIC NUMBER (CUNO).

$CUNO$ = length x beam x depth = $L_H \times B_H \times D_M$



Estimated weight of the boat with engine and equipment

Lightship = no load

Weight = k x CUNO tonnes 1 tonne =1 000 kg

English long ton = 2 240 lb =1 016 kg

OPEN BOATS

	Wood	FRP
k	0.08	0.06
Cubic number CUNO m³	**Lightship no load tonnes**	**Lightship no load tonnes**
4	0.3	0.2
6	0.5	0.4
8	0.6	0.5
10	0.8	0.6
15	1.2	0.9
20	1.6	1.2
25	2.0	1.5
30	2.4	1.8
35	2.8	2.1
40	3.2	2.4

DECKED BOATS

	Wood	FRP	Steel
k	0.13	0.09	0.16
Cubic number CUNO m³	**Lightship no load tonnes**	**Lightship no load tonnes**	**Lightship no load tonnes**
20	2.6	1.8	3.2
25	3.3	2.3	4.0
30	3.9	2.7	4.8
40	5.2	3.6	6.4
50	6.5	4.5	8.0
60	7.8	5.4	9.6
70	9	6.3	11
80	10	7	13
100	13	9	16
120	16	11	19
140	18	13	22
160	21	14	26
180	23	16	29
200	26	18	32

Service displacement is the weight of the boat with an average load. The average load is usually calculated with the weight of the crew and fishing gear, with fuel and water tanks half full, and the fish hold half full of fish.
The calculation is made in kg and the total result converted to tonnes (1 000 kg).
CUNO from measurements of the boat: CUNO = L_H x B_H x D_M = ________ m^3

A. Lightship displacement = boat with no load (kg)
Use the table on page 49 to estimate the lightship displacement using the CUNO
Lightship displacement: (no load) = ________ kg

+ B. Weight of crew Number of crew x 80 = ______ x 80 = ________ kg

+ C. Weight of fishing gear
The weight of the fishing gear has to be estimated. = ________ kg
Remember that fishing nets will be heavier when soaked with water.

+ D. Weight of freshwater (1 litre = 1 kg)
½ Volume of freshwater tanks in m^3 x 1 000 = ________ m^3 x 1 000 = ________ kg

+ E. Weight of fuel (1 litre = 0.8 kg)
½ Volume of fuel tanks in m^3 x 800 = ________ m^3 x 800 = ________ kg

+ F. Weight of fish and ice
Inside volume of fish hold: V_{FI} = ______ m^3

The inside volume of the fish hold or fish box should be accurately calculated. If the fish-hold volume is not known, the maximum fish hold volume can be estimated for decked boats: V_{FI} = 0.15 x CUNO = ______ m^3

½ V x weight in kg per m^3 (from table below) = ______ m^3 x ______ kg/m^3 = ________ kg

Weight in kg per 1 m³ of fish-hold volume

	Fish	Ice	Fish and ice
Sardines and herring in bulk	800		
Fish in bulk	700		
Frozen tuna in bulk	600		
Fish in chilled sea water	700	200	900
Fish and ice , 1 : 1, in bulk	350	350	700
Fish and ice, 1 : 1, on shelves	250	250	500
Fish and ice, 1 : 1, in boxes	250	250	500

