SAIL FURTHER, WITH LESS FUEL

Fuel effectivity on the ALP STRIKER

Final Thesis

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Preface

Kindly I would like to thank my mentors: professor de Groot and captain Nieuwhof. I also thank the crew and my parents. Without the support received, this thesis would not have gotten were it has.

Brian Slotema

Vlissingen, 17-04-2021

Abstract

This thesis is concerning effective use of fuel on board the ALP STRIKER. The recent transfer from heavy fuel oil, to the more expensive marine gas oil led to ongoing discussions about the effective use of fuel on board. The goal was to find the optimum propulsion configuration on board for any attainable given speed, with concern to the effective use of fuel.

The main question was as follows:

"During free sailing, what is the most economic propulsion configuration and speed on the ALP STRIKER?"

To answer this the following sub-questions were purposed:

1. "How can the fuel consumption and speed accurately be measured?"
2. "How can external factors be taken into account?"
3. "How can the data be processed reliably?"

By answering these questions, a test procedure was composed. The test procedure used reliable instruments, already installed on board to assess the parameters. To exclude other variables such as: sea state, weather and ship condition, they were monitored well and conditions were set to not let them alter the results of the trial. The ship was to conduct the tests in a narrow time schedule. This way the same fuel could be used and variables such as hull, propeller and engine condition would be stable enough to be dismissed. So, the main test was performed on one day, testing a two-engine and one-engine configuration. The test ran with engine load varying from 40% to 95% in four steps. All the while taking note all dependent, independent and control variables. After, the data was processed and to verify the accuracy of the results, individual datasets were added until the testing window came to an end. More full configuration tests were intended, also testing different propulsion configurations, though the time window for testing was already at an end. To add validity, the current test data was also compared to previous consumption data. And accuracy of the primary variables was also assessed.

The tests were not run entirely as intended and not without its' imperfections. The time window for the tests was coming to an end. The rudder was damaged and added resistance. The wind was slightly exceeding the 11 knot limit and the shaft generator load was not as stable as hoped. The amount of measurements meeting test requirements were not as hoped. Though, the test procedure proved to have a good foundation and recommendations for additional research were made.

Regardless of all, the results did indicate that the one-engine configuration was most fuel effective and provided the most miles traveled for the least amount of fuel. The maximum speed with this configuration was 10.6 knots with a shaft generator load of 547 kilowatts.

There were more propulsion configurations possible on the ALP STRIKER and the full speed range possible was not tested. Also the obstructions did put into question the validity of the results. Further research, following the existing procedure and recommendations made, should provide a sound basis, from which reliable and more insightful conclusions can be made.

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1. Introduction

ALP Maritime services is a relatively new company in the shipping industry. The company is a specialist in the field of ocean towing, offshore positioning and mooring of floating platforms, heavy transport and salvage operations. It has a fleet of ten powerful, versatile DP II long-distance towing and anchor-handling vessels.

“The fuel cost is one of the most significant contributors to the ship operational expenditure” (Maritime Safety Research Centre, 2018). With the recent switch from heavy fuel oil (HFO) to the more expensive Marine Gas Oil (MGO), fuel costs became even more significant. Also critical to determine the price of projects ALP carries out. Ongoing discussions in the company regarding fuel consumption left the need to clear up the discussion with a clear report on the vessels’ efficiency performance and costs.

The purpose of this research was to determine the economically optimal drivetrain configuration for any given speed through the water (STW) on board the ALP STRIKER.

To answer the main question: “During free sailing, what is the most economic propulsion configuration and speed on the ALP STRIKER?” the following sub-questions were proposed:

4. “How can the fuel consumption and speed accurately be measured?”
5. “How can external factors be taken into account?”
6. “How can the data be processed reliably?”

Naturally there are other important factors that greatly influence fuel consumption and economic speed, such as: fuel prices, maintenance, crewing, fouling of machinery and hull, effective energy management from the engine control room and updating the voyage plan in accordance with the latest weather report. These factors, including towing, are not discussed in this research. Due to limited time and resources available the data collection had to place while sailing the predetermined course to the next port of call.

The ALP STRIKER is one of four long ultra-long distance anchor handling tugs. It has two separate propulsion trains that are mirrored to each other as seen in *attachment four* (Ship Operation Manual, 2016). Each side has two main engines connected to a gearbox, from where the propeller shaft and the shaft generator can be clutched in. The propeller is a controllable pitch propeller, giving better maneuvering performance. When not driven, the propeller can also be put into feathering mode, where the shaft is put on a brake in the position that minimizes drag. (Caterpillar Propulsion Production AB, 2014)

In the theoretical framework, the available background theory was collected to form an accurate vision of how the questions will be answered, keeping in mind all the variables. In the method, it is made clear how exactly the questions were to be answered, measured and processed to reach a valid conclusion. After, in the bibliography all the mentioned sources can be found. Finally, further material relevant to the thesis can be found in the attachments.

With the found results it was made clear what speed combined with which operational configuration is most economic, so operators on the future class vessels can save on fuel costs.

2. Theoretical Framework

2.1 Literary review

There is plenty of research done in the area of efficiency and shipping. From the design of individual components such as hull, propellers or engines, to research on operational efficiency. For instance, in "*Energy effectiveness of ocean-going cargo ship under various operating conditions*" (Congbiao Sui, 2019), research was done on providing a simulation tool to determine the "energy effectiveness" of ocean going vessels. In "The effectiveness and costs of speed reductions on emissions from international shipping" (Corbett, Wang, & Winebrake, 2009), the effectiveness and cost of altering ship speed on emissions was explored by applying profit maximizing equations including lost profit opportunities. And in "*A new logic for controllable pitch propeller management*" (Balsamo, De Luca, & Pensa, 2012), a new way to control the controllable pitch propeller was developed to increase efficiency.

As mentioned in the introduction, it is clear as fuel is one of the very substantial expenses for shipping companies. It is also noted that the shipping industry is one causing a substantial part in air pollution. To counteract this, the International Maritime Organization (IMO) has set up a committee, Maritime Environment and Protection Committee (MEPC). The Energy Efficiency Operation Index (EEOI) has come into play. This index is calculated by dividing the amount of CO2 emitted by tons of cargo transported and miles travelled. It forces the industry to become more efficient by making the EEOI more strict.

For some time now the shipping industry has relied on energy saving devices as well as exhaust gas treatment. This is a costly endeavor. It then became clear that much capital can be saved immediately. By optimizing the speed of vessels to the market and its' possible profit a lot of money can be saved while also emitting less exhaust gasses. In the book "*Sustainable Shipping: A Cross-Disciplinary View*" (Psaraftis, 2019), reducing speed to reduce CO2 emissions was mentioned. "Reducing speed could also have important side benefits: cost reduction is one" (Psaraftis, 2019).

In the report *"Real-time optimization of ship energy efficiency based on the prediction technology of working condition"* (Chang & Wang, 2014), researchers did calculations on speed optimization on container vessels, bulk, and tanker ships. The study took four different circumstances to determine optimum speed based on: Ship speed, bunker prices and time charter rates. "Our results indicate that attaining the optimum speed reduction is a dynamic process depending largely on charter rates and fuel prices. The benefits in cost savings afforded by a reduction in shipping speeds should be sufficient to encourage shippers to voluntarily implement such measures without the need for governmental intervention." (Chang & Wang, 2014)

Also in "*Tramp ship routing and scheduling with speed optimization"* (Norstad, Fagerholt, & Laporte, 2010), this was investigated, by making a mathematical model to consider fuel costs, speed and possible extra spot cargoes each leg of the journey. "Taking variable speed into consideration significantly improves the profit, partly because increasing speed can make it possible to carry additional spot cargoes, and partly because reducing speed results in less fuel consumption per distance." (Norstad, Fagerholt, & Laporte, 2010)

In a Chinese research on an inland cruise ship, was shown that by optimizing engine speed to the weather conditions ahead significant fuel can be saved. They experimented with making real-time optimization by taking weather updates and a ship profile to calculate the optimum speed with Wavelet Neural Network. “Determining the real-time optimal engine speed can reduce the fuel consumption per unit distance by about 19.04% on average in the ideal cases.” (Wang, Yan, Yuan, & Li, 2016)

The major losses are well known. Finding the optimum economical speed however is still discussed on board and in the office. As fuel is one of the major costs it should be clear what it takes to find the most economical speed and configuration. As described before, there is some difference between most economic, most fuel efficient and most fuel effective.

Most economic takes into account lots of other costs, such as crewing and maintenance, but also chances at increased income. *Most fuel efficient*, just takes into account the best energy conversion. How much fuel/energy is being put in and how much of it, is being used for the wanted outcome? *Most fuel effective* use of fuel is described as the “Fuel Index” in “Sailing at Various Loads” (Congbiao Sui, 2019). It describes how much fuel is used per ton deadweight and miles crossed. Though deadweight is not a big factor in the ALP ships as the cargo is towed, fuel consumed per mile is a big factor. Fuel effectiveness is the main theme for this thesis.

Some of the research found on this subject will be mentioned below. First the speed trials, conducted in the sea trials, will be discussed. Then other related research will be mentioned.

2.2 Seatrials

Seatrials are organized to measure the performance of a vessel. It generally tests the speed, maneuverability, equipment and safety features. Overall the general seaworthiness is tested. Along with this general engine room parameters are taken. While testing for speed, the consumption is taken at various operating points. This part is tested in the speed trial.

Seatrails have to be conducted for every ship, so standardized guidelines are set to make the result comparable and trustworthy.

The purpose of the speed trial is to see whether the builder met the speed and power figures promised before the build. These figures relate to a condition without external disturbances, meaning, no wind, waves, current and shallow water.

