

Exploring Options To Reduce Fuel Consumption

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INTRODUCTION

Fuel Conservation

For any vessel, the ability to reduce fuel consumption at sea leads to:

- Reduced fuel purchase costs;
- A reduced logistical cost of fuel acquisition;
- Reduced exhaust emissions of all types.

For a naval replenishment tanker, reduced fuel consumption allows for longer lines of logistics support and the ability to operate at a range of speeds and an upper sustainable speed which matches fleet operations.

Increasingly the benefits of reduced engine emissions both for climate change and pollution legislation reasons are also a strong influence. Therefore, with the continuing upward trend of fuel costs, all those means by which fuel consumption can be reduced require consideration.

Those means which seek to reduce the fuel demand may also allow operational benefits possibly through an increased top speed (subject to adequate qualifications for machinery loading).

This paper presents a range of energy saving technologies in the context of the Royal Australian Navy's replenishment tanker, HMAS SIRIUS. The study seeks to show, from an independent viewpoint, how such technologies may be employed to achieve real financial, environmental and possibly operational benefits. Machinery performance is identified along with a consideration of the parasitic loads such features can require. The estimated acquisition and implementation costs are compared with the benefits to the ship's resultant in-service costs to show how the choice of an energy saving solution needs to be considered in conjunction with the ship's overall design, its machinery and its operating role.

Scope

Since the widespread use of propeller driven steel ships in the past 100 years, there has been a sustained but sometimes unsteady effort to identify technologies which offer to improve the energy efficiency of marine propulsion. As each ship and its operations are different and each technology has a specific design point, clearly not all technologies will suit each ship.

The current emerging requirement for improved energy efficiency has three main drivers: the increasing cost of energy, its impact on the environment and to a lesser extent, energy security. BMT has assessed the benefits of a set of relevant emerged and emerging technologies in the context of HMAS SIRIUS.

Context

BMT conducts power and propulsion studies for a wide range of commercial and naval clients. Often this is to improve propulsion efficiency and to promote energy conservation. BMT actively seeks to monitor those technologies which offer potential for these aims and maintains a database of over 150 technologies of varying degree of maturity. For each project, these are applied to a given

platform and its operating profile to identify those which have the most merit, i.e. those with the greatest savings in terms of fuel and emissions at an appropriate acquisition cost.

For shipping as a whole, the price of fuel and its usage is likely to continue to rise due to the triple pressures of:

- Public and regulatory pressure on environmental emissions
- Peak oil is/will lead to higher fuel prices
- Rising world demand for energy.

With the world's known available fossil fuel reserves apparently dwindling, future prices will rise in real terms due to the anticipated future growth in real demand. However, rising fuel prices are nothing new: Figure 1 shows the situation in the 1970's which underlines how events such as wars and natural disasters can affect the prices of commodities.

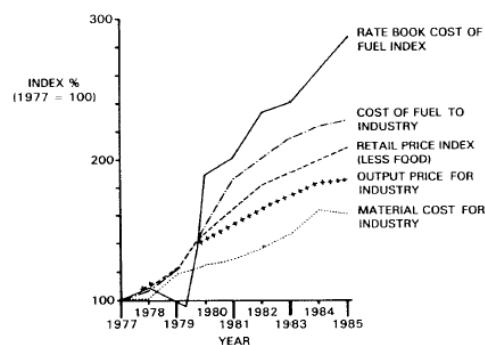


FIG. 1—COMPARISON OF A 'RATE BOOK' COST OF FUEL INDEX WITH SEVERAL IMPORTANT INDICES

Figure 1- Past Fuel Price Increases

ENERGY DEMANDS

For various reasons, nations have been struggling to meet the carbon reduction targets set by various to meet international agreements. Closure of inefficient coal-fired power stations has removed some large contributors but as the accountable emissions are identified and reduced, the contribution from shipping will come under greater scrutiny and pressure.

Alternative fuels such as LNG may be much discussed, but for military operations liquid fuel and specifically oil will still be the most important fuel in 2020, especially in transport due to the limited substitution options.

IMO

The International Maritime Organisation (IMO) has tabled measures to be introduced to limit or reduce shipping's emissions of CO₂. The IMO has laid out design guidance to enable designers to reduce marine-based Green House gases (GHG) (MEPC 58) which employs the concepts of:

- Energy Efficiency Design Index (EEDI);
- Energy Efficiency Operational Index (EEOI).

