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Technology evaluation : Propulsion methods for a 32' auxiliary yacht

This document provides a brief overview of the advantages and disadvantages of several propulsion methods for a small auxiliary craft. The systems analysed are as follows.

1) Volvo D1-13 marine diesel with conventional gear box drive.
2) Volvo D1-13 bobtail (no gear box) driving a serial diesel/electric transmission.
3) Volvo D1-13 bobtail driving a serial hybrid system.
4) Volvo D1-13 with conventional gearbox in a parallel hybrid configuration.

Fig 1 provides a top level schematic of these four systems.

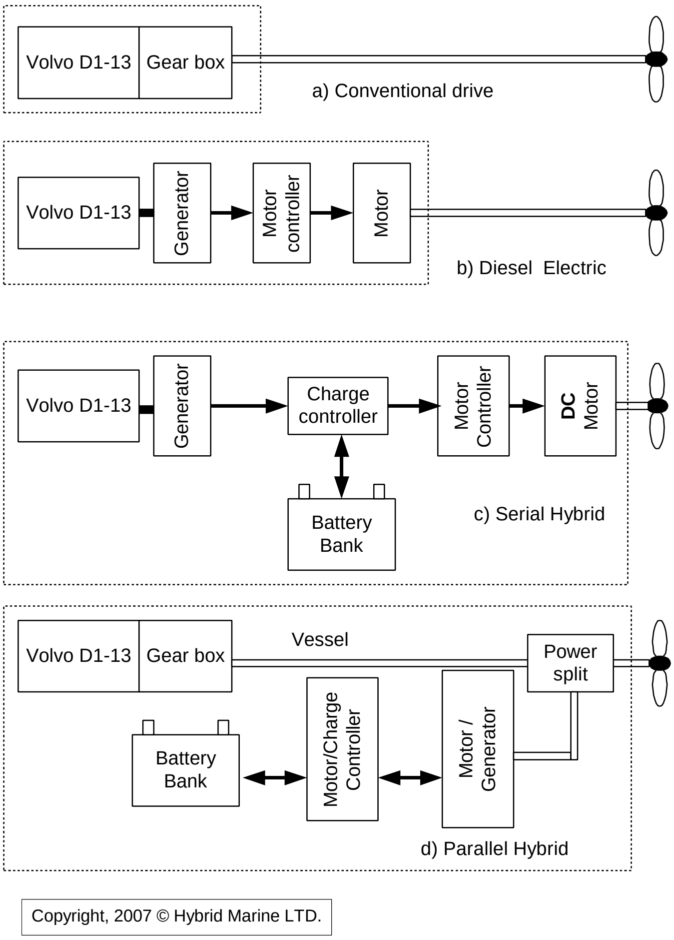


Fig1

Each of the four systems were analysed for their performance in the same craft, (see table 1).

Vessel Name	"Maud"
Vessel type	Auxiliary sailing craft
Length	32'
Displacement	6,230kg
Max shaft speed	1030 RPM
Propeller	3 blade, 18" by 11"
Conditions	Smooth water calm conditions

Table 1

Fig 2 provides the Shaft power V speed characteristics for the vessel using a 18"/11" propeller with a maximum shaft speed of just over 1,000 RPM.