ITTC speed-power trial guidelines

The International Tank Towing Conference (ITTC) have developed their own recommended procedures for this. The purpose of their speed-power trials is to verify whether the builders met the ship speed plan formulated in the contractual agreement. This will also provide the data needed to calculate the Energy Efficiency Design Index (EEDI) as required by law.

The contracted ship speed is to be determined under specified conditions. Usually ideal environmental conditions such as deep water no wind, waves and current. However, these environmental conditions are normally not present during the actual trial. For this reason other relevant ship and environmental data is also taken during the trial. The trial is conducted so the speed and required power, as well as EEDI Power are within 0.1 knots and 2 percent shaft power.

The guidelines specify numerous matters, but relevant are:

- Preparations
- Vessel conditions
- Limiting weather and sea conditions
- Trial procedure
- Trial execution
- Required measurements
- Data acquisition
- Processing results

Preparations

Ensuring correct functioning of:

- Torque measuring system
- RPM measuring system
- DGPS
- Gyrocompasses
- Wind meter
- Speed log system
- Propeller pitch
- Ship draught measuring system
- Water dept measuring system

Furthermore all ship data that is recorded during the trial is to be calibrated prior to the trial.

Ship condition

Displacement deviation	< 1 percent
Trim deviation	< 1 percent from T_{mid}

Clean prop & hull

Boundary conditions

It is important to keep the test as free from variables as possible. Therefore an area must be chosen where high winds and heavy sea states can be avoided. These will cause excessive rudder action to maintain course and will impede test results. This means an area of low traffic to no traffic is preferred as well.

Wind

To measure the wind, it is allowed to use the ship's own anemometer as long as it is as clear as possible from the superstructure. During the trial the wind speeds shall not exceed a strength of 6 Beaufort for vessels when (length between particulars (L_{pp}) < 100 m.

Sea wave & swell

If wave height is measured visually the following formula for total wave height is used:

$$H \leq 1.50\sqrt{\frac{Lpp}{100}}$$

Where $H = \sqrt{H_{W1/3}^2 + H_{S1/3}^2}$

Where $H_{W1/3}$ is significant wave height from local wind and $H_{S1/3}$ is significant wave height from swells. Significant wave height is defined as: the average wave height, from trough to crest, of the highest one-third of the waves.

Current deviations

Regions with considerable current variations are to be avoided.

Water dept

Shallow waters do have impact on the trials and therefore should not surpass the following dept:

$$h = 3\sqrt{B \cdot T} \quad \text{and} \quad h = 2.75\frac{V_s^2}{g}$$

Where: h = total water dept [m]

B = moulded breath [m]

T = draught [m]

V_s = vessel's speed over ground [kts]

g = gravitational pull [m/s^2]

Trial procedure

From the figure to the right, the measured parameters are noted, along with the measurement devices used.

Before the trials, the weather forecast is to be checked. Trials shall be conducted by daylight as waves data is obtained visually. Engine plant is in normal operation mode. Draught, wind and water density and temperature shall be measured in standstill.

When all is satisfactory, the trial will commence by running double runs. To manage external factors, the speed trials contain a double run, where the ship sails directly into the waves and again with the waves. This way, the average can be taken and the waves, wind and current can be ruled out as a variable. The trajectory is shown in the figure below. The steady approach is used to get a steady ship condition, after this the following 10 minutes are used to take data measurements.

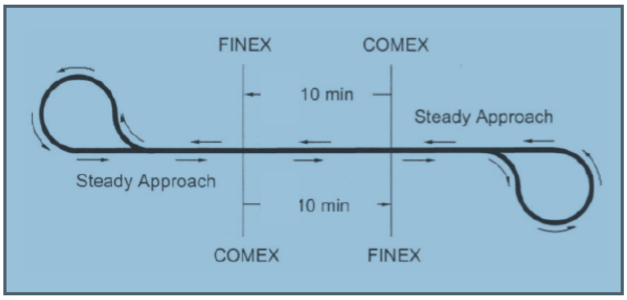


Figure 2 Ship Trajectory during Speed Trial (International Towing Tank Conference, 2017)

	Acceptable measurement devices	Unit
Ship Track	DGPS	[Latitude, Longitude] or [m]
Speed over Ground	DGPS	[Knots]
Shaft Torque or Shaft Power	Torsion meter with calibrated permanent torque sensor or strain gauges. Power calculated from torque and RPM	[kNm], [kW]
Shaft RPM	Pick-up, optical sensor, ship revs counter	[RPM]
Propeller Pitch	Bridge replicator	
Time	GPS Time, Stopwatch	[s]
Water depth	Ship echo sounder + nautical charts	[m]
Ship heading	Gyro compass, or compass- DGPS	[deg]
Relative wind, speed and direction	Ship anemometer, dedicated trial anemometer	[m/s], [knots], [deg]
Wave height, period and direction	Wave measuring device such as wave buoy, radar, or lidar. Observation by multiple Mariners.	[m], [sec], [deg]
Draughts	Physical observation and / or calibrated draught gauges	[m]

Table 1 Primary parameters

7.3 Secondary parameters

Seawater density	Salinity sensor, Conductivity Density Temperature (CDT) sensor	[kg/m³]
Seawater temperature	Thermometer, CDT sensor	[°C]
Air temperature	Thermometer	[°C]
Air pressure	Barometer	[hPa], [mBar]

Figure 1 measured parameters (International Towing Tank Conference, 2017)

Table 1. Approach time and distance (International Towing Tank Conference, 2017)

Size of ship [DWT]	Approach distance [nm]	Approach time [min]		
		15 knots	20 knots	25 knots
50,000	4 – 5	20	15	12
100,000	5 – 7	26	20	16
250,000	8 – 10	40	30	24
500,000	12 – 15	60	45	36

On *table 1*, the minimal approach time can be read. The bigger the vessel and the lower the speed, the more approach time is needed so the parameters have time to stabilize.

Trial Execution

1. Sail approach distance in straight course
2. Prepare to take all measurements
3. Start speed run. Control levers will remain untouched and maximum rudder angle cannot exceed 3 degrees to either direction. After a minimum of 10 minutes the speed run shall stop.
4. Make environmental observations throughout the trial
5. Turn the vessel with small rudder actions to sail the same geographical region as the first run
6. Repeat steps 2 to 6 until all data is complete or boundary conditions are exceeded

(International Towing Tank Conference, 2017)

2.3 Known Research

Real-time optimization of ship energy efficiency based on the prediction technology of working condition

Here a university team found a way to optimize the ship speed in real-time. It was based on the weather forecast of a preset route and acquired ship efficiency data. It achieved it through setting up a mathematical model for the ship and introducing the forecasted weather on each leg of the journey to give a recommended engine speed. To set up the model various sensors were installed. The sensors tested for ship speed, shaft speed, fuel consumption rate, wind strength and water dept.

(Wang, Yan, Yuan, & Li, 2016)

Brandstofbesparing door Trimoptimalisatie

In this research was done on the effect of trim on fuel consumption. The information gotten was conclusive, though not much data was acquired. Still, an effective measuring protocol was set up, without having to do a test run in two directions. It also factored out external disturbances. The measuring protocol took into account similar data as the speed trial and the speed optimization research. Though it did a straight trial run over a longer period to get a good average per setpoint. External disturbances were factored out by only doing the trial on a day, where the disturbances were negligible. Interestingly it was noted that a 10 cm change in trim could cause a three percent increase in fuel used per nautical mile. (van Asten, 2015)

ALP Future Class Fuel Consumption

Fuel consumption in shipping has always been a big cost factor and therefore it was continuously something to monitor. So it was for ALP as well and there has been some investigation into the topic. Some captains have done tests to find out how efficiently they can run the ship and where the optimums lie. The efforts to do so have been noted and shown below.

Consumption Table ALP Striker

M.E.						Pitch					
1	2	3	4	Load	Fixed Speed	PS	SB	Shaft Gen.	STW	Consumption	Remarks
				85%	Yes	Feathering	57%	Yes	8,5	16.9 a 17.3 Ton	Wind 15-36 kn, Sea 1-3m, WB=63%,Draft F-7.3m: A-7.6m
				89%	Yes	60%	Feathering	Yes	10,2	17 a 17.5 Ton	Calm sea & no wind, vessel almost empty
				95%	Yes	62 a 63%	Feathering	Yes	10,6	18.5 a 19 Ton	Calm sea & no wind, vessel almost empty
				80%	Yes	Feathering	55%	Yes	8,8	17 Ton	
				85 a 90%	Yes	68%	68%	Yes	13,1	34 Ton	
				62 a 66%	Yes	50%	50%	Yes	10,3	x	Calm sea & no wind, Draft 6.1/6.5 mtrs Displ. = 7024
				65 a 69%	Yes	55%	55%	Yes	11,4	x	Calm sea & no wind, Draft 6.1/6.5 mtrs Displ. = 7024
				73 a 74%	Yes	60%	60%	Yes	12	x	Calm sea & no wind, Draft 6.1/6.5 mtrs Displ. = 7024
				78 a 83%	Yes	65%	65%	Yes	12,8	x	Calm sea & no wind, Draft 6.1/6.5 mtrs Displ. = 7024
				87 a 93%	Yes	70%	70%	Yes	13,9	x	Calm sea & no wind, Draft 6.1/6.5 mtrs Displ. = 7024

Figure 3 ALP Consumption Table (ALP Maritime Services B.V., 2018)

Here some data is displayed concerning the fuel consumption for one and two engines running. Consumption was in tons fuel used per day. The amount of data is somewhat limited and incomplete.

