Fishing Vessel Power & Propulsion: Future Evolutions

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ABSTRACT

The European Union fishing fleet comprises nearly 100,000 vessels of which 15,000 are trawlers. A major problem in fisheries, and particularly in trawling, is the high consumption of energy with bottom trawling using the most energy. In North European waters, trawlers can use up to 1kg.fuel per 1kg fish caught which is twice that for other fleets. In Iceland, the consumption of fuel by the fishing fleet is greater than that of industry or air traffic, and is comparable to that of all the motor vehicles on the island.

Therefore, fishing vessel fuel economy is important both for their operating economics and for the greenhouse gas emissions they emit.

The paper presents the findings of a study which examined the scope for improvements to the power and propulsion system on a 27m trawler. In many vessels, the power and propulsion systems are separate so with a combined system there are possibilities for a more flexible use of the installed prime movers. The benefits and issues with the adoption of different fuels, propulsors (such as underwater waterjets) and the introduction of supplementary hybrid electric drives are presented.

Keywords: marine propulsion, hybrid propulsion, low carbon, fishing, trawling

1. INTRODUCTION

The European Union (EU) fishing fleet comprises nearly 100,000 vessels of which 15,000 are trawlers. With over 1 billion people in the world depending on fish as their primary source of protein, and with fishing stocks being located further from home ports due to depleted stocks in home waters, the range of fishing vessels is likely to continue to increase and there will continue to be a need for the use of trawling as a cost-effective means for commercial fishing of pelagic species. From an EU perspective, the distances travelled by trawlers continues to increase as shown in Ref 1.

A major problem in fisheries, and particularly in trawling, is the high consumption of energy, with bottom trawling using the most energy. In North European waters, trawlers can use up to 1kg.fuel per 1kg fish caught which is twice that for other fleets, and consequently the fuel costs are a high proportion of the cost of fishing operations (Ref 2). Although higher fuel costs may force less efficient vessels out of business and should provide an incentive for more fuel efficient vessels, the cost of fuel may be subsidised and the challenge of including energy efficient equipment onboard is also problematical unless it is introduced into a new build vessel. The issue then is one of risk as it is difficult to reliably project the future cost of fuel and to make a firm case for the extra capital investment.

Efforts to reduce the energy consumed when dragging the trawl nets has led to the adoption of more modern materials which are fine whilst still being strong and can be used in flexible netting structures leading to a reduced fuel consumption of up to 40%. Refs 3 & 4.

2. STUDY BASIS FISHING VESSEL

A 27m Adriatic trawler as defined in Altosole, 2014, Ref 5 was used as the study basis vessel. For the purposes of this study, this vessel is assumed to be a “day-trawler” with no or very limited accommodation. The principal particulars of the vessel are shown in Table 1.

Table 1: Main Particulars

Parameter	Value
Length, overall	27 m
Beam	7.0 m
Draught	2.5 m
Maximum speeds Transit Trawling	At sea state 1 11.7 knots 4.4 knots
Nominal range	500nm at 10 knots
Ship's non-propulsion electrical load	72kWe trawling 40kWe transit
Displacement	200 tonnes
Standard Power & Propulsion	
Diesel gensets	2 x Caterpillar C44 each 99 kWb
Propulsion	1 x 2m diameter Fixed Pitch Propeller (FPP) Wageningen B4-55 driven by a Caterpillar C32 engine: 634kWb.

The vessel's resistance in transit and trawling conditions are shown in Figure 1.