The EEDI seeks to simplify the machinery arrangements onboard a ship and uses a relatively simple equations to generate the mass of CO₂ emitted per tonne.nm (g. CO₂/tonne-nm) travelled. The EEDI is subject to much debate as it makes swingeing assumptions about the way in which power is generated and used onboard. The EEDI continues to be a disputed index for designers: it is

contested that it cannot form the basis of a legally binding design objective as it does not consider the commercial aspects of ship operations.

The EEOI uses actual data from ship operations to identify the same metric. This index is clearly more accurate and as there are so many new ships due to the large production of the past ten years it is these which may benefit most from retro-fitting opportunities.

Although sea shipping is relatively "climate friendly" compared to other modes of transport when measured with the efficiency indices, in absolute consumption terms, it is a considerable consumer of fuel, much of it is of poor quality and it is a significant source of air pollutants of all types.

In Europe, GHG emissions from land-based sources have decreased in the last 20 years, but emissions of GHG from sea shipping have been rising due to the increase in the global trading of goods. With unchanged legislation, it has been claimed fuel usage and emissions from international shipping will "more than double by 2020" within the European Union. Even if this is not so and the fleet stays the same, its fractional contribution will grow as other forms of transport become more efficient.

CARBON DIOXIDE EMISSIONS

In 2007, worldwide shipping CO₂ emissions were estimated to be of the order of 3.3% of the total with 2.7% of this being international shipping [Ref 1]. The shipping industry is increasingly expected to share in the burden of reducing global emissions of CO₂. Therefore, the shipping community needs to act now to take responsibility for their share of the GHG burden.

Shipboard

Fuel tankers due to their large size, consume significant quantities of fuel and so HMAS SIRIUS is used in this study as a basis for exploring the feasibility of a set of energy conserving technologies.

MACHINERY

Improvements to inboard machinery may offer the following benefits:

- Reduced Fuel Usage;
- Increased endurance between refuelling;
- Reduced machinery maintenance burden;
- Potential for reduced heat stress in the machinery spaces;
- Actual cost savings if the efficiencies outweigh the price increases;
- Helps save the environment.

However to use the source energy more efficiently, extra and/or more complex machinery is often required. There is therefore a real ship and upfront financial impact with a more efficient plant. With regard to the ship, the basic impacts are footprint, insertion and removal routes, maintenance access as well as the added complexity: interfaces, controls and interfaces to the ships control systems.

The new plant may also place additional demands on the ships services and a need for better heat management. Thus these demands may detract from the full benefits of the original energy saving measure.

Specifically additional weight from the machinery and its supporting structure increases displacement and hence resistance, unless the bunker fuel is reduced accordingly. There may also be stability aspects due to the location and the weight of the plant.

The opportunity for changes to existing ships is also a challenge as scheduled refits are planned to be short for economic reasons. The changes to the baseline machinery also lead to:

- Operating and support (upkeep) changes
- An increase in the manning and training burden.

All these issues affect the cost-benefit balance and so many of these financial impacts need to be factored into the assessment.

MAKING IT PAY

The cost of change and its impact on the return on investment is always an issue when decisions on whether to proceed with the introduction of an energy conservation technology. The size of the benefit needs to be significant therefore to make the effort worthwhile although unfortunately the need for a low-risk short-payback period often dominates the decision making assessment. The increased cost of fuel is making these payback periods shorter than ever.

Cost assessments of manning and training needs are complex but the main financial benefit is reduced fuel consumption. The efforts to simply reduce emissions measures do allow for a green image to be presented and until carbon taxes are enforced, it is fuel reduction that saves the money and allows for the savings to recover the outlay costs. The main criterion used in the study was the balance of through life fuel savings to the estimated changes to the acquisition costs.

HMAS SIRIUS

Context

BMT Defence Services do not have access to the whole set of machinery and resistance data related to the HMAS SIRIUS. With the limited available data on the MT DELOS as she was once known and the public information on HMAS SIRIUS and also using first principles, BMT has developed a definition of the ship to allow a power and propulsion assessment to be undertaken. To ensure the assumed data is clear to the reader, it has been shown in italics.