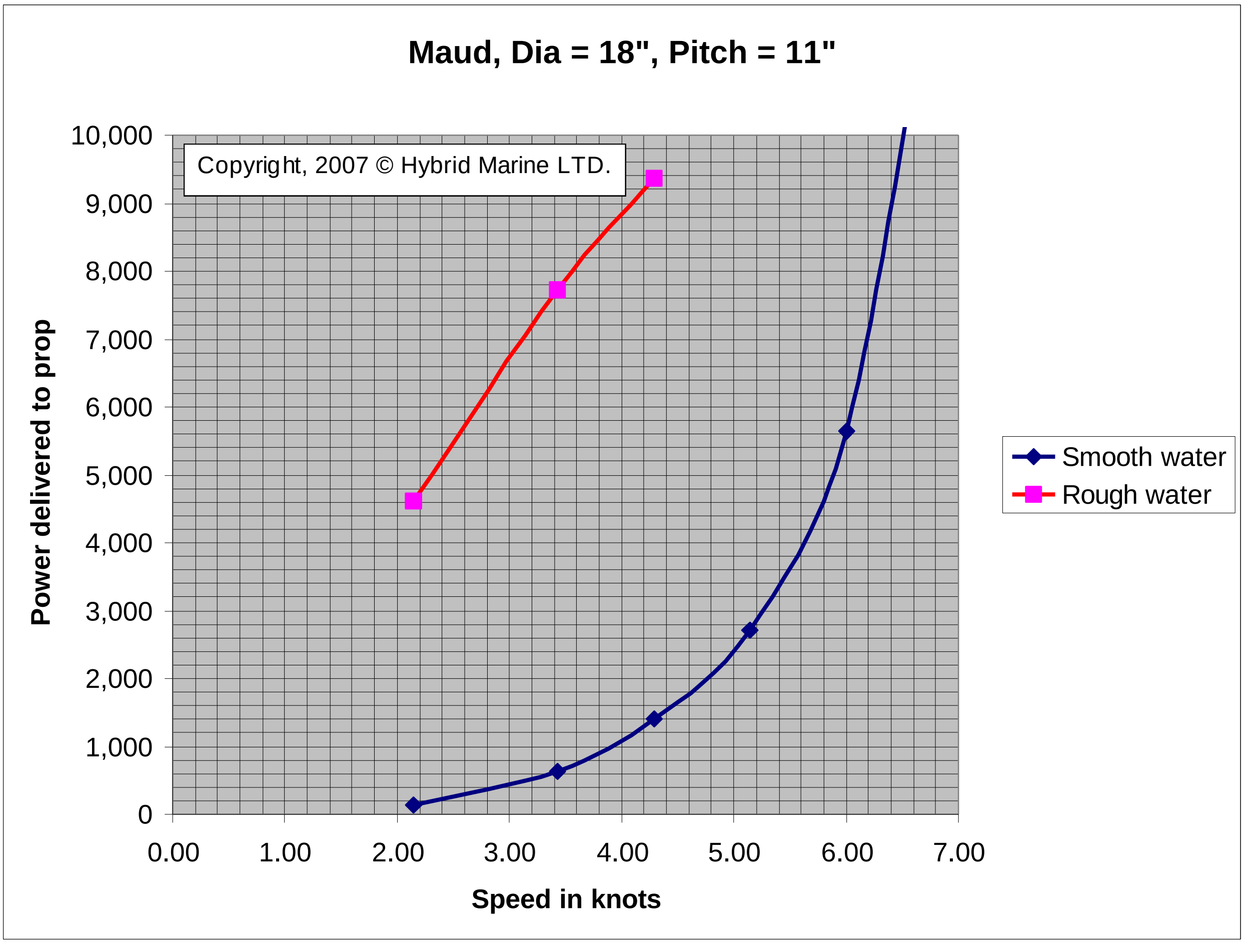


Fig 2

Fig 3 is the power characteristics provided by Volvo for the D1-13 marine engine.

Black line = Maximum rated power for the D1-13
Red line = Volvo's measured propeller power curve when taking fuel consumption data.
Blue line = A propeller curve with an index of 3.0 showing a fit to Volvos measured prop power.
Green line = The prop curve for Maud, this has an index of 3.3 and shows a lower Power Take Off than Volvo's standard curve.