ALP Speed trials

Trials to be measured over a distance of 1 Nautical Mile

2 Main Engines

Load of M/E	Draft FWD/AFT	Displ.	Start time	Weather	Wave	Swell	Current (Relative)		Wind (Relative)		Water Depth	Rudder (deg)		Run time		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	m	T	UTC		(m)	(m)	deg	kt	deg	m/s	(m)	PS	SB	min	sec	(kt)	(kt)
50	8.2 / 7.8	9822	09:01	good	1	1,5	180	0,7	30	0,36	3600	0	0	8	38	7,7	7,1
75	8.2 / 7.8	9822	09:24	good	1	1,5	180	0,7	30	0,36	3600	+1 / -1	+1 / -1	4	43	12,6	12,1
85	8.3 / 7.7	9822	09:33	good	1	1,5	180	0,7	30	0,36	3600	+2 / -2	+2 / -2	4	25	13,6	13
100	8.3 / 7.7	9822	09:42	good	1	1,5	180	0,7	30	0,36	3600	+2 / -2	+2 / -2	3	59	14,7	14,2

Load of M/E	FO Cons	Main Engine RPM				CPP RPM		Blade Angle %		Main Engine output KW					Propulsion Power KW (If applicable)	
%	kg/h	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB
50	725	592			592	112	112	32	33						1570	1495
75	1165	592			592	112	112	61	63						2615	2730
85	1360	592			592	112	112	67	68						3080	3250
100	1640	592			592	112	112	74	75						3775	3800

Speed trials done without shaft generators online for a more stable load. AE generator load ~600kW. Fuel in use on PS engine's: Curacao 963.2 kg/m3, SB engine's OPL Walvis bay (apr 2018) 985.2 kg/m3. (VAF consumption meters on engine's setup on Curacao fuel type)

Figure 4 ALP Speed Trials 2 Main Engines (ALP Maritime Services B.V., 2018)

ALP Speed trials

Trials to be measured over a distance of 1 Nautical Mile

4 Main Engines

Load of M/E	Draft FWD/AFT	Displ.	Start time	Weather	Wave	Wave (Relative)	Swell	Swell(Relative)	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Run time		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	[m]	[T]	UTC		[m]	[deg]	[m]	[deg]	[deg]	[kts]	[deg]	[m/s]	[m]	PS	SB	[min	[sec]	[kts]	[kts]
50	8.2 /7.8	9822	09:55	good	1		1,5	1,5	180	0,7	30	0,36	3600	+2 / -2	+2 / -2	4	12	14	13,4
75	8.3 / 7.7	9822	10:07	good	1		1,5	1,5	180	0,7	30	0,36	3600	+3 / -3	+3 / -3	3	35	16,7	16,2
85	8.4 / 7.6	9822	10:19	good	1		1,5	1,5	180	0,7	30	0,36	3600	+4 / -4	+4 / -4	3	25	17,2	16,9
100	8.4 / 7.6	9822	10:30	good	1		1,5	1,5	180	0,7	30	0,36	3600	+4 / -4	+4 / -4	3	20	17,9	17,5

Load of M/E	FO Cons	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [KW]					Auxilary power demand [KW]		Propulsion Power [KW] (If applicable)	
%	[kg/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	PS	SB
50	1517	592	592	592	592	112	112	70	71								3200	3600
75	2305	592	592	592	592	112	112	86	87								5400	5570
85	2680	592	592	592	592	112	112	91	92								6340	6700
100	3330	592	592	592	592	112	112	96	97								7500	8180

Speed trials done without shaft generators online for a more stable load. AE generator load ~600kW. Fuel in use on PS engine's: Curacao 963.2 kg/m3, SB engine's OPL Walvis bay (apr 2018) 985.2 kg/m3. (VAF consumption meters on engine's setup on Curacao fuel type)

Figure 5 ALP Speed Trials 4 Main Engines (ALP Maritime Services B.V., 2018)

Here a more thorough test was done giving a bit more complete image of the fuel consumption. The test was done without shaft generator now to give a more stable load. It can be seen that the external factors were quite small, except for swell. At 1.5 meters this can still be considered significant according to the ITTC speed trail procedure.

Measuring Speed

By IMO law, all ships upwards of 300 GT are required to have a device on board that can measure STW. It has to be able to display the speed with a maximum error of two percent or 0.2 knots, whichever is greater. For analog displays that is 2.5 percent or 0.25 knots. It also needs to fulfill these requirements when the ship is rolling up to five degrees and pitching up to five (Netherlands Regulatory Framework, 2015).There is a variety of such devices on the market.

To measure speed there are a few options

1. Dutchmen's log
2. Sailing a set distance
3. Using GPS/DGPS
4. EM log
5. Doppler log
6. Pitot tube flow meter

Because measuring STW is chosen, method 2 and 3 do not qualify. Method 1 is inaccurate and outdated. Method 6 is based on the static and dynamic pressure difference in the water passing the ship, which small when traveling at low speed. Because of this the accuracy at low speeds is insufficient. This only leaves the EM log and the Doppler log for suitable methods. Both are accurate. The EM log can have an error of only 0.1%. Though this log needs frequent maintenance and calibration. (Reedijk, Nautische Instrumenten en Systemen, 2007)

DOPPLER LOG

To measure STW accurately the doppler log is used. This device measures both Speed Over Ground (SOG) and STW. It functions are based on the doppler principle. A ultrasonic signal is send, and the signal reflected back to the receiver is at a higher frequency due to the Doppler effect. With the difference in frequency, the speed is calculated.

The error with the simple configuration can be noteworthy. Though, with the Janus configuration, where a signal is send both forward and aft, the error becomes insignificant. The Doppler log does have an Achilles' heel though. That is air bubbles. Though only during extreme weather or reversing the ship, this can cause issues.

(Reedijk, Nautische Instrumenten en Systemen, 2007)

Measuring Fuel Consumption

Tank Soundings

All ships have ways of doing tank soundings. It is critical to determine the weight inside the tanks so one is able to make statements about the stability condition of the ship. By measuring the volume of liquid inside the tank, the weight can be calculated. Measuring the quantity of liquid inside the tank can be done: mechanically, electronically or manually.

Electronic sounding
In electronic sounding, a sensor is used which senses the pressure inside the sounding pipe or by sensing the tank pressure and sends a signal to the receiver. Here the signal is translated to the tank's content value with the help of a PLC circuit. The value is displayed using electrical operated servo gauge or electrical capacitance gauge.
Mechanical sounding
Mechanical provisions are made inside the tank so that the quantity of tank can directly be read through a level marker or an indicator or a float level sensor. In the tank a float can be attached to a pointer through a pulley. As the level varies pointer readings will change accordingly. A level gauge glass is also attached to the tank to read the quantity of the fluid inside the tank. The gauge may also be a pneumatic/hydraulic operated gauge or differential pressure gauge.
Manual sounding
In this method, a sounding tape is used with a heavy weight bob attached to one end of the tape using a strap hook. It is the most commonly used method used for calculation of tank capacity. If the capacity inside a tank is more, free space of the tank is measured to calculate total capacity of the tank. This method is called ullage measurement.

Figure 6 Sounding (Faber, Nelissen, & Smit, 2013)

On average, the accuracy of tank monitoring is estimated to be 2-5 percent.

(Faber, Nelissen, & Smit, 2013)

Flow meters

Flow meters determine the amount of flow that flows through a pipe. By using this the fuel oil consumption of ships can be measured accurately. There is a diverse range of flow meters available. It can be measured: electronically, mechanically, optically and pressure based. For use of measuring fuel consumption the following types are used:

- Electronic flow meters
- Velocity sensing flow meters
- Inferential flow meters
- Optical flow meters
- Positive displacement flow meters
- Mass sensing flow meters

On board the "Future Class" vessels the turbine flow meters are installed. These have turbines inside a pipe. The speed of the turbine is converted to an electronic signal which is converted to volumetric flow. By also measuring temperature, the fuel consumption in kilograms can be calculated.

"In industry axial turbine flow meters are used to measure volume flows of gases and liquids. They are considered reliable flow meters and at suitable conditions can attain high accuracies in the order of 0.1% for liquids and 0.25% for gases. An accuracy up to 0.02% can reached for high accuracy meters at ideal flow conditions." (Wadlow, 1998) In (van Asten, 2015) this is confirmed again by mentioning a accuracy of 0.1 to 0.2% for turbine flow meters.

2.4 External Factors

To have reliable results, external factors are ideally excluded. For a real test at sea, it would not be feasible to wait for all the external factors to diminish.

Though in (van Asten, 2015) was chosen to wait for near perfect conditions and the trial was conducted during a steady 4 to 7 knots and 0.4 to 0.6m waves. As long as the conditions were stable, the weather was ruled a constant. During the trial and afterwards, the conditions versus expected results were analyzed to see if the conditions interfered with the results.

To manage external factors, the sea trials contain a double run, where the ship sails directly into the waves and again with the waves. This way, the average can be taken and the waves, wind and current can be ruled out as a variable. For speed trial analysis, there are four main methods:

- Means of means method
- Schoenheer's method
- Taniguchi-Tamura's method
- BRSA standard method

All methods sail against and with the waves. The only differences lie in the ways of analyzing and correcting the data gotten from the trial.

(Naoji, 2015)

Currently the following analysis procedure is used.

According to the ITTC the analysis of the speed/power trial should contain the following:

- "Evaluation of acquired data
- Correction to ship power for resistance increase due to wind, waves, water temperature and salt content
- Correction to ship's speed at each run for the effect of current
- Correction to ship's speed at each run for the effect of shallow water
- Correction to ship power for displacement
- Presentation of the trial results"

(International Towing Tank Conference, 2017)

By looking at figure seven, the process overview becomes clear. The procedure takes the filtered data and uses the average for further correction. Then it offers multiple correction methods for correcting wind and waves. From here current correction takes place can by either the “Iterative” method or the “means of means” method. Now possible corrections for shallow waters are made. After, a final correction is made if the trial displacement differs from contract displacement. Then the final result is shown. It shows the ship performance with no wind, wave, current and shallow water effects at contract displacement.

