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HALIFAX-CLASS EFFICIENCY IMPROVEMENT STRATEGY

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AIM

1. This paper is a discussion of options to increase efficiency of the Royal Canadian Navy (RCN) platforms and presents a recommended approach to improving both the efficiency and effectiveness of the *Halifax*-Class frigates. The application of efficiency technologies and emissions reductions methods will be discussed and used to support the recommended approach.

INTRODUCTION

2. The Department of National Defence (DND) consumes the most fuel of any department in the Government of Canada, and as a result is the largest emitter of greenhouse gasses.[1] Canada has committed to reducing greenhouse gas emissions by 40% by 2025 and 90% by 2050, as compared to 2005 levels.[2] Consequently, the RCN has an obligation to identify emission reduction opportunities and implement them wherever they do not conflict with the operational imperative of the fleet. The twelve *Halifax*-Class frigates form the core of the RCN fleet and represent the focus of this paper.

3. In order to reduce emissions from the *Halifax*-Class fleet, two main options exist. The first is to consume a drop-in replacement fuel that emits fewer greenhouse gasses or to retrofit equipment which reduces the greenhouse gases in the exhaust. The second option is to implement technology and equipment upgrades which allow the maintenance of existing capabilities while at the same time consuming less fuel. These options will be discussed and the efficiency improvements of selected technologies will be compared to support the recommended strategy.

DISCUSSION

4. RCN ships consume naval distillate fuel oil (DFO), commonly known as North Atlantic Treaty Organization code (NATO) F-76. This fuel is used in the main engines for propulsion and by the ship's generators to produce electrical power at sea, or when alongside without suitable shore power.

5. The use of biofuels or renewable (synthetic) diesel is sometimes proposed as the simplest option to reduce emissions. This drop-in replacement avoids the requirement for design changes, however, the options available that meet the F-76 fuel specification do not offer any reduction in emissions. Some of the biofuel containing blends do meet the F-76 fuel specification, however, rather than offer any reduction in emissions, they offer an alternative fuel source or more secure supply chains.[3] Significant work is progressing on this front, however, the primary efforts are focussed on reducing the dependency on fossil fuels rather than the associated emissions reductions.

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[1] Canada, "Government of Canada's Greenhouse Gas Emissions Inventory," November 26, 2020.

[2] Canada, "Inventory of Federal Greenhouse Gas Emissions Fiscal Year 2019 to 2020," November 26, 2020.

[3] Cory J. Morgan, "Evaluation of Hydrotreated Biofuels for Use in Naval Diesel Engines" (2014).

6. The primary pollutants in ship exhaust streams are nitrous oxides (NO_X), sulphur oxides (SO_X), carbon dioxide (CO_2) and particulate matter (PM).[4] The emission of these pollutants from a ship are traditionally controlled by fuel selection, combustion process/engine selection and after-treatment. Specific to the Halifax Class, the fuel used is considered ultra-low sulphur, which is compliant with the F-76 specification and establishes the SO_x and CO_2 emission levels (independent of equipment selection). The combustion characteristics of the main engines and diesel generators establishes the base NO_x, and PM emissions. Exhaust after treatment options exist to reduce all the above pollutants, however, they require significant modifications, including specialized spaces and supplies.[5] For the purposes of "greening" the current fleet by reducing emissions and increasing efficiency, they are not practicable. The addition of exhaust after treatment options would only be considered appropriate when conducting a clean-sheet warship design due to the fundamental link to the ship's design and the requirement for integration at the lowest level. For the purposes of this analysis, the focus will be on technologies which could be applied to the *Halifax*-Class without significant redesign or should be considered for addition to the Canadian Surface Combatant (CSC).

7. Reducing fuel consumption of the *Halifax*-Class, serves two purposes. It both reduces the emissions and increases the effectiveness of the ships by enabling longer periods between refuelling. The following discussion will investigate options for reducing fuel consumption of the Halifax Class, however, this is synonymous with reducing emissions due to the direct correlation between fuel consumption and emissions.[6] Options to reduce propulsion power required at a given speed will be discussed, followed by technologies to reduce the propulsion system fuel consumption for a given power output, and lastly, the options available for reducing the electrical power consumption of auxiliary systems and therefore the fuel consumption by the ship's generators.