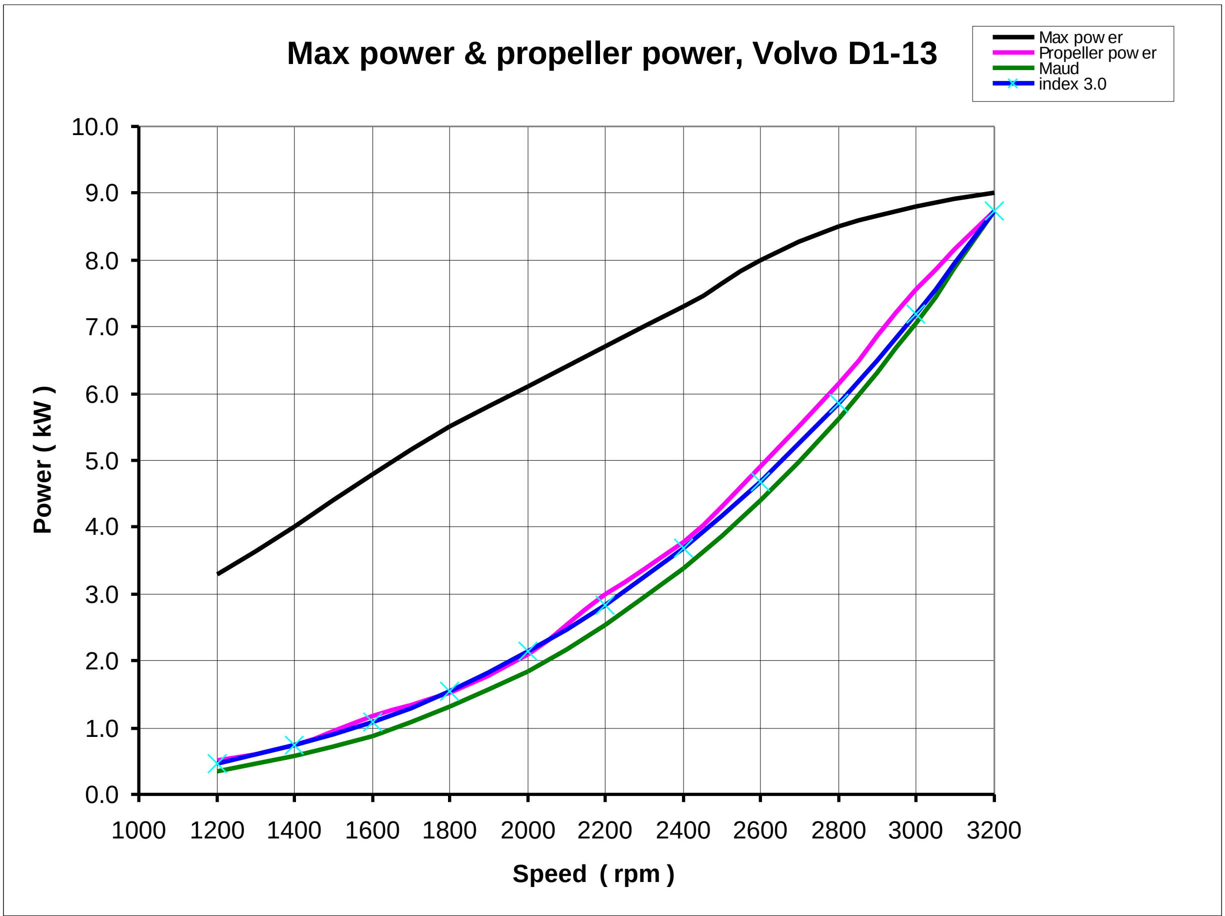


Fig 3

