The Efficient Powerboat

What Efficiency Means, How It Can Save Money and How it Makes for Better Boats — Part 1

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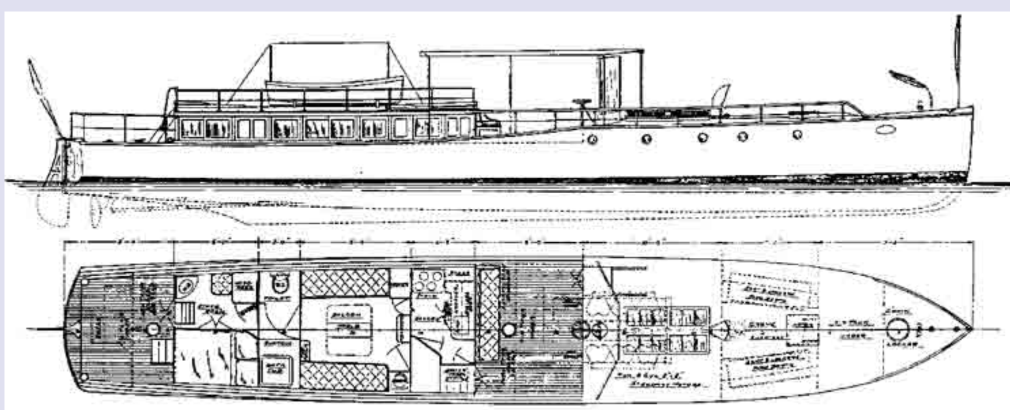
To paraphrase Yogi Berra, about a century ago, "boating came to a fork in the road and took it." Over the years, I've noted that we may have taken the "wrong fork." In light of today's ever-rising fuel costs, this appears to be no idle concern. If a few things had gone otherwise early on, we might well be tooling around in powerboats that looked quite different from what we currently think of as "normal" boats.

Macho Boats?

Think of racing . . . powerboat racing offshore. What do you envision? More than likely, you're picturing 50- to 60-foot, macho, deep-vee muscle boats. Careening along at 100 knots, or thereabouts, you can be sure they're being driven by iron-men, fellows with the brawn required to endure the endless pummeling pounding; the roaring crescendo of engine, exhaust, wind, and wave; and yet still able to retain hair-trigger steering and throttle response. ("Look, there's a lobsterpot." You have about a tenth of a second to make exactly the right decision at the helm . . . or else.) A moment of deeper reflection will bring to mind fuel consumption in the order of 180 gallons an hour, avgas! If you're young and tough this sort of thing is certainly exciting, but is it for you and your family? Is even a more modestly powered 35-knot cruiser?

Sailing to Bermuda

Most boaters have at least heard of the Bermuda Race. Dreamed up by Thomas Fleming Day, the editor of *Rudder* magazine (Day was probably the most influential marine editor of all time), the Bermuda race—with a few minor gaps due to wars—has been held almost every other year since. Since when? Since 1906 . . . a long time ago. Now, Day's intent was to improve both sailing yacht design and construction, and sailors' confidence in going offshore. (Back then, it was generally large, fully crewed yachts that ventured off soundings.) Few would argue that Day's Bermuda Race hasn't achieved its goals. Folks currently think little (perhaps too little) of making offshore passages on very small sailboats indeed.



Typical ultra slender motorcruiser of the nineteen-teens and twenties. This 66-footer is 10 ft. 7 in. beam. She was built by Consolidated.

The Forgotten Race

Sadly, it's largely forgotten that the very next year (1907 naturally) the irrepressible Day, sponsored a powerboat race from New York to Bermuda. Not only did he initiate the race but he skippered one of the entrants. Again, Day's intent was to prove that small internal-combustion-engine craft were safe and reliable offshore. This was—at the time—a downright crackbrained point of view. Steam was the only power plant suitable for ocean work . . . everyone knows that!

