Design Options to Address the Low-Carbon Future Frigate

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Summary - Context

- Western navies are now subject to greater scrutiny on their green credentials due to their government ownership and the conspicuous use of fuel for their duties.
- The ability to reduce the fuel consumption is now foremost consideration both for the benefit of increased operating range and endurance in theatre, but also for the reduced emissions of greenhouse gases.
- The adoption of more energy efficient warships cannot be allowed to lead to any reduction in naval warfighting capability and so the energy saving technologies (EST) have to be chosen, adopted, and implemented so there is a win-win outcome.

Summary - Considerations

- Frigate power & propulsion topologies can vary with ship operating duties and the speed-time operating profile.
- Increasingly there are trends towards diesel-electric with Energy Storage System (ESS) so that peak demands from mission systems can be accommodated.
- However, there is normally a need to have two prime movers running at any one time to cover for a single failure.
- ESS offers the potential benefit to allow Single Generator Operation (SGO) and reduce engine maintenance hours, and fuel consumption.
- This aspect, and the introduction of novel propulsion motor topologies, are also examined to identify their impact on savings to the annual fuel consumption (AFC).

Baseline Vessel

- The BMT Venator 110 design has been used as the baseline vessel for this study. The principal particulars are shown below.

Parameter	**Value**	**Comments**
Length overall	117m	
Length waterline	107m	
Draught	4.3m	Standard displacement
Displacement, standard	4,000 tonnes	Nominal
Beam, maximum	18m	
Top speed	27 knots	Calm, clean hull
Range	6,000nm at 15 knots	

Main Machinery

- The baseline design main machinery comprises two CPP shaftlines each driven by two high-speed diesel engines. Rolls-Royce MTU engines are used here but other suppliers are available.
- There are four high-speed DG sets to supply electrical power

Equipment	Make-model	Comments
Main engines	4 x MTU 16V8000M71, each rated at 7,280kWb	Temperate conditions
DG Set	4 x MTU 16V2000M41B, engines rated at 930kWb.	Temperate conditions
Propeller	Twin shaft, Controllable Pitch Propellers (CPP), baseline	Five blades, 3.8m diameter
Ships Electrical load (SEL)	1,500kWe	Temperate conditions

Scope of EST

- The study which explored the benefits of operating with different types of energy saving technology (EST) on BMT's Venator 110m frigate design. The principal EST considered are:
  - Hull anti-fouling solutions;
  - Hull air lubrication systems (HALS);
  - Hull Vane resistance reduction;
  - Absorption Chiller Plant (ACP) Chilled Water (CW) production
  - Single generator Operation (SGO) & & Energy Storage Systems (ESS);
  - DC network-based power systems with advanced electric motors

Hull anti-fouling solutions – The Context

- Hull fouling has a large impact on the additional energy consumed by the propulsion system above its original design intent. Fouling can often grow quickly in warm waters when the ship is not underway - something common with warships
- Hull anti-fouling systems are commonplace on many commercial vessels and are increasing used on warships but may not yet be considered as business as usual (BAU).
- The UK approach to the allowance for hull fouling is to add 20% to the **viscous friction coefficient** (VFC) to represent the condition after six months out of dock (6MOOD). This value factors in the benefits of self-polishing hull surface treatments, for it was previously 56% in tropical waters, and 28% in temperate conditions.
- The addition of self-polishing hull preservation and coating systems (HPCS) helps stop the fouling, but a relatively novel treatment is the adoption of **hull ultra-sonic cleaning** (HUSC) treatments

Hull anti-fouling solutions – The Solution

- Whilst the adoption of HUSC is in its early days, the approach seeks to stop fouling from initiating a presence on the surface of the hull whereas numerous HPCS rely on the fouling growing with weak contact forces such that its sloughs off when the ships reaches a threshold speed.
- Hull ultra-sonic cleaning (HUSC) treatments usually emit sound at ~23MHz to dissuade marine life from approaching and settling on the ship’s hull.
- Whilst there continues to be an interest in the adoption of this technology for commercial ships, an installation on a warship could only be used when in harbour to avoid any obvious Underwater Radiated Noise (URN) signature issues.
- Whilst most fouling is understood to develop when stationary, in harbour, the insertion of such a technology would probably be costly as it would have to be a shipwide integration with the many other hull-mounted mission systems.

