

Powering of Stepless, Hard-Chine, Planing Hulls.

This is a very simple method using formulas that were derived from the **CATERPILLAR** Hull Speed Estimator slide-rule. This was issued in 1961, under copyright, by the CATERPILLAR TRACTOR CO., Engine Division in Peoria, Illinois as Form No. 40-20442.

Because the output is calculated at relatively large increments in speed the sudden drop in required power at around $2.5 V/L$ may not sometimes be seen on a chart, instead it may appear as a much smoother curve.

The Speed~Power relationship for planing-boats is very complex and the deduced formulas were necessarily simplified in order to keep it simple and this process also lessened the hump-hollow.

Spreadsheet

The method was used as the basis for an Excel spreadsheet, which is given freely for guidance and information only and is used entirely at your own risk.

The intention was to prepare something that can be easily used in the early design stages when doodling. As the design progresses and more information or data is prepared then powering should be checked carefully using recognized methods so details such as the effect of deadrise angles etc can be accurately determined. This spreadsheet required only the length and displacement so it is simple but it will always give “middle of the road” values and cannot account for other variables.

The spreadsheet was “clean” when first posted here and was verified using the Norton AntiVirus module of Norton SystemWorks 2002 with the latest virus definitions.

The spreadsheet was saved as a **Microsoft 97-2002 and 5.0/95 Workbook** so it will run in all versions of Excel since **Office 97**.

Fuel and engine efficiencies

The choice is made between diesels or gasoline powered engines due to the difference in fuel consumption. No particular engine model has been used and a generalized fuel consumption curve has been adopted that is diesel engine oriented. Each manufacturer has his own twist so that with 2 and 4 strokes it gives four basic types but each of these can have a different usage rating so it is not possible to give one fixed pattern for all. Nevertheless that is what has been done so the fuel consumption and range results are only approximations.

A few words about fuel in an attempt to clarify the mess of published ill-advised misinformation on the Internet. The thermal energy of petroleum-derived fuels depends on the SG (specific gravity where fresh water is 1.0) at a standard temperature. The accepted US method is to use the **API degrees** system and the relationship between SG and the API scale is;

$$\text{specific gravity} = \frac{141.5}{131.5 + \text{deg. API}} \quad \text{with water and the tested fluid at } 60^\circ \text{ F (15.6}^\circ \text{ C)}$$

Therefore, a fuel of 10 degrees API has a specific gravity of 1.000 and a US gallon would weigh 8.328 pounds or a litre would weigh 1 kilogram. API is the American Petroleum Institute.

In the US there are several grades of diesel fuel and gasoline but the averages, quoted by the Federal Gov't, are diesel with an SG of 0.84 and gasoline at 0.73. The energy content of fuel is termed the HHV (High Heat Value) and it is the maximum released energy of a fuel free from impurities. The following formula gives the HHV;

$$\text{HHV} = 22,320 - 3,780 \times \text{SG}^2 \text{ Btu per lb } \pm 1\% \text{ for normal products}$$

The values typically used on the Net are the HHV times SG and are the Btu per gallon.

The spreadsheet uses a range in SG of 0.70 to 0.75 SG for gasoline and 0.82 to 0.87 for diesel. Intermediate values are assumed to be a blended fuel running in a diesel engine but they should only be used for rough guidance.

It seems to be impossible to find reliable information on engine efficiencies and dependable data on the differences between diesel and gasoline engines. Almost everyone has a point to make so there is an immediate bias or the description is unclear. Simply declaring that one is x% more efficient than the other is insufficient. The following list is merely a sample of comparisons on the net of diesel compared to gasoline engines;

- Engine efficiency rises from
 - 20% to 30%
 - 25% to 33%
 - 25/28% to 40%
 - 33% to 50%
- Better fuel consumption
 - Up 20%
 - Up 24%
 - Up 27%
 - Up 34%
 - Up to 50%

It is almost certainly a case of confusion of efficiencies due to engine types compounded with differences in fuel. A diesel engine is more efficient than a gasoline engine mainly because of the higher engine compression. Then there is the fuel to take into account. It is clear that the high heat value of fuel **reduces** as the specific gravity rises but this is only because it is based on weight, we buy fuel by the gallon or by the litre and the heat value **rises** with SG.

