

OceanSMART

1.6

ECOLOGICAL

Fuel Efficiency Guide

For Our Environment

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Please note: This guide is focused on slower speed displacement vessels; no attempt has been made to cover high-speed planing vessels. However, in many cases, the basic principles outlined are applicable to both low- and high-speed vessels. All vessel design modifications should be done under the direction of a Naval Architectural Engineer that will work to make the vessel as safe and economic to operate as possible.

Our Message

Canada's coast, with over 243,042 kilometres of coastline, is home to over 10,000 marine species and over 3 million small commercial and pleasure vessels that ply these waters. Mariners enjoy the rich bounty of these waters, which continue to provide us healthy fisheries and some of the finest sailing in the world.

Human activity is changing the physical and chemical properties of our oceans: acidification, changes in salinity and oxygen content, changes in hydrographical structure and currents, and of course sea-level rise. These changes have already led to shifts in abundance and distribution of fish populations, the spread of invasive species, and the migration of warm water fish into "cold" ecosystems.

If we continue unchecked, acidification of our oceans will lead to the death or altered migration of fish stocks. Climate change will disrupt marine food webs which will have serious consequences for the survival and productivity of fish species.

By taking the right actions now, mariners can reduce green house gas emissions, decreasing the damage on marine ecosystems, while reducing fuel costs. This guide outlines some of the steps to take to minimize fuel consumption, reducing environmental impacts. The first step: Slow down and enjoy the voyage!



For Our
Environment

1

Operational
Measures

Running PULL'ER BACK

Speed is the singular most important factor to influence fuel consumption. The underlying principles are worth going over.

- A vessel is pushed through the water by the propeller.
- Energy is expended in making surface waves alongside and behind the boat.
- The effort expended in creating these waves is known as the wave-making resistance.
- As speed increases, more energy is spent making these waves than moving the vessel.
- At higher speeds the engine itself may not be operating at its most efficient, particularly as it approaches maximum RPM.

Saving fuel through speed reduction requires two principle conditions:

- Knowledge of what can be gained by slowing down.
- Preparation to go slower.

Factors involved in slowing down:

- The vessel slows down and the journey takes longer.
- The efficiency of the engine will change, but it will consume less fuel per hour.
- The resistance of the hull in the water drops very rapidly.
- The efficiency of the propeller changes.

Both large and small vessels benefit when speed is reduced. The chart on the following page shows the fuel savings that can be made on a 35' vessel over a 20-mile trip. By slowing down from 9 knots to 8 knots, you would save a total of \$42. That's over \$150 per hour. If you were to slow down to 6 knots, you would take 1.1 hours longer to get there but you would save \$100 per hour!

2

Estimates in Fuel savings for a 20 nautical mile trip (one day)

Speed	Time taken	Consumption gallons per day	Total fuel used	Fuel Cost	Total Savings	Savings (per hour/knot)
9	2.2	41.1	41	\$ 186.50	\$ 0	\$ -
8	2.5	31.7	32	\$ 143.96	\$ 42.54	\$153.14
7	2.9	23.5	24	\$ 106.87	\$ 79.62	\$125.40
6	3.3	16.6	17	\$ 75.24	\$ 111.25	\$100.13
5	4.0	10.8	11	\$ 49.07	\$ 137.43	\$ 77.31

Fuel Monitoring

WHERE IT GOES

A fuel meter is your tool to help you track consumption. Keep a log of what your consumption is during different operating conditions. A fuel monitor will:

- Provide you with fuel consumption information
- Help you change your fuel consumption habits
- Help you monitor how changes in displacement and trim affect fuel efficiency
- Help you modify your actions to get the most out of your specific boat and engine



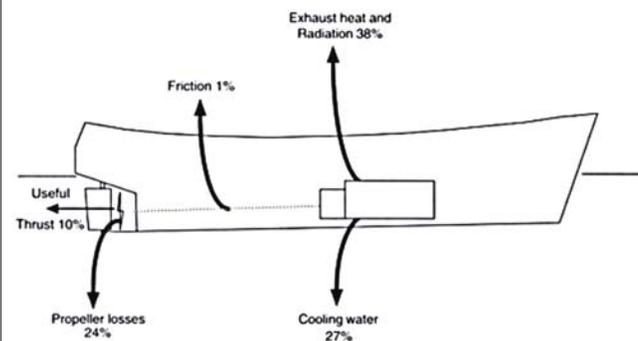
FloScan Meter
General purpose for mid-sized engines
Price range: \$1,200 to \$1,700



