Mitigation of CO2 Emissions from Marine Seismic Surveys via Drag Reduction and Digital Transformation Initiatives

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Summary

We describe a family of digital transformation initiatives that collectively are allowing us to simultaneously optimize marine seismic survey performance and fuel consumption through the real time deployment of machine learning solutions, as well as develop long term insights into better survey design and vessel management practices to reduce drag forces and fuel consumption. Other benefits to more sustainable operations include better survey planning to optimize shooting plans, better maintenance of physical assets, and less associated physical waste.

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Introduction

Several regulations relevant to the global maritime shipping industry, either in place or soon to be approved, seek to incentivize the use of fuels with zero or low-Greenhouse Gas (GHG) emissions through a combination of CO2 reduction targets, the adoption of emissions trading schemes (ETS), or various forms of financial penalties for emissions above prescribed annual thresholds, e.g., FuelEU (2021). 'Emission factors' are used to linearly convert the mass of combusted maritime fuels to computed CO2 emission mass according to the fuel type and grade, so until it becomes practical to convert vessels to alternative fuels, the most obvious way to reduce CO2 emissions during the acquisition of marine seismic surveys is to systematically reduce the consumption of traditional petroleum distillate maritime fuels. As discussed below, CO2 emissions can be computed both in absolute terms (e.g., the net emissions per vessel per calendar year) and in relative terms (e.g., the emissions per km of common midpoint acquisition).

Long term analysis of electric power consumption from the generators on our seismic vessels shows that, on average, about 85% of power is used by the thrusters for vessel propulsion, 10% used by air compressors connected to the pneumatic source arrays, and the remaining 5% is used by 'hotel' and auxiliary consumers. Of the power consumed for propulsion, about 80% of the overall drag is associated with all the trailing equipment (the seismic streamers, source arrays, and all the associated physical assets), wherein the number of generators used at any time vary according to engine load, and the fuel consumption varies accordingly. It therefore follows that a systemic focus upon drag reduction should be a priority to reduce the associated fuel consumption. Figure 1 schematically illustrates the engineering priorities when seeking to reduce hydrodynamic drag forces. A notable contributor to reduced *form drag*, highly dependent upon the shape of an object and resulting from the pressure differences that are created around the object as it moves through the water (Cengel & Cimbala, 2006), has been the development of seismic streamer models that incorporate acoustic positioning sensors into the streamer body so that hundreds of bulky devices externally clamped to the streamer are no longer required. Similarly, the engineering of depth control and steering devices ('birds') integrated into the form of the streamer body have each contributed to reduced form drag. Reduced *friction drag*, highly dependent on the roughness of the object's surface and resulting from the friction between the surface of the object and the water, has been achieved through a family of barnacle mitigation and prevention solutions (Skadberg et al., 2021) and by developing deep towing profiles able to exploit multisensor technology and the associated befits for lower noise broadband signal recording.

Better project management to maximize daily production rates (measured as square km of seismic data acquired) and minimize non-production time (i.e., less transit, less standby, and less downtime) will make even greater contributions to reduced fuel consumption and the associated absolute and relative CO2 emissions. One paradox with increased survey efficiency is that all drag quadratically increases as a function of the towing speed through the water, so a 'sweet spot' needs to be found between increased vessel speed to improve survey efficiency, optimal signal-to-noise characteristics of the recorded data, and reduced fuel consumption. This management challenge is complicated by the highly dynamic environment affecting marine seismic surveys, including variable currents and variable sea states. The solution to these challenges is the appropriate development and deployment of digitalization solutions across most aspects of marine seismic operations.

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Digital Transformation Use Cases to Reduce Drag and Associated Fuel Consumption

The ingestion of all vessel data assets into a common format for analysis has enabled several use cases to be developed for applications such as the following:

- Optimal vessel speed management
- Real-time monitoring of tension affecting each towed object
- Performance management of all streamer depth control and steering devices
- Optimized ballasting of all streamer sections
- Energy efficiency
- Emissions monitoring and reporting

Custom dashboards integrating common tools such as Power BI, Grafana, etc., help onboard crew manage complementary data diagnostics efficiently. Sheridan and Verplank (1978) proposed a scale with ten levels for measuring automation (or the autonomy of a system). Level 1 gives full control to the operator, while level 10 has the machine acting on its own without even informing the human. Where feasible, our digital management of vessel operations aspire to level 7 of Sheridan and Verplank's scale: The computer executes automatically, then necessarily informs the human.

