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Optimized Use of Thrusters During Transit with a Passenger Ferry

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ABSTRACT: This paper aims to address the impact that optimized use of propulsion equipment would have on a ferry during transit. Assuming that the ship arrives at it's destination on schedule, a potential reduction in fuel consumption would cut the overall cost of the voyage. The idea of optimizing propulsion equipment fostered a series of sea trials on board a passenger ferry in Norway. Modern aft-bow symmetrical ferries allow several different methods of manoeuvring, each with it's own advantages and disadvantages. The goal was to uncover the method that used the least amount of KWh per nautical mile during transit. The results are presented in this paper and there are several interesting findings. For instance, applying equal RPM on both thrusters gave the lowest KWh per nautical mile. However, increasing the RPM on the aft thruster and reducing the RPM on the bow thruster gave the highest speed over ground.

1 INTRODUCTION

Transportation is the largest contributor to climate gas emissions in Norway and within this segment, shipping accumulated 6% of the total emissions in 2018 [1]. Ferries play a major part in the domestic shipping emissions and in 2019 there were 112 number of ferry connections, transporting 34.249.453 PBE [2]. Even though several modern ferries are built as electric ships, the annual emission from this sector accumulates to 2,7 TWH annually, including coastal passenger ships [3, p. 22]. Naturally, companies and government agencies work towards lowering emissions as well as reducing the cost of transportation. One area of focus has been to reduce pollution through energy efficiency measures on existing ships, as stated at MEPC 62 in 2011 [4}. Energy efficiency of a ship can probably be improved through careful planning, monitoring and evaluation of operations. One important focus area has been fuel efficiency and energy consumption during daily operations. The scope of this paper is to describe and assess how small RPM adjustments and power allocation, affect fuel consumption.

2 FERRY OPERATIONS

This paper delves into ferry operations, which are usually split into 6 phases [5, p. 3]:

1 Ferry arrives at dock and keeps itself in place using its thrusters.
2 Hatches and doors open which let the vehicles and passengers off the ferry.
3 Ferry personnel guides waiting vehicles and passengers on-board the ship.
4 Hatches and doors close, and ticketing is performed.
5 Ferry undocks from the current harbour and starts transiting to the next one.

6 During transit and docking/undocking ferry personnel takes care to follow the International Regulations for Preventing Collisions at Sea (COLREGS) to avoid any collision.

The different phases of operation require unequal amounts of power. The transit phase often accumulates most of the energy consumption during ferry operations. Moreover, when the optimized transit speed is known, the navigator must choose how to achieve this speed through the propulsion equipment.

3 OPTIMIZED USE OF THRUSTERS

While most ships have the main propulsion at the stern and auxiliary propulsion at the bow, modern ferries are not always designed this way. They are often aft-bow symmetrical with equal amounts of propulsion equipment in both ends [5, p. 9]. This enables different configuration possibilities regarding power allocation on thrusters during transit, as shown on figure 1. In transit mode, most ferries can choose between the following methods:

- Method 1: Equal RPM applied on aft and bow thrusters.
- Method 2: More RPM applied on the aft thruster and less RPM applied on the bow thruster.
- Method 3: More RPM applied on the bow thruster and less RPM applied on the aft thruster.

It is also possible to use only one thruster during transit or combining the different methods in a single voyage. Unfortunately there is a limited supply of literature regarding propulsion efficiency on car passenger ferries and which method to adhere to. Nonetheless, some basic principles of hydrodynamics are applicable.

To move a ship through water, it is necessary to overcome resistance [6]. A ship in motion will experience several forces working against the propulsion equipment, such as viscous friction, residual resistance, and air resistance [6, pp. 9-11]. The friction of the hull will create a boundary layer around the hull consisting of water moving in the same direction as the hull and at the same velocity. This velocity is reduced depending on the distance from the hull, until it reaches zero. The thickness of the layer increases along the length of the hull. All this creates a wake field aft, which the stern propeller often operates in.

Techet states that a propeller working in the wake field is more efficient and demonstrates this mathematically [7, pp. 17-18]. To clarify, the propeller pushes through water going in the same direction as the hull, thus increasing efficiency. In theory, the stern propeller would therefore be more efficient during transit than a propeller mounted closer to the bow.

Furthermore, the extent of viscous resistance depends on the type of flow it is experiencing [8, ch 7, p. 11]. Generally, we have laminar flow and turbulent flow as shown on figure 2. Laminar flow is characterized by smooth lines and a minimum of frictional resistance. Turbulent flow, located in the boundary layer, provides resistance. If turbulent flow is increased, the frictional resistance increases as well. This is important when using a bow thruster. The bow propeller provides additional turbulent flow that travels along the ships hull, increasing viscous resistance and reducing propulsive efficiency.