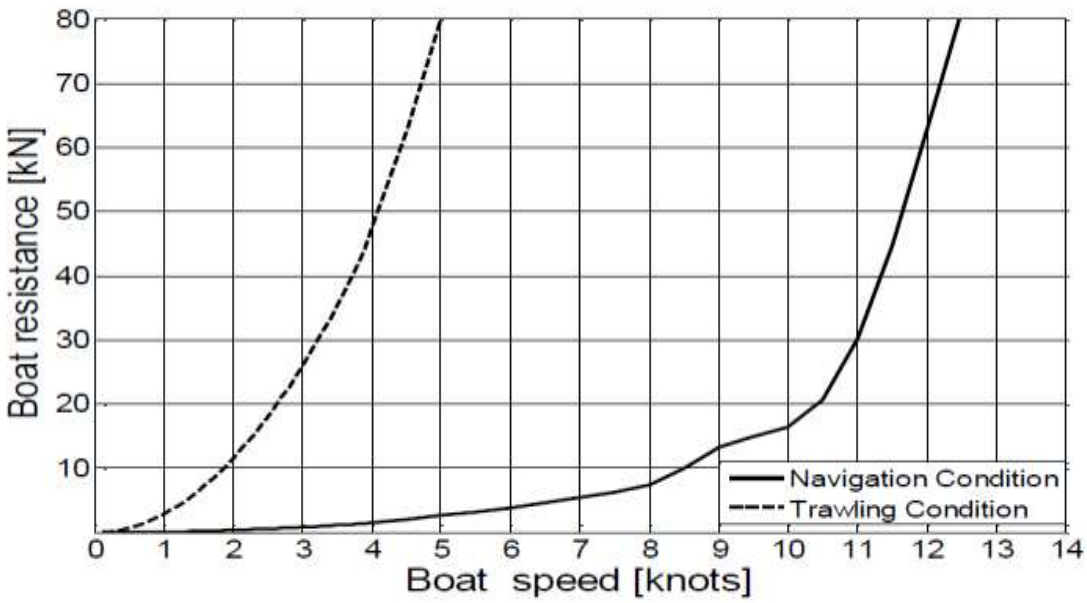

Figure 1: Vessel resistance in navigation and trawling conditions.

The baseline operating profile comprises 6 hours steaming at 11.7 knots per day with 5 hours trawling at 4.4 knots per day, i.e. ~55% of the time is spent in transit or manoeuvring.

Using the BMT proprietary marine Power & Propulsion (P&P) analysis tool, Ptool (Ref 6), a comparison has been made between a series of design options.

3. PROPULSION STUDIES

The options for the propulsion of a fishing vessel have grown with the introduction of new technologies and the proving of those technologies which have been used elsewhere.

3.1 PROPULSORS

This study has addressed the use of the following propulsors:

- fixed pitch propeller (FPP);
- controllable pitch propeller (CPP);
- Kort-type 19A nozzle ducted propeller;
- Voith Linearjet propulsor.

3.2 CRP & NUMBER OF PROPULSORS

Contra-rotating propellers may offer an efficiency benefit but they are not known to be commercially available for this application. Due to the limited space at the transom, the number of shaftlines is limited to one.

3.3 ENERGY STORAGE

The provision of energy storage may be an attractive concept for the storage of power from an engine-driven Organic Rankine Cycle when transiting. The stored energy could then be used for peak power demands during the heavy-winching during trawling duties.

Most fishing vessels have a limited battery storage capability and it is likely that space would prohibit a truly useful and cost-saving solution and so energy storage is not addressed in this study.

3.4 HYBRID POWER & PROPULSION

A hybrid solution where the main engine can drive a power take-off (PTO) to provide an electrical supply would save DG running hours but would require the main engine to be oversized to supply both the propulsion and the electrical load. For the baseline propulsor it is not attractive to reduce speed or find space for a larger engine. If the propulsor offers a much reduced engine load in transit then this may be feasible.

The complexity of such hybrid solutions would only be merited when they offers significant fuel savings which can be offset against the increased initial capital costs.

In an analysis of the BMT Aegir design, as presented in Ref 7 and Ref 8, the economy of hybrid systems is demonstrated, both for fuel economy and reduced engine running hours. Couch & Fisher, Ref 9, describe the design methodology for achieving the hybrid P&P design and outline its operating envelope and inherent flexibility. Simmonds et al, Refs 10 & 11 explain that to achieve a robust hybrid design, where there are changes from one set-up to another, requires specific design insight, analysis and integration.

For a fishing vessel, it is suggested that a full hybrid solution cannot be easily inserted into the limited space due to the space required for the power conversion equipment. However, a limited PTO capability is explored as a performance feature.

4. Study Set

The study has considered the following specific design options:

a. Option 1. (150) Diesel Mechanical (DM) drive to FPP (baseline design described above)
b. Option 2. (151) DM drive to CPP
c. Option 3. (153) DM drive to Kort nozzle 19A 4-55
d. Option 4. (154) DM drive to Voith Linear Jet (VLJ)
e. Option 5. (155) Gas engine drive to Voith Linear Jet (VLJ)
f. Option 6. (253) Diesel Electric (DE) with VLJ
g. Option 7. (780) CPP Hybrid

4.1 OPTION 1 (150): DIESEL MECHANICAL DRIVE TO FPP

The vessel’s baseline propulsion system comprises one FPP, 2.0m diameter, Pitch-to-Diameter ratio (PD) of 0.87 and a Blade Area Ratio (BAR) of 0.55.

The propeller is driven by a 634kWb Caterpillar C32 engine.

A 5.6:1 reduction gearbox reduces the engine top speed from 1,600rpm to 300rpm drive shaft speed.