Description

The HMAS SIRIUS is a converted product/chemical tanker formerly known as the MT DELOS. The original vessel was rated at product tanker of 37,000 tonnes deadweight with a service speed of 15 knots at the design draft of 9.0m. The ship is 175.93m overall with a beam of 31m.

The estimated resistance of the hullform was derived using Holtrop and Mennen [Ref 2] with suitable assumptions for appendages. The single four-bladed fixed pitch propeller of diameter 5.8m. It is assumed to have a blade area ratio of 0.6025 and a pitch-to-diameter ratio of 0.735. The Wageningen 4B blade series was used to model the propeller behaviour.

The single main engine is a Hyundai-B&W MAN 6S50MC which is rated at 11,640 bhp at 127 rev/min, 100%MCR. Engine power is 9,890 bhp at the normal service speed with a shaft speed of 120 rev/min.

There are three MAN 6L21/31Diesel Generating sets (DG sets) rated at 1290kWb to supply the ships electrical power demand of 800kWe seagoing, and in port discharging 2,000kW (max discharge rate).

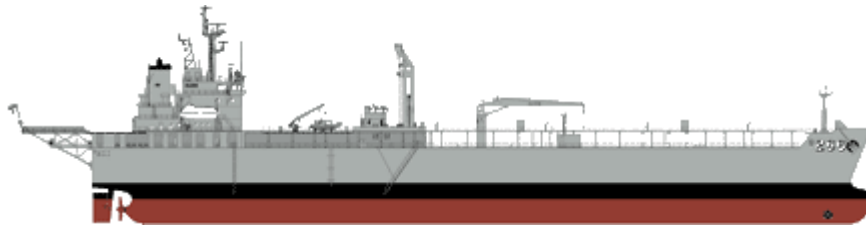


Figure 2 - Replenishment Tanker: HMAS SIRIUS ¹

Operating Profile

The assumed ship's time-speed operating profile is shown in Figure 1. This profile considers the principal operating speed but also the small time spent operating in confined waters and when performing operations with craft of different sizes and speeds.

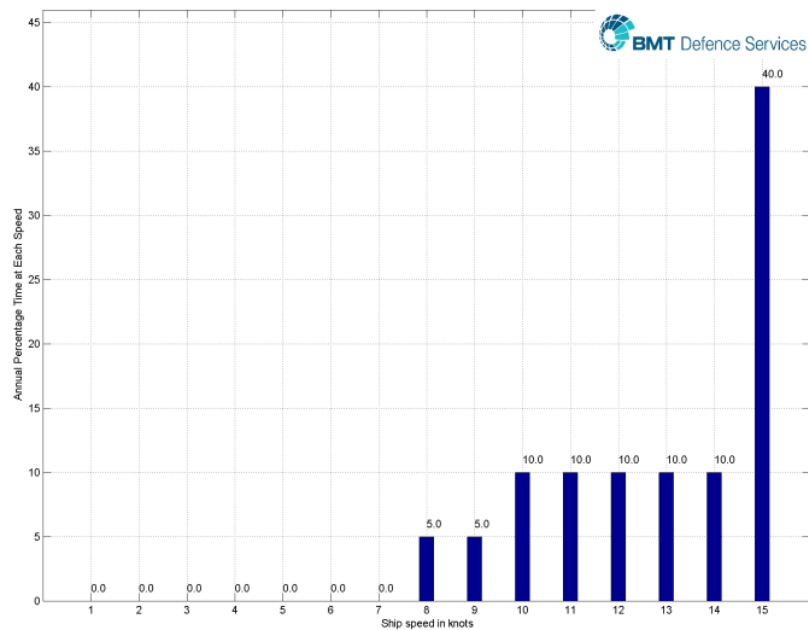


Figure 3: Operating Profile

TECHNOLOGIES

Whole Set

A set of over 150 technologies were reviewed to identify a sub-set which were most applicable to the ship under study. The benefits for each technology were identified using first principles energy-based assessments together with a consideration of the feasibility of retro-fit in terms of ship impact and the likely increases in the upkeep burden. The set technologies identified in Table 2 were assessed against the operating profile.