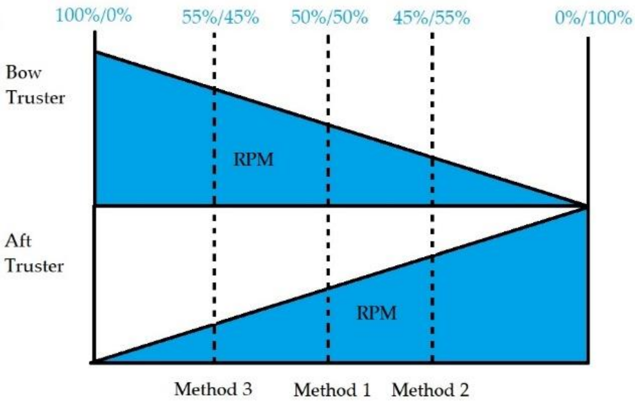

Figure 1. Illustration of propulsive possibilities, including methods from this study.

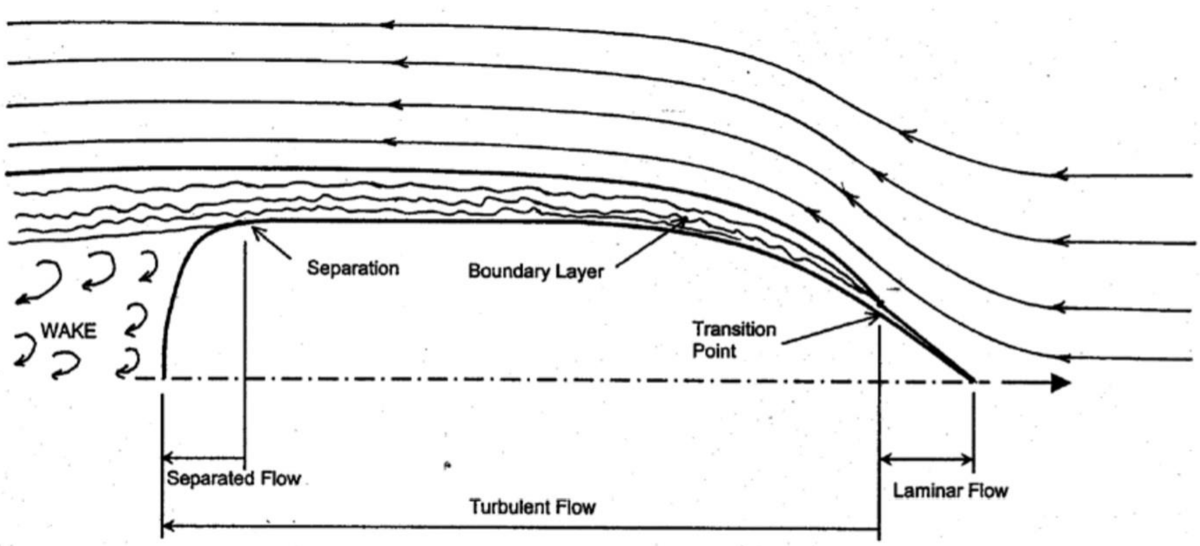

Figure 2. Flow pattern around a vessel in motion. [8, ch 7, p. 11]

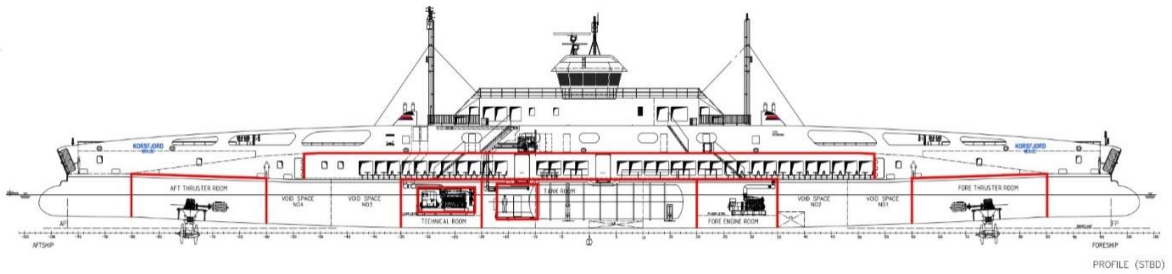

Figure 3. Starbord profile of M/F Korsfjord (courtesy of Fjord1)

These facts suggest that method 2 would probably reach the highest speed, while method 1 would be slightly slower and method 3 the slowest. However, there is a difference between highest speed achieved and fuel consumption. Model testing on this ferry manifested that method 1 is more fuel efficient compared to other configurations [9].

It should be mentioned that these tests investigates fuel consumption primarily, and velocity secondarily. Course keeping abilities, vibration or other factors present within the different methods will not be assessed. An important moment here is that the testing is done without changing course. Method 2 is perhaps the most preferred propulsion configuration on ferries in general, partially because the aft thruster has the most authority over yaw moment during transit [10, ch 1, p. 11].

4 QUANTATIVE RESEARCH STUDY

This study would be characterized as a quantitative research study with an experimental design [11, ch 7]. The purpose was to examine how different propulsion methods affected power consumption. However, considering that transit time is of great importance to passenger ferries, this variable was also included. The concept was to have a ferry travel a certain distance during transit, while logging consumption and time, for each of the given methods. The tests would be repeated several times to strengthen the validity and hopefully a trend would be uncovered. The method applied can be referred to as a simple time-series design. [11, p. 208].

4.1 *MF Korsfjord*

Every observation was made on MF Korsfjord, which is a ro-ro passenger ferry that runs on liquid natural gas (LNG). The ferry operates on the Molde-Vestnes connection as part of E39 in Norway. There are three other identical ferries on this connection and to keep the scheduled timetable, each ship must have a transit speed of around 11,5 knots. The ferry is a monohull, aft-bow symmetrical vessel as seen on figure 3. Korsfjord has 2 Schottel STP 1010, N=1000kW azimuth thrusters, one in each end [12]. Both have fixed pitch propellers. This design allows fully actuated manouvering where surge, sway and yaw is controllable. Power is generated from two MITSUBISHI GS16R-MPTK (900 kw) gas engines and a MITSUBISHI S12R-MPTA (1000 kw) in standby. These engines provide the thrusters with power and consumption is logged using an energy monitoring system [13]. Consumption is directly affected by RPM on the thrusters. An increase in RPM gives an increase in consumption.

The ship has a set of azimuth thrusters with a twin screw configuration in each end. Each propeller has a diameter of 2m, and they are placed 1,8m below baseline. Each thruster is placed 45,40m from midship and 15,97m from length overall.

4.2 *Data collection*

Data was collected over a period of three months. First, a designated test area was thoroughly marked on the vessels TECDIS, as shown on figure 4. Because the ferry still had to operate the route as usual, the area is part of the normal sailing route. The area is also in the middle of the transit phase, and the ship does not need to change course or alter speed during normal operation. It also allows the ship to reach transit speed when leaving the quay in Vestnes. The testing procedure is described as follows:

- Before approaching the test area, the navigator carefully regulate RPM on each thruster accordingly to the chosen method.
- The navigator plots the designated course in the autopilot.
- The navigator then waits for the SOG and the autopilot to stabilize.
- When the ferry enters the designated test area the navigator places a mark in the TECDIS.
- When the mark is placed the navigator immediately logs KW and time in IAS.
- When the TECDIS shows sailed distance of 1 nautical mile the navigator logs KW and transit time.

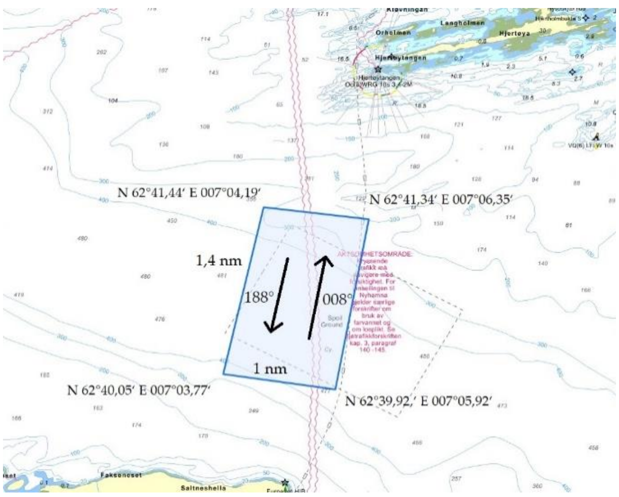

Figure 4. Test area for observations. Recreated from ships TECDIS using online charts. [14]

When conceding such full-scale testing there are a number of factors that must be assessed, to avoid corrupting the data collection. A ship in motion will experience interactions that affect energy usage, in both positive and negative ways. Current, wind and waves are some of the dominant external forces that affect ship motion, resulting in drift or change in speed. Internal factors such as trim, heeling angle, growth or loading condition will also affect overall performance [15, pp. 34-43]. To reduce the impact of these interactions, every test was carried out during calm weather. An upper limit of wind was set at 6 m/s from any direction and wave height at maximum 0,5m. Every test was carried out by the same navigator and to compensate for current, the results are based on average consumption and transit time both northbound and southbound direction, as seen in fig. 4. Since the ferry transports a number of different vehicles on every voyage, the loading condition will vary on almost every single test. Loading condition is therefore not possible to compensate for during these tests.

These measures mentioned above will reduce the impact of interactions but not eliminate them. Any data acquired in this trial must therefore not be viewed as flawless.

5 RESULTS

There were conducted 45 valid tests during this trial. Several other tests were carried out but eventually removed due to corruption of data from sudden changes in weather or increased marine traffic in the area. The results are outlined in the following tables.

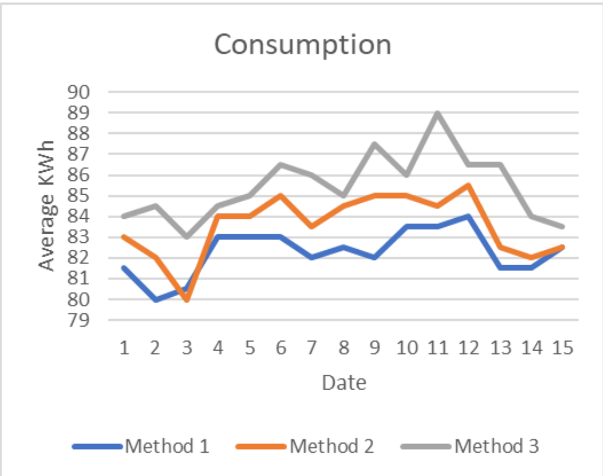

Figure 4. Line graph describing consumption.

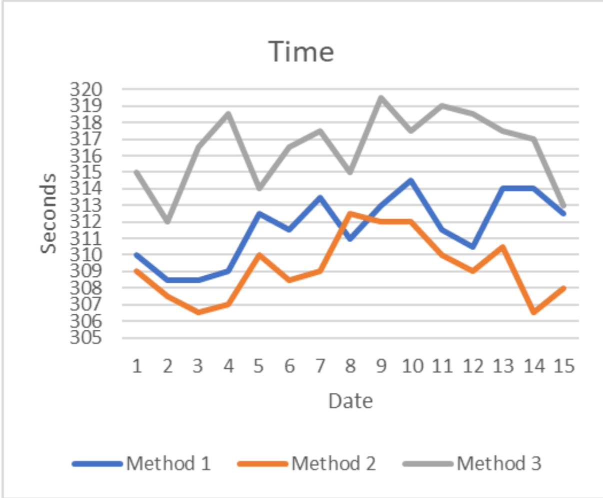

Figure 5. Line graph describing time spent transiting.

Table 1. Average KWh per nautical mile.

	Average KWh		
Day/Method	Method 1 (220/220)	Method 2 (200/240)	Method 3 (240/200)
29.04.20	81,5	83	84
30.04.20	80	82	84,5
01.05.20	80,5	80	83
18.05.20	83	84	84,5
19.05.20	83	84	85
20.05.20	83	85	86,5
21.05.20	82	83,5	86
22.05.20	82,5	84,5	85
25.05.20	82	85	87,5
26.05.20	83,5	85	86
27.05.20	83,5	84,5	89
28.05.20	84	85,5	86,5
22.06.20	81,5	82,5	86,5
23.06.20	81,5	82	84
24.06.20	82,5	82,5	83,5

Table 2. Average time per nautical mile.