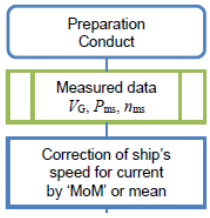
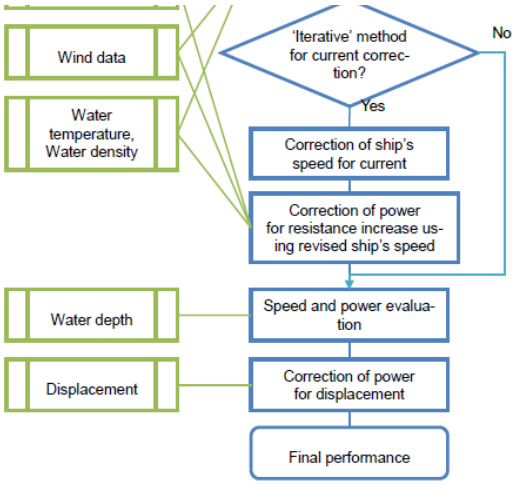


Figure 7 Flowchart Result Processing ITTC (International Towing Tank Conference, 2017)



3. Method

The purpose of this research was to determine the economically optimal drivetrain configuration for any given speed STW on board the ALP STRIKER.

In line with this is the main question: "During free sailing, what is the most economic propulsion configuration and speed on the ALP STRIKER?". To answer this the following sub-questions were proposed:

1. "How can the fuel consumption and speed accurately be measured?"
2. "How can external factors be taken into account?"
3. "How can the data be processed reliably?"

3.1 Research Design

To find out what propulsion configuration is most economic, quantitative tests were to be done. By looking at similar research and the sea trails, the important parameters for operational efficiency on a ship were found. The measuring protocols of the existing research and sea trials tests were combined and adapted to the protocol found in *chapter 3.2*. While on route to the next job, a day with calm and steady weather was chosen for the trials to take place. These tests were performed with several configurations that seem the most economic. The ship sailed in a steady course, varying its' speed in steps. When a test in one configuration was completed it went on to the next configuration.

Most importantly it was noted how much fuel consumption the ship has at certain main engine load points and to which speed and pitch that corresponds. The other factors recorded are all factors of influence as seen in the conceptual model. The data that was divided into the following categories:

- Ship condition
- Primary parameters
- Secondary parameters
- External disturbances

From general knowledge of the losses in the drivetrain configurations and some previous testing, the following configurations were chosen as they were likely to be the most economic. Note that the configurations are only comparable for the limited time that they overlap in speed.

- 1 engine, feathering engaged, 1 SG
- 2 engines, 2 propellers, 2 SG's

3.2.1 Data Collection Protocol

To get accurate results a guideline was made for the test results to be valid. The test were conducted on a day with good weather and not much external disturbances. The engine room crew had to put the ship into the required drivetrain configuration. Then the ship had to speed up or down in by adjusting the pitch of the propeller till a set main engine load point was reached. Then there was some time for the parameters to stabilize, after which data was taken.

Ideally the ship would follow the same track as with the sea trails heading into the waves, then turning and run the same track with waves from the aft. The average of the two would well rule out significant external factors. Though the ship was bound by a schedule from which it cannot vary much. So this was unfortunately not possible and the ship sailed in a straight course.

To get reliable results the ship had to adhere to the following guidelines at all times during the test. If it was not possible, the test had to be stopped.

The crew was requested to stay within 5 percent of the load requested in the first row of the table (see *appendix 1*). Once the speed had stabilized, the engine crew was to be notified. They would collect the remaining data including the actual load. Once they had collected all data, they called the bridge to move to the following load point on the list. This continued till all the load points were filled in.

All data was taken directly from K-Chief or other displays, though fuel consumption could only be taken reliably at the booster modules' fuel counters. From there initial value was written down and after 20 minutes the value was taken again.

All the following points was to be checked off, otherwise the data was not valid.

- Take **note** of **External disturbances** (current, sea state & wind) and <u>minimalize</u>
  To be stable throughout the test of one configuration.
- **Waves** and **swell** should not exceed the height of ± 1.5m, according to the following formula:

$$\mathrm{H}_{wave} \leq 1.5 * \sqrt{\frac{L_{pp}}{100}}$$

- **Wind** should remain under 11 knots or 4 Beaufort
  The wind resistance then is insignificant when compared to the total resistance.
- Areas with large **variations in current** are to be **avoided**
  To rule out current the vessel will only use speed through water as its' speed and will not undergo the trail in areas with large current variations
- **Shaft generator loads** to be kept **constant** or average over 10 minutes is to be taken
  Changes in shaft generator load will change fuel consumption of the main engines and possibly speed, when the load gets high enough to enable load reduction of the engine and reduce pitch.
- **Time to stabilize condition** (load and speed)
  At least 10 minutes should be taken after the data has stabilized before it is collected. Total stabilization time varies with the amount of engines running.
- **No course changes**
  Changing course destabilized the data by the extra drag involved with use of the rudder.
- **No trim changes**
  Trim also has an effect on propeller efficiency, therefore no ballast water should be displaced.
- **No draft changes**
  A change in draft changes the resistance of the vessel and there the speed and consumption. Again the fuel used should not affect the draft enough to be sufficient.
- **Minimum water dept** should be should be met, satisfying both of the following formulas:

$$h_{min} = 2 * \sqrt{B * T} = 166{,}95 \text{ m} \quad \text{and} \quad h_{min} = 2 * \frac{{v_s}^2}{g} = 28{,}8\text{m}$$

- **Load reduction** should not be activated so keep the load under 95 percent. Load reduction will vary pitch and the data will be unusable.
- **Amount of measurements**
  For each drivetrain configuration at least four data points have to be taken across the range 10-25, 25-50, 50-75, 75-100 percent load of the main engines.
- The **same type of fuel** is to be used. Different quality of fuel impacts engine fuel consumption and will influence the results.
- **Rudder actions** should be **minimized** by checking proper controller settings and rudder angles are not to exceed 5 degrees.

Data to be collected

Table 2. Data to be collected

Parameters	Data collection method	Unit
Speed through Water	Doppler log	Kts
Fuel consumption	Flow meter at booster modules	Liters
Load	K-Chief	%
Heading	Gyrocompass	Degrees
Pitch	Engine management system	%
Shaft and Engine speed	K-Chief	RPM
Auxiliary Power Demand	K-Chief	kW
Draughts	K-Chief	Meters
Water dept	Dept log	Meters
Wind direction, speed	Anemometer	Degrees, kts
Wave Height, Period, Direction	Visual check	m, sec, Degrees
Propulsion Power	PEM efficiency Display by Torque Sensor	kW
Fuel Temperature	Temperature transmitter at booster module	°C
Charge Air Temperature after Cooler	Temperature transmitter at Intake Manifold	°C
Air Pressure	Barometer	hPa

3.2.2 Data processing

After the data was noted down in the test sheets (see attachment 1), the data was put into Microsoft Excel (see attachment 2) to be processed. Fuel consumption was calculated in liters and from there the fuel effectivity was calculated. The data was checked as discussed before and evaluated for validity. After, the data from all configurations was put into the following graphs:

- Fuel consumption → Fuel consumption [mt/day] to speed [kts] (STW)

- Fuel effectivity → Fuel effectivity [kg/nm] to speed [kts] (STW)

In the conclusion the differences in fuel consumption, fuel efficiency and fuel effectivity are explained to clear up the confusion and show what configuration is really the most profitable for any

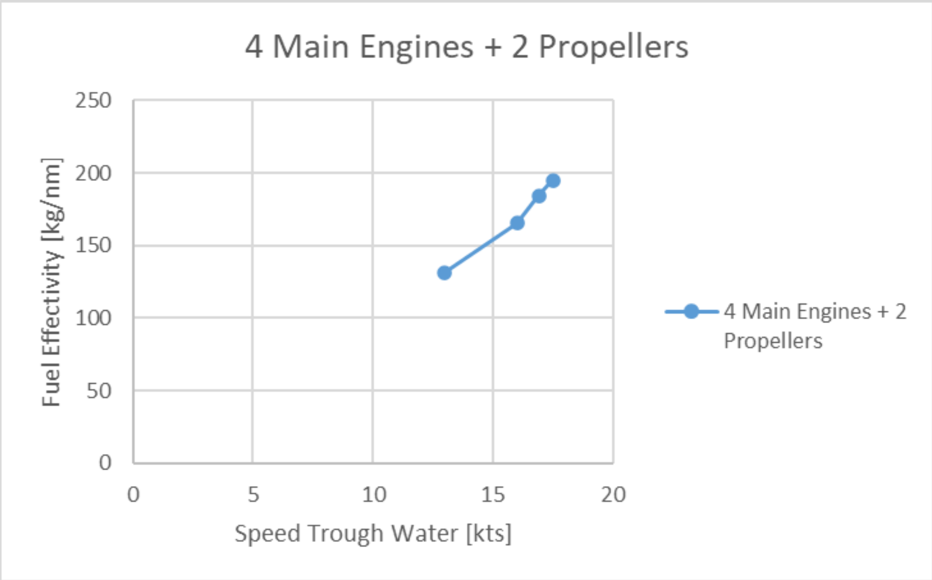


Figure 8. Example Fuel Effectiveness

given speed (disregarding schedule). When all the configurations show, the bottom line is the most fuel effective configuration for that speed.

The graphs were collected for all configurations and put in a single graph to compare. Then the following graph represents clearly how efficient each configuration is at any given speed. Now could be clearly seen what configuration is most fuel effective at what speeds. The lower the figure, the better.