Hull anti-fouling solutions – The Assessment

- Anti-fouling hull preservation & coating treatments are now business as usual for many commercial ships.
- With such a hull preservation coating combined with the HUSC the hull can be assumed to be largely free from fouling.
- Over the six-month period of naval operations after a hull clean, the baseline hull will have an average increase in VFC is 10%, (i.e. it is assumed to be 20% after 6 months).
- The design option with HUSC will have a fully clean hull over the whole patrol period & is assumed to have no additional to the VFC.

Hull air lubrication systems (HALS) – The Context

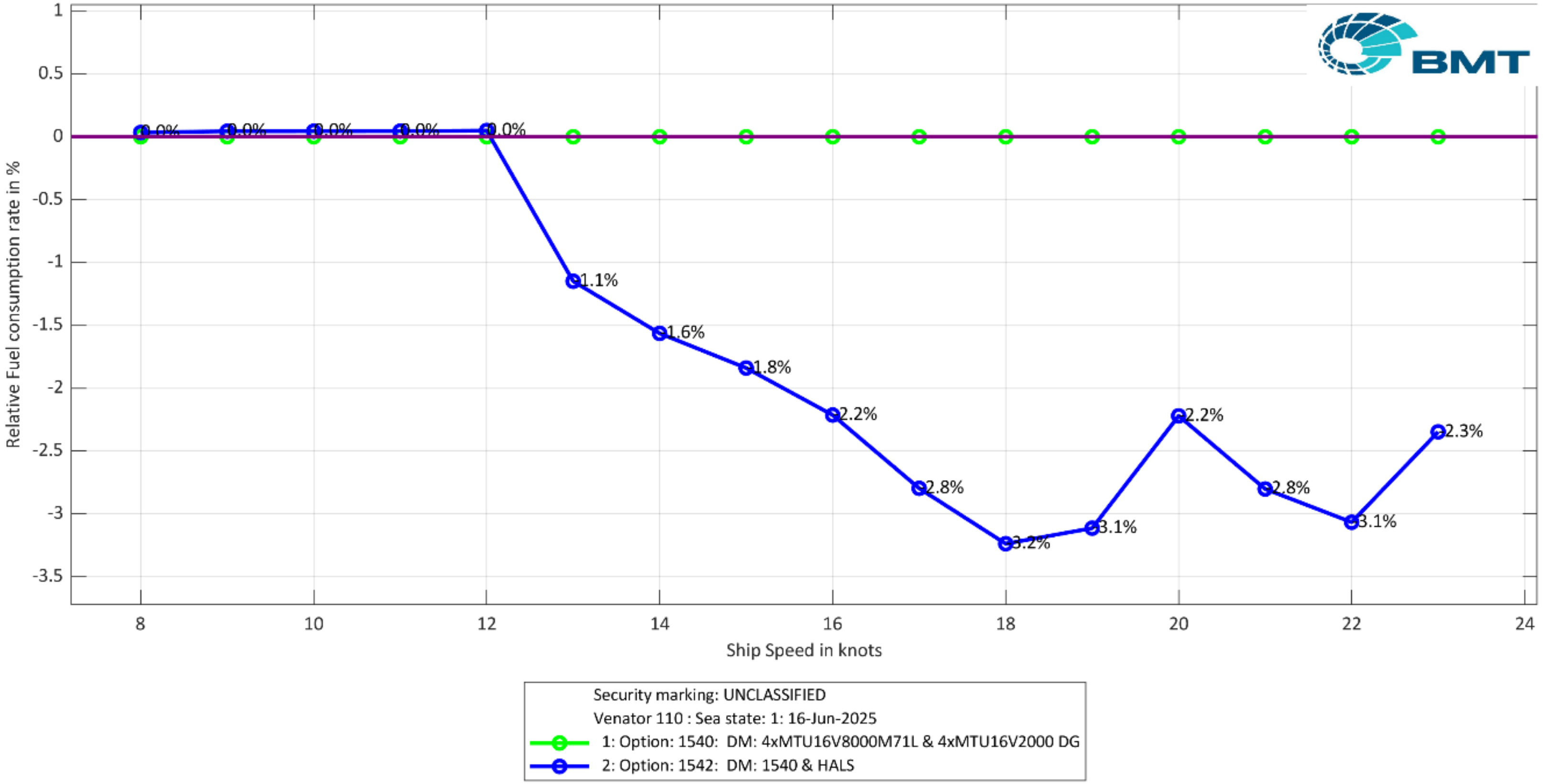
- The earliest use of Hull Air Lubrication Systems (HALS) is related to the measures taken by the US and UK navies to use air bubbles in the sea space under the machinery spaces of their vessels to attenuate the dispersion of URN.
- Since 1990, extensive studies on drag reduction using micro-bubbles have allowed their effectiveness to be assessed. In this approach, air bubbles of between 2mm and 6mm diameter are injected into the boundary layer of ships.
- The technology is now offered by a number of shipyards and in Europe by specialist suppliers such as:
    - Silverstream Technologies,
    - Alfa Laval OceanGlide
    - Armada Technologies.
- The first two solutions employ air compressors to draw in atmospheric air which is compressed and released under the hull. Armada has adopted an alternative approach whereby local air is drawn into low pressure sea water by a venturi using the Bernoulli effect.

Hull air lubrication systems (HALS) – The Solution

- The application of HALS is usually favoured with vessels with a high block coefficient and hence a larger flatter hull bottom. Warships have a much finer hull and so the scope for the fitting of HALS equipment to the hull is limited to a smaller flat area assumed to be up to 30° above horizontal.
- In this study it is assumed that one third of the wetted surface of the hull can be treated with the HALS.
- From BMT's experience on recent projects, the assumed average reduction in the VFC of the clean hull is ~35%. As the VFC of the total vessel resistance diminishes at speeds above 10 knots, the actual net annual fuel savings (AFS) with HALS is usually closer to 8-10%.
- An allowance has been made for the energy required to drive the air compressors based on actual air compressor power-air delivery rates. The power required is much affected by the static head of the supply points.
- The reduction in the ship's resistance with HALS in sea state 1 (wind speed 3 knots) leads to resistance reductions between 3% and 6% across the speed range. The resistance saving diminishes at speeds above 12 knots as the wave making component of resistance becomes a more significant part of the overall hullform resistance.

HALS – Fuel Saving v Speed

- The figure shows how the reduced hullform resistance is translated in changes to the fuel consumption in percentage terms when operating at SS1. With the operating profile and the time at sea considered, the adoption of HALS leads to an annual saving of 1.8%.