	Average Time		
Day / Method	Method 1 (220/220)	Method 2 (200/240)	Method 3 (240/200)
29.04.20	310	309	315
30.04.20	308,5	307,5	312
01.05.20	308,5	306,5	316,5
18.05.20	309	307	318,5
19.05.20	312,5	310	314
20.05.20	311,5	308,5	316,5
21.05.20	313,5	309	317,5
22.05.20	311	312,5	315
25.05.20	313	312	319,5
26.05.20	314,5	312	317,5
27.05.20	311,5	310	319
28.05.20	310,5	309	318,5
22.06.20	314	310,5	317,5
23.06.20	314	306,5	317
24.06.20	312,5	308	313

Table 3. Analysis with descriptive statistics

	Method 1		Method 2		Method 3	
Statistic:	KWh	Time	KWh	Time	KWh	Time
Median	82,5	311,5	84	309	85	317
Mean	82,26	311,63	83,53	309,20	85,43	316,46
Mode	81,5/ 83	308,5/ 311,5/ 312,5/ 314	85	309	86,5	317,5
Range	4	6	5,5	6	6	7,5
Standard deviation	1,09	1,95	1,46	1,89	1,56	2,15

6 DISCUSSION

In this section the tables and line graphs from section five will be interpreted and discussed. As mentioned earlier the data in this study is gathered through an uncertain method. Several variables thought to affect the results are present and can neither be measured nor ruled out due to lack of equipment on the vessel. Such variables include, but are not limited to, wind, waves, current and loading condition. Interactions would explain why the data is not completely identical for each column. On the other hand, the differences are surprisingly small and not severe enough to invalidate the results.

Table 1 and figure 4 presents the data regarding consumption per nautical mile. With a few exemptions, method 1 has the lowest values followed closely by method 2 and finally method 3. As shown on the line graph the different methods remain relatively stable during the tests, without rapid or substantial changes in value.

Table 2 and figure 5 describes transit time per nautical mile. Method 2 proved to be the fastest, except on one occasion, followed closely by method 1 and lastly method 3. Again, the values are quite consistent, similarly to the results for consumption. This suggests that the readings underline a trend.

Table 3 presents some measures of central tendency. The median, the mean and the mode for all methods do not differ significantly. They seem to revolve around the same numbers, in their respective columns. Still, the results are the same, leaving method 1 as the most fuel efficient and method 2 as the fastest. Furthermore, table 3 provides measures of variability. The range indicates the spread of data for each variable and it seems to be quite low for all columns. In turn this suggest that the spread is minimal. This argument is further proven when looking at the standard deviation. Again, the values are relatively low, indicating a highly concentrated set of data. In conclusion the data is mostly homogenous and without values that deviates far from the norm. All columns seem to cluster around their points of central tendency and with a minimal spread.

Given the above, the results indicate that there are measurable differences between the aforementioned methods when it comes to power consumption and time spent transiting.

Method 1 has turned out to be the most fuel efficient method during transit and the result is consistent with the model testing completed by LMG Marine [9]. A possible cause for this phenomena, is that the overall engine load is slightly lower when allocating equal amounts of power to each thruster, compared to an unequal distribution. Increasing RPM on one thruster and decreasing correspondingly on the other one results in a minimal, but still noticeable change in engine load between 1% and 2%.

On the contrary, reduced consumption is meaningless if the vessel fails to achieve a sufficient velocity and uphold the timetable. As stated above method 1 is the most fuel efficient. On the other hand it is only the second fastest method, closely beaten by method 2. An exceedingly plausible explanation for this is that the stern propeller works in the previously mentioned wake field, which in turn provides increased propeller efficiency. Coincidentally the bow thruster has reduced its RPM, thus reducing potential hull resistance accordingly.

Perhaps unsurprisingly, method 3 turned out to be the slowest and least fuel efficient method. As stated above the unequal distribution led to higher consumption compared to equal power allocation. Concurrently, using a bow thruster as the main propulsion and the stern thruster as auxiliary propulsion resulted in lower speed during transit. A noticeable increase in RPM on the bow thruster probably led to increased hull resistance, whilst the auxiliary thruster worked in the wake field. This method is therefore not recommended under any circumstances.

Ultimately the testing showed that the methods were not that disparate. A possible explanation comes from the hull design and placement of the thrusters. As shown on figure 3, the thruster placement might be unconventional. Compared to other vessels the thruster are located closer to midship. Any potential differences would therefore be minimized compared to other ferries, where thrusters are closer to the perpendiculars.

7 CONCLUSION

This paper aimed to investigate how daily operations could be optimized on a ferry, specifically through the propulsion equipment. It can be concluded that method 1 is recommended for fuel efficiency, while method 2 is recommended for transit time. Method 3 is unfavourable in both aspects and not recommended. On the contrary, the differences are surprisingly small per nautical mile and the potential reward is quite low. Finally, these results only apply to this particular ship, but it may be relevant to other ferries with similar design and propulsion equipment.

8 FURTHER RESEARCH

Considering that the uncovered differences were minimal, it would be interesting to measure energy usage and transit time for each method at different velocities. Perhaps speed reduction could have greater potential for fuel efficiency.

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