8. Options to reduce required propulsion power for a given speed are to decrease hull resistance or increase propeller efficiency in the conversion of torque from the main shafts to thrust, which propel the ship forward.[7] The hull form and propeller designs have been optimised to reduce underwater noise of the platform, therefore, only options that do not alter the sound profile of the ship are acceptable. Advanced hull and propeller coatings and cleaning regimes have been demonstrated as the primary options.[8] There is an ongoing effort in the RCN to trial the use of reduced drag hull coatings and implement a hull and propeller cleaning program, however, it has yet to be implemented. The Royal Navy (RN) implemented a hull and propeller fouling condition monitoring program in

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[4] Vard Marine Inc, "Green Technology Review - Part 2 Emissions Reduction" (Ottawa, ON, November 15, 2019).

[5] Ibid.

[6] Nicoleta Acomi and Ovidiu Cristian Acomi, "The Influence of Different Types of Marine Fuel over the Energy Efficiency Operational Index," Energy Procedia 59.

[7] Vard Marine Inc, "Green Technology Review - Part 3 Efficiency Enhancements" (Ottawa, ON, November 15, 2019).

[8] Adam Valenta, "Director Maritime Equipment Program Management Biofouling Focus Group," Royal Canadian Navy (Ottawa, ON: Canada, June 2020).

2007 and have since provided empirical evidence to demonstrate the benefits.[9] The RCN does not have an underwater hull and propeller cleaning program, and as such they are only cleaned once each five year operational cycle. Extrapolating the data from the RN and combining with an analysis of biofouling on the United States Navy (USN) *Arleigh Burke*-Class, it is estimated that the average *Halifax*-Class frigate consumes 10.3% more fuel over a five year operational cycle than it otherwise would have with a clean hull and propeller.[10]

9. The implementation of a hull and propeller cleaning program, combined with the application of appropriate foul release coatings represents an opportunity to reduce fuel consumption (and associated CO_2 emissions) by up to 10%. The actual fuel savings will be greatly impacted by the operational profile of each ship, however, the RN and USN have demonstrated the benefits of such a program. The RN implementation includes a tool to monitor the increase in shaft power as fouling increases over time and based on the readings, recommends the preferred time for a hull and propeller cleaning. Such a system would easily integrate into the *Halifax*-Class and provide a meaningful efficiency improvement.

10. Technologies to improve the efficiency of a ship's propulsion system typically either decrease the losses in the transmission system between the main engines and the propeller, or increase the efficiency of the main engines themselves. Conventional ship designs include the use of a gearbox to convert the high speed, low torque input of the main engines and output it as low speed, high torque to the main shafts, which deliver the power to the propellers. This conventional transmission system has been highly optimised and represents efficiencies of 99 to 99.5%.[11] Some contemporary ship designs such as the RN Type 45 and the USN Zumwalt class destroyers have deviated from this configuration and replaced the gearbox with a large electrical motor placed closer to the propellers. The benefits of this configuration include increased flexibility and efficiency over a broad range of speeds as the minimum required number of generators can be operated at their most efficient points to provide propulsion. This results in increased conversion losses as the mechanical power of the main engines is converted to electrical power, then again converted to the level required of the motors, before being converted back to mechanical power at the propeller shaft. These increased conversion losses result in an overall lower peak efficiency, however, have the potential to deliver efficiency peaks at different operating points. The *Halifax*-Class propulsion system consists of three main engines, connecting both main shafts via three gearboxes. This configuration allows the propulsion diesel engine (PDE) to deliver extremely high efficiency at speeds up to 18 knots (kt), one gas turbine (GT) at speeds up to 26 kt, and two gas turbines up to the ship's maximum speed in excess of 30 kt. This propulsion system has already been

[9] Defence Equipment & Support, "Surface Ship Hull Fouling Management" (United Kingdom: Maritime Acquisition Publication, June 2011).
[10] M. P. Schultz et al., "Economic Impact of Biofouling on a Naval Surface Ship," Biofouling (Chur, Switzerland) 27, 27, no. 1 (2011): 87–98.
[11] W. Shi, D. Stapersma, and H. T. Grimmelius, "Analysis of Energy Conversion in Ship Propulsion System in Off-Design Operation Conditions," vol. 121, Transactions on Ecology and the Environment 121 (Boston MA; Southampton: WIT Press, 2009), 461–72

optimized for the operating profile of the ship and represents an extremely efficient configuration and does not present significant opportunities for improvement.

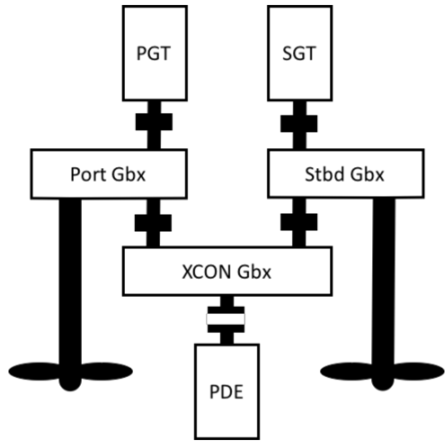

Figure 1- *Halifax*-Class Propulsion System Schematic

Source: Author

11. The PDE represents the most economical and efficient drive mode for the *Halifax*-Class. At the most common operating speeds, the PDE consumes between 60 to 75% of the fuel as compared to a single GT.[12] Recent investigations have demonstrated that the PDE suffers from reliability issues due to the age of the control system and is used less than would be appropriate. An analysis of data on the usage profile of the HALFAX Class since 2013, indicates that 96% of the propulsion requirements at sea could be achieved on the PDE, however, in practice the PDE is only operated 34% of the time.[13] When this is combined with the average propulsion engine operating hours of just under 2,000 hours per year, the resulting fuel consumption increase is up to 16% per year.[14] This represents an idealised value and does not take the operational requirements of a warship into account. Initial estimates by the RCN indicate that by increasing the reliability of the PDE and increasing its usage, an 8 to 10% reduction in fuel consumption could reasonably be expected.[15]

12. The two LM2500 gas turbines fitted in each *Halifax*-Class represent the most common marine GT in use today.[16] Although not based off the most modern technology, their 36% thermal efficiency compares well with the 39% efficiency of the more modern Rolls-Royce MT30 (used in the CSC).[17] While the modern GT will undoubtedly be more efficient at off peak loads due to advanced engine control, the flexible propulsion system design of the *Halifax*-Class minimizes the difference. The most efficient of modern marine gas turbine applications, the Rolls-Royce WR-21 fitted in the RN Type 45 claims

[12] Fraser Work, "Opportunities for Improved Warship Energy: A Canadian Patrol Frigate's Operational Energy Use" (Harvard University, 2016).
[13] Shany Belanger, "Propulsion Diesel Engine Usage," MEPM Energy Efficiency Focus Group (Ottawa, ON, February 2020).
[14] Ibid.
[15] Ibid.
[16] "The LM2500 Engine," General Electric, accessed February 2, 2021.
[17] "MT30 Marine Gas Turbine," Rolls-Royce, accessed February 2, 2021.

a 30% overall fuel consumption reduction as compared to a ship powered by simple cycle GTs.[18] When the above numbers are considered, accounting for the flexibility offered by the PDE, a fuel consumption reduction of 2-3% could be expected by the replacement of the GTs with a more modern design. This would involve a significant redesign of the ship structure and control systems, and as such is not a recommended option.

13. The final area for investigation is the reduction of fuel consumption by the ship's electrical generators. The Halifax-Class has recently had all diesel generators (DGs) replaced with modern diesels and generators. This leaves the reduction of electrical load, or the power consumed by the onboard systems as the final area for discussion. Significant efforts have been undertaken by the RCN since 2017 to survey the *Halifax*-Class electrical power consumption. The survey has identified that 23% of total ship fuel consumption services the power generation requirements at sea, and that this ratio will increase as the efficiency of the propulsion systems increases (or the PDE is used more).[19] Assuming that the electrical load supporting the ship's combat and navigational abilities are off-limits for the purposes of this discussion, an analysis of auxiliary systems leads to several conclusions. Many pre-qualified technologies exist that do not require significant design or re-engineering to retrofit. A recent study has demonstrated that by applying the currently accepted and qualified technology to the heating, ventilation and air conditioning (HVAC) system, ship's lighting, and fire pump speed control, an overall fuel consumption reduction of 2.5% is attainable.[20] The gains are achieved via the use of variable speed motor controllers, modern electronics and an improved chilled water plant, already in service with the USN. These examples are not intended to be exhaustive, rather to demonstrate that meaningful efficiency improvements can be achieved by encouraging the intelligent selection of auxiliary systems during ongoing procurements.