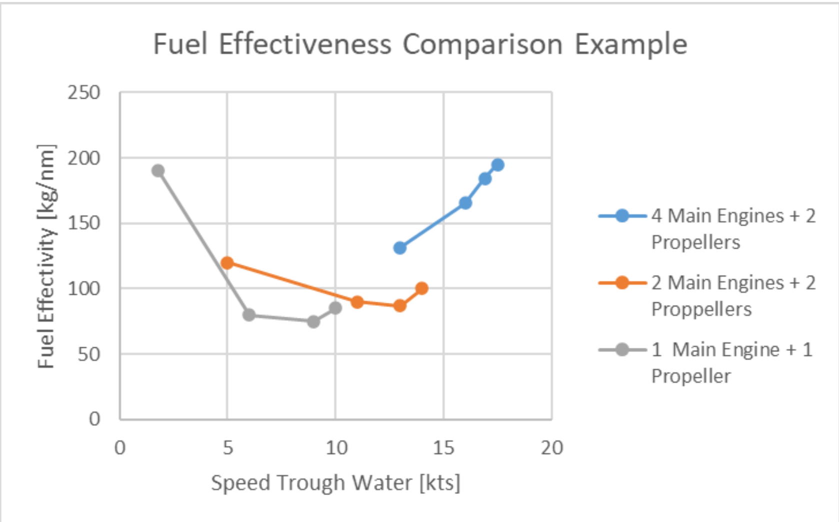


Figure 9. Example Fuel Effectiveness Comparison

Formulas

One of the important conversions was fuel consumption. The fuel consumption was measured in liters per 20 minutes. This was converted to liters per hour. To convert this to kg/h the correction factor from the fuel supplier was required. As the density varies with temperature a correction factor was needed. See the following formula:

$$\rho_{fuel} = \rho_{15°C} \cdot (1 - ((T - 15) \cdot correctionfactor))$$

Where:

ρ_{fuel} = density of the fuel at the flowmeter [kg/m^3]

$\rho_{15°C}$ = density of fuel at 15°C [kg/m^3]

T = temperature at flowmeter [°C]

To then convert to fuel consumption:

$$V_{fuel} \cdot \rho_{fuel} = Fuel\ Consumption$$

Where:

V_{fuel} = volume of fuel past through the flowmeters [m^3/h]

Fuel consumption = total fuel consumption [kg/h]

Using the fuel consumption per hour and the speed over ground, the fuel effectivity was calculated.

$$Fuel\ Effectivity = \frac{Fuel\ Consumption}{STW}$$

Where:

Fuel effectivity = effectiveness of the fuel used to power the ship through the water [kg/nm]

STW = Speed through water [kts]

3.3 Fuel Effectiveness Comparison to previous Research

In *chapter 2.3* previous research on fuel consumption on the ALP STRIKER was discussed. By converting these figures to fuel effectiveness, the new test data was compared to the old data. This way the old data adds validity to the new test results or prove an error was overlooked. To convert the old fuel consumption to the new fuel effectiveness data, the fuel consumption was converted to kilograms per hour. Then the fuel effectiveness calculation in the previous paragraphs was used. Then it was put into a graph and then compared in a graph like in *figure 10*. Any significant differences in secondary parameters or ship condition are discussed.

3.4 Validity of the measurements

To make sure the questions would get answered accurately, it was important to take a critical look at the data collected. In the theoretical framework it was made sure that all the important factors were included to correctly answer the questions.

First of all the tests used had to adhere to all the points mentioned in the test protocol. Secondly, to get a reliable results, the amount of tests conducted per configuration had to be at least 4 times.

Though, the full configuration tests could not be conducted. Consequently, adding individual datasets to the existing data had to suffice.

3.4.1 Accuracy of main testing equipment

The main parameters are vital to get accurate results. The doppler log only gave its' reading in tenths of knots. The fuel counter at the booster module gave the reading in whole liters. This was not ideal and the accuracy was determined by showing the worst case scenario. The flow and speed were quite steady, but a figure rounded up could give a significant difference which will have to be tested.

As the fuel counter counts in whole liters, one liter was added or subtracted. Then the same was performed with tenths of knots. The fuel effectivity was calculated again with the highest error this could give. From this the positive and negative errors across the range were given.

Note that this was a possible error from the way the fuel counter and doppler log were read from the display. Not from the sensor itself.

4. Results

By use of the sub-questions, the main question: “During free sailing, what is the most economic propulsion configuration and speed on the ALP STRIKER?” is answered. To answer the sub-questions, the theoretical framework was put together. Following this, the method provided trial procedures to get valid results. Following this, the main question of this thesis is answered in the conclusion.

4.1 Accuracy primary measurements

This chapter will assess the first question: “How can the fuel consumption and speed accurately be measured?” How, was already considered in the theoretical framework and the method. Now a critical assessment was made of the resolution of the final numbers.

Table 3. Possible Error Primary Variables

Orig. No.		ERR HIGH		ERR LOW	
kg/nm	kts	kg/nm	kts	kg/nm	kts
118,1	5,3	121,3	5,2	115	5,4
87,3	10,9	88,6	10,8	86,1	11
100,4	13,3	101,5	13,2	99,2	13,4
100,8	13,8	101,9	13,7	99,7	13,9

As described in the method, the primary variables: fuel flow and ship speed were rounded up or down. Whole liters for fuel consumption and tenths of knots for ship speed. The situations given the biggest error are shown in the table. Here, fuel consumption in liters was increased, when the speed in knots was decreased, giving a higher fuel effectivity. Vice versa for the lower error. After it was put in the graph shown on the next page.

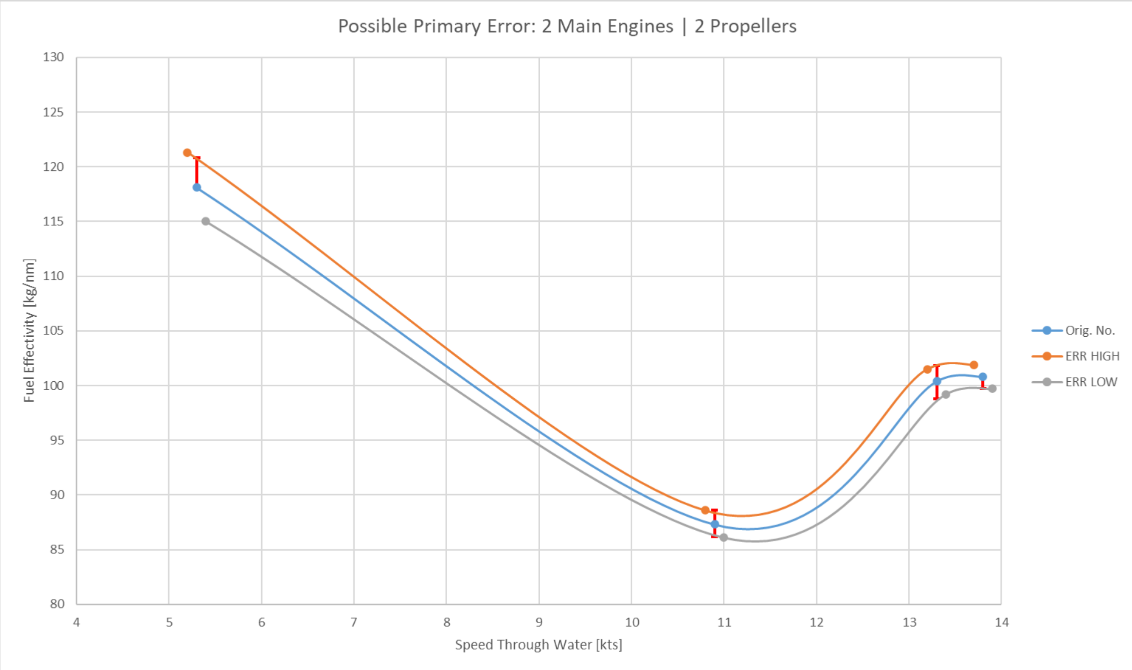


Figure 11. Possible Primary Error: 2 Main Engines

Table 4. Possible Final Error

Fault High [%]	Fault Low [%]
2,71	-
1,30	1,10
1,45	1,60
-	1,10

By using individual error bars the following errors in *table 2* were found. Again, note that this is a possible error from the way the fuel counter and doppler log are read from the display. Not from the sensor itself.

Now the same was done for the configuration with one main engine and one propeller running.

Table 5. Possible Error Primary Variables: 1 Main Engine

Orig. No.		ERR HIGH		ERR LOW	
kg/nm	**kts**	**kg/nm**	**kts**	**kg/nm**	**kts**
187,9	1,8	200,4	1,7	176,7	1,9
65,6	6,8	66,9	6,7	64,3	6,9
63,3	9,1	64,2	9	62,3	9,2
67,7	10,6	68,6	10,5	66,9	10,7