Two Cat C44 DG sets each rated at 99kWb provide electrical power to the ship.

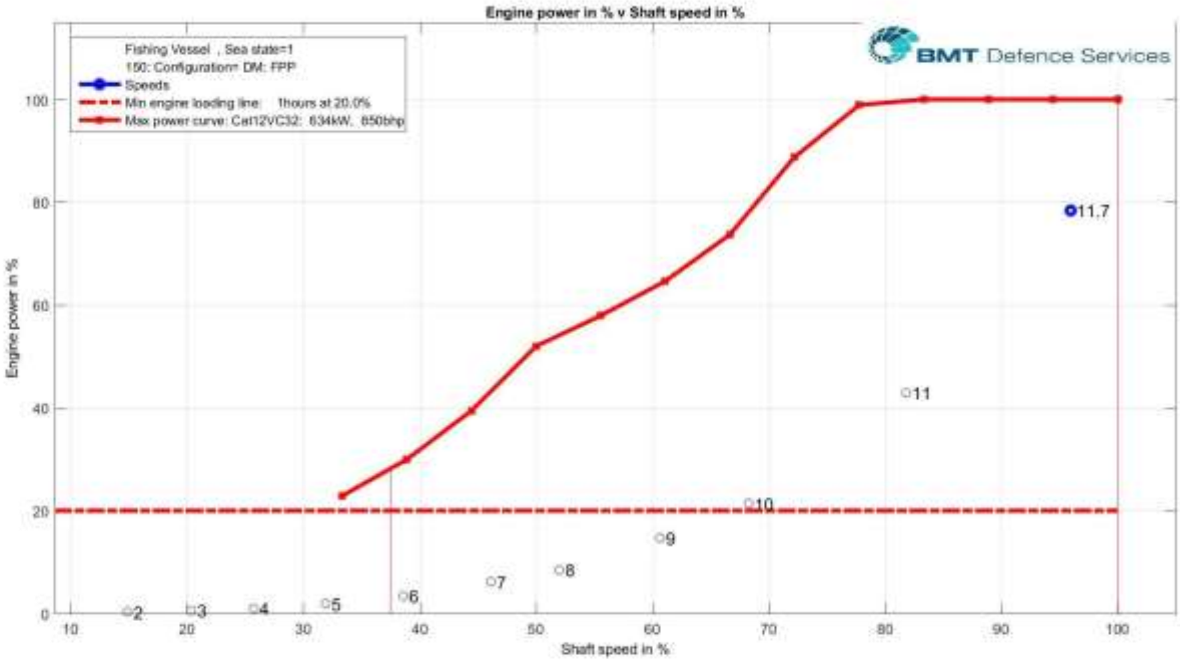

Figure 2: DM FPP drive: Engine characteristic

Figure 2 shows the main diesel engine power-speed characteristic with the individual vessel speed point indicated.

4.2 OPTION 2 (151): DIESEL MECHANICAL DRIVE TO CPP

In this design the FPP is replaced with a CPP of similar size which allows the engine and propeller to operate at the best (slowest) speed for a given load. The slower shaft speed leads to propeller efficiencies.

4.3 OPTION 3 (153): KORT NOZZLE

A 2m diameter Kort nozzle with four blades and 55% BAR was introduced as this is also a common trawler propulsor. The design is based on the well-known 19A nozzle-duct design which converges the flow towards the propeller thus straightening the streamlines and accelerating the flow to achieve better efficiency when trawling with high bollard pull-load at low speeds.

4.4 OPTION 4 (154): DIESEL MECHANICAL DRIVE TO VLJ

The VLJ has been used on a windfarm support vessel where high static thrust at low speeds and good efficiency over the transit speed range is required (Ref 12). This operating situation is comparable to a trawler and so has been considered here. Figure 3 shows a VLJ installation indicating how the thruster rotor is protected by the nozzles.