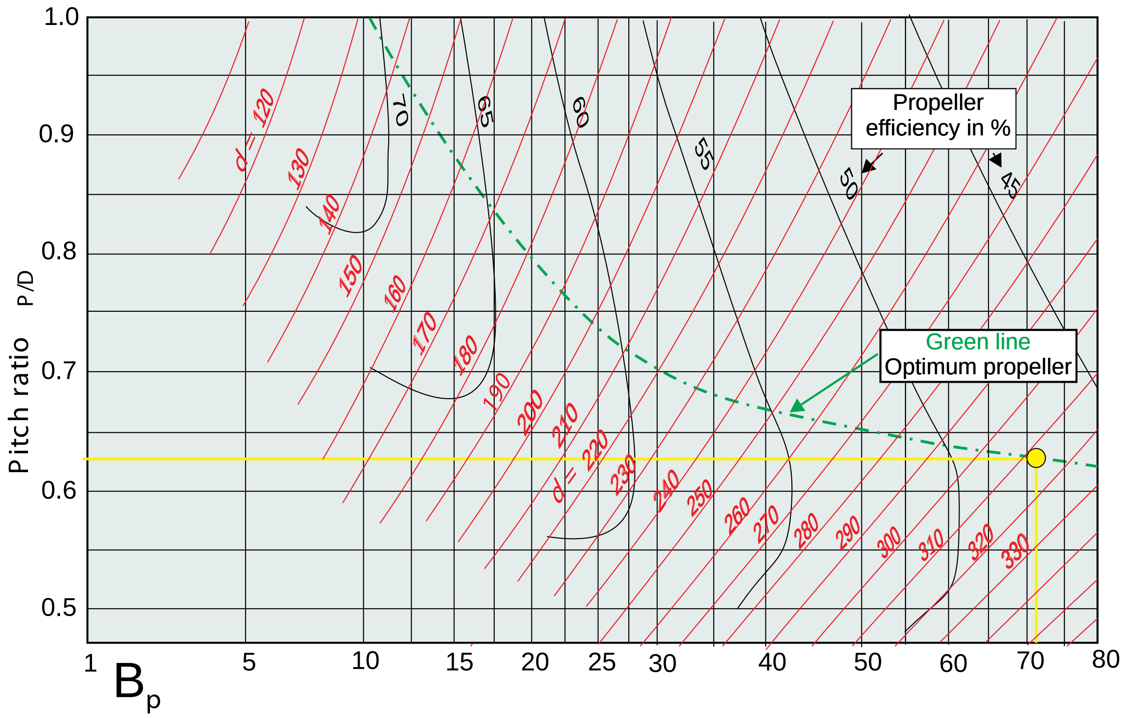
+ G. Weight of miscellaneous Ballast = ____________ kg

Other heavy equipment = ____________ kg

= Service displacement Total = kg

Service displacement = $\frac{\text{Total}}{1\ 000}$ = ________ tonnes

The diagram below shows calculations for the 3-bladed propeller from the Wageningen propeller series B 3-50. The blade area ratio is 0.5. However, the diagram can also be used for propellers of blade area 0.35–0.5. The original optimum line has been modified for a 5% reduction in the propeller diameter (as experience suggests).



$$B_p = \frac{\text{Prop. rpm} \times \sqrt{\text{hp at prop.}}}{\text{Speed of water at prop.}^{2.5}}$$

$$\text{Propeller diameter: } D = \frac{\text{Speed of water at prop.} \times d \times 12}{\text{Prop. rpm}} \quad \text{(inch)}$$

Propeller pitch: P = Pitch ratio x propeller diameter (inch)

The yellow line in the diagram above is where gear reduction ratio = 2, propeller A.
See the following page for an example of how to do the calculations.

Boat: SILVER FISH (new engine)

Engine declared power, continuous duty	18hp
Engine maximum rpm, continuous duty	3000 rpm

			Red. 2:1 Prop. A	Red. 3:1 Prop. A	Red. 3:1 Prop. B	
①	Service shaft power	hp	13	11,3	10,9	
②	Square root of shaft power ①$^{0.5}$		3,6	3,36	3,30	
③	Engine service rpm	rpm	2700	2700	2250	
④	Gear reduction ratio		2	3	3	
⑤	Propeller shaft rpm ③/④	rpm	1350	900	750	
⑥	Boat service speed	knots	6,0	6,0	6,0	
⑦	Wake factor		0,1	0,1	0,1	
⑧	Speed of water at propeller (1-⑦)x⑥	knots	5,4	5,4	5,4	
⑨	(Speed of water at propeller)$^{2.5}$ ⑧$^{2.5}$		67,8	67,8	67,8	
⑩	B_p (② x ⑤) / ⑨		71	44	36	
⑪	With B_p, read d from the diagram	d	312	258	238	
⑫	Propeller efficiency from diagram	%	47	54	56	
⑬	Pitch / diameter ratio from diagram	P/D	0,63	0,66	0,67	
⑭	Propeller diameter D = (⑧x ⑪ x 12) / ⑤	in	15,0	18,6	20,6	
⑮	Propeller pitch P = ⑬ x ⑭	in	10,2	12,3	13,8	
⑯	P x D ⑭ x ⑮		153	229	284	
⑰	Selected new diameter Dnew	in	15	18	20	
⑱	P x D / Dnew ⑯ / ⑰		10,2	12,7	14,2	
⑲	Selected new pitch Pnew	in	10	13	14	
⑳	Effective propeller power ① x ⑫	hp	6,1	6,1	6,1	

All three propellers give the same effective propeller power = 6.1 hp

Propellers are normally sold with diameter and pitch indicated in whole inches. Follow the procedure above to select the closest diameter and pitch.

Worksheet for calculations – Boat

Engine declared power, continuous duty	
Engine maximum rpm, continuous duty	

①	Service shaft power hp					
②	Square root of shaft power $①^{0.5}$					
③	Engine service rpm rpm					
④	Gear reduction ratio					
⑤	Propeller shaft rpm ③/④ rpm					
⑥	Boat service speed knots					
⑦	Wake factor					
⑧	Speed of water at propeller (1-⑦)x⑥ knots					
⑨	$(\text{Speed of water at propeller})^{2.5}$ $⑧^{2.5}$					
⑩	B_p $\frac{② \times ⑤}{⑨}$					
⑪	With B_p, read d from the diagram d					
⑫	Propeller efficiency from diagram %					
⑬	Pitch / diameter ratio from diagram P/D					
⑭	Propeller diameter D = $\frac{⑧ \times ⑪ \times 12}{⑤}$ in					
⑮	Propeller pitch P = ⑬ x ⑭ in					
⑯	P x D ⑭ x ⑮					
⑰	Selected new diameter Dnew in					
⑱	P x D / Dnew ⑯ / ⑰					
⑲	Selected new pitch Pnew in					

Propellers are normally sold with diameter and pitch indicated in whole inches. Follow the procedure above to select the closest diameter and pitch.

Boat service speed = 5 knots

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
4 hp	800	16.1	10.8	56
	900	15.0	10.1	54
	1 000	14.0	9.3	53
	1 100	13.3	8.6	52
	1 200	12.6	8.2	51
	1 300	12.0	7.8	50
	1 400	11.5	7.4	49
	1 500	11.0	6.9	48
	1 600	10.6	6.7	47
	1 700	10.2	6.3	46
	1 800	9.9	6.1	46
	1 900	9.6	5.9	45
	2 000	9.3	5.7	44
6 hp	800	17.4	11.5	54
	900	16.2	10.5	52
	1 000	15.2	9.9	50
	1 100	14.3	9.2	49
	1 200	13.6	8.7	48
	1 300	13.0	8.2	48
	1 400	12.5	7.8	47
	1 500	12.0	7.5	46
	1 600	11.7	7.2	45
	1 700	11.1	6.8	44
	1 800	10.8	6.6	43
	1 900	10.4	6.3	42
	2 000	10.3	6.1	41

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
8 hp	800	18.5	12.0	52
	900	17.1	11.1	50
	1 000	16.1	10.3	49
	1 100	15.2	9.6	47
	1 200	14.5	9.0	46
	1 300	13.8	8.4	45
	1 400	13.2	8.1	44
	1 500	12.7	7.6	43
	1 600	12.3	7.4	42
	1 700	11.9	7.0	42
	1 800	11.6	6.8	42
	1 900	11.2	6.4	41
	2 000	10.9	6.2	40
10 hp	800	19.2	12.5	51
	900	17.9	11.4	49
	1 000	16.8	10.6	47
	1 100	16.0	9.9	46
	1 200	15.2	9.4	45
	1 300	14.6	8.7	44
	1 400	13.9	8.4	43
	1 500	13.4	7.9	42
	1 600	13.0	7.5	41
	1 700	12.5	7.3	40
	1 800	12.0	6.8	40
	1 900	11.8	6.6	39
	2 000	11.5	6.3	39

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
12 hp	800	20.0	12.8	49
	900	18.6	11.7	47
	1 000	17.4	11.0	45
	1 100	16.5	10.3	44
	1 200	15.8	9.6	43
	1 300	15.0	9.0	43
	1 400	14.2	8.4	42
	1 500	14.0	8.1	41
	1 600	13.5	7.7	40
	1 700	13.0	7.4	40
	1 800	12.7	7.1	39
	1 900	12.4	6.8	38
	2 000	11.9	6.6	37
14 hp	800	20.6	13.2	48
	900	19.2	12.1	46
	1 000	18.1	11.2	45
	1 100	17.1	10.5	44
	1 200	16.2	9.7	43
	1 300	15.6	9.2	42
	1 400	15.0	8.7	41
	1 500	14.5	8.2	40
	1 600	13.9	7.8	39

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
16 hp	800	21.1	13.3	47
	900	19.8	12.3	46
	1 000	18.6	11.4	44
	1 100	17.7	10.6	43
	1 200	16.9	10.0	42
	1 300	16.1	9.3	41
	1 400	15.5	8.8	40
	1 500	14.9	8.3	39
	1 600	14.4	8.1	38

Boat service speed = 6 knots

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
6 hp	800	17.3	12.5	59
	900	16.2	11.3	58
	1 000	15.2	10.4	57
	1 100	14.4	9.7	56
	1 200	13.7	9.2	55
	1 300	13.0	8.6	54
	1 400	12.4	8.2	53
	1 500	11.9	7.8	52
	1 600	11.5	7.4	51
	1 700	11.1	7.1	50
	1 800	10.7	6.8	49
	1 900	10.3	6.5	48
	2 000	10.0	6.3	47
8 hp	800	18.5	12.6	58
	900	17.1	11.6	56
	1 000	16.2	10.9	55
	1 100	15.2	10.2	54
	1 200	14.5	9.6	53
	1 300	13.8	9.0	52
	1 400	13.1	8.5	51
	1 500	12.6	8.1	50
	1 600	12.2	7.8	49
	1 700	11.7	7.4	48
	1 800	11.3	7.1	47
	1 900	11.0	6.9	46
	2 000	10.7	6.6	45

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
10 hp	800	19.3	13.1	56
	900	17.9	12.0	55
	1 000	16.8	11.3	53
	1 100	16.0	10.5	52
	1 200	15.1	9.8	51
	1 300	14.5	9.3	50
	1 400	13.8	8.8	49
	1 500	13.2	8.3	48
	1 600	12.8	8.0	47
	1 700	12.3	7.7	46
	1 800	11.9	7.4	45
	1 900	11.5	7.5	44
	2 000	11.2	6.8	43
12 hp	800	20.0	13.4	55
	900	18.6	12.3	53
	1 000	17.5	11.5	52
	1 100	16.5	10.7	51
	1 200	15.7	10.2	50
	1 300	15.0	9.6	49
	1 400	14.3	9.0	48
	1 500	13.7	8.7	47
	1 600	13.2	8.2	46
	1 700	12.8	7.9	46
	1 800	12.5	7.6	45
	1 900	12.0	7.2	44
	2 000	11.7	7.0	43

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
14 hp	800	20.7	13.8	54
	900	19.2	12.7	52
	1 000	18.0	11.7	51
	1 100	17.0	11.0	50
	1 200	16.2	10.4	49
	1 300	15.4	9.7	48
	1 400	14.8	9.3	46
	1 500	14.2	8.9	45
	1 600	13.6	8.5	45
	1 700	13.2	8.1	44
	1 800	12.8	7.7	43
	1 900	12.4	7.4	42
	2 000	12.1	7.1	42
16 hp	800	21.1	14.0	53
	900	19.7	12.8	52
	1 000	18.5	12.0	50
	1 100	17.5	11.2	49
	1 200	16.6	10.4	48
	1 300	15.9	10.0	47
	1 400	15.2	9.6	46
	1 500	14.6	9.0	46
	1 600	14.1	8.6	45
	1 700	13.6	8.2	44
	1 800	13.2	7.8	43
	1 900	12.8	7.4	42
	2 000	12.4	7.2	41

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
18 hp	800	21.7	14.3	52
	900	20.2	13.1	50
	1 000	19.2	12.3	49
	1 100	17.8	11.4	48
	1 200	17.0	10.7	47
	1 300	16.2	10.2	46
	1 400	15.6	9.6	45
	1 500	15.0	9.1	44
	1 600	14.4	8.7	43
	1 700	13.9	8.3	42
	1 800	13.5	8.0	41
	1 900	13.1	7.6	40
	2 000	12.8	7.3	40
20 hp	800	22.3	14.5	52
	900	20.5	13.3	50
	1 000	19.3	12.4	49
	1 100	18.3	11.5	48
	1 200	17.4	11.0	47
	1 300	16.7	10.4	46
	1 400	16.0	9.7	45
	1 500	15.3	9.2	44
	1 600	14.9	8.3	43
	1 700	14.3	8.4	42
	1 800	13.9	8.0	42
	1 900	13.5	7.7	41
	2 000	13.1	7.5	40

Boat service speed = 7 knots

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
10 hp	800	18.9	14.2	61
	900	17.8	12.8	59
	1 000	16.8	11.7	58
	1 100	15.9	10.8	57
	1 200	15.1	10.3	56
	1 300	14.4	9.7	55
	1 400	13.8	9.3	54
	1 500	13.3	8.9	53
	1 600	12.8	8.4	52
	1 700	12.3	8.0	51
	1 800	11.8	7.7	51
	1 900	11.4	7.4	50
	2 000	11.2	7.1	49
12 hp	800	19.7	14.3	60
	900	18.6	13.1	59
	1 000	17.5	12.1	57
	1 100	16.6	11.3	56
	1 200	15.8	10.6	55
	1 300	14.9	10.0	54
	1 400	14.3	9.4	53
	1 500	13.7	9.0	52
	1 600	13.2	8.6	52
	1 700	12.7	8.3	51
	1 800	12.3	7.9	50
	1 900	11.9	7.6	49
	2 000	11.5	7.4	48

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
14 hp	800	20.4	14.7	59
	900	19.3	13.3	57
	1 000	18.0	12.2	56
	1 100	17.0	11.4	55
	1 200	16.3	9.4	54
	1 300	15.4	10.2	53
	1 400	14.7	9.6	52
	1 500	14.1	9.2	51
	1 600	13.6	8.7	50
	1 700	13.1	8.4	49
	1 800	12.7	8.1	48
	1 900	12.3	7.7	48
	2 000	11.9	7.5	47
16 hp	800	21.3	14.9	58
	900	19.7	13.4	57
	1 000	18.6	12.5	55
	1 100	17.5	11.7	54
	1 200	16.7	11.0	53
	1 300	15.9	10.3	52
	1 400	15.1	9.8	51
	1 500	14.5	9.4	50
	1 600	13.9	8.9	49
	1 700	13.5	8.6	49
	1 800	13.0	8.2	48
	1 900	12.7	8.0	47
	2 000	12.2	7.7	46

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
20 hp	800	22.2	15.1	57
	900	20.6	13.8	55
	1 000	19.4	13.0	54
	1 100	18.3	12.1	53
	1 200	17.4	11.3	52
	1 300	16.8	10.9	51
	1 400	15.8	10.1	50
	1 500	15.2	9.7	49
	1 600	14.6	9.2	48
	1 700	14.1	8.9	47
	1 800	13.7	8.6	46
	1 900	13.2	8.2	45
	2 000	12.9	8.0	45
25 hp	800	23.2	15.5	55
	900	21.6	14.5	54
	1 000	20.3	13.4	53
	1 100	19.1	12.4	51
	1 200	18.1	11.8	50
	1 300	17.3	11.1	49
	1 400	16.5	10.6	48
	1 500	15.9	10.0	47
	1 600	15.3	9.6	46
	1 700	14.8	9.2	45
	1 800	14.4	8.9	45
	1 900	13.9	8.5	44
	2 000	13.5	8.1	43

Service power	Propeller rpm	Propeller		
		Diameter inch	Pitch inch	Efficiency %
30 hp	600	28.6	19.4	58
	700	26.1	17.5	56
	800	24.1	16.1	54
	900	22.3	14.7	53
	1 000	20.9	13.6	51
	1 100	19.8	12.9	50
	1 200	18.8	12.0	49
	1 300	17.9	11.3	48
	1 400	17.2	10.8	47
	1 500	16.5	10.4	46
	1 600	15.9	9.9	45
	1 700	15.4	9.4	44
	1 800	14.9	8.9	43
35 hp	600	29.5	20.0	57
	700	26.8	17.9	55
	800	24.9	16.4	53
	900	23.1	15.0	52
	1 000	21.7	14.1	50
	1 100	20.5	13.1	49
	1 200	19.4	12.4	48
	1 300	18.5	11.7	47
	1 400	17.7	11.2	46
	1 500	17.0	10.6	45
	1 600	16.4	10.0	44
	1 700	15.9	9.6	43
	1 800	15.5	9.3	42

Boat service speed = 7 knots

Service power	Propeller rpm	Propeller Diameter inch	Pitch inch	Efficiency %
40 hp	500	33.6	23.5	59
	600	30.2	20.4	56
	700	27.5	18.5	54
	800	25.3	16.7	52
	900	24.0	15.6	51
	1 000	22.2	14.2	49
	1 100	21.0	13.5	48
	1 200	20.0	12.6	47
	1 300	19.1	12.0	46
	1 400	18.3	11.3	45
	1 500	17.5	10.7	44
	1 600	17.0	10.2	43
50 hp	400	40.1	28.8	60
	500	36.0	24.5	57
	600	31.5	21.5	55
	700	28.8	19.0	53
	800	26.5	17.2	51
	900	24.8	15.9	49
	1 000	23.2	14.6	48
	1 100	22.0	13.9	46
	1 200	21.0	13.2	45
	1 300	20.0	12.4	44
	1 400	19.2	11.7	43
	1 500	18.3	11.0	43

Boat service speed = 8 knots

Service power	Propeller rpm	Propeller Diameter inch	Pitch inch	Efficiency %
20 hp	800	21.6	16.2	61
	900	20.5	14.8	59
	1 000	19.4	13.4	58
	1 100	18.6	12.7	57
	1 200	17.4	11.7	56
	1 300	16.6	11.1	55
	1 400	15.9	10.6	54
	1 500	15.1	10.0	53
	1 600	14.6	9.6	52
	1 700	14.1	9.2	51
	1 800	13.5	8.8	51
	1 900	13.1	8.5	50
	2 000	12.8	8.2	49
25 hp	800	22.9	16.5	60
	900	21.6	14.9	58
	1 000	20.3	13.8	56
	1 100	19.5	13.1	55
	1 200	18.2	12.2	54
	1 300	17.3	11.6	54
	1 400	16.5	10.9	53
	1 500	15.8	10.3	52
	1 600	15.2	9.9	51
	1 700	14.6	9.5	50
	1 800	19.1	12.2	49
	1 900	13.8	8.8	48
	2 000	13.3	8.4	47