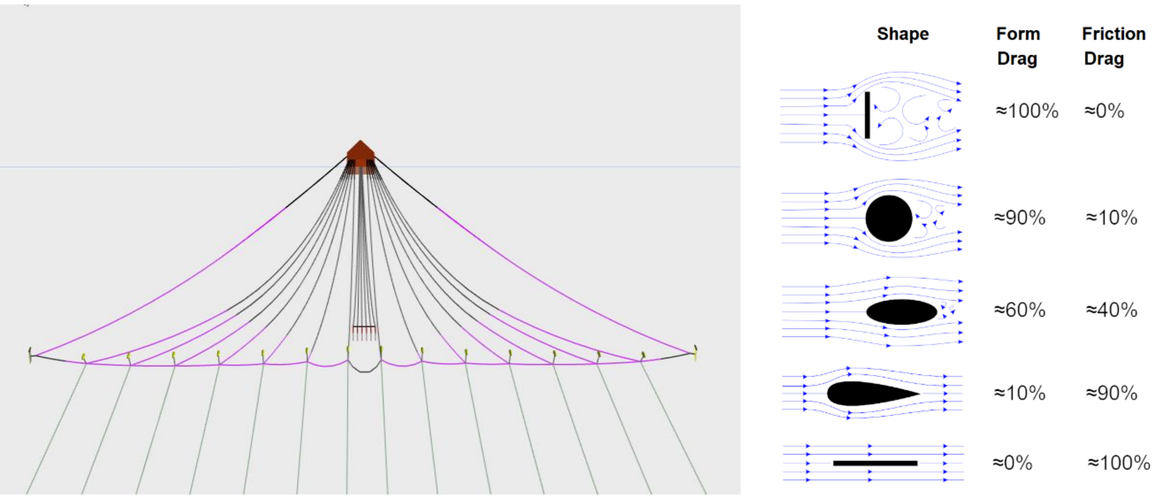

Figure 1 *(left) Schematic seismic vessel configuration showing the 'superwide' ropes to the paravanes, the 'lead-ins' connecting the vessel to each seismic streamer, and the 'umbilicals' connecting the vessel to each 'source sub-array' of air guns; and (right) Relative contribution of form and friction drag for a variety of hydrodynamic shapes affected by laminar flow during underwater towing. Drag reduction initiatives for marine seismic operations seek to improve hydrodynamic streamlining of trailing equipment (reduced friction drag) and the eradication of all 'external' devices and objects on the trailing equipment that contribute to form drag*.

Figure 2 shows part of the vessel speed dashboard linked to a trained neural network that simultaneously accounts for tensions measured at the front of each streamer and 'superwide' rope connected to the paravanes, various noise modes measured throughout the streamer spread, vector vessel speed through the water, vector wind speed, specified temporal intervals (if relevant) between consecutive shots, fuel consumption, and other specified parameters, when recommending the vessel speed in a real time manner. The top row of Figure 2 is a seven-day interval measured in 10-second increments that superimposes the main power consumers on the vessel (note there are two generators available per thruster). The number of generators active at any point in time varies according to loads. The middle row superimposes vessel speed through the water (blue) vs. vessel speed over the ground (green), and instantaneous fuel consumption (red). Similarly, the lower row superimposes tension measured in the superwide ropes (orange and green) vs. the same fuel consumption curve (red) and vessel speed through the water (blue).

Fuel consumption varies in a dynamic manner according to prevailing conditions, vessel speed, and towing drag. The non-linear relationships between each curve illustrate why fuel consumption (and associated CO2 emissions) cannot be accurately modelled or predicted. Instead, comprehensive real-time data measurement, ingestion and analysis from vessel data assets must be pursued before vessel management can be enhanced to minimize fuel consumption in a real-time manner too.