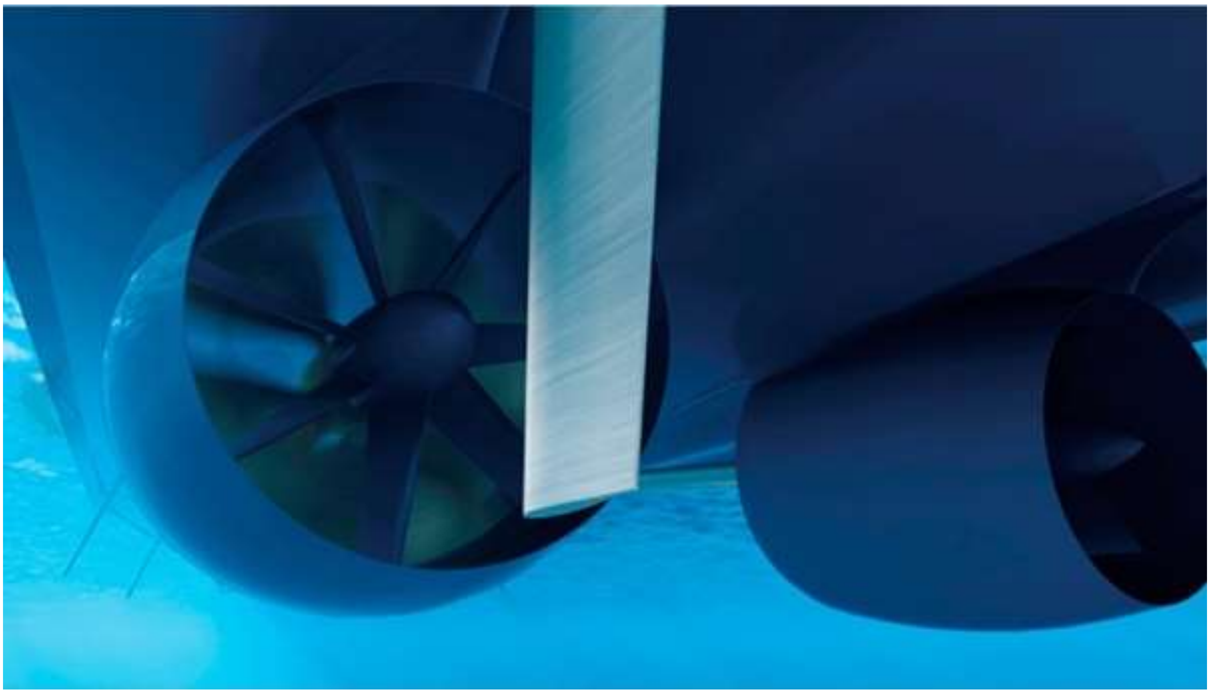

Figure 3: Voith Linear Jet Installation

The VLJ design has the same arrangement as the baseline but the main engine drives one VLJ of diameter 1.98m as this is the supply size. The gearbox is a reversing gearbox which may be an epicyclic or simpler design. This is required because the VLJ, as with a FPP, cannot provide reverse thrust on its own. The aft end is redesigned to accommodate the VLJ but in this study the resistance is assumed to be the same and the thrust deduction factor is 0.01.

Figure 4 shows the VLJ and propeller efficiency curves against the advance coefficient. The current design of the VLJ (Ref 13) has a maximum possible propulsive efficiency of ~70% which is comparable to the propeller design for option 150. However, in practice, both propulsors will have much lower efficiencies as they will be highly loaded in this application.

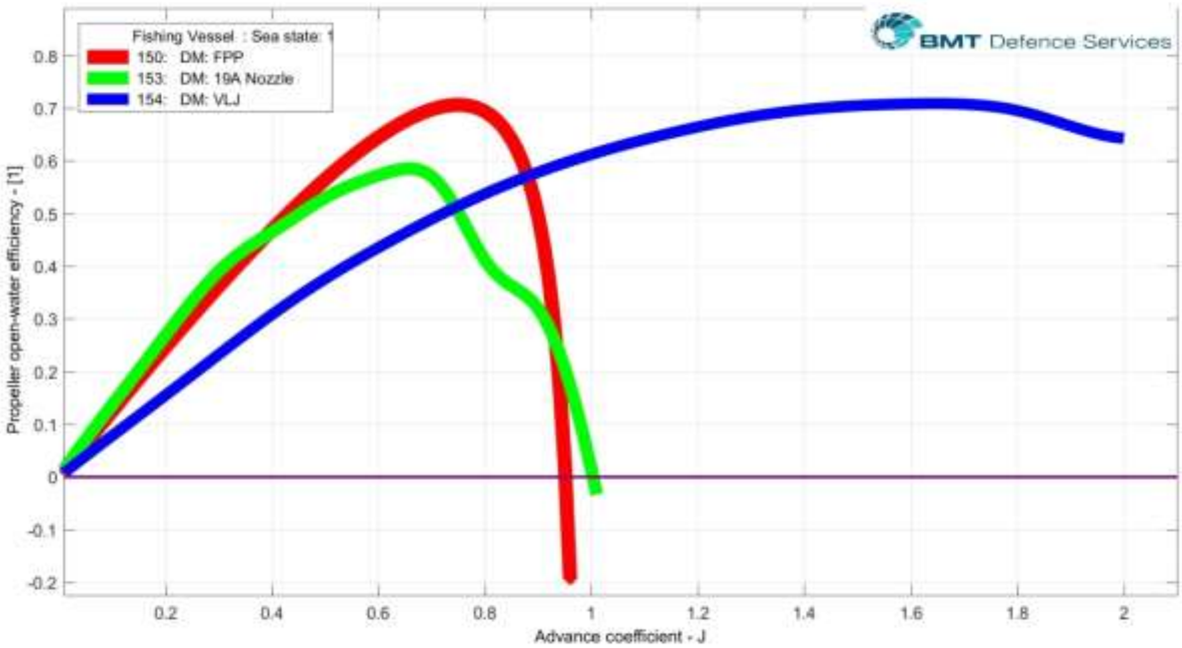

Figure 4: Propulsor Efficiencies v Advance Coefficient

The VLJ has a good efficiency across a broader range of advance coefficient values and therefore loads. This makes it a robust design solution for trawler applications.

4.5 OPTION 5 (155): VLJ WITH CNG FUELLED ENGINE

To achieve further savings it is likely that the use of methane as a fuel would be feasible and affordable. Ship fit issues are not examined in detail here but modern buses have been able to identify storage points for the compressed natural gas (CNG). The liquefied natural gas (LNG) used in larger ships require too much plant for a fishing vessel of this size and so CNG is the natural option.

There are no gas-fuelled marine engines at the 600-700kW point and the biggest gas-engine for buses is the Scania 16 litre, V8 engine which delivers 580hp at 1900rev/min, (Ref 14) . This is too small for this application (and is not marinised) so the engine size has been factored up to a V12 for the purposes of this study. Scania have not declared the heat rates so data from Bergen engines has been scaled and used as a comparator and so the results are therefore purely indicative.

4.6 OPTION 6 (253): DIESEL ELECTRIC DRIVING VLJ

The VLJ is driven by variable speed electric motors rated at 520kWb. The electric motor provide direct drive to the VLJ at 150rpm. Power is from 2 x Cat C18 DG sets with each engine rated at 452kWb.

4.7 OPTION 7 (780): CPP HYBRID SOLUTION

A hybrid solution with a 90kW PTO generator allows one of the DG set to be removed. If the main engine is still the notional Scania 16 litre V12 running on CNG then the DG set need not be run at transit speeds.

5. RESULTS

The principal results for all design options are presented together below with a short commentary to each.

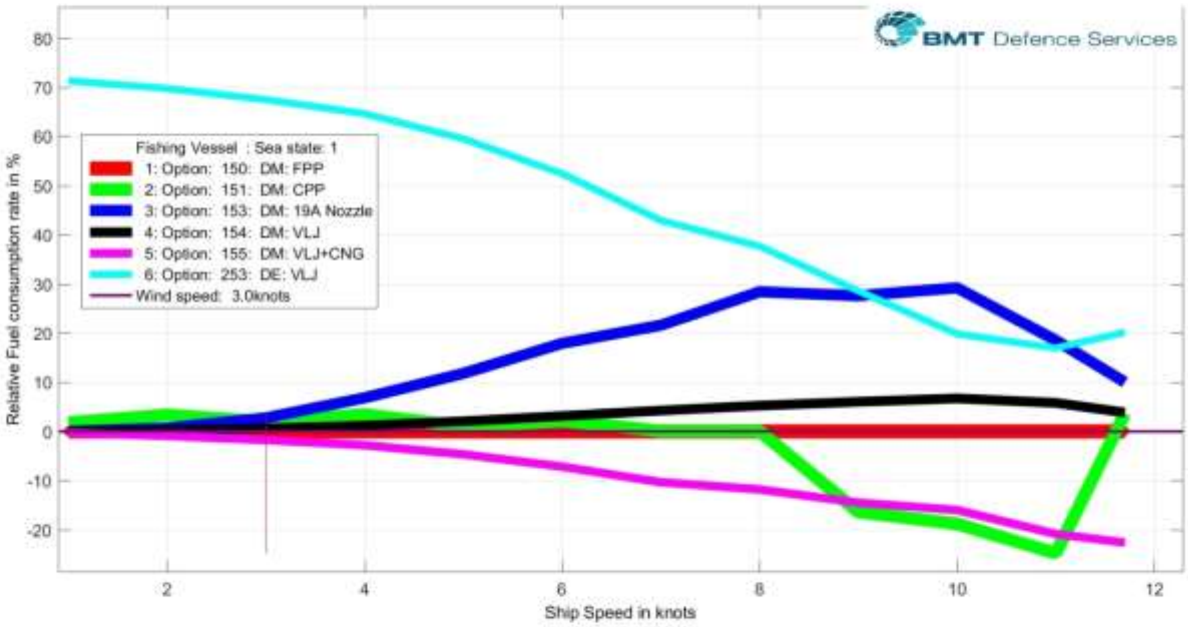

Figure 5: Transit fuel consumption relative to the baseline design

Figure 5 shows how the CPP and the VLJ with CNG designs have an apparent lower fuel consumption than the baseline design for most of the range of steaming speeds. However, the VLJ+CNG data is for the mass flow of natural gas and as such is not a valid comparison.

At the top speed of 11.7 knots the CPP and the FPP are comparable as their blades are at almost at the same pitch angle. The diesel electric solution is clearly not appropriate for this vessel.

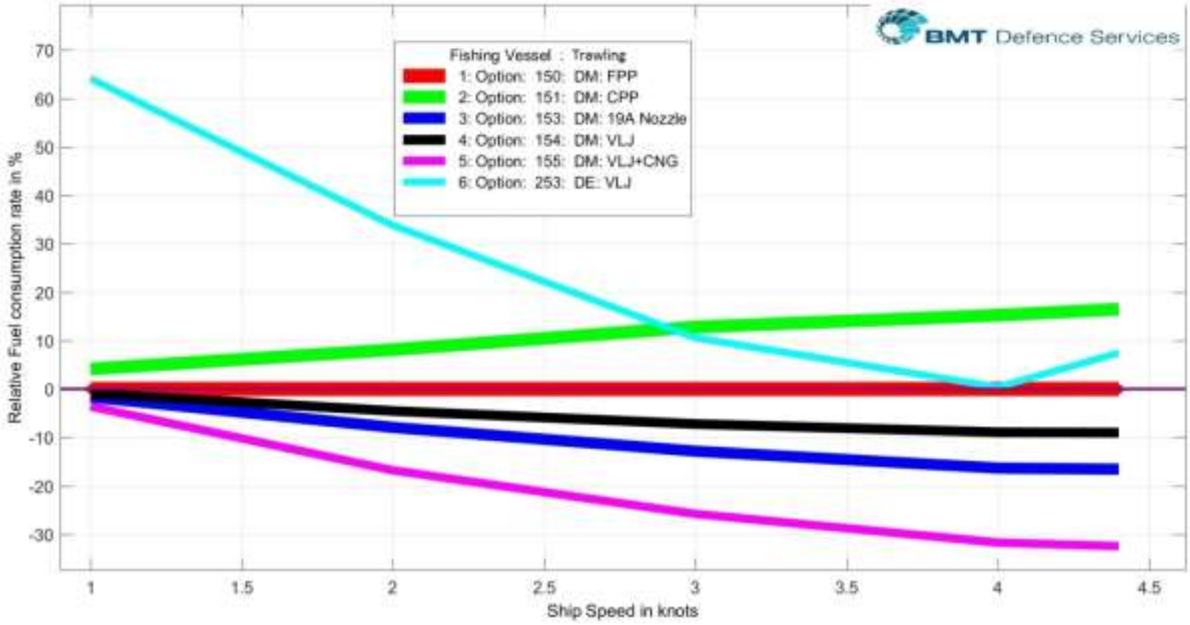

Figure 6: Transit fuel consumption reference the baseline design

Figure 6 shows how the VLJ and the Kort nozzle are better than the FPP for high-loaded low-speed propulsion. The vessel will spend a different proportion of time at transit and trawling speeds. Figure 7 shows which propulsor design is best for each proportion.

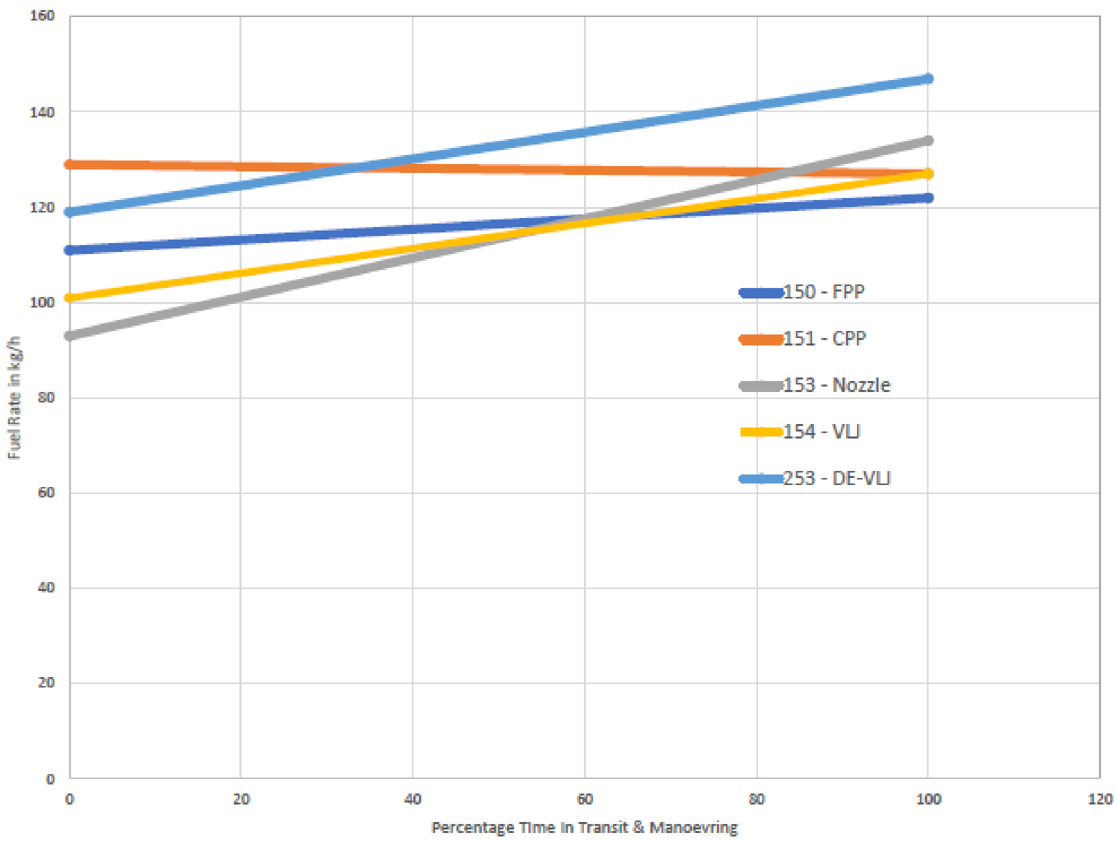

Figure 7: Fuel Rate v Time spent in Transit

Figure 7 shows that for short transit and extend trawling time then the nozzle is the most economical, for longer transit and a shorter proportion of time spent trawling, the FPP is the best design. The time spent in transit in this study is 55% and at this condition the VLJ is maybe the best for lowest fuel consumption.

As the VLJ is the best for this vessel, the Cat C32 engine running on fuel-oil (FO) was replaced with the notional CNG-burning engine with a view to further reducing CO_2 emissions.

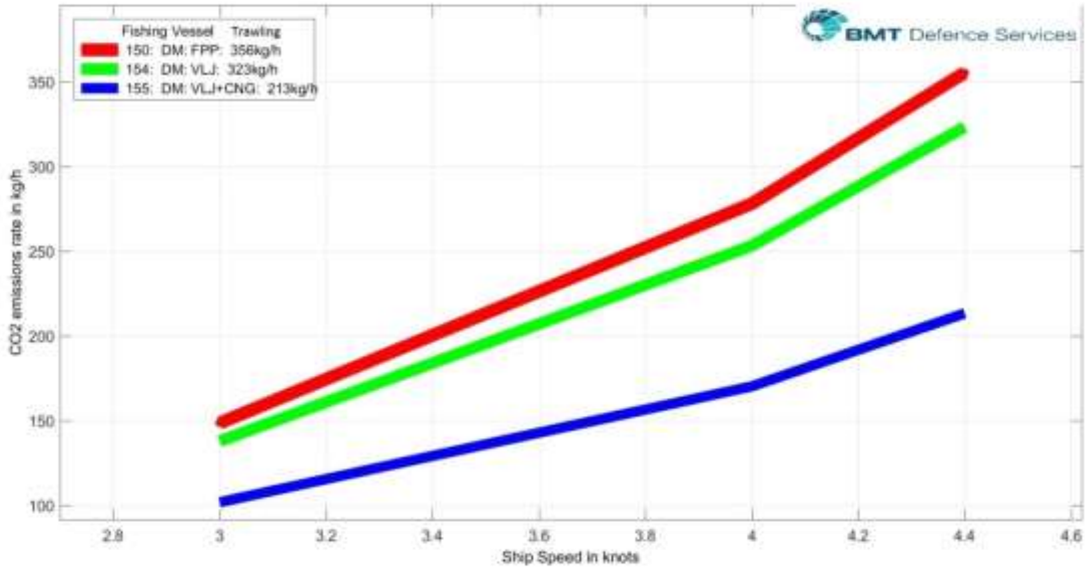

Figure 8: CO2 emissions when trawling

Figure 8 shows how the DM-VLJ+CNG offers a significant 40% CO2 emissions reduction when trawling with a 32% reduction when in transit.

It is recognised that when methane is used as a fuel there is the risk of methane slip which can undermine the CO2 reductions made by avoiding diesel fuel-oil. Sternersen (Ref 15) cites a Mitsubishi gas-fuelled marine engine GS6R2-MPTK rated at 500kW which has a methane slip of between 3.0 and 3.5 g/kWh depending on the air/fuel ratio.

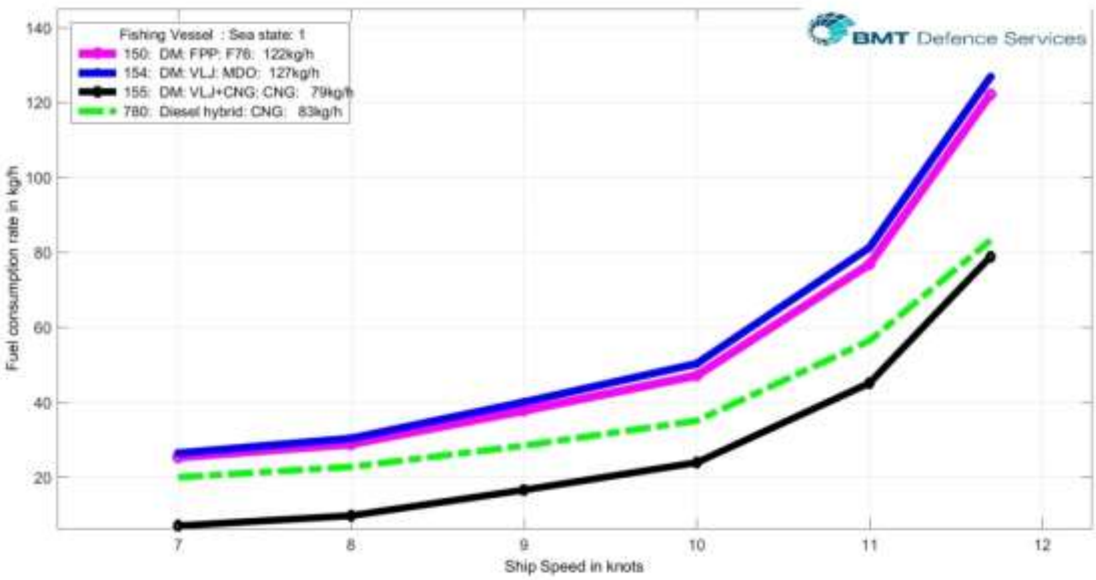

Figure 9: Comparison of Fuel & Hybrid Options

Figure 9 shows that the hybrid allows for a better fuel consumption across the transit speed range with GHG emissions comparable to the VLJ+CNG design at full speed.

6. OTHER CONSIDERATIONS

The study and results presented above has focussed on fuel efficiency and CO_2 emissions reductions. The former is an important consideration for a fishing vessel design because it results in the following benefits: reduced fuel load for a given range resulting in reduced fuel costs or increased payload; the improved propulsive efficiency may also allow smaller power generation plant or increased speed. Although these are all important benefits, the following factors should also be considered:

1. Acquisition cost: CNG engines are not marinised at these power and the CNG storage is costly.
2. Speed operating profile: slight changes alter the financial arguments.
3. Space and weight: CNG storage is bulky but not likely to be a weight issue.
4. Availability (reliability) and maintenance requirements: unproven marine equipment (i.e. CNG) always brings risk, but they should be less than LNG. Safety procedures and class and flag state rules will still require careful procedures, crew training and strict upkeep.
5. A hybrid solution removes one engine to allow more flexibility between the two remaining engines with generally lower fuel consumption.

7. CONCLUSIONS

This study has explored the use of a range of propulsors and the fuel consumption benefits for the propulsion of a typical 27.0 trawler fishing vessel design.

The use of electric propulsion is not efficient and is costly. Such a design is too complex for a fishing vessel even though the use of a motor-drive CPP allows for rapid changes in thrust.

The standard engine-drive solution with VLJ is an attractive solution as it allows good system response with an efficient propulsor. Although the VLJ is a new product and has not been much used to-date, its broad efficiency in this application is worthy of further analysis.

The use of a CNG-fuelled main engine would go some way to achieve useful reductions in GHG emissions.

8. ACKNOWLEDGEMENTS

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