To put 1907 in perspective: The cinema—forget the movies; Hollywood was just a sleepy little village—was brand new. The airplane was barely four years old. The first Model-T Ford wouldn't roll out of Ford's plant for over a year. Indeed, the few fantastically expensive early cars in operation on Bermuda had been banned—too noisy and obtrusive—in July of that very year. It'd be nearly forty years in the future before Bermuda relented on it's condemnation of the automobile.

Those Reliable Infernal Machines

The 1907 Bermuda Powerboat Race had two entries, the *Ailsa Craig* and the *Idaho*. Both were long, slender 60-footers. The *Alisa Craig* was powered by a single 65-hp gas engine, and the *Idaho* by a 25-hp machine. You'd think that *Idaho* wouldn't have stood much of chance—what with the power difference—but there was a handicap formula that gave *Idaho* a

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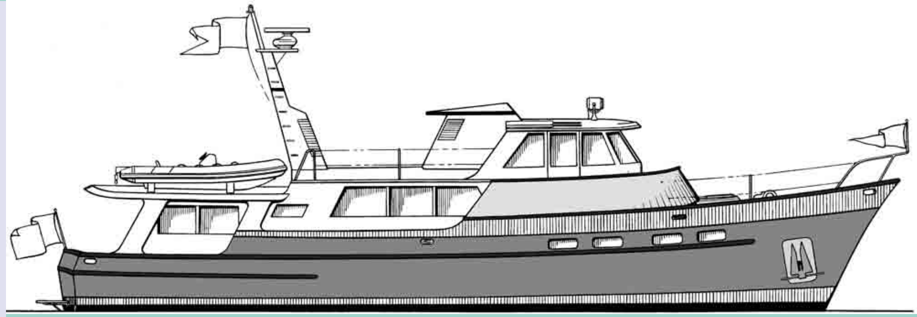
reasonable shot to win on corrected time. Nevertheless—in this case—the *Craig* (skippered by none other than Fleming Day himself) did win. Winning time was 2 days, 16 hours, and 20 minutes—a nice, leisurely ocean passage. If two boats taking between two and three days to run 650 miles doesn't seem impressive remember the year. The reaction from the boating world, even the world at large was:



Imagine—57-ft. Voyaging Motorcruiser

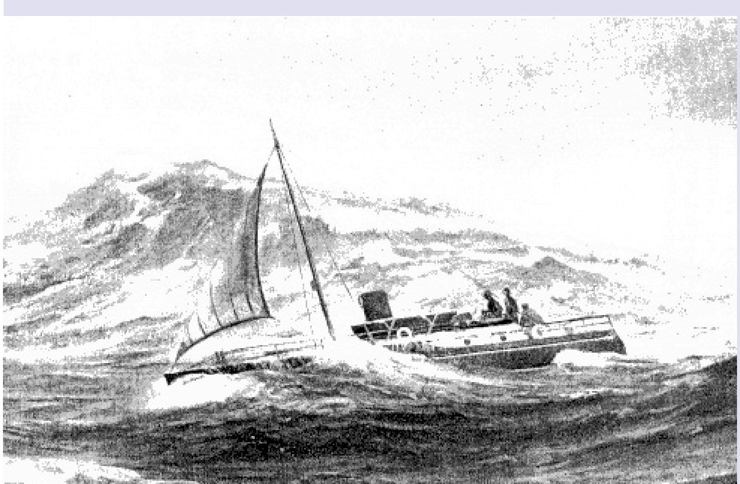
> Until the finish of the race, the name 'internal combustion engine' was a joke, only good enough to understudy steam. The race has demonstrated to the whole world that the internal combustion engine is reliable, and if it is reliable, it is adaptable to all commercial purposes!

This first offshore powerboat race was critical in convincing people to buy new powerboats of all types.

This wasn't the last Bermuda powerboat race. One was held every year except 1911 up to 1914 (including a return race back from Bermuda in '09 and in '12), when the War To End All Wars, finished the competition for good. From 1912 on, however, the race started in Philadelphia, rather than New York.