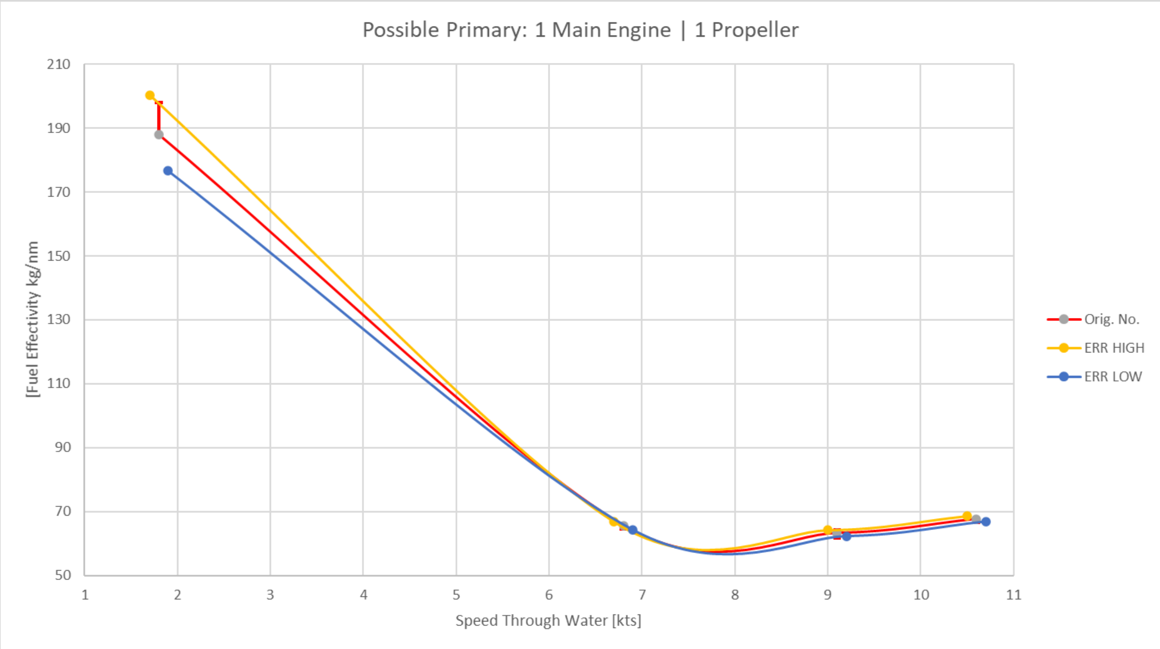


Figure 12. Primary Error: 1 Main Engine

Here the table and graph show that in the bottom of the speed range, the resolution of the primary dataset was quite low and could cause a significant error of 10%.

Table 6. Possible Final Error: 1 Main Engine

Fault High [%]	Fault Low [%]
10,0	-
0,5	1,0
1,0	1,6
-	1,2

4.2 External Variables and Ship Condition

This chapter involves the sub-question: “How can external factors be taken into account?”. This was answered in the theoretical framework and the method by setting up test procedure and requirements.

Ideally the fuel consumption and ship speed would be the only dependent variables. In practice there will always be other variables of influence that are changing. Weather being a primary one. The goal here was to keep the external variables stable and low, so that they could be ruled out as insignificant. To do so, these variables and ship condition were monitored for the whole duration of the trail. In the following tables, weather and ship condition are shown.

4.2.1 Configuration: 2 Main Engines and 2 Propellers

Table 7. Ship Condition and External Variables: 2 Main Engines

2 Main Engines + 2 Propellers				11/Oct						
Load of ME	**Draft FWD/AFT**	**Displ.**	**Start time**	**Ambient Pressure / Temperature**	**Wave**	**Wave Direction (Relative)**	**Wave Period**	**Swell**	**Swell Direction (Relative)**	**Swell Period**
%	[m]	[t]	UTC	[Bar]/[°C]	[m]	[deg]	[sec]	[m]	[deg]	[sec]
20										
40	7,2 / 6,8	7949,5	08:25	1015 /22	0,8	21	3	0,5	1	5
60	7,2 / 6,8	7949,5	08:55	1015 /24	0,8	21	3	0,5	1	5
80	7,2 / 6,8	7949,5	09:24	1015 /26	0,8	21	3	0,5	1	5
95	7,2 / 6,8	7949,5	09:55	1015 /29	0,8	21	3	0,5	1	5

Table 8. External Variables: 2 Main Engines

Load of ME	**Current (Direction Relative)**		**Wind (Direction Relative)**		**Water Depth**	**Rudder Deviation [deg]**		**Average Speed Over Ground (SOG)**	**Average Speed Through Water (STW)**
%	[deg]	[kts]	[deg]	[kts]	[m]	PS	SB	[kts]	[kts]
20									
40	71	0,5	43	14	2672	5	5	5	5,3
60	71	0,5	45	13	3060	5	5	10,6	10,9
80	71	0,5	51	14	3500	5	5	12,9	13,3
95	71	0,5	58	14	4100	5	5	13,1	13,8

As the tables above show, the external circumstance appear to be stable. Though the wind was a bit above the predetermined limit of 11 knots. Unfortunately at this time, the test had to be continued as the planned time window for the trials were coming to an end and the weather forecast looked stable.

Table 9. Secondary Parameters: 2 Main Engines

ME Load	**Main Engine RPM**				**CPP [RPM]**		**Blade Angle [%]**		**Main Engine output [%]**					**Auxiliary Power Demand [kW]**		**Total Aux Power Demand**	**Propulsion Power [kW]**	
%	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total [kW]	PS	SB	PS + SB	PS	SB
20																		
40	592			592	112	112	27	17	38			40	3510	168	272	440	1100	1100
60	592			592	112	112	59	53	59			59	5310	168	280	448	1920	2100
80	592			592	112	112	69	72	81			81	7290	176	256	432	3000	3130
95	592			592	112	112	73	73	73			90	7335	175	297	472	3300	3100

Also here all the figures look stable. The auxiliary power only went up by 32 kW’s. At 6400 kW’s of propulsion power this was negligible.

4.2.2 Configuration: 1 Main Engine and 1 Propeller

Table 10.Ship Condition and External Variables: 1 Main Engine

1 Main Engine + Feathering Shaft						11/Oct				
Load of ME	**Draft FWD/AFT**	**Displ.**	**Start time**	**Ambient Pressure / Temperature**	**Wave**	**Wave Direction (Relative)**	**Wave Period**	**Swell**	**Swell Direction (Relative)**	**Swell Period**
%	[m]	[t]	UTC	[Bar]/[°C]	[m]	[deg]	[sec]	[m]	[deg]	[sec]
20										
40	7,2 / 6,8	7949,5	10:33	1015 /29	0,8	21	3	0,5	1	5
60			11:10	1015 / 30	0,8	21	3	0,5	1	5
80			11:40	1015 / 30	0,8	21	3	0,5	1	5
95			12:10	1015 / 30	0,8	21	3	0,5	1	5

Table 11. External Variables: 1 Main Engine

Load of ME	**Current (Direction Relative)**		**Wind (Direction Relative)**		**Water Depth**	**Rudder Deviation [deg]**		**Average Speed Over Ground (SOG)**	**Average Speed Through Water (STW)**
%	[deg]	[kts]	[deg]	[kts]	[m]	PS	SB	[kts]	[kts]
20									
40	71	0,5	49	11,5	3500	10	10	1,4	1,8
60	71	0,5	54	11	3500	8	8	6,1	6,8
80	71	0,4	51	7	3440	7	7	8,4	9,1
95	71	0,4	51	6	3440	7	7	10	10,6

Ship condition was the same, as the this configuration was tested the same day. Though, the wind now was at the predetermined maximum, it did go down by almost half during the trial. This is not ideal. Also rudder deviations were increased at lower speed and actually exceeding the five degree limit for the whole time.

Table 12. Secondary Parameters: 1 Main Engine

Load of M	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW]		Propulsion Power [KW]	
%	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	PS	SB
20																	
40				592		112		5				44	1980		526		1065
60				592		112		35				58	2610		520		1700
80				592		112		54				75	3375		536		2420
95				592		112		65				92	4140		547		3200

Again during this test the figures were stable. Though, comparing it to the previous configuration, the auxiliary power demand did show a 100 kW difference. During all the trials the same fuel was used with a heat value of 43.02 MJ/kg.

4.3 Trial Measurements

When the trial was conducted, the spreadsheet seen in *attachment 1* was filled in. Afterwards, that data was filled into an Excel spreadsheet to process the data. The data is the same, only with calculations for fuel consumption added. Two configurations were tested on the same day. First two engines were started on either shaft and the trail began. After all the datapoints were taken the configuration with one engine running and the other propeller in feathering mode was run. The complete results are shown in *Attachment 5 and 6*. Not a single course change was made for the entire duration of the trial.

4.3.1 Fuel Effectivity: 2 Main Engines and 2 Propellers

Table 13. Fuel Consumption

Load of ME	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (Read over 20 minutes)	
	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)
%	Litres start	Litres end	Litres start	Litres end	L	L
20						
40	528748	528879	478558	478682	131	124
60	528996	529202	478790	478972	206	182
80	529335	529619	479095	479355	284	260
95	529762	530044	479500	479785	282	285

After the fuel oil consumption was measured in liters, it was multiplied by three to show consumption per hour. Then the fuel density of 827.1 kg/m^3 at 15°C, was corrected for actual temperature on both port- and starboard side fuel systems. Now the consumption could be calculated in kilograms per hour.

Table 14. Density Correction to Calculate in kg's

Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)
[°C]		[kg/m3]		Given by fuel supplier	Portside (no.1)	Starboard (no.2)	TOTAL
Portside (no.1)	Starboard (no.2)				[kg/h]	[kg/h]	[kg/h]
30,7	33,4	818,79	817,36	0,0006	321,78	304,06	625,84
30,7	34,2	818,79	816,94		506,01	446,05	952,06
30,9	34	818,68	817,04		697,52	637,29	1334,81
31	33,5	818,63	817,31		692,56	698,80	1391,36

Total fuel consumption and average speed through the water were used to calculate the fuel effectivity. From here the graph from *figure* 11 took form.