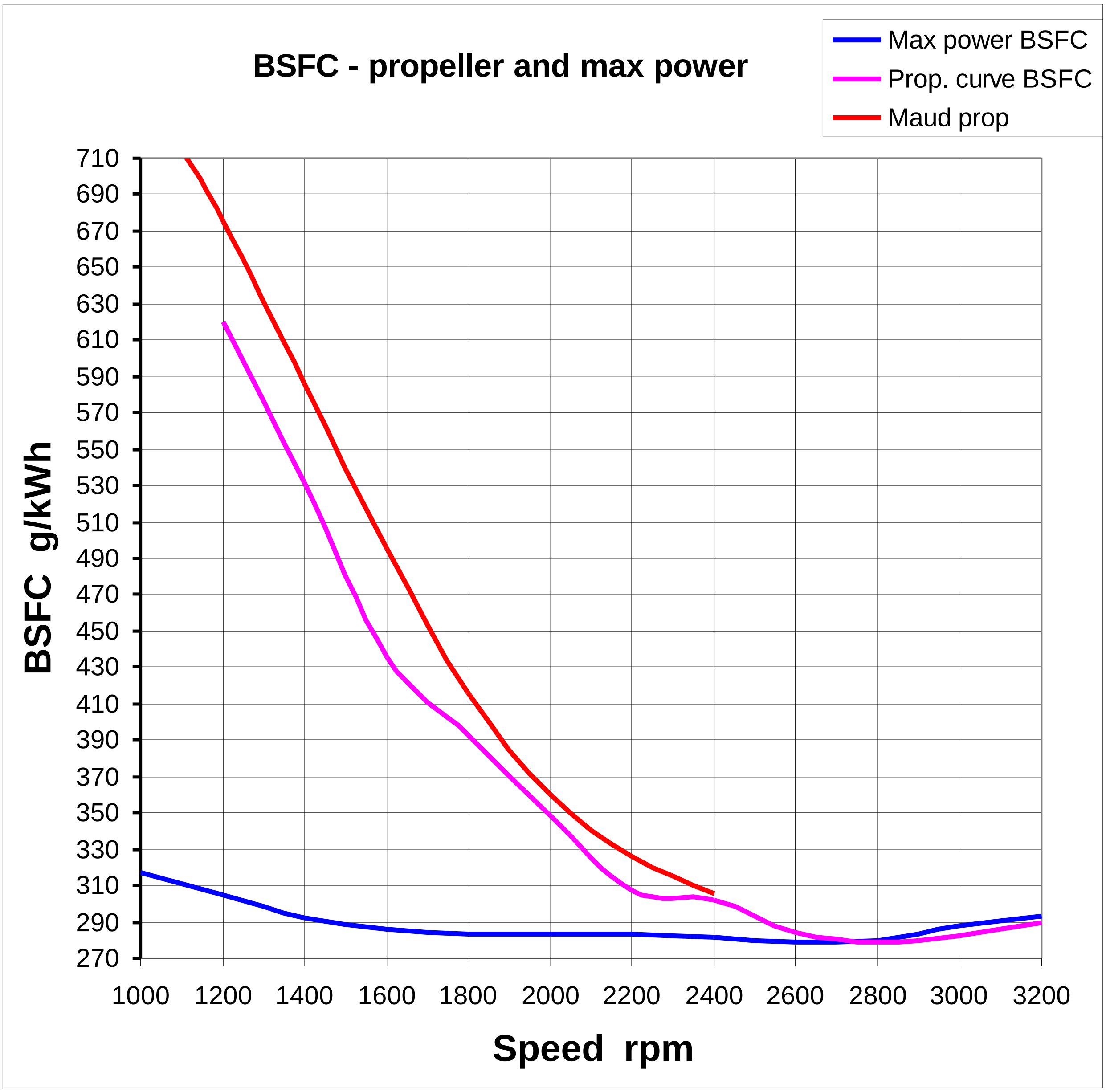
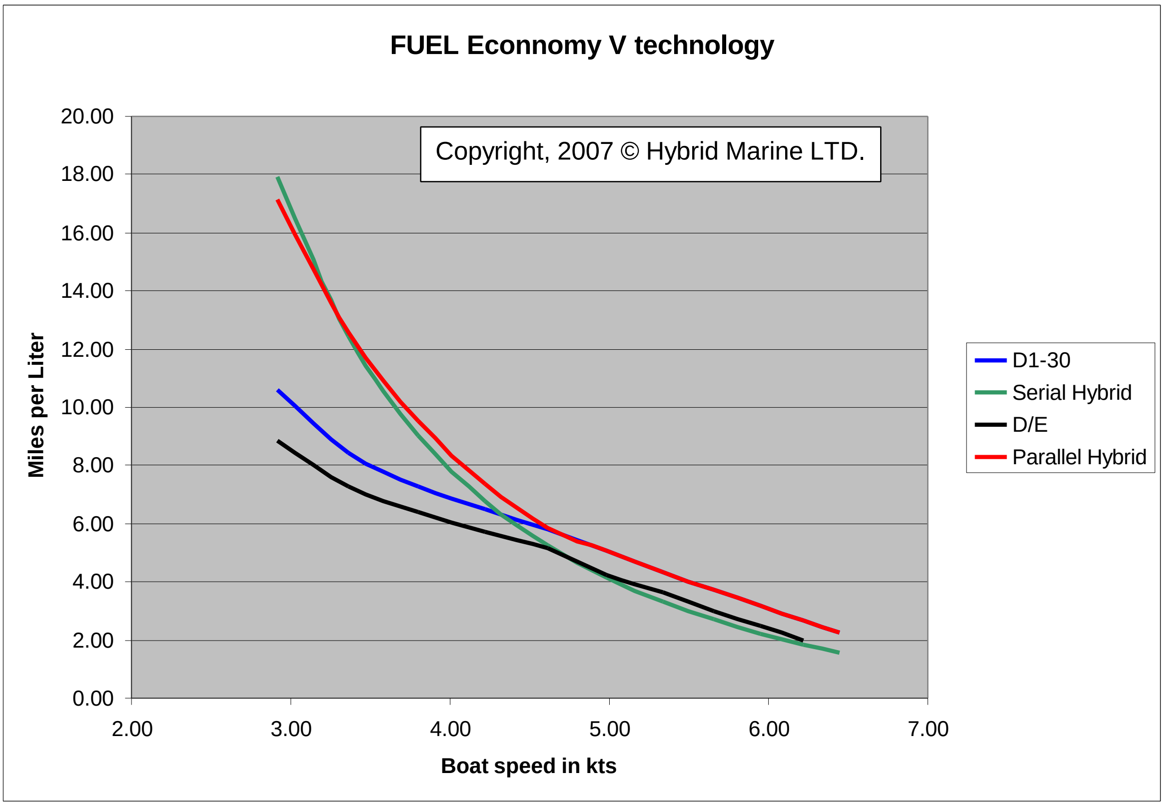


Fig 4

Fig 4 shows Volvo's measured fuel consumption performance (in BSFC) when under maximum load (blue line) and at the prop load (purple line). Maud has a higher prop index than the standard Volvo test conditions. The red line is the extrapolated BSFC performance to the Maud prop load (index =3.3).

The comparative fuel consumption performance has been simulated using the following assumptions.

1) All four system in identical craft with the same propeller size and max shaft speed.
2) Volvos specified gear box loss of 3%
3) Transmission loss of 20% for the diesel electric system (loss in generator, controller and motor). This System attempts to keep the engine running near to 100% PTO at all boat speeds
4) Transmission loss of 30% for the serial hybrid (loss in generator, battery charging, controller and motor)
5) The Parallel hybrid extracts power from the prop shaft to keep the engine running near 100% PTO at all speeds. At intervals, when the battery is charged, the engine is cycled down and drive is effected through the electric motor. This energy is extracted, stored and returned to the propeller shaft with an efficiency of 70% (loss of 30%).



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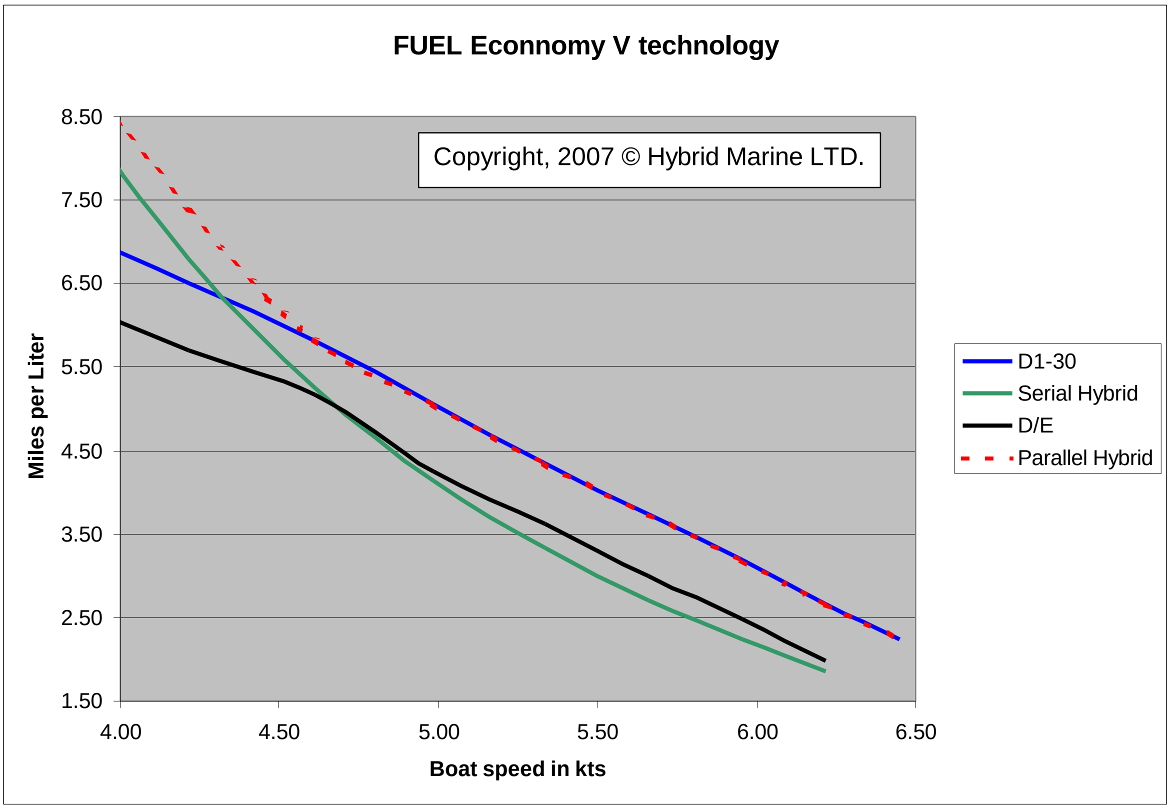
Miles per Liter
Boat speed in kts
D1-30
Serial Hybrid
D/E
Parallel Hybrid