A Good Influence Lost

It wasn't only the bigger fellows who won this race, by the way. In 1912, *Dream*—a 40-footer with just 9-foot beam and a single 16-hp engine (yep, only 16 horses)—beat its 50-foot competitor, the 25-hp *Kathemma*. These power ratings give one indication of the reason it's such a pity that the Bermuda Powerboat Race has been forgotten. The *Ailsa Craig*, with fully 65-hp (the most power entered in the race's history), consumed about 4.5 gallons per hour, burning up a total of 290 gallons on the entire trip! Compare this to airplane fare for your entire family. If only the Bermuda Power Boat race had continued after World War I, modern cruising powerboats would likely be rather different—somewhat slower, longer and more slender, and very fuel efficient. Superb seaboats as well.



Dream in heavy weather on her way to Bermuda

A modern cruising *Ailsa Craig*, around 13,700 pounds, would be fitted with, say, a single 300-hp diesel or twin 150s. Cruise would be around 13 knots making the trek from New York to Bermuda in just over two days. This would cost you no more than 520 gallons in fuel for the hop over, and you could take your whole family, a friend or two, and all your belongings along. Spend seven or eight days exploring the islands, then turn around and head home. This would be one pleasant and economical vacation. Slow down to 11 knots and the crossing would take you all of two and a half days and you'd use only 370 gallons of diesel.

How to Make an Efficient Boat

I've read a lot about efficiency on boats over the years and much of it hasn't added up. Almost any knowledgeable designer will tell you that just three basic things make for efficiency:

1) Going slower
2) Long, slender hulls
3) An efficient propulsion package

I'd like to make this seem more complicated, but that's it. Yes, you can improve efficiency with tweaks and adjustments to the hull form—refinements in shape. Also, certainly, the hull form must be properly matched to the intended operational speed, but hull-shape refinements add small percentages to efficiency, the three items above are—by a good margin—the overriding factors.

Transport Efficiency

The bottom line is fuel consumption and this is what determines a powerboat's efficiency. How much fuel it takes to get it from point A to point B. Naval architects have a specific formula for efficiency, which is called "transport efficiency," or "E_T." There are minor variations of E_T. Ship designers are really interested in the weight of cargo moved from place to place efficiently. Transport efficiency for cargo ships is thus:

E_T = speed x cargo weight ÷ power

Since fuel consumption is directly proportional to power,

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dividing by power gives you the efficiency.

In yachts, patrol boats, small passenger vessels, it's really the entire weight of the fully-loaded boat that should be evaluated, so for our purposes transport efficiency would be:

E_T = speed x loaded displacement ÷ power

Engineers are fussy about units (for good reason), and to be more accurate we should define transport efficiency, E_T as:

$$E_T = \frac{5.144 \times \text{Kts} \times \text{Tonnes}}{\text{kW}}$$

(The 5.144 converts knots to meters per second and keeps all the units consistent.)

or in English units:

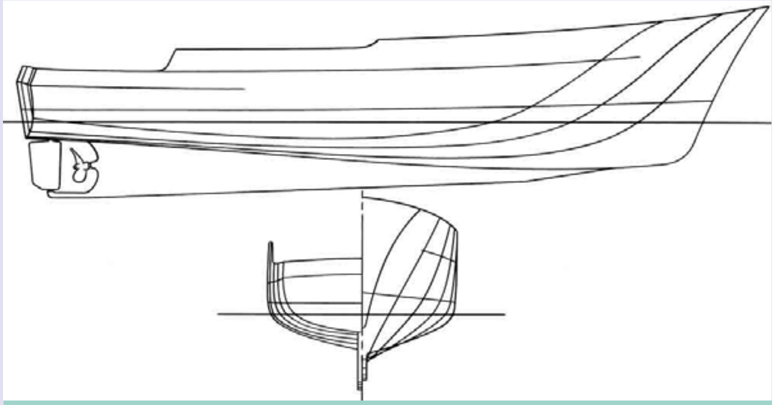
$$E_T = \frac{7 \times \text{Kts} \times \text{Tons}}{\text{BHP}}$$

(The units here aren't internally consistent but, instead, are set up to give the same result as the standard metric E_T.)

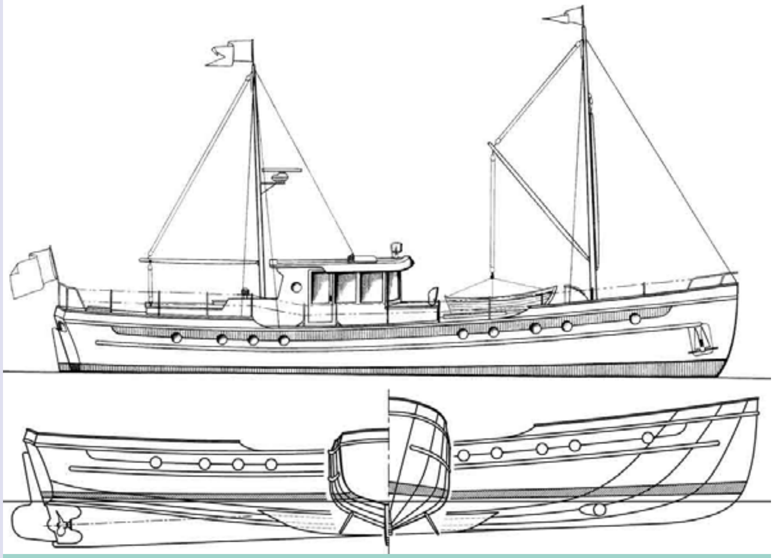
Where:
E_T = Transport efficiency
Kts = Boat speed, in knots
Tonnes = Metric tons
Tons = Long tons of 2,240 lb.
kW = Total installed propulsion power, kW
BHP = Total installed engine power, brake horsepower

Propulsion Efficiency
Almost all ordinary boats are driven by propellers. (Jets are the other alternative, see part 2.) Except for high-speed boats, the larger the propeller diameter and the slower the shaft RPM, the more efficient the propulsion. Remember, for large diameter you need low shaft RPMs. Indeed, one of the most frustrating things I run up against as a designer is finding deep reduction gears to mate with smaller engines—engines under 300 or 400 HP. It's like looking for a unicorn. No one seems to make them.

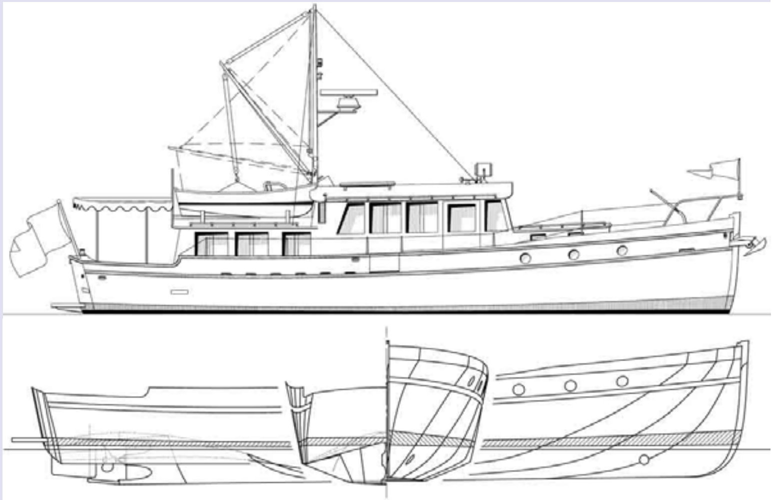
Comparing Boats
In order to clearly see the effects of our three basic efficiency criteria: going slower, slender hulls, and efficient propulsion, we can compare four different boats. In fact, there are four designs from my office: the long and very slender 67-foot *Ironheart*, the medium-slender 57-foot *Imagine*, the 47-foot ultra-shoal (27-in. draft.), medium-slender, beachable tunnel-drive *Peregrine/Nancy Lakin*, and the rather solid chunk of a tug yacht, *Iron Kyle* at 45 feet.