1. Copyright Australian DoD

Drag Reduction Or Propulsion Assist	Drives & Power Sources
Air Lubrication	Exhaust Gas Waste Heat Economiser
Skysails	Organic Rankine Cycle
Wing-sails	Wind Turbines
Flettner Rotor	Photo-voltaic solar panels
Mewis Duct	Larger Engine

Table 2 - Technology Merit Set

Some of these technologies are described in detail below.

Air Lubrication

Although a full air layer approach to air lubrication is becoming a popular area for study, the more limited use of air in the principle of Microbubble Drag Reduction (MBR) is a more conservative approach. MBR involves the injection of very small air bubbles into the boundary layer of ships to reduce friction drag. Since 1973 [Ref. 3], extensive studies on drag reduction using micro-bubbles have allowed their effectiveness to be assessed [Ref. 4]. The detailed research and methods used were addressed in a previous BMT paper [Ref. 5]. Also known as an Air Lubrication System (ALS) it has been fitted to ships from MHI and Maersk have their own WingedAir Induction Pipe (WAIP) system which has limited success [Ref 6)].

Figure 5 shows how the resistance varies with speed after microbubbles have been introduced. The rate of air supply is proportional to the ship's speed and the application area by a factor $1e-4$ in accordance with the guidance of Kodama [Ref. 7].

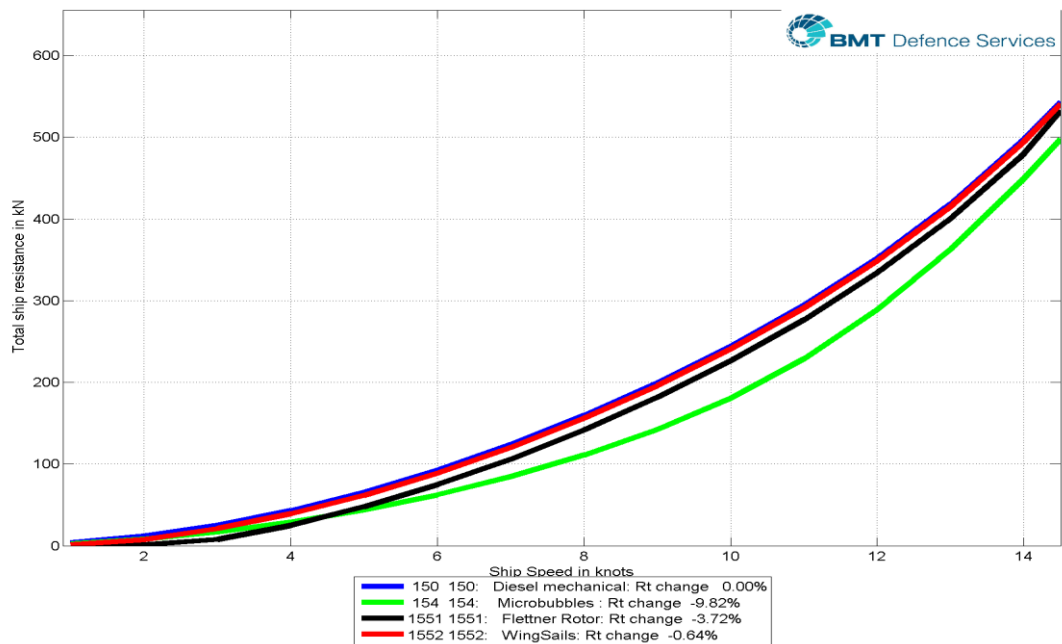


Figure 4: Resistance Reduction

Figure 4 shows the benefit of microbubbles for an air supply provided at a pressure of ~1 barg. The power for the air compressor would go some way to offset resistance power saving. Therefore a microbubble solution is best suited to a ship which has a surplus of compressed air.

Flettner Rotors

Flettner rotors use the Magnus effect to provide a lateral thrust from a spinning vertical cylinder placed in a moving air stream. The effect was first used in the 1920's to propel a ship [Ref. 8]. WindAgain Ltd of Singapore now offer modern collapsible versions and Poulsen offers a large single monorotor located aft [Ref 9] . BMT designed a Flettner rotor solution comprising three cylinders, 15m tall, 1.1m diameter. Their performance was calculated from first principles using North Atlantic wind spectra with the full azimuth of wind directions considered for each ship speed.

Photo-Voltaic Solar Panels

Photo-voltaic solar panels (PVSP) have already been fitted to ships to provide auxiliary power. This is an area of fast-moving technical development with the latest efficiency figures exceeding 13%. The Toyota car carrier MV Auriga Leader is the world's first cargo ship to be partially powered by PVSP. [Ref. 10].

A conservative 10% efficiency figure with a conservative annual solar radiation of 900kWh/sq.m/year has been used to derive the average power supply from the onboard installation using 90% of the free weather deck area: in practice the super-structure roof could also be covered.

Wind Turbines

To quantify the scope for harvesting useful energy from the wind that strikes the port and starboard sides, a 2m by 2m wind turbine design was developed. The unit provides a modest average power of 0.5kW when wind spectra and ship's heading factors have been factored in. This is considered to be a conservative yield with plenty of scope for further efficiency improvements. 58 units are located each side.

Sky Sails

Sky Sails from the German company of the same name are simple and light (Ref ¹¹). Real benefits have already been realised but the performance is clearly dependent on the ship's heading relative to the wind and for ship's operating fixed routes this compromises the benefits.

At 15 knots with the wind aft the savings can be as much as 10%. For faster vessels the ship speed may exceed the wind speed and the benefits will be much lower. A 400m² design with a 300m tether has been modelled using weather data for the North Atlantic.

Wing Sails

The current Wing Sails market offering is from Shadotec/WingSail PLC. BMT has used their own variant of a wing-sail for this study: it comprises 3 blades each 15m high. A model of this has identified the kind of performance that might be achieved with North Atlantic wind spectra for a range of ship speeds and the whole circle of headings. The wind speed and ship heading was used to identify the average thrust from the wing-sails for each ship speed. Installation capability is limited by the necessary clearance height between the bridge top and the lowest bridge it has to pass under.