14. The applicability of battery or hybrid technology to the *Halifax*-Class is a frequently asked question. This question is best addressed by understanding the fundamentals of ship design. An initial ship design revolves around the base requirements of range, speed and capability. By fixing these initial variables, initial sizing of the platform can be performed and the design can progress. Although battery technology is rapidly progressing, it has not yet approached the energy density of DFO. For this reason, the discussion on the implementation of battery or hybrid technologies to the fleet is one of reducing requirements and limiting capability. Should the RCN be willing to accept a reduced requirements-set for the *Halifax*-Class, then a separate analysis would have to be completed to determine what technologies would be most suitable for implementation. As a rough guide, diesel fuel has a specific energy of 12,667 Wh/kg and an energy density of 10,722 Wh/L compared to the current state of the art lithium batteries at 250 Wh/kg and 730 Wh/L.[21] These numbers do not account for the safety systems or charging

[18] Anthony Crisalli and Michael Parker, "Overview of the WR-21 Intercooled Recuperated Gas Turbine Engine System," The American Society of Mechanical Engineers, 1993.

[19] Naval Engineering Test Establishment, "HMCS VANCOUVER Fuel Consumption Trial" (Canada, 2019).

[20] Emil Schreiner, "Warship Auxiliary Systems – Efficient Design and Emissions Reduction" (University College London, 2016).

[21] Yuan-Li Ding, "Automotive Li-Ion Batteries: Current Status and Future Perspectives," Waterloo Institute for Sustainable Energy, 2019.

infrastructure required. As a surface warship is a typically volume restricted design, the comparison becomes 10,722 Wh/L for diesel fuel versus the 730 Wh/L of the most idea battery technology. The reality is that the application of batteries to marine surface ships is not well developed and the additional requirements would likely half that capacity due to the additional supporting equipment requirements. Depending on the specific configuration, a *Halifax*-Class normally carries 650 m^3 of DFO, a direct conversion and comparison with the energy densities would result in a reduction to 7% of the initial range (17% if the most optimistic estimates of conversion efficiencies are used). The application of batteries to warship design undoubtedly has merits, and as the technology further matures will likely be used for short term energy storage to assist with equipment failure or peak usage smoothing, however, it is not suitable for reducing the fuel consumption or emissions from the *Halifax*-Class in the foreseeable future due to the impact on range.

CONCLUSION

15. Reducing RCN fuel consumption can provide meaningful emissions reductions to Canada and increased capability to the RCN by increasing a ship's endurance. Focusing on the Halifax-Class, the RCN's primary warship, there are several areas of interest. Alternative fuels and exhaust cleaning strategies were discussed and were not determined to be suitable for the *Halifax*-Class. The implementation of a hull and propeller cleaning program, including the use of suitable coatings was estimated to reduce emissions and increase endurance by 10%. Propulsion system improvements and engine replacements with more modern designs was demonstrated to provide a possible 2-3% benefit, however, would involve significant re-engineering. Increasing the use of the PDE wherever possible, and providing engineering support for an aging control system was demonstrated to have an 8-10% fuel consumption reduction without the need for any design changes. Finally, the implementation of updated auxiliary systems was shown to reduce the fuel consumption by an additional 2-3% without the additional burden of impacting ship design.

16. Battery technology was briefly discussed and the negative impact to the ship's capabilities was used to demonstrate that it is not currently suitable for implementation in the *Halifax*-Class. It is likely that battery technology will play a role in warship design in the future, however, it does not provide a viable option to reduce the emissions of the current fleet.

RECOMMENDATION

17. It is recommended that the RCN actively support efforts to implement a hull and propeller cleaning program, increase PDE usage wherever possible, and pursue improvements to auxiliary systems. The efficiency improvements are attainable in the near term and present an opportunity to reduce the *Halifax*-Class emissions by up to 23% and extend the ship's endurance by the same amount.

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