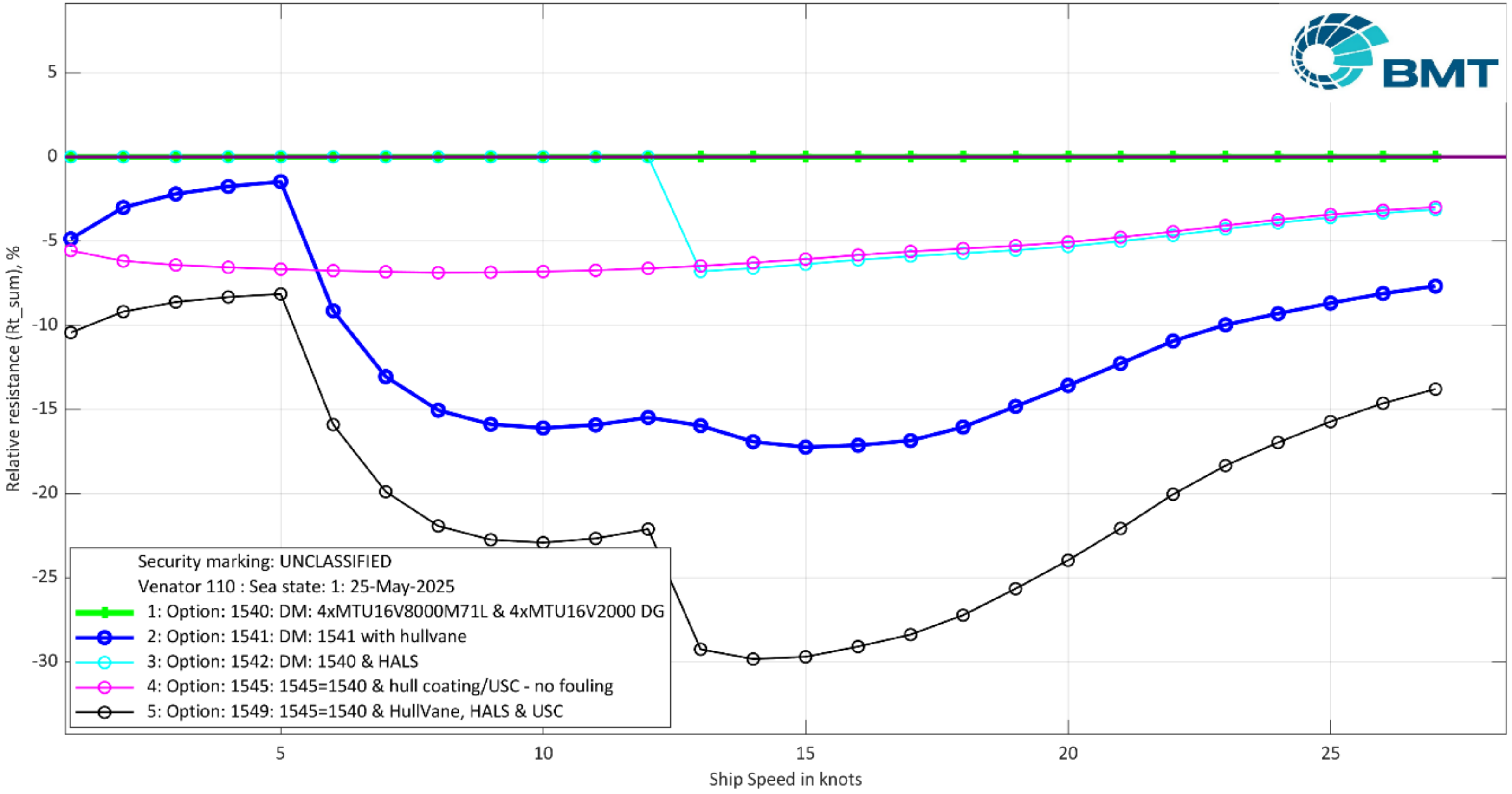
The savings are very dependent on the speed-time operating profile as there is a peak beneficial point near 18 knots which could increase this to over 3%. This observation may affect the chosen ship speeds as often ships speeds will be selected to meet a more economic speed of advance.

Hull Vane resistance reduction - Context

- A Hull Vane, located at the aft end of the vessel uses the angled flow of the underwater streamlines to generate a forward thrust over the foils which comprise the vane.
- By accelerating fluid flow at certain design speeds, a Hull Vane can generate forward thrust, stabilise trim and reduce the vessel’s stern wake, all of which contribute to reducing overall hull resistance by up to 15%.
- As with the reduced fouling resistance, a reduction in resistance and subsequent effective power requirements can further allow for reduced propeller loading and improved propulsive efficiency accordingly

Combined Hullform Resistance Benefits

- Figure shows the relative resistance reduction in % (y-axis) v the ships speed, knots (x-axis).
- At sea state 1, the combined benefit of the three combined hullform EST at 14 knots can be as much as 30% reduction in ship's hull resistance.