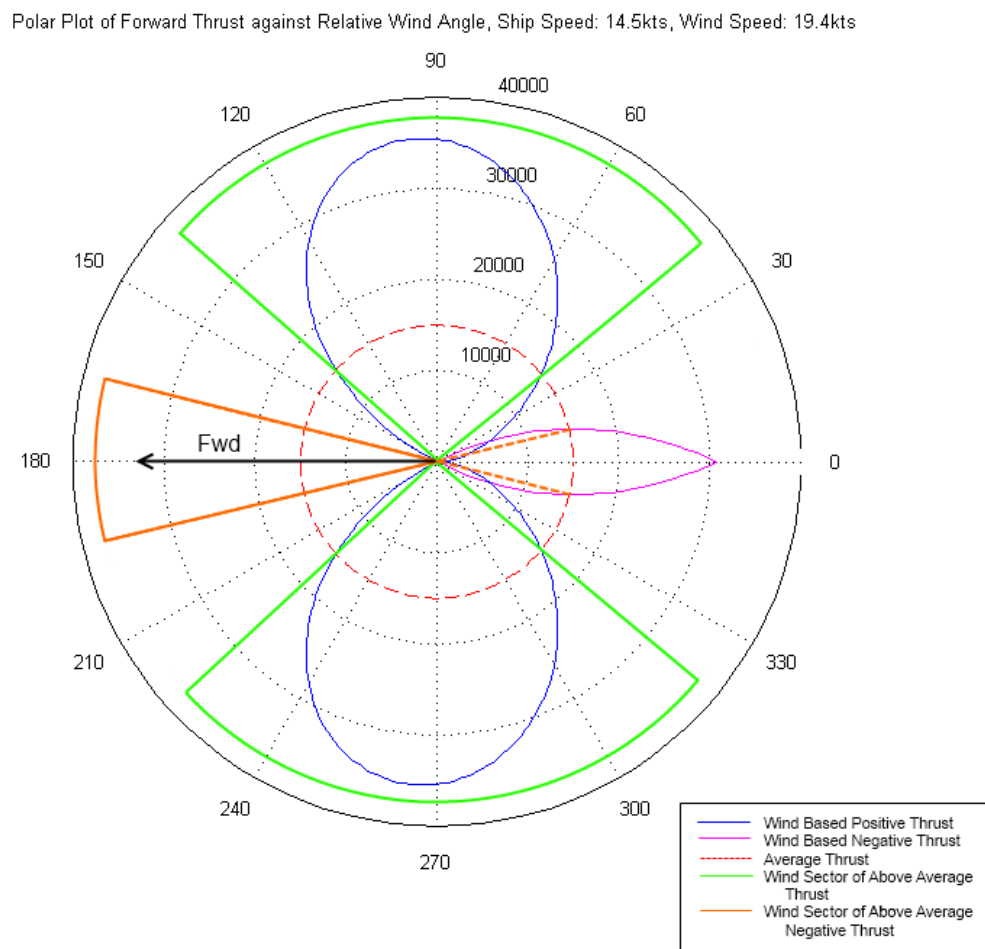


Figure 5: BMT version of WingSail: Force generated by azimuth angle

Figure 5 shows how the above-average positive thrust generated is limited to wind angles $\sim 50^\circ$ either side of the beam, or 200° in all.

Exhaust Gas Waste Heat Recovery

Exhaust gas waste heat recovery (EGWHR), is an energy recovery method whereby the heat in the engine exhaust is used to create steam which can then be used for:

- Space heating;
- A feed to a steam turbine generator to produce electrical power.
- A feed to an absorption chiller to reduce the load on the chilled water plant.

For many ships EGWHR can allow for the effective use of fuel into the engine to be increased by 12% or so. This technology is widely used in ships such as the Queen Mary 2 and in offshore applications. As of the order of 35% of the engine's waste heat is in the exhaust gas this is an obvious source of recoverable energy.

The MAN Thermo Efficiency System [Ref. 12] is one example of a modern means of saving energy from a two-stroke design. A fraction of the exhaust gas is bypassed from the turbochargers and fed directly to a turbine driving an alternator. This turbine is combined on a shaft with the steam turbine with a reduction gear and over-speed clutch between the high speed exhaust gas turbine and the slower steam turbine. Energy savings have been estimated using first principles and considering the effectiveness of heat exchangers and the efficiency of the Rankine cycle.

For the SIRIUS the MAN 5S60MC engine exhaust gas temperature is low at 245°C. This provides a source of wet steam from the steam generator. This steam enters a oil-fired super-heater to raise it to 8 bar, 170°C before it enters the steam turbo-generator rated at 1,800kW.

At slow ship speeds the exhaust mass flow is low and there is a greater demand for added heat from the oil-fired boiler. Figure 6 shows how the fuel demand (in green) is much higher in this case. As the ship's speed increases, the increasing load on the engines allows more heat to be available for steam and hence less heat is required from the boiler. However at full speed the fuel-saving benefit is very small indeed. Additionally to collect sufficient heat from the exhaust gas would require very large heat recovery devices which would exceed the size of the current casing.