Table 15. Fuel Effectivity

Load of ME	Total FO Consumption (Calculated)	Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
%	[kg/h]	kg/nm	[kts]
20			
40	625,84	**118,1**	5,3
60	952,06	**87,3**	10,9
80	1334,81	**100,4**	13,3
95	1391,36	**100,8**	13,8

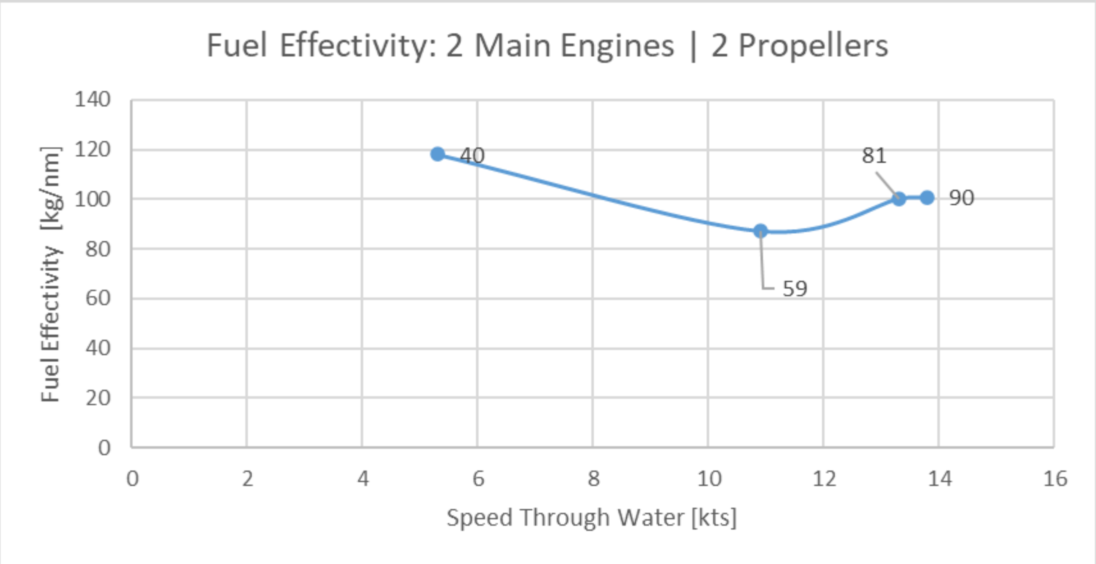


Figure 10. Fuel Effectivity: 2 Main Engines

Now could be seen that with this ship condition and propulsion configuration the ship sails most effectively at approximately 11 knots with an engine load of 60% and 60% pitch. Note that this was with an auxiliary power demand around 400 kW's.

4.3.2 Fuel Effectivity: 1 Main Engine and 1 Propeller

The same was repeated with the configuration of one main engine and one propeller. The other propeller was put into feathering mode.

Table 16. Fuel Consumption

Load of ME	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (Read over 20 minutes)	
%	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)
	Litres start	Litres end	Litres start	Litres end	L	L
20						
40			479974	480112		138
60			480211	480393		182
80			480482	480717		235
95			480969	481262		293

Table 17. Fuel Density Correction to Calculate in kg's

Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)
[°C]		[kg/m3]		Given by fuel supplier	Portside (no.1)	Starboard (no.2)	TOTAL
Portside (no.1)	Starboard (no.2)				kg/h	kg/h	[kg/h]
	34,1		816,99	0,0006		338,23	338,2
	34,5		816,78			445,96	446,0
	34,7		816,67			575,75	575,8
	34,2		816,94			718,09	718,1

Table 18. Fuel Effectivity: 1 Main Engine

Load of ME	FO Consumption (Calculated)	Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
%	[kg/h]	kg/nm	[kts]
20			
40	338,23	**187,9**	1,8
60	445,96	**65,6**	6,8
80	575,75	**63,3**	9,1
95	718,09	**67,7**	10,6

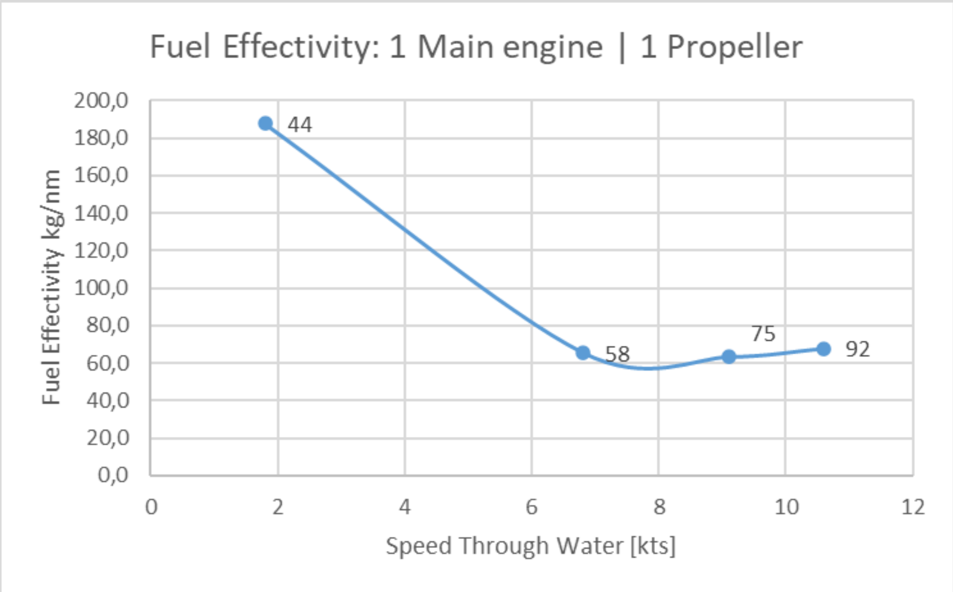


Figure 11. Fuel Effectivity: 1 Main Engine

For this configuration the optimum lies at approximately 7.9 knots with an engine load of roughly 65% and 45 percent pitch. Note that this was with an auxiliary load of approximately 450 kilowatts.

4.3.3 Fuel Effectivity Comparison

Now that both the configurations were examined independently, it was time to compare the two so we could answer the main question: "During free sailing, what is the most economic propulsion configuration and speed on the ALP STRIKER?"

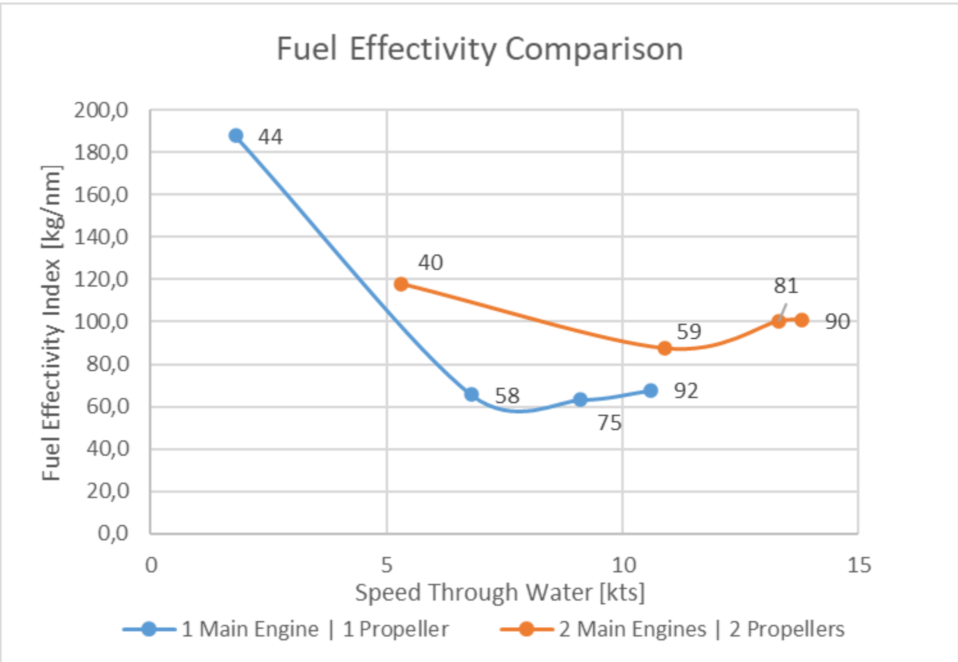


Figure 12. Fuel Effectivity Comparison

The figure now showed that one main engine was most efficient as long as the desired speed could be reached. It is noted that with the two engine configuration the wind was about two times as strong at 14 knots, but the auxiliary load up to 100 kW's lower at one point.

4.4 Previous Research Comparison

For making the calculations, consumption data from *figure 3* was taken. It was converted to kilograms per hour and from there the fuel effectivity was calculated and put into *Table 19* and *Figure 14*.

Table 19. 1 Main Engine and 1 Propeller + Feathering

Load [%]	Pitch [%]	STW [kts]	Consumption [kg/h]	Fuel Effectivity [kg/nm]	Fuel Effectivity Average
85	57	8,5	704,17 - 720,83	82,84 - 84,80	83,82
80	55	8,8	708,33	80,49204545	80,49
89	60	10,2	708,33 - 729,17	69,44 - 71,49	70,465
95	62,5	10,6	770,83 - 791,67	72,72 - 74,69	73,705

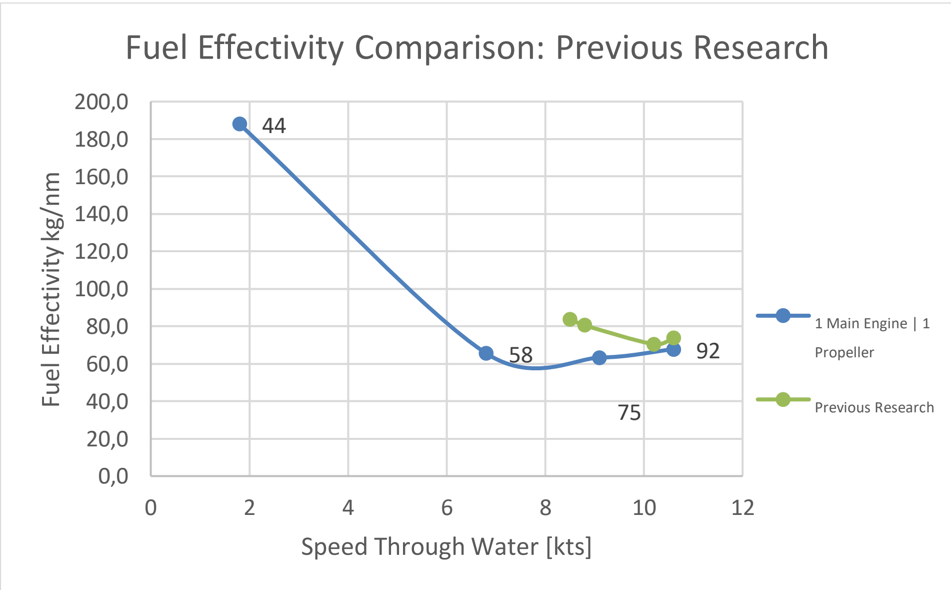


Figure 13. Previous Research Comparison: 1 Main Engine

The propulsion configuration was the same and electrical power was also generated by the shaft generator. For the first two datapoints, test requirements on wind or sea were not present or exceeded liberally. For the second two data points the wind and sea state were acceptable. For those datapoints we see that they are quite similar to ones gotten with the current tests.