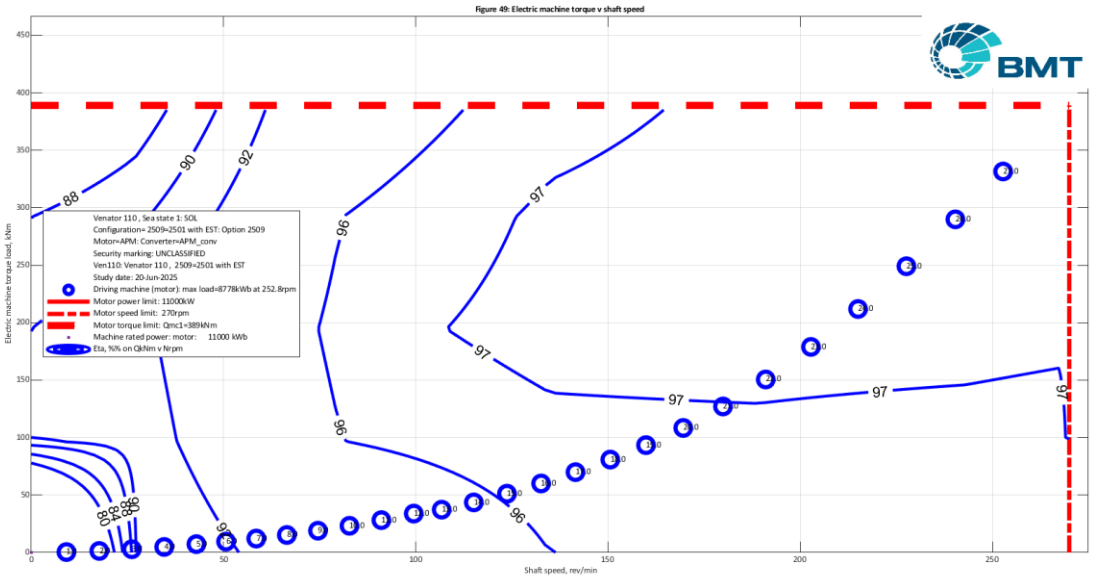


Absorption Chiller – The Context

- An Absorption Chiller Plant (ACP), uses a heat source such as engine cooling water or exhaust gas, to drive internal evaporation of the working fluid and thus, when also combined with sea water (SW) cooling, creates a capability to cool chilled water (CW).
- If the heat rejection of the high temperature cooling load of the diesel engines is 1,000kW.th, in the range of 90-80°C, this can be used to drive the hot water supply side of a single-effect ACP. With a Coefficient of Performance (COP) of 0.71, the ACP can then provide a CW cooling capacity of 710kW.CW.
- For this ship, the heat rejection from the diesel engines is such that the temperate CW load of 700kW.CW is met by the ACP when at 17.7 knots. The effective weighted electrical power saving considering the ship speed-time operating cycle leads to an effective steady power saving of ~100kWe. This is a conservative figure as the studies have shown values up to twice this with different design solutions.
- If the engine exhaust gas heat were also added to the HT line heat to generate steam at 6 bar, a double-effect ACP could be used to offer the total CW demand at speeds up to 20.8 knots.
- With the current challenge of finding suitable refrigerants for conventional standard CW Plant which meet limits for Ozone Depletion and Global Warming Potential whilst also being non-flammable with no risk of toxic smoke, the ACP offers an alternative approach which also reduces the electrical load on the DG sets.
- When the benefit of the ACP is combined with the three technologies to reduce hullform resistance, the effect is an 18.3% reduction in AFC.