Mid Range Meter
Can give hourly rates.
Can give trip consumption
Price range: \$700 to \$1,200

Energy Use

CATCH IT ALL



Of the energy that reaches the propeller:

- 35% is used to turn the propeller
- 27% to overcome wave resistance
- 18% to overcome skin friction
- 17% to overcome resistance from the wake and propeller wash against the hull
- 3% to overcome air resistance

The following sections show ways where gains can be made, or losses minimized.

Engine Maintenance

KEEP 'ER OILED

Perform regular maintenance:

- Change oil, filters and separators regularly.
- Make daily inspections of the shaft, bearings, couplings and stuffing box for increased vibrations, dirty filters and sufficient lube.
- Follow the engine manufacturer's maintenance program.
- Entrust complicated mechanical work to a qualified mechanic.
- Run in a new or reconditioned engines carefully.

Telltale signs that engine maintenance is required

Black exhaust smoke indicating: an overloaded engine; a shortage of air; or worn injectors.

White exhaust smoke indicating: mistimed injectors/valves; leaking inlet or burnt exhaust valves; damaged/worn piston rings; low compression; or exhaust back pressure.

Blue exhaust smoke indicating: oil in the combustion chamber indicating either worn valve guides or worn/ broken piston rings; or oil in the exhaust side of a turbocharger following seal failure.

Generators

SPARK UP THE INVERTER

Generators can be a great feature on any vessel; they can also guzzle the gas. They should be matched to the electrical draw from your equipment. Turn them off when they're not being used.

Most small electrical devices, like computers or monitors, can be run using an inverter, operating off an existing battery bank. This is usually much more efficient than running a generator, the better option for small vessels. Check with your electrician to install one.

Hull Maintenance

SMOOTH THE BOTTOM

Any vessel that travels significant distances or is involved in an activity that requires steaming, such as trolling, should stand to benefit from regular hull maintenance.

Frictional resistance, or skin friction, is a measure of the energy expended as the water passes over the wet surface of the hull.

The causes of increased skin friction can be placed in two categories:

- **hull roughness** resulting from age deterioration of the shell of the hull or poor surface finish prior to painting.
- **marine fouling** resulting from the growth of seaweed, barnacles etc. on the hulls underwater surface.

Keep It Clean

Fairing

LOWER THE FRICTION

The amount of effort spent on hull maintenance should consider:

- The speed of the vessel, the faster the vessel the more important the surface condition of its hull.
- The rate of growth of fouling or deterioration of hull surface.

Significant savings can be made by:

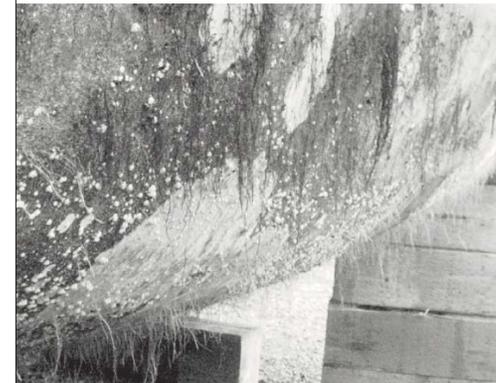
- Treating the forward quarter of the hull where one-third of the benefits are gained from treating the whole hull.
- Cleaning the propeller can result in very significant savings.

Fouling

Rate of weed and mollusk growth on vessel hulls depends on:

- The mode of operation of the vessel.
- The effectiveness of any antifouling paint that has been applied.
- Local environmental conditions, especially water temperature. (i.e. the warmer the water, the faster weeds grow)

The more attention paid to the surface finish of the vessel during construction and maintenance, the less energy will be wasted overcoming skin friction!



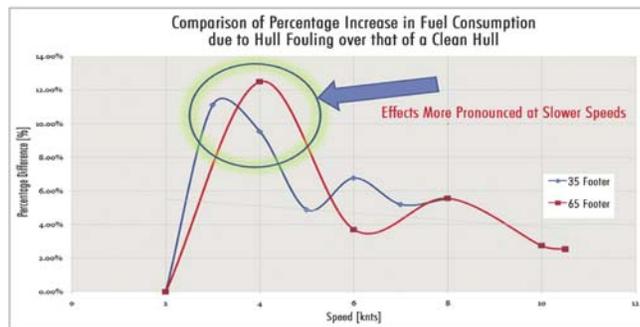
Fouling can increase fuel consumption by 7% after only one month, and 44% after six months!

Keep It Clean

Antifouling paints range from cheaper, harder paints to more effective and more expensive hydrolyzing or self-polishing paints.

Self-polishing antifouling paints become smoother over time and can offer reasonable protection from fouling for up to two years, but the paint system is expensive to apply and requires complete removal below the waterline of all previous paint.

Self-polishing antifouling paints can result in fuel savings of up to 10 percent, but are only likely to be viable for vessels that travel long distances and that are hauled out or dry-docked about once a year.



Roughness

Wooden vessels, and even to a certain extent fiberglass vessels, experience an increase in hull roughness with age. The effect is more significant with steel which is also subject to corrosion. Mechanical damage to the hull surface owing to berthing, cable chafing, running aground and beach landing can also cause roughness.

On steel vessels up to 65' the increase in power requirement to maintain speed can be 1% per year. After ten years the vessel requires as much as 10 % more fuel to maintain the same service speed as when it was launched.

This loss can be minimized by careful hull maintenance and, in the case of steel vessels, regular replacement of sacrificial anodes and anticorrosive paint.

Keep It Clean

Appendages

ONLY IF NEEDED

Anything attached externally such as sonar domes, external heat exchanger pipes, and shaft struts, affects the flow of water around the hull. This can create significant pressure changes, leading to increased vessel resistance.

- Consider using internal heat exchangers.
- When adding anything to the hull ensure that all shape changes are gradual, and “faired in” minimizing pressure changes.
- Ensure that all struts are always submerged to avoid air suction. This is especially important for shafts near the propeller to optimize propeller performance.
- Stern posts should be faired to a point in order to let the water flow to slip off the end of the hull forward of the propeller. This will avoid high drag forces.
- A squared off stern post will result in significant eddies being formed which when entering the propeller can create several problems including significant reduction in propulsive efficiency.

*Only install underwater appendages
when absolutely necessary.*

Ghost Weight

DROP THE POUNDS

Excess weight accumulates on-board vessels over time. This can include spare parts, partially used products, waste, dirt, and excess ballast.

- Perform regular bow-to-stern cleaning.
- Remove rarely used equipment.
- When replacing old equipment consider lighter products.
- Clean and re-treat fuel, ballast and hold tanks and all other parts of the hull.

Trip Planning

RUN THE TIDE

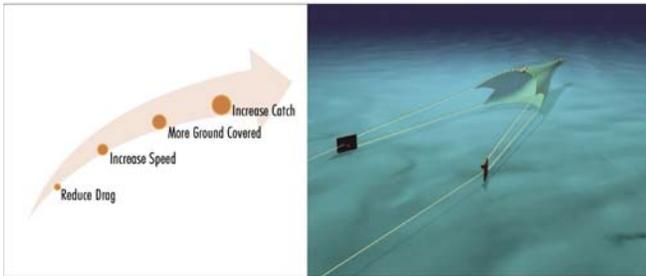
The operational patterns of the largest ships take currents and tides into consideration. Small vessels can benefit from the same trip planning. Getting to know the tides and currents in the area that you travel can save you time and fuel.

- Keep tide and current books handy.
- Look for currents and eddies to gain speed.
- Keep a straight course, point to point.

Fishing

LOSE THE DRAG

More efficient gear may increase productivity and catch rates, while reducing energy costs. Audit your system to discover areas where you can reduce drag and fuel consumption. Monitoring gear during operations should be considered.



Over 60% of all resistance comes from the drag on the netting while fishing.

Ways to reduce drag:

- Reduce the amount of netting surface.
- Increase mesh sizes.
- Decrease twine sizes.
- Introduce super fibers.
- Add a net monitor to audit fishing operations.

Design Measures

Propulsion

NOT JUST THE SHAFT

The propulsion system needs to be tuned for efficiency, matching propeller to gear, engine size and hull design.

Signs of a faulty propulsion system

Abnormally low steaming speed vs. RPM compared to similar vessels.

High levels of vibration not attributed to engine, generators or other on-board machinery.

Little or no gain in vessel speed with significant RPM increase.

Engine unable to meet target RPM.

Black smoke expelled through exhaust.

Chronic blade damage not resulting from striking underwater objects.

Several options to improve the efficiency of your propulsion system are:

- Have your propeller matched to your vessel. Suitable propeller characteristics (discussed in the next section) can lead to major efficiencies.
- Consider installing a nozzle either ahead or around the propeller. Nozzles capture and positively alter water flowing towards the propeller.
- Consider installing a controllable pitch propeller (CPP). A CPP is equipped with complex machinery that allows the operator to alter the pitch on command. This makes it ideal for both optimized towing and steaming speeds.
- Match your engine and transmission to your propeller. If your vessel is over or under powered, it means that the engine is not operating at its optimal RPM.

Propellers

PUSH OUT ASTERN

Propeller design and specifications have a direct influence on vessel fuel efficiency. It is important that propeller technical specifications be entrusted to a qualified professional.

The propeller is the most significant single technical item on a vessel.

Factors affecting propeller efficiency:

The diameter of the propeller is the most important single factor in determining propeller efficiency.

In terms of efficiency, it is better to push out astern a large amount of water relatively slowly, than push out a small amount of water very quickly in order to achieve the same forward thrust. Hence, the diameter of the propeller should always be as large as can be fitted to the vessel so that as much water as possible passes through the propeller.

The diameter of the propeller should be as large as the hull design and engine allow.

Shaft Speed The larger the diameter of the propeller, the slower the shaft speed RPM required to absorb the same power.

The gearbox should be chosen to give a maximum of 1000 RPM at the propeller

Cavitation results when excess bubbles form around the propeller. This problem is a result of a poorly designed or mismatched propeller. In the long run, the effects of cavitation will increase fuel consumption.

Propellers continued...

Cavitation occurs when the pressure on the forward face of the propeller blade becomes so low that vapour bubbles form and the water boils. As the vapour bubbles pass over the blade face away from the lowest pressure areas, they collapse and condense back into water.

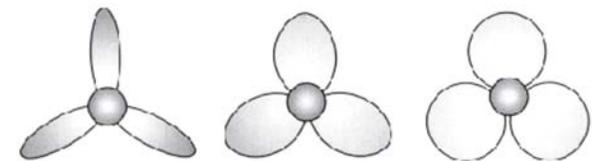
The collapsing of the vapour bubbles might appear trivial, but in reality a very violent event, resulting in erosion and pitting of the surface of the propeller blade, and even cracking of the blade material. Cavitation is often associated with low fuel consumption, as the propeller is unable to absorb the power of the engine, and the engine runs underloaded.

Keep It Clean

The only solution to cavitation is to change the propeller.

Number of blades In general the fewer blades a propeller has, the better. However the trade-off is that each blade carries more load which can lead to increased vibration and contribute to cavitation. When the diameter of the propeller is limited by the size of the aperture, it may often be better to keep shaft speed low and absorb the power through the use of more blades.

Blade area Propellers with narrower blades, with low blade area ratio, are more efficient than ones with broad blades. However, propellers with low blade area ratios are more prone to cavitation as the thrust that the propeller is delivering is distributed over a smaller blade surface area.



--> Increasing blade area ratio -->

Clearances The distances between the propeller and the hull affect how efficiently the propeller operates within the flow of water around the hull, and the vibration caused by the propeller.

In general:

- Blade tip clearances should be as small as possible, within the guidelines, to accommodate the largest possible propeller.
- The distance from the propeller to the rudder should be kept small to maintain steering control.
- The distance from the deadwood to the propeller should be large.

Blade condition Poor condition of propeller blades owing to damage, fouling, corrosion or erosion reduces propeller efficiency.

Roughness and damage The efficiency of a propeller is most influenced by surface roughness and damage towards the outer regions of the blade, particularly on the leading edge of the forward (low-pressure) face, where roughness provokes early cavitation.

Fouling The effects of weed and mollusk growth on propeller efficiency are much more important than roughness. The extent depends on whether the weed remains attached to the propeller when it is in service.

Signs of a incorrectly specified propeller

The engine fails to achieve designed RPM and is overloaded.

The engine passes designed RPM at full throttle, over-revs and is underloaded.

The propeller is overloaded and shows signs of cavitation and surface erosion.

Propellers continued...

Overloading of the engine after the installation of a propeller with too much pitch is the most common source of fuel inefficiency. Overloading can also result from the use of a propeller with too large a diameter, but this is less common. Overloading can result in burnt valves, a cracked cylinder head, broken piston rings and a short engine life.

It is important to note that, with a diesel engine, it is the load and not the revs that determines fuel consumption. Therefore, continuous overloaded operation results in unnecessarily high fuel consumption and increased maintenance costs.

Underloading of the engine from the installation of a propeller with too small a diameter or of insufficient pitch affects vessel performance. It can also result in engine damage if it is allowed to rev above its specified maximum RPM. Engine underloading is likely to be accompanied by low fuel consumption and, often, cavitation.

Controllable Pitch Propellers can enable efficient operation while both towing and free running, but its operation requires both skill and knowledge. In general, the use of controllable-pitch propellers is not recommended where the correct setting of the pitch cannot be guaranteed. The setting of an incorrect pitch can easily result in significantly increased fuel consumption.

A **Nozzle** is a short duct enclosing the propeller. Under certain circumstances, it can significantly improve the efficiency of a propulsion system. The duct is close fitting to the propeller, slightly tapered with an aerofoil cross-section.

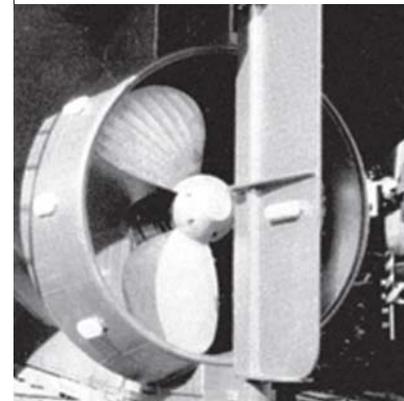


Photo from KORT PROPULSION CO. LTD

Anti-roll Devices

STOP THE ROLL

Ideal conditions for deck related activities exist when the number of times that a vessel's crew has to stop all actions to hold on, are less than one per minute.

One way to decrease rolling and create an effective work platform is to fit anti-roll devices onboard. These help to minimize hold on time during trips, making operations more efficient, saving time and fuel.

The degree of motion experienced on a vessel depends on:

- The hydrostatics of the particular vessel.
- The actual loading condition.
- The vessel speed and heading.
- The wind, wave and current conditions. (excitation forces)

Stabilizers are located off poles or arms that are lowered off both sides of the vessel. These wedge or plough shaped fins act by generating lift forces that dampen the roll action.

The drawbacks include:

- The increased resistance they generate through the water can reduce cruising speed by 1 knot or increase the required power by 10%.
- When not deployed, they raise the centre of gravity of the vessel, further reducing effective stability.

Fin Stabilizers and Batwings are similar to stabilizers in their operation, these mechanically deployed fins built into the vessel hull below the waterline act to dampen roll motions while the vessel is in motion. They are mainly effective when underway.

The drawbacks include:

- They are expensive to install.
- They require regular mechanical maintenance.
- They increase hull resistance.



Bulbous Bow

BULB'N IT OUT

When moving through the water, a vessel's bow sets up what engineers call a "pressure field". This resulting bow wave adds "wave-making" resistance.

A bulb added to the bow will set up another pressure field and a resulting wave that is out of phase with the bow wave. The wave counteracts and significantly reduces the bow wave, decreasing resistance. A properly designed bulb will also reduce a vessel's pitch motion thereby creating a more stable work platform.

By adding a bulb, fuel saving of up to 15% can be achieved.

Bulbous bows are effective in reducing resistance at the following cruising speed:

- 4.4 to 7.5 knots for a 35' vessel
- 5.0 to 8.5 knots for a 45' vessel
- 5.5 to 9.5 knots for a 55' vessel
- 6 to 10 knots for a 65' vessel

Lengthening

STRETCH 'ER OUT

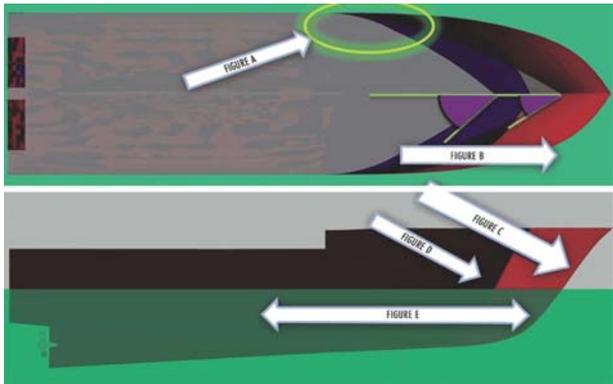
Vessels with a higher length to beam ratio are inherently more efficient because:

- Hydrodynamic efficiency increases with the vessel length.
- Stability and sea-keeping characteristics can improve.
- Increased length can also improve course-keeping and directional stability.

Lengthening can lead to significant reductions in fuel consumption combined with a larger vessel.

Bow Lengthening

The redesign of the vessel's bow along with lengthening can reduce overall resistance in water and can increase performance, primarily by reducing the half-angle entry.



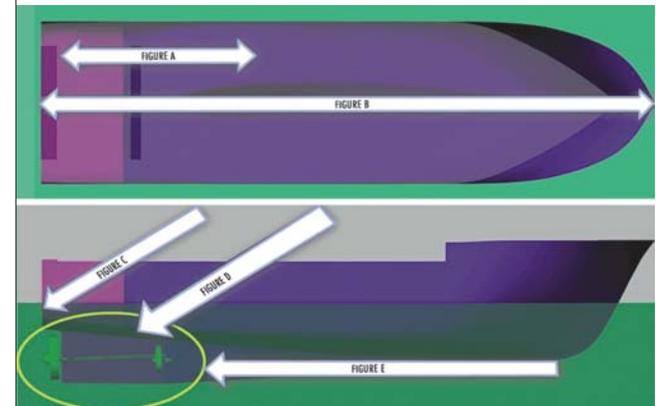
- Figure A: Reduction in Shoulder
- Figure B: Reduction in Half Angle
- Figure C: Finer bow shape results in smaller bow wave
- Figure D: Blunt bow shape
- Figure E: More gradual change in hull submerged area

Simulations on a 65-ft. vessel have indicated that a 70% reduction in the bow's half-angle can lead to a 25% reduction in fuel consumption. A realistic improvement is in the 10% range.

Lengthening continued...

Stern Lengthening

An extension to the stern allows for the introduction of a rise in the immersed surface area, resulting in a more streamlined form and lower pressure drop. Larger clearance at the stern enables a larger diameter propeller to be installed, which increases the propulsive efficiency. Stern lengthening increases the potential deck space working area and hold capacity. If a piece is added at the stern the entire hull may not need to be glassed over if it can be proven that the connection is strong enough to remain intact even in extreme conditions.



- Figure A: Increase in working deck area
- Figure B: Increase in directional stability and hydrodynamic efficiency - Better course keeping and reduction in service power
- Figure C: Reduced transom immersion
- Figure D: Gradual stern rise = Transom is less immersed, and less water is pulled behind boat
- Figure E: Moving skeg and stern tube aft = Increase in propeller clearance

Simulations on a 65-foot vessel indicate that a decrease in immersed transom from 100% of amidships draught (no rise a perfect box shape) to a transom immersion of 10% could result in savings of 50% in required power at cruising speeds. The rudder and propeller should be moved aft to gain full benefits, which include improved propulsive efficiency and directional stability.

Midship Lengthening

A lengthening at amidships will:

- Maximize the increase in added displacement and deck area.
- Reduces vessel pitching motion.

The energy efficiency gain by is primarily due to the longer length which reduces the wave-making resistance at cruising speed.

Building New

LAYING KEEL

Having a new vessel designed and built is the best way to get a safe and energy efficient vessel. This requires engaging a well qualified naval architect or engineer to work with you to create the vessel that meets your needs in the best possible way.

The following factors are some of the main issues to consider when having a new energy efficient vessel designed.

- The length to beam (L/B) ratio is very important. A higher L/B is more efficient.
- Select a design service speed that is appropriate relative to vessel length and hull form.
- Eliminate or minimize the transom immersion.
- Achieve the smallest 'Bow Half-Angle' possible without creating an abrupt change at the shoulder.
- The stern tube and submerged stern shape should maximize the space for the propeller and ensure clean flow.
- Optimize propellers for cruising (in most cases) at the most efficient speed and engine RPM while ensuring sufficient Bullard pull.

Building New continued...

- A lower superstructure is best for reduced windage.
- Fewer above water decks mean a lower centre of gravity. There is no need for permanent ballast in a properly designed vessel, though ballast tanks may still be necessary.
- Consider a controllable pitch propeller, nozzles, alternate rudders and other technologies.
- Properly designed bulbs are very useful at minimizing required power, and hence RPM, at intended speed design.
- Properly designed bulbs reduce pitch motions in seaway.
- Fuel-efficient engines and monitoring system.
- Modular gear installation for easy conversion to different use.
- Changes in hull shape should be as gradual as possible, a fine bow and faired rising stern.

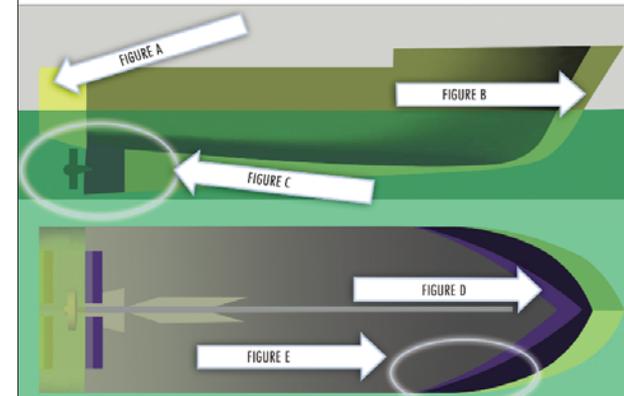


Figure A: Lengthened stern - Less submerged transom

Figure B: Lengthened bow - Finer and gradual shape

Figure C: Rising faired stern - Larger propeller - Clearance and better inflow

Figure D: Lengthened bow - Finer and gradual shape

Figure E: Reduced shoulder - Reduced flow separation

Feedback & Support

GET ONBOARD

Help care for our coastal waters. The T. Buck Suzuki Environmental Foundation is a charitable marine conservation organization whose goals are to protect habitat, prevent pollution, and promote sustainable fisheries on Canada's coastal waters — truly one of the world's richest marine ecosystems.

You can help us ensure that future generations get a chance to enjoy these magnificent waters too, by making a tax deductible donation online at www.BuckSuzuki.org or by mail to: #100 - 326 12th Street, New Westminster, BC V3M 4H6

All donations to T. Buck Suzuki Environmental Foundation are tax deductible. If you would like a receipt for donations less than \$20, please request one.

Tips

If you have a green boating or fuel efficiency tip that you think should be in our guide, contact us at **1-866-960-1398**, or at: www.BuckSuzuki.org. An award may be made to the person providing the best tip of the year.

What you do on the water matters. **Think of the impacts** if 3 million commercial and pleasure boaters do the same thing!

Get involved! Most boaters prefer harbours, marinas, and shipyards with high environmental standards. Ask your harbour, marina, and shipyard to look at ways to improve its environmental performance. This includes providing facilities such as pump-out stations and oil collection, as well as signs on docks showing how and where to recycle products. There are many people working to protect and restore our coast and its watersheds, your help is appreciated!

Get Involved

We welcome your comments and feedback. Please contact us at BuckSuzuki.org or 1-866-960-1398.

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The materials has been adapted for use by commercial vessel operators. All errors and omissions are the fault of the T. Buck Suzuki Foundation.



www.BuckSuzuki.org
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