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Fuel usage data analysis for efficient shipping operations

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ABSTRACT

There are incentives from maritime regulatory bodies to operate ships more efficiently, driven by the need to reduce CO_2 budget.

In order to establish more efficient ship operations, fuel consumption across the full operational profile of a vessel is needed. This could be accomplished through a complete characterisation through extensive sea-trials, or interpretation of data from monitoring systems. Results from repeated testing under controlled sea-trial conditions provides high-fidelity data, however, this approach is prohibitively expensive and requires repeating as the condition of the vessel changes with time. Conversely, data monitoring devices are relatively inexpensive, however, the process of analysing data can be complex, particularly when a ship's activities are diverse.

This paper describes a methodology for associating ship activity with corresponding segments of a data-stream from a commercially available monitoring system. Further analysis is then performed to determine the fuel efficient performance of the ship. The case-study used is a harbour tug, although the approach used is applicable to other ship types, its success on this basis indicates the methodology is robust. To validate the methodology, results from the data analysis are compared to fuel consumption data measured under sea-trial conditions, and are found to be in close agreement.

1. Introduction

There is a requirement not only for economic reasons, but also for environmental reasons, to reduce the fuel consumption of ships.

Regulations on exhaust gas emissions from ships are becoming increasingly stringent, as laid out in Annex VI "Regulation for the Prevention of air pollution from ships" of the International Convention for the Prevention of Pollution from Ships (MARPOL), which came into force on 19th May 2005 (MARPOL, 1997).

These regulations, for example, cover a requirement to reduce the sulphur content of fuel when being burned in Emission Control Areas. A revision to Annex VI coming into force on 10th October 2008, introduced a new Regulation 4 "Equivalents", stating that: "An Administration of a Party may allow any fitting, material, appliance or apparatus to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as an alternative to that required by this Annex if such a fitting, material, appliance or apparatus or other procedures, alternative fuel oils, or compliance methods are at least as effective in terms of emissions reductions as that required by this Annex…"

The results of the methodology presented in this paper allow ship operators to demonstrate their fuel consumption usage and exhaust gas emissions, related to the day-to-day operation of their vessel, aiding operators when showing compliance with Annex VI.

The 2nd IMO GHG Study (Buhaug et al, 2009) highlight six "Principal options for improving energy efficiency", split into two categories: "Design" and "Operation". Data analysis from monitoring devices, as described in this paper, can address concerns in both categories, including "voyage optimisation" from the "Operation" side, where, for example, an optimally fuel-efficient speed may be chosen, in typical day-to-day running conditions, rather than an artificial, theoretical running point, such as trial conditions. This aspect can cross over into the "Design" category, allowing designers to optimise the propulsion system with the hullform for expected service conditions, obtaining more efficient designs for in-service conditions. This is an iterative procedure however, which is financially impractical, and emphasises the importance of using realistic simulators when designing for in-service conditions (Trodden, 2014).

As Hideyuki (2011) points out, Performance Monitoring and its analysis can be used to not only assess the base-performance of a ship, but also the effect of changes in draft and trim, hull condition, weather and operating procedures. Furthermore, the approach taken in this paper can be adapted and used for condition monitoring (Simon and Litt, 2010), an important component in predictive maintenance.

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Nomenclature

SFOC	specific fuel oil consumption [g/kW h]
FCM	measured fuel consumption [l/h]
SoG	speed over the ground [knots]
SSFRC	steady-state free-running condition
NSSFRC	non-steady-state free-running condition
SSNFRC	steady-state non-free-running condition
tol	tolerance used when identifying SSFRC periods
n	number of data points to be within tolerance. Used for identification of SSFRC periods

The methodology described in this paper uses equipment already commonly found on most ship types. Algorithms are described which separate the data-stream, as output from monitoring devices, into periods associated with steady-state, free-running condition, and non-steady-state free-running condition. This allows performance analysis of not only base-line, steady-state performance, associated with factors such as hull fouling, but also transient performance, associated with factors such as the way the vessel is being operated.

This paper applies the described data analysis methodology to isolate the steady-state free-running condition of a harbour tug, and shows that the tug is being operated in a fuel efficient manner, making the most of a retrofitted economy engine speed selector.

2. Particulars of the basis ship

The basis ship used in this study is a harbour tug, whose main duties are assisting ships on and off their moorings, and assisting their manoeuvring in and out of port. A harbour tug exhibits widely varying operation in typical everyday scenarios, are often operated, on the whole, by their masters independently of control or orders from shore. These factors lead to potential ambiguity and fluctuations in data which vary from one voyage, or job, to the next. This makes the analysis of such a data-stream challenging when determining ship activity type. It is for these reasons that a harbour tug has been chosen as the basis ship type for this analysis, the argument being that if analysis can successfully be conducted on a tug boat, it can certainly be done for ship types with less variance in their data-streams for a specific activity.

The main specifications of the basis ship are found in Table 1.

2.1. Propulsion system

The speed of the engines are controlled digitally by selecting one of four pre-sets, labelled in the wheelhouse as “13%”, “50%”, “70%” and “100%”, nominally corresponding to engine rotational speeds of approximately 380, 570, 620 and 740 rpm. The “%” designation will be used throughout this paper.

Table 1
Particulars of the basis ship.

Main particulars	
Length overall	30.58 m
Draught	2.66 m
Gross tonnage	296
Performance	
Maximum speed	12 knots
Bollard pull	40 tonnes
Main Engines	
Number of engines	2
Continuous rating	1700 BHP
Propulsion	
Type of propulsion	Voith Schneider
Number of propulsors	2

The pitch of the Voith Schneider propulsors are controlled by analogue levers, ahead and astern, graduated from 0 to 10 corresponding to zero and maximum pitch. When the tug is free-running, that is, not assisting another vessel, steering is achieved by setting the pitch levers to the same value, and using a wheel which vectors the net thrust of the two Voith Schneider units in the intended direction of travel.

As a result of the analysis carried out by Murphy et al. (2012), a new “eco-button” has been installed, which corresponds to an additional engine rotational speed setting of approximately 33%. Murphy et al. (2012) claim that a reduction of approximately 20% in fuel consumption could be made at a speed of 67% of the maximum recorded value. The following analysis will determine if this claim has any foundation, and whether or not the eco-button is being utilised.

2.2. On-board monitoring devices

On-board data monitoring devices installed on board this study's basis ship, comprise two main units; a Global Positioning System (GPS) receiver and main engine fuel consumption meters. The equipment used to measure fuel consumption consist of differential flow meters placed on both the inlet and outlet fuel lines of the engines with the difference between the fuel entering and leaving the engine resulting in fuel consumption. The System accuracy for the flow meters have a repeatability rating of $\pm 0.5\%$ for the positive displacement flow meters (Enginei, 2015).

The basis ship is not equipped with a conventional speed log to measure speed-through-water, however the speed-over-ground, location and heading is recorded from the GPS receiver.

There are numerous factors such as atmospheric conditions, sky blockage and receiver quality which make it challenging to determine the accuracy of a GPS receiver at any one time. Typically, for a basic receiver conforming to the GPS Standard Positioning Service (SPS) Performance Standard (Department of Defence, 2008), real world data from the Federal Aviation Administration (2014) show that modern high-quality GPS SPS receivers provide an horizontal accuracy of at least 3.5 m.

Any fluctuations in the accuracy of the measurement systems will cause unsteady oscillations in the data-stream.

If these oscillations are relatively large and densely populate the data-stream, the filtering algorithms will recognise them as unsteady periods and discard them from steady-state analysis. If the oscillations are relatively small or sparse, then they will not affect the identification of SSFRC due to the “look forward, look back” nature of the filtering algorithms, as described in Section 4.

In practise, any inaccuracies arising the measurement systems do not present any issues as a sufficiently high number of SSFRC are identified to perform further analysis on.

The on board data monitoring systems are recording constantly, regardless of the ship's activities. A data-point from each of the monitored parameters is logged every sixty seconds.