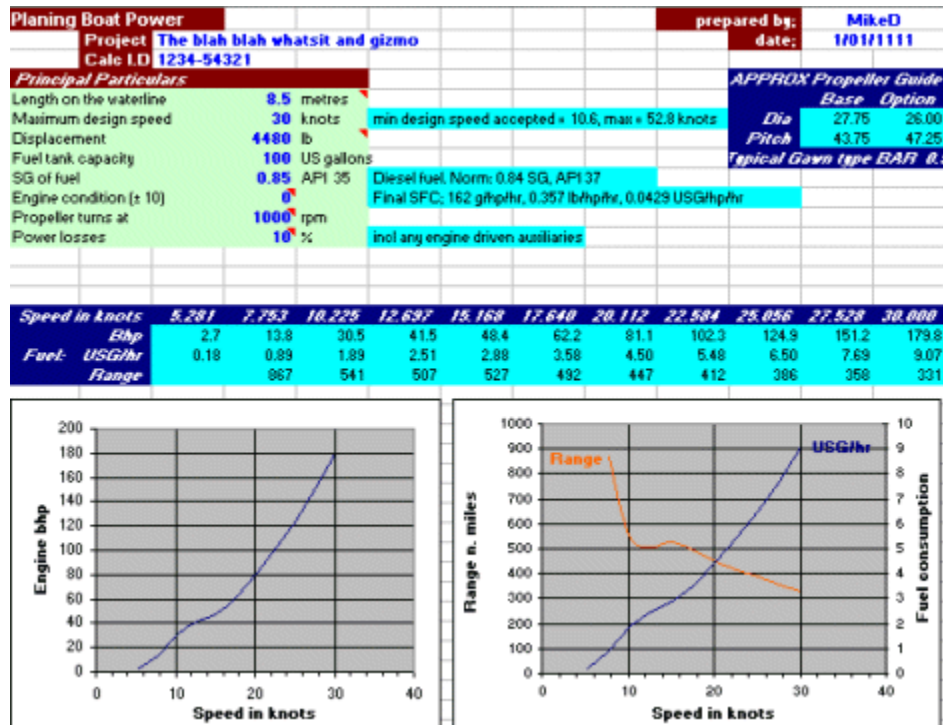
Anyway, for better or for worse, I arranged it so that the diesel powered boat has a range that is 35% greater per gallon of fuel than the gasoline version using the 0.74:0.84 ratio of SG.

Spreadsheet guidance

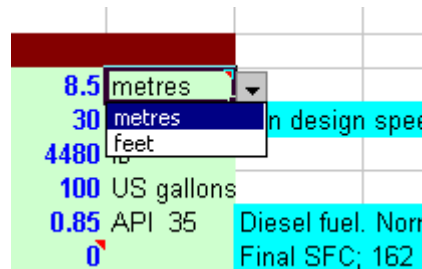
It is arranged as a one page output sheet that fits on both North American Letter Size (8 ½ x 11 inches) or the International Letter Size (210 x 297 mm).

There is only one worksheet and the calculations that are at the side and below the main output page are hidden so as not to clutter things up. It is also protected to prevent accidental data entries in the wrong places - don't worry, there isn't a password.

Here is a screen image



The entries are made in the bold blue font, such as **The blah blah whatsit and gizmo** or **4480**. The table of Principal Particulars is all the input that is required.



You may use metric or US measure entries, click on metres for length, for example, and a short list opens, see the picture on the left. Make your selection in the standard way.

The calculations are performed in US measurements and the spreadsheet makes any conversions that are required.

The same applies lower in the table for the displacement in pounds or kilos. The example has length in metres but displacement in pounds, use either system you wish. The answers are in US horsepower but there is so little difference compared to the metric horsepower (1 US = 1.014 metric approximately) that the difference can be ignored in practical terms.