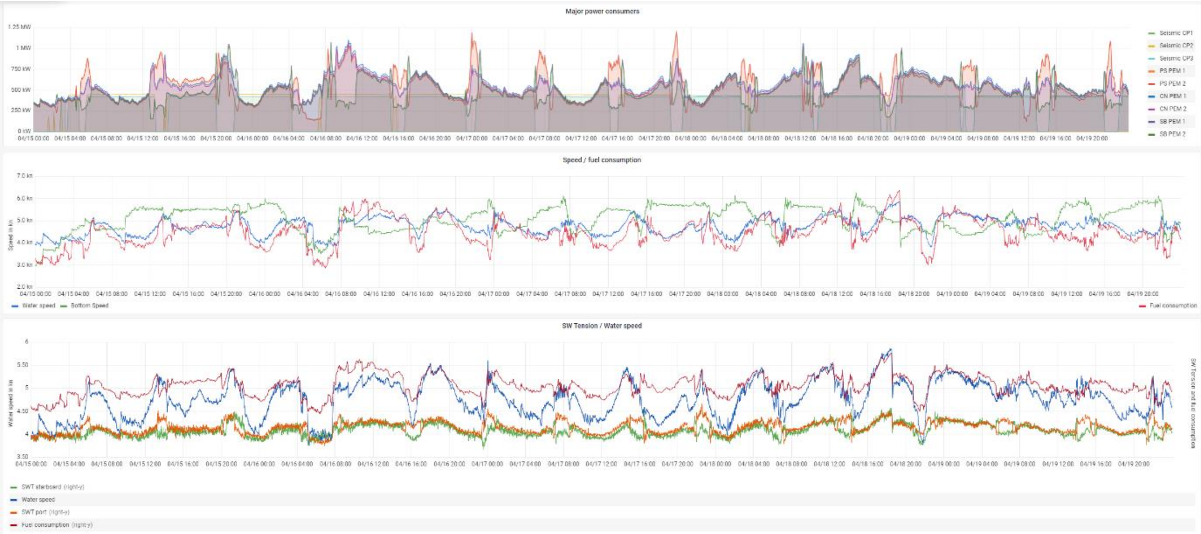

Figure 2 *Vessel power consumption, speed, superwide rope tension, and fuel consumption for a five-day period when the vessel had an average bottom speed of 5.1 knots. These represent a small part of various dashboards available. (Top row) Major power consumers (CP = compressor, PS = port thruster, CN = centre thruster, SB = starboard thruster); (Middle row) Vessel speed through water (blue), vessel speed over ground (green), fuel consumption (red); (Lower row) Fuel consumption (red), vessel speed through water (blue), superwide rope tension (orange = port, green = starboard).*

Other vessel dashboards within specific applications ("Apps") analyse and manage data relevant to the ambition to reduce towing drag and the associated wear and tear on the trailing equipment. An App to provide informed decisions to accurately ballast each streamer section (required because water temperature and salinity affects buoyancy) demonstrably translates to uniform streamer depth profiles, less associated drag forces on the wings of streamer depth control and steering devices ("eBirds"), less mechanical noise recorded throughout the streamers, and less equipment fatigue. Another related App specifically provides comprehensive metrics for individual eBird wings (each containing an independent motor, power supply and control system) and the total eBird system affecting the streamer spread. Optimization of eBird loads and performance translates to better streamer spread steering practices, reduced overall towing drag, less unit failures, and improved lifetime management and performance tracking. The App to understand and optimize load sharing for the front of each streamer monitors tensions in real time, provides alerts when the relationship between certain parameters exceeds prescribed thresholds, and exploits historical data. In addition to reducing maintenance and HSEQ exposure, the system will become a key contributor to optimized drag load vs. fuel consumption as time progresses.

Apps explicitly focused upon reduced energy consumption benefit from the granularity of the data ingested, and our ability to isolate and track the effect of specific initiatives to reduce emissions. From a compliance perspective, an informed platform will help accurately target necessary investment to comply with future relations. Figure 3 plots the specific fuel oil consumption (SFOC: representative of fuel efficiency) vs. engine load for six (electric) engines on a seismic vessel. Such analyses have revealed that engines can run efficiently over a larger range of loads than specified by the manufacturers—measurably translating to better fuel consumption practices. These use cases mentioned above highlight the diverse considerations necessary for efficient marine seismic operations and how reduced fuel consumption is a complex challenge that must account for dynamic factors.

Intelligent Survey Design versus Absolute and Relative CO2 Emissions

Pre-survey modeling of the rope lengths, diameters, and predicted tensions for each component of the trailing equipment is used to design the optimum towing configuration (refer to Figure 1) to achieve the geophysical specifications for each survey design (shooting plan, spatial sampling and offset parameters, temporal and spatial bandwidth parameters, etc.). Future survey planning to include minimized CO2 emissions will obviously target lower-drag configurations and shooting plans with minimum vessel time not acquiring data, however, the dynamic nature of survey execution illustrated in Figure 2 reinforces the fact that improvements can only be incremental. The most fundamental reductions in CO2 emissions, as sought by regulatory changes such as FuelEU (2021), can only be achieved using alternative fuel types. Unfortunately, a study to investigate the compatibility of maritime vessels with alternative fuels (DNV, 2022) suggests that conversion to most non-petroleum distillate fuel types is logistically difficult and commercially challenging. An implication is that efficient operations augmented by digital solutions described here is going to be the most impactful influence upon measurable long-term reductions in CO2 emissions.

Increased common midpoint (CMP) subline density, typically achieved by a combination of small streamer separations and multi-source shooting, will decrease relative CO2 emissions (per CMP km) if the associated increase in drag and associated fuel consumption from the trailing equipment does not become excessive. Again, efficient survey management augmented by digital solutions is the only reliable strategy to measure and manage emissions.

Conclusions

Long term engineering initiatives to reduce towing drag complemented by optimized trailing equipment configurations will reduce absolute CO2 emissions but cannot account for the effects of dynamic survey conditions on maritime fuel consumption. Real time digital vessel management solutions are necessary to optimize fuel consumption for all vessel configuration scenarios in all environments. We have established the merits of digital transformation initiatives across vessel and survey management, the relevance of which will increase with future experience and improved practices.

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