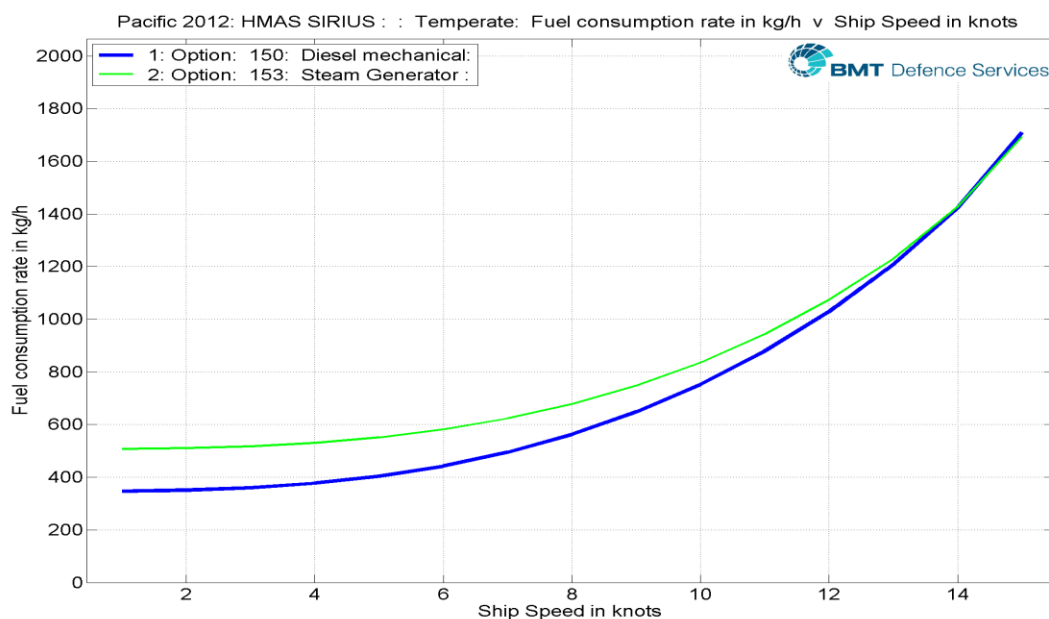


Figure 6: Steam Generator Fuel Benefit

Organic Rankine Cycle

An Organic Rankine Cycle (ORC) driven by the exhaust gases may allow for higher efficiencies depending on the design parameters. The heat transfer to the ORC system could be via thermal oil. Again thermal oil operates at 300°C so an additional heater would be required.

TECHNOLOGY COMPARISONS

Figure 7 shows how the SkySails installation offers significant fuel savings with the Mewis Duct and the Microbubble feature also offering a tangible benefit. Flettner rotors also offer a benefit but it is thought they would not be feasible on the working weather deck.

If these features are all added as a composite design then it is estimated that over 20% fuel savings can be achieved.

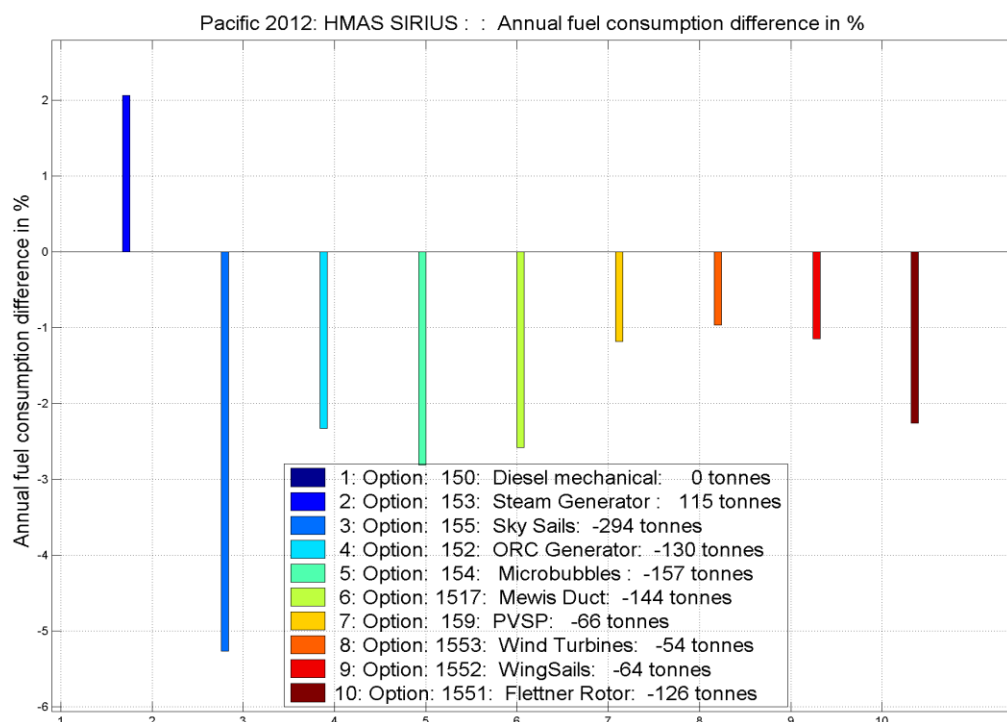


Figure 7: Annual Fuel Consumption Benefits

Figure 8 shows the estimated balance between the cost of acquiring and inserting the new technologies versus the accrued financial benefits through life. The equipment acquisition costs are shown accruing in the first three years of build.

The Mewis Duct is shown to be the most cost-effective solution with a whole life saving of ~£300,000.

Other technologies are marginally not cost-effective but future changes to fuel costs may affect this outcome.

Clearly this assessment is based on the author's best estimates of equipment costs and these can vary with market-forces, volume of purchase and many other factors.