Imagine—57-ft. Voyaging Motorcruiser



Ironheart—66-ft. Voyaging Motorcruiser



Peregrine—45-ft. Ultra-Shoal Motorcruiser

Though we could make the comparison using the non-dimensional transport efficiency alone, it makes it easier to

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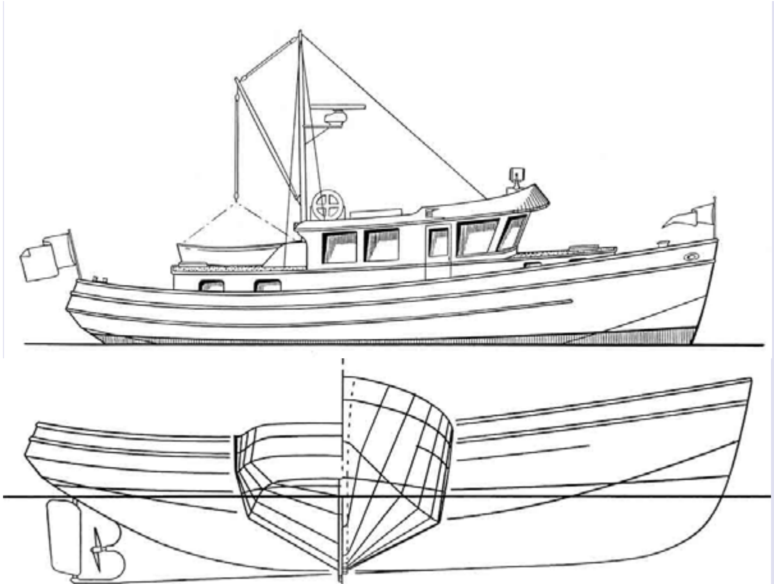

Iron Kyle—45-ft. Tug Yacht

follow if all the boats are the same size. The important consideration here is that size is not length but displacement (weight), which is the same as volume. Accordingly, I've normalized the *Imagine*, *Peregrine*, and *Iron Kyle* designs to the same 45,000-pound displacement as *Ironheart*. I'll refer to the normalized example boats using the designation (n). Thus, our four comparison boats are in Table 1 on the previous page.

Obvious Differences and "Normal" Boats

The differences between these normalized boats are obvious and they are primarily in how long and slender (or wide and beamy) they are. The DL ratio (displacement-length ratio) is the clearest indicator and the lower the DL ratio the longer a boat is for its weight. You could, however, get a low DL ratio with a wide hull that was very flat and shallow. The other indicator is simply DWL divided by BWL (datum waterline length divided by beam waterline), also called "length-to-beam ratio."

Interestingly, the seemingly rather chunky tug yacht *Iron Kyle* has a DL ratio of 334 and a DWL/BWL ratio of 3.2:1. Though heavy and beamy compared to the other boats in our sample group, both a DL of 334 and a length-to-beam ratio of 3.2:1 are not at all unusual these days. Many a so-called trawler yacht is in this range. Indeed, there's nothing specifically "wrong" with a heavy, beamy boat, but—what we're discussing here is efficiency. It's the fact that boats of such proportions are not uncommon which indicates that we took that "wrong fork" in design so long ago.

Comparing Speeds and Efficiency at Hull Speed

The common, and as we'll see in a bit, incorrect belief is so-called displacement hulls are limited to a fixed hull speed. This is a speed-length ratio (SL ratio) of 1.34. Assuming we drive all three boats to an SL ratio of 1.34, we get the results in Table 2.