GE Vernova HALO & Active Stator Concept

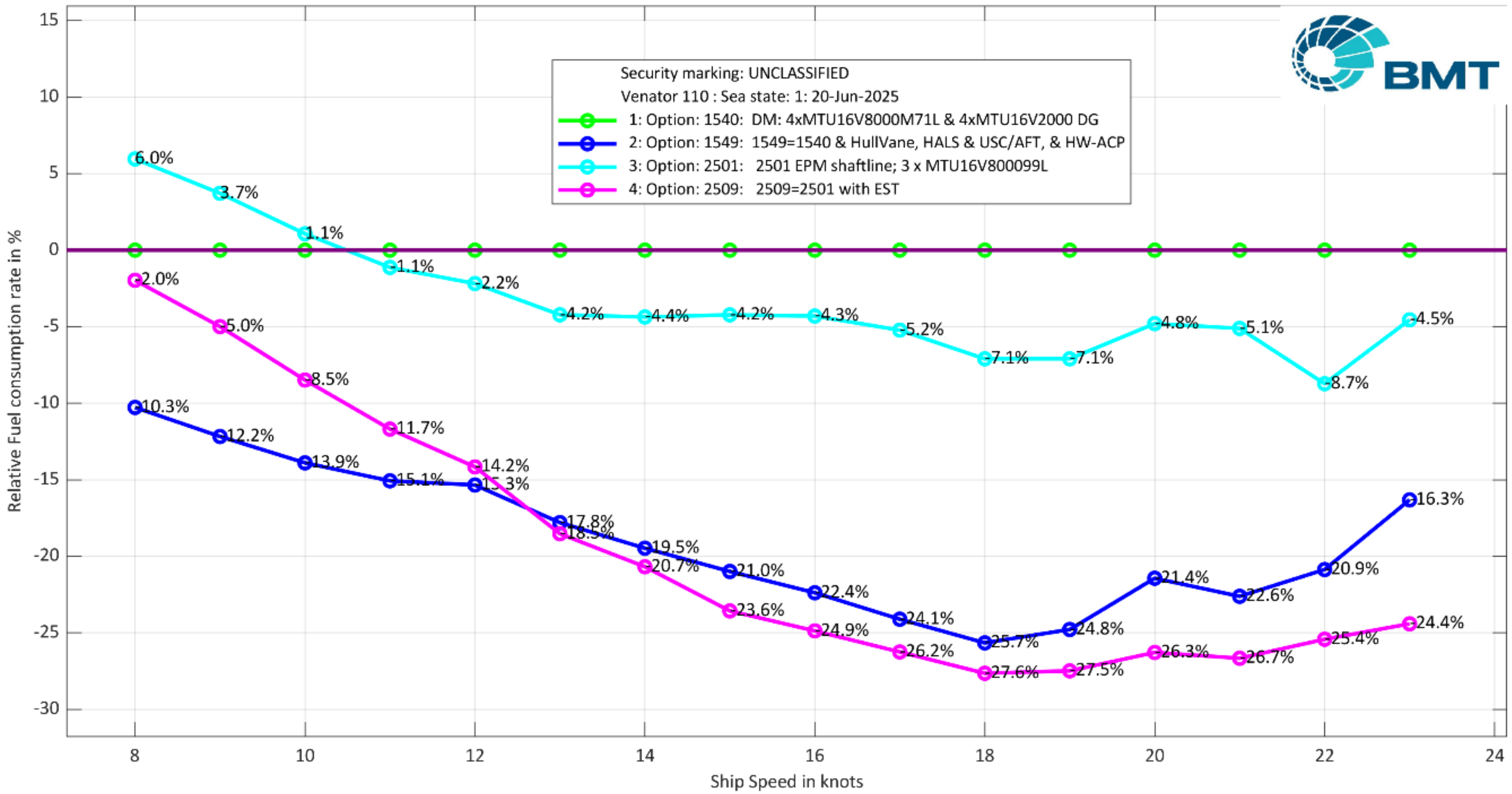
- The introduction of the GE Vernova (GEV) Active Stator Motor (AST) and its HALO concept to the market bring with it the opportunity to have direct power supplies from alternators to the motor removing need for HV switchboards, and the weight, space and cost associated with them.
- Protection and discrimination are provided by the individual power conversion devices on the motor which are switch in and out as the motor power demand requires.
- Due to the design of the AST, the efficiency of the power conversion electronics is assumed to be a steady 94% across the speed and load range, compared to a falling efficiency when the load falls towards zero with standard designs.



The motor is a permanent magnet motor (PMM). For these studies its efficiency is assumed to be comparable to that provided by another supplier, The Switch of Finland, as shown above. For an all-electric solution, the V110 would be driven by two 11,000kW Electric Propulsion Motors (EPM).

Combined EST

- The percentage fuel consumption savings of the four main EST options are shown reference the baseline design. In summary, the different design solutions considered in this study, and presented in this paper, are shown below



Design Option	Annual Fuel Savings, %
#1540: Mechanical drive & four DG sets Baseline for studies	No savings
#1549: #1540 with HALS, Hull vane, USC/AFT & HW-ACP	18.3%
#2501: Diesel electric solution with variable speed DG & standard motor and power electronics	2.4%
#2509: #2501 with HALS, Hull vane, USC/AFT & HW-ACP	19.6%

Conclusions

- BMT has undertaken theoretical studies into the combined effect of fouling-free treatments, the Hull Vane and a hull air lubrication system (HALS) on its Venator 110 frigate design.
- When combined, these three energy saving technologies can reduce the AFC by 18.0%.
- Studies are looking into surface treatments that can reduce the acoustic signature of the hull, and also reduce fouling.
- The adoption of a hot-water single-effect absorption chiller plant saves an additional 0.3-0.6% AFC by reducing CWP loading.
- The GE Vernova Active Stator Motor (AST) and the HALO system design concept when combined with the three EST & a variable speed DG set on a DC network, allow a fixed pitch propeller design to be adopted which is preferred for reliability and shock-withstand, and offers a 19.6% saving in AFC.

Thank you for your kind attention

I look forward to your questions

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