Fig 5



FUEL Econnomy V technology
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Miles per Liter
Boat speed in kts
D1-30
Serial Hybrid
D/E
Parallel Hybrid

Fig 6

Fig 5 shows the predicted fuel efficiency performance of each technology. Fig 6 zooms in on the high speed region.

With regard to fig 5 and fig 6 we can make the following observations .

Standard Volvo D1-30

The fuel economy performance shown is extrapolated from the Volvo data. The Volvo provides BSFC at a prop curve of 3.0. Maud however has a prop curve of 3.3 giving a lower PTO at low speeds and a consequential higher BSFC.

The best fuel performance at high speed is achieved by the standard drive chain. In this region the engine is working with high PTO and high efficiency. The gear box loss is only 3%, much less than the serial hybrid or diesel electric.

Serial Hybrid

The serial hybrid generates and stores it's energy with the engine running at it's most efficient point. Despite the extra transmission losses this provides a significant improvement in low speed fuel economy where the required power is very low.

In the serial hybrid the transmission loss is 30% . At higher speeds the conventional D1-13 is running with good BSFC. At these speeds the losses in the serial hybrid exceed any minimal improvement made in BSFC giving a degraded fuel economy.

Top speed is reduced due to the extra transmission loss.

Parallel Hybrid

The Parallel hybrid also buffers energy and is able to show a significant improvement in low speed economy. At very low speeds, the engine runs at low revs with less than optimum BSFC this explains why the parallel hybrid has slightly lower fuel economy than the serial system at very low speeds.

At high speed the Parallel hybrid performance matches the standard drive train. This is because at high PTOs the hybrid has nothing to offer by way of fuel economy and is switched off. We just use the standard drive train at speeds above 4.25 kts.

Diesel / Electric

Due to the high transmission loss (20%) the diesel/electric had a lower performance than the standard system at high speeds. Degraded fuel economy is seen and a lower top speed, this is expected.

A first glance the results at low speed look rather surprising. You would expect to see some improvement in economy at lower speeds. This performance can be explained with reference to fig 7.

At all times the Diesel/ Electric system attempts to keep the engine running at maximum PTO. As speed drops from maximum the power requirement falls off rapidly. In a conventional system this results in a reduced PTO at the lower engine speed. The D/E rapidly cycles down the engine speed to keep the engine at high PTO for the required power.

The graph shows a near 100% PTO for the D/E at speeds down to 4.5kts. This results in some improvement in BSFC but this is swamped by the extra losses.

At about 4.5kts the engine has been cycled down to idling speed (850RPM). The engine can not go any slower. Therefore at speed below 4.5kts the PTO of the D/E rapidly falls off. The engine loading is still higher than a conventional system and this still provides a better BSFC. This improvement in engine efficiency is still swamped by the extra transmission losses.

Caveat : Very little engine BSFC performance data is available. This has only been provided at full load and at a prop curve with a 3.0 index. A lot of extrapolation has been used here and the D/E case can only show a rough indication of actual performance. In order to conduct a thorough analysis a full two dimensional engine fuelling map would be required.

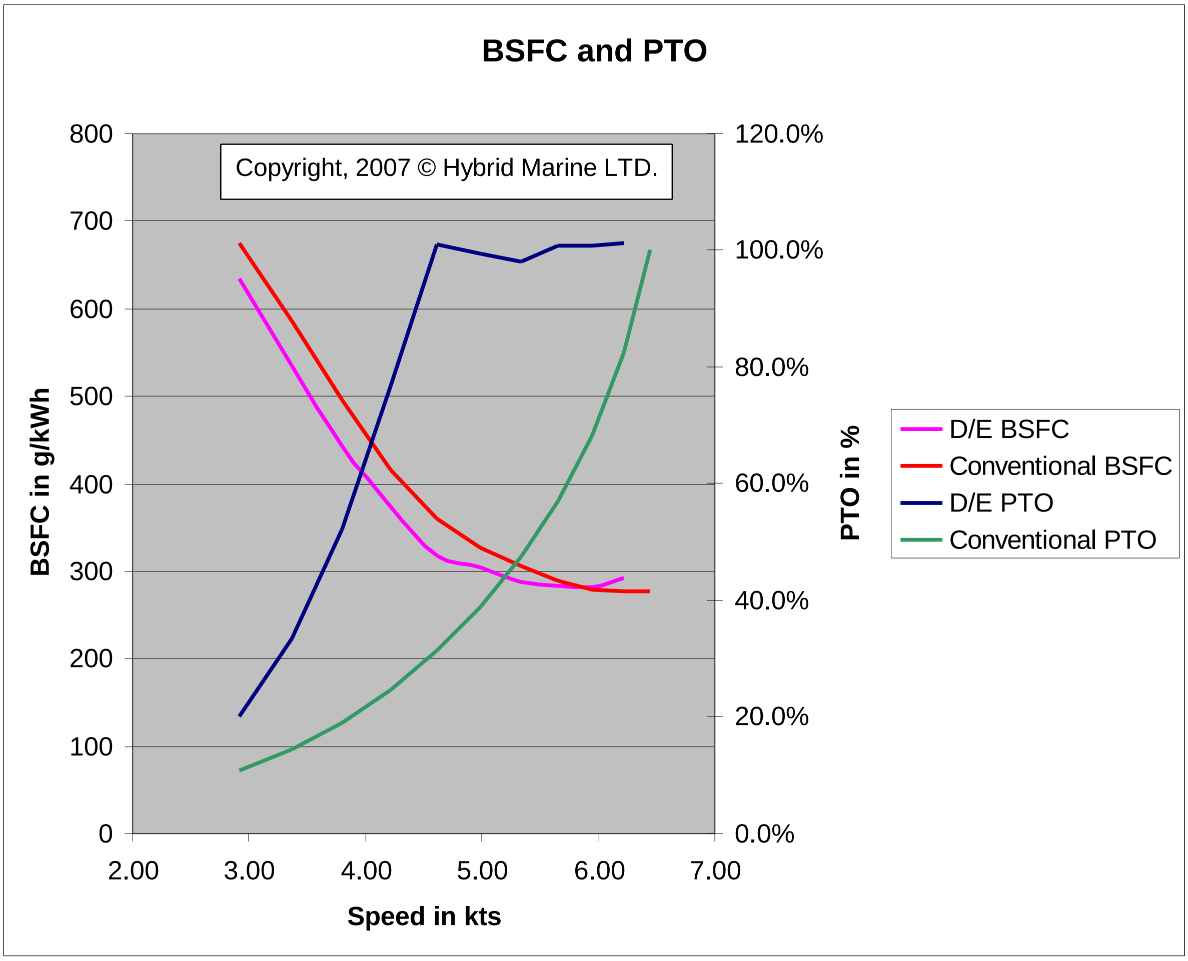

Fig7

<u>Conclusion</u>

This analysis is based around a small, 9kW marine engine and provides an indication of potential performance in four possible systems.