Table 1 - Normalized Boat Characteristics

BOAT NAME	LOA	DWL	BEAM	BEAM WL	DISP lb.	DISP tons	DL Ratio	DWL/ BWL
Iron Kyle (n)	43.42	39.17	13.00	12.25	45,000	20.1	334.4	3.2
Imagine (n)	51.17	45.67	13.17	12.00	45,000	20.1	210.9	3.8
Peregrine (n)	51.72	50.67	14.88	13.13	45,000	20.1	154.4	3.9
Ironheart	67.00	63.25	11.00	10.25	45,000	20.1	79.4	6.2

Original (Not Normalized) Boat Characteristic Table

BOAT NAME	LOA	DWL	BEAM	BEAM WL	DISP lb.	DISP tons	DL Ratio	DWL/ BWL
Iron Kyle	45.17	40.67	13.50	12.670	50,400	22.5	334.5	3.2
Imagine	56.50	50.52	14.50	13.340	60,900	27.2	210.9	3.8
Peregrine	45.17	44.25	13.00	11.476	29,975	13.4	154.4	3.9
Ironheart	67.00	63.25	11.00	10.250	45,000	20.1	79.4	6.2
Summer Moon 2*	82.25	72.92	17.00	16.260	137,400	61.3	158.2	4.5

*Summer Moon 2 will be discussed in p

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You can see that at nearly the same power the longer slender boats go faster. More important, transport efficiency (E_T) grows higher as the boat becomes longer and more slender. This is reflected in higher nautical miles per gallon—in improved mileage.

Table 2 - Performance at Speed-Length Ratio 1.34

Boat Name	Knots	HP @ SL 1.34	E_T @ SL 1.34	gal/hr	mpg
Iron Kyle (n)	8.4	99	11.86	5.4	1.56
Imagine (n)	9.1	106	12.00	5.7	1.58
Peregrine (n)	9.5	109	12.31	5.9	1.62
Ironheart	10.7	113	13.29	6.1	1.75

Slender Hulls Mean Higher "Hull Speeds"
It gets better still for slender hulls. The fact is that the rule-of-thumb "hull speed" is not accurate. Maximum hull speed is not a constant 1.34 times the square root of the waterline in feet. Instead, the constant 1.34 is a variable and that variable is proportional to DL ratio. The formula I've developed that defines this relationship is:

Max Hull SL Ratio = $8.26/(\text{DL ratio})^{0.311}$
But never less than 1.34.

This gives the maximum speed-length ratio a hull can be driven without planing. Applying this to our example boats, we get the results in Table 3, previous page.

Table 3 - Max Speed and Hull Length

Boat Name	Max Knots	Max SL Ratio	Power For Max Knots	High Cruise Speed	Cruise SL Ratio	Cruise HP	Cruise E_T	Cruise mpg
Iron Kyle (n)	8.5	1.36	117	7.5	1.20	81	13.1	1.7
Imagine (n)	10.6	1.56	220	9.5	1.41	130	10.3	1.4
Peregrine (n)	12.3	1.72	458	10.0	1.40	156	9.0	1.2
Ironheart	16.9	2.12	419	14.0	1.76	256	7.7	1.0

This shows just how much faster long, slender hulls can be driven without planing. Of course, going faster uses more power on any hull form (long and slender or short and wide) and this shows up as lower transport efficiencies and miles per gallon at the higher speeds. The important thing here is that the longer boats can be driven at these speeds, where the short wide boats can't—at least without modifying their hulls.

Driving all Boats to the Same Maximum 16.9 Knots
Indeed, the wider shorter boats *Iron Kyle (n)* and *Imagine (n)* can't be driven anywhere close to the 16.9 knots of the very slender *Ironheart*, though you'll note that the medium slender *Imagine* (n) can achieve a max SL ratio of 1.56. You can take hulls of these displacements, and overall hull proportions and modify them—by giving them planing-hull characteristics—to allow them achieve 16.9 knots. They would then be true semi-planing hulls. The resulting power required is in Table 4.

Table 4 - Driving all Boats to the Same Maximum 16.9 Knots

Boat Name	16.9 knot SL Ratio	HP for 16.9 knots	E_T @ 16 knots	mpg
Iron Kyle (n)	2.70	635	3.74	0.49
Imagine (n)	2.50	558	4.26	0.56
Peregrine (n)	2.37	511	4.65	0.61
Ironheart	2.12	419	5.67	0.75

Once again—if we drive to the same high speed the slenderest hull is capable off—we see just how much more efficient more slender hull forms are. The transport efficiency and miles per gallon delineate this clearly.