There are some cells with comments that are indicated by a red triangle in the upper right corner, one is shown in the image above. The blue highlighted cells to the right of the green table give some intermediate answers that help you make decisions:

1. The speed is calculated from V/\sqrt{L} 2 to 10 and these are shown in knots.
2. The specific gravity of the fuel determines the API ranking and HHV which is used to find the SFC (specific fuel consumption) which is declared in various units after the Engine Condition entry.
3. The Engine Condition allows you a 10% margin up or down in the consumption.

The propeller revs are quite important and they are to be given at about 80% of the rated number. This is typical for diesel engines with ratings for recreational purpose. The diesel

engine has a torque curve that rises quickly and then levels off at about 70 or 75% rated rpm and falls usually just before the 100% point. The gasoline engine curve is quite different as it continually rises. The fuel consumption and range values are based on a diesel as described so the curve is something like a gasoline engine up to that point. Ideally, the system should be diesel-electric where the motor gives virtually constant torque at all speeds and is hence almost impossible to overload. So the values of consumption are rather iffy but better a SWAG answer than nothing.

The all blue tables (except the fonts) are the output, the power and fuel figures on the bottom and two propellers top right.

The two charts don't need any explanation.

The power needed to propel the boat is measured at the propeller and is the SHP (shaft horsepower) but the term can have several meaning and nowadays P_D meaning delivered power is the standard although neither is directly quoted on the spreadsheet. There are several losses of power working from the propeller back to the engine – engine bearing, gearing, universal joint, engine drive auxiliaries etc. so care must be taken to ensure that the engine has all these included in its rating for BHP which is the brake horsepower measured at the output and the power that drinks the fuel, not the SHP. Manufacturers use various rating systems so be sure you understand which one they use.

The range drops as speed increases and in the spreadsheet it is the range only at the declared speed using 100% of the fuel capacity declared in the input. The true range is obviously a mix of the declared values and depends on how the boat is operated. So say it is half an hour at slow speed, one hour at 10 knots, two hours at 15 knots, two at 25 and two at 30 then we can make a table like this;

Duration hours	Speed knots	Distance n.m.	Gallons/hr	OGallons
0.5	~6	3	.5	.25
1.0	10	10	1.8	1.8
2.0	15	30	2.8	5.6
2.0	25	50	6.5	13.0
2.0	30	60	9.1	18.2
<u>7.5</u>		<u>153</u>		<u>38.85</u>

So the total distance is 153 nautical miles in 7 ½ hours, an average speed of 20.4 knots. A total consumption of 38.85 gallons, an average of 5.18 gallons per hour or say 0.254 gallons per nautical mile (3.94 n. miles per gallon).

Going there at full speed all the time would take 5.1 hours and burn about 46.26 gallons. Or we could dawdle along at 15 knots, take over 10 hours and use only 29 gallons. Such simple exercises clearly show the penalty of speed and all that without accounting for the engine cost, higher maintenance etc.

The propeller guide top right is probably the least accurate of all the output. It is based on some old typical rules of thumb that are stretched to the limit and then some! There was little point in trying to design a proper propeller as the CATERPILLAR method in the spreadsheet deduces SHP i.e. the propeller inefficiency is already built in. In addition, more details would be needed so it would defeat the whole purpose.

I had considered a spreadsheet for Savitsky's method but I could only find about half of what I need. I found Shuford's method but it utilizes Savitsky's early work which surprisingly also turns up in Barnaby's book under different names. Too bad, not enough hard data so I just called it quits.

Wrap-up

There is a danger that the method concentrates on old hull forms and is not characteristic of present forms. This could cause wide errors over most of the output so everything should be treated with caution. But anyone having solid and reliable data could easily prepare a few fudge factors.

If anyone has any suggestions and can supply some info I could include it and make any necessary corrections.

I would appreciate any comments concerning the spreadsheet. Even better would be a copy of D.L Blount's paper "Small Craft Power Prediction" in MARINE TECHNOLOGY January, 1976.

Michael D
8 Nov, 2002