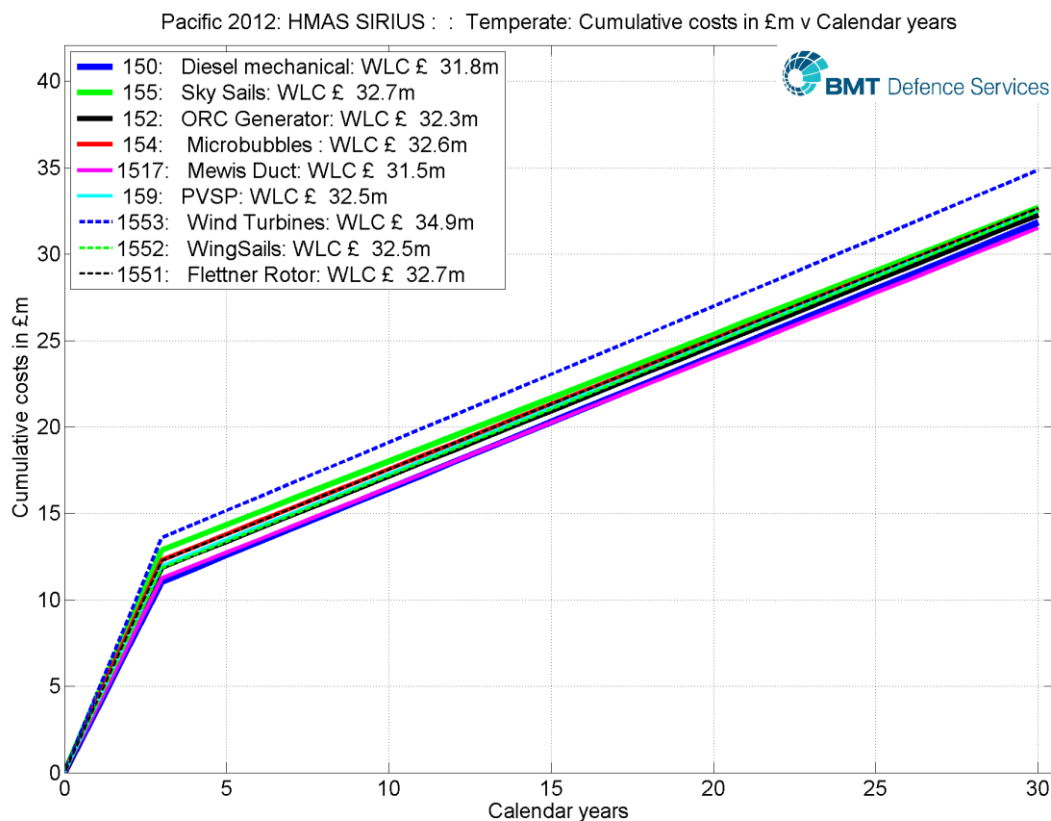


Figure 8: Estimated Whole Life Costs

HIGHER TOP SPEED

Comments have been made about top speed of the vessel, since selection of the MT DELOS and then the introduction into service of the HMAS SIRIUS. A higher upper sustained speed was originally sought by the RAN but during the process of ship selection a decision was made to obtain a slower ship. A review of the technologies considered for this vessel indicate that the drag reduction and propulsion assist features do not offer any significant benefit to achieving a higher upper sustained speed of any significance.

The scope for replacing the current engine with one that is two cylinders longer was considered. The ship's general arrangement drawings give an approximate indication of the size of the engine room and an engine with two extra cylinders was considered to be feasible in terms of engine length. No assessment was made of the scope for the propeller shaft to absorb a higher power as such detailed information was not available to BMT. Such a new engine would allow an estimated top speed of ~16.5 knots.

CONCLUSIONS

The greatest scope for fuel saving onboard a ship is usually with the Power and Propulsion system, here there is more scope to render the main engine and the propellers more efficient to yield significant fuel savings.

The adoption of a Mewis duct together with SkySails and Microbubbles offers scope for fuel savings and a reduced carbon footprint.

However each candidate technology needs to be considered with the specific operating profile of the ship and the method used by BMT allows changes of ships loads and usage to be assessed quickly to yield information on the comparative benefits.

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