For slow speed operation (below 3kts) the Serial hybrid shows the highest potential for fuel efficiency

Across all speeds the Diesel / Electric shows degraded performance with regard to the conventional system.

The Parallel hybrid provides enhanced economy at low speeds while not degrading performance at high speed. Based on fuel efficiency and maximum power this system has the best overall performance for a craft that operates over the full speed range.

An important point to understand here is why the hybrids have shown a marked improvement in fuel economy at mid to low speeds. This can be understood by looking at fig 4. The BSFC of the D1-13 increases rapidly at lower speeds. The buffering capability of the hybrids helps to improve the BSFC by running the engine under higher load. When looking at larger engine plants, say the D2-75 from Volvo, the BSFC performance is very different (see fig 8). The BSFC does not degrade nearly so much as the D1-13 at low speeds, so a hybrid could not offer such a large improvement in fuel efficiency here.

This analysis has concentrated only on the efficiency of getting the energy in the fuel to propel the boat. A hybrid (either parallel or serial) has an electrical energy buffer (battery) this allows other energy sources to provide power for moving the craft. The batteries can be charged by solar & wind generators, via the AC mains and by regeneration when sailing. This allows many sources to contribute to the power budget and further reduce the use of fossil fuels. When considering hybrid technology these factors should be taken into account.

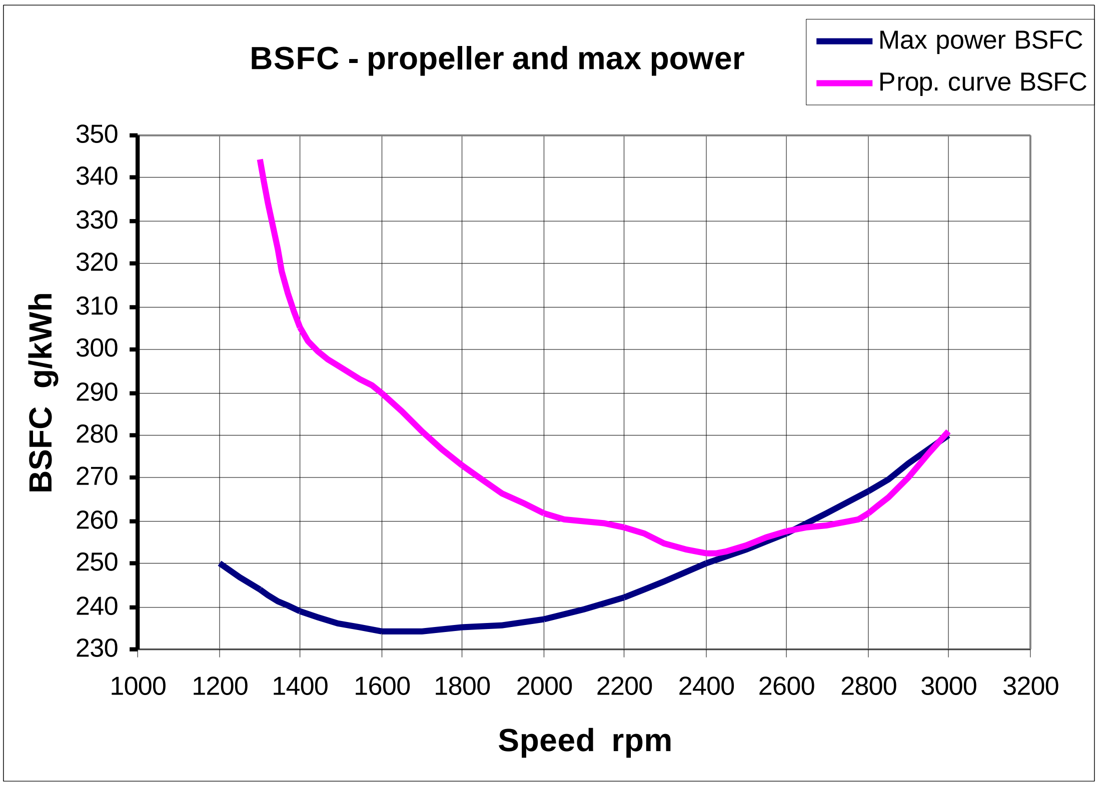

Fig 8