In part two, we'll conclude our investigation of powerboat efficiency by looking at the effect of propulsion efficiency, at the effect of overall size, and we'll examine the considerations in slender hull forms with regard to seakeeping and accommodations.

Displacement-Length Ratio
Displacement-length ratio is a non-dimensional measure of how light a boat is for it's length. The heavier a boat for its length the higher it's DL ratio and the lighter the boat the lower its DL ratio.

$$\text{DL ratio} = \frac{\text{Disp.T}}{(0.01 \times \text{WL, ft.})^3}$$

Where:
DL ratio = Displacement-length ratio
Disp.T = Displacement in long tons of 2,240 lb.
WL = Waterline, ft.

Hybrids Are Not The Answer

Fuel-economy being as important as it is these days, there's a natural feeling that hybrid diesel/electric or gasoline/electric vessels may offer improved mileage (better efficiency). It seems obvious: It works on cars so it should work for boats. Unfortunately, hybrid propulsion is not the solution for boats.

All ground vehicles (cars, truck, buses, etc.) spend a significant portion of their time either braking, coasting, going downhill, or creeping along in bumper-to-bumper traffic. In all of these situations, the internal combustion engine needs to deliver little or no power, yet—in conventional vehicles—it must continue to run inefficiently nevertheless. Hybrid electric cars take advantage of this by effectively shutting down or electronically nearly shutting down the internal combustion engine and using stored electric power during these specific periods. If you add in capturing regenerated power during braking and going downhill, the fuel savings are significant.

Speed-Length Ratio (SL Ratio)

Speed-length ratio (SL ratio) is the non-dimensional method of assessing how fast a boat is going relative to its length. Boats operating at SL ratios under 1.34 are considerd displacment-speed boats and boats running at SL ratios over 3 are considerd fully planing. In between 1.34 and 3 is the semi-displacment or semi-planing regime. Long, slender hulls can operate in this speed range without actually planing.

$$\text{SL ratio} = \frac{\text{Knots}}{\sqrt{\text{WL, ft.}}}$$

Where:
SL ratio = Speed-length ratio
Knots = Boat speed, knots
WL = Waterline length, ft.

So, why doesn't this work on boats? Simple. Boats never do any of these things. They don't brake, coast, roll downhill, or spend hours creeping in slow traffic. Marine propulsion engines are always producing the continuous power needed to generate the constant thrust required to overcome the resistance of the water at any speed the boat is operating at. There's simply no gain to be had from the hybrid approach.

Worse still, every time you transfer energy from one form to another, there's a loss. So, going from, say, a diesel generator to storage batteries, looses power, and then going from the batteries to the electric propulsion motor looses more power. Even without the step to batteries, hybrid would require: internal combustion engine driving a generator, the generator through cables driving an electric motor, the electric motor driving the prop. A conventional marine installation, by contrast, just has the main engine directly diving the prop through single shaft. The normal reduction-gear loses about 1.5% in power along the way. Even including the reduction gear, a good direct-shaft standard propulsion system will deliver 95% to 96% of engine brake horsepower to the propeller (shaft horsepower—SHP). A hybrid diesel/electric- or gasoline/electric-drive installation will find it difficult to deliver even a mere 88% of engine brake horsepower to the propeller.

Interestingly, diesel/electric drive is quite old in marine propulsion. The first such installations were used about a hundred years ago. Diesel/electric is not "wrong" or "bad." There are definitely instances where it makes sense, but they are not installations where direct improvement in propulsion fuel economy is the goal. A typical example of an appropriate diesel/electric propulsion system is in a large cruise ship. Here, the huge domestic electric loads are handled by several large generators (as well as a number of smaller auxiliary ones). These same generators can be switched—in various combinations depending on speed and sea state—to drive the main-propulsion electric motors. In this way, the domestic loads and the propulsion loads can be intelligently shared among the generators for maximum overall efficiency factoring in both the domestic demands and propulsion demands *combined*.

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