Boat service speed = 8 knots

Service power	Propeller rpm	Propeller Diameter inch	Pitch inch	Efficiency %
30 hp	700	25.7	18.7	60
	800	24.0	16.8	59
	900	22.4	15.2	57
	1 000	21.0	14.1	56
	1 100	20.3	13.6	54
	1 200	18.9	12.5	53
	1 300	17.9	11.7	52
	1 400	17.2	11.2	51
	1 500	16.4	10.7	50
	1 600	15.6	10.1	50
	1 700	15.2	9.8	49
	1 800	14.8	9.3	48
	1 900	14.3	9.0	47
35 hp	600	28.8	21.6	61
	700	26.7	18.9	59
	800	24.8	17.1	58
	900	23.2	15.6	56
	1 000	21.8	14.6	55
	1 100	20.5	13.5	53
	1 200	19.4	12.8	52
	1 300	18.5	12.0	51
	1 400	17.6	11.4	50
	1 500	17.0	10.9	49
	1 600	16.3	10.4	48
	1 700	15.7	9.9	47
	1 800	15.3	9.6	47

Boat service speed = 8 knots

Service power	Propeller rpm	Propeller Diameter inch	Pitch inch	Efficiency %
40 Hp	500	32.8	25.3	62
	600	31.2	22.0	59
	700	27.6	19.4	58
	800	25.5	17.3	57
	900	23.8	16.0	55
	1 000	22.2	14.9	53
	1 100	21.1	13.9	52
	1 200	19.9	13.0	51
	1 300	18.9	12.3	50
	1 400	18.1	11.6	49
	1 500	17.5	11.2	48
	1 600	16.8	10.6	47
	1 700	16.2	10.2	46
50Hp	500	34.6	25.9	61
	600	31.2	22.0	59
	700	29.9	19.6	57
	800	26.5	17.7	55
	900	24.8	16.6	54
	1 000	23.2	15.3	52
	1 100	21.8	14.2	51
	1 200	20.7	13.5	50
	1 300	19.8	12.7	49
	1 400	18.9	11.9	48
	1 500	18.3	11.5	47
	1 600	17.6	11.1	46
	1 700	17.0	10.6	45

This manual aims to provide practical advice to fishing boat owners and crews, boatbuilders and boat designers and fisheries administrators on ways to reduce fuel costs. It also serves as a guide for those involved with fuel savings for small vessels used in support of aquaculture activities. It focuses on small boats measuring up to 16 m (50 ft) in length and operating at speeds of less than 10 knots. This covers the majority of the world's fishing boats. The manual provides information to boat designers and boat builders on hull shape for low resistance an the selection of efficient propellers. The first chapters of this manual deal with fuel saving measures that can be taken on existing boats without incurring major investment costs. The most effective measures include reducing boat service speed, keeping the hull and propeller free from underwater fouling and maintaining the boat engine. It also suggests that changing fishing methods can save fuel. The final chapters of this manual provide information regarding the fuel savings that are possible by changing from a 2-stroke outboard engine to a diesel engine, installing a diesel engine, and using sail. Selecting economic engine power on the basis of the waterline length and the weight of the boat is discussed. Advice is given on the choice of gear reduction ratio and of propeller related to service speed, service power and propeller rpm. Data are provided to assist with the design of a new fuel-efficient boat and the selection of an optimum propeller. The information contained in this manual is accompanied by many illustrations to make the main points more easily understood. Detailed background information is provided in the appendices. The appendices also contain blank tables that may be used to calculate potential fuel savings, cost of engine operation, the weight of a boat and the diameter and pitch of a propeller.

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