For the two and four engine configuration, data from *figure 4* and *5* was taken and put into *table 20* and *21,* from where the fuel effectivity was calculated. The data from *figure 5* and *6* was a bit more complete with regard to control variables. The configuration was slightly different. Electrical power was generated from the auxiliary generators, where the current research took it from the main engine through the shaft generators. As fuel consumption from the auxiliary generators was not added to the fuel consumption by the main engine, one would expect the fuel effectivity for the current research to be higher. Though, this was not the case, as can be seen in *figure 15.*

Table 20. 2 Main Engines and 2 Propellers

Load [%]	Pitch [%]	STW [kts]	Consumption [kg/h]	Fuel Effectivity [kg/nm]
50	32 & 33	7,1	725	102,11
75	61 & 63	12,1	1165	96,28
85	67 & 68	13	1360	104,62
85 & 90	68 & 68	13,1	1416,67	108,14
100	74 & 75	14,2	1640	115,49

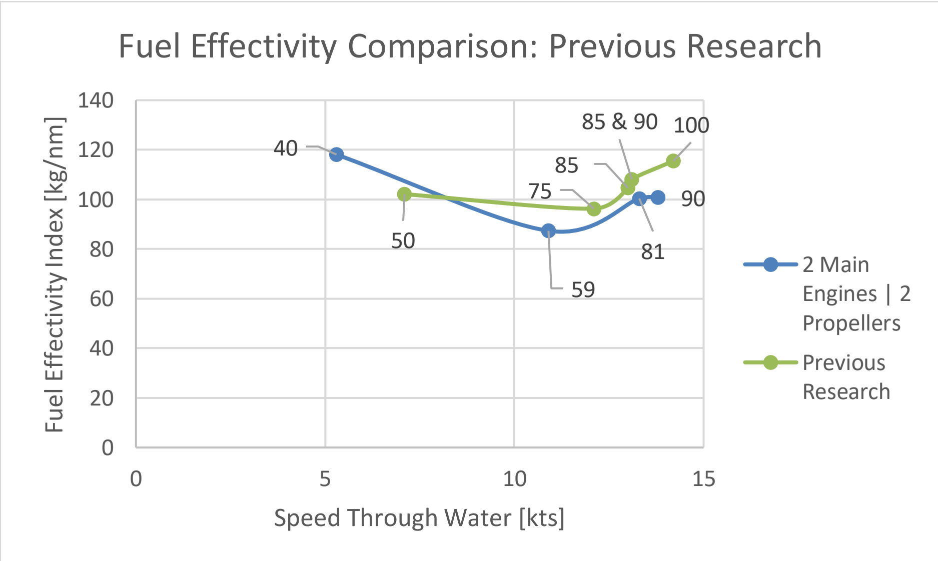


Figure 14. Previous Research Comparison: 2 Main Engines

Table 21. 4 Main Engines and 2 Propellers

Load [%]	Pitch [%]	STW [kts]	Consumption [kg/h]	Fuel Effectivity [kg/nm]
50	70 &71	13,4	1517	113,21
75	86 &87	16,2	2305	142,28
85	91 &92	16,9	2680	158,58
100	96 &97	17,5	3330	190,29

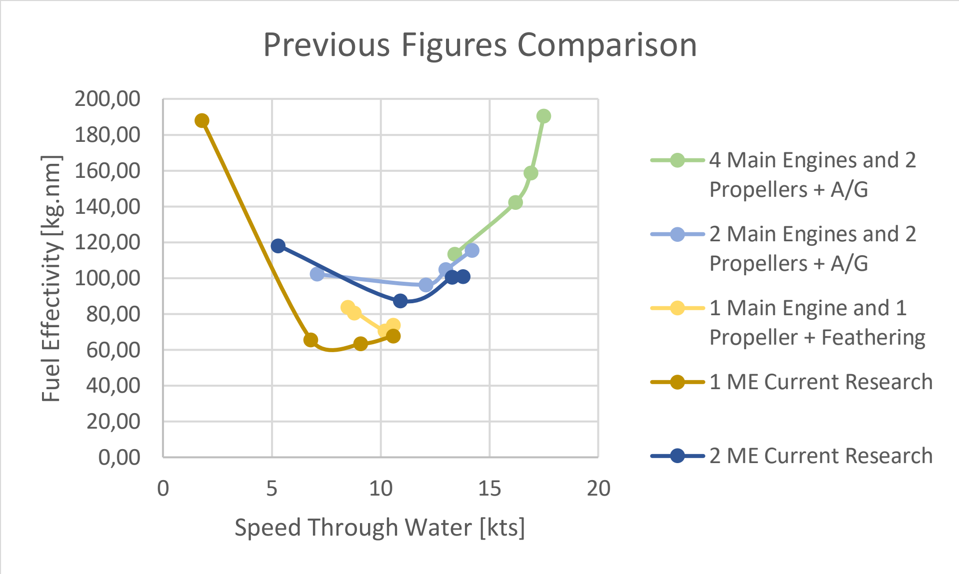


Figure 15. Current and Previous Data Comparison

In the darker colors the current data is seen. The more transparent colors represent data collected from the previous, more general research. Really, only the one-engine configuration was comparable, as the configuration was exactly the same. For the datapoints that match there, the control variables linked to weather were considered of negligible influence.

The two-engine configuration should have had a lower fuel consumption as electrical power was generated by auxiliary generators and not added to the main engine fuel consumption. This should have lowered the fuel effectivity below the current research figures. The remaining control variables were within the current test requirements.

4.5 Trial Error Examination

Finally as way to assess the accuracy and validity of our results, twelve extra data points were taken with in a variety of conditions. At some points the requirements for external variables were exceeded and the results show the effect of this. This way there is some verification to see if the test requirements were stringent enough.

Table 22. Ship Condition and External Disturbances: Trial Examination

Date	Draft FWD/AFT	Displ.	Start time	Ambient Pressure / Temperature	Course	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period
dd/mm	[m]	[t]	UTC	[Bar]/[°C]	[deg]	[m]	[deg]	[sec]	[m]	[deg]	[sec]
11/Oct	7,5/7,1	7949,5	19:06	1015 / 24	270	NIL			NIL		
19/Oct	7,5/7,1	x	19:30	1.021 / 20	300	0,5	0	2	0,5	30PS	4
20/Oct	7,0/6,45	7934	16:11	1019 / 21	272	0,8	157PS	4	0,2	42PS	4
22/Oct	6,5/7,2		11:55	1012 / 26		0,3	210	2	0,9	130	5
22/Oct	6,5/7,2		21:15	1015 / 21	255	0,4	55SB	2	0,6	165PS	0,6
23/Oct	6,5/7,2		07:55	1021 / 20	270	0,8	0	4	1	45PS	5
25/Oct	7,7/7,4	8874	14:23	1020 / 19	270	1,2	20PS	3	1,2	50PS	7
26/Oct	7,7/7,4			1022 / 22	345	0,7	15SB	4	4,1	75PS	13
27/Oct	7,6/7,3	8740	17:08	1015 / 16	359	3,3	134PS	5	3	44PS	12
28/Oct	7,6/7,3		11:00	1020 / 16	23	1,2	138PS	5	6,1	88PS	16
28/Oct	7,6/7,3		14:23	1020 / 16	25	2,5	180	8	7	85	16
31/Oct	7,6/7,3		19:00	1013 / 14	45	1,4	160SB	5	0,8	135SB	6

Table 23. External Disturbances: Trial Examination

Date	Current (Relative)		Wind Absolute		Water Depth	Rudder Deviation [deg]		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
dd/mm	[deg]	[kts]	relative[deg]	[kts]	[m]	PS	SB	[kts]	[kts]
11/Oct	340	0,4	180	3,5	2200	5	5	8,9	8,8
19/Oct	0	0,2	50PS	8	2000	1	1	9,2	9,2
20/Oct	47PS	0,5	157PS	23	300	1	1	8,9	9,3
22/Oct	130	0,5	154	8	2700	1	1	8,5	8,7
22/Oct	20PS	0,6	20PS	14	2100	1	1	7,8	7,9
23/Oct		0,6	5SB	18	2075	1	1	8,2	8,7
25/Oct	0	2,1	0	20	320	2	2	8,5	10,8
26/Oct	120PS	0,3	10	6	1200	5	5	8,8	8,6
27/Oct	46SB	0,2	134PS	24	3000	5	5	8,2	8
28/Oct	92SB	0,3	123PS	21	1500	8	8	8,1	8
28/Oct	70SB	0,1	145PS	18	1400	8	8	8,1	8
31/Oct	135PS	0,8	145PS	29	28	5	5	7,9	8,8

The cells marked red show days where the test requirements were exceeded and therefore invalid. This left only three valid extra datapoints for the one engine configuration. One extra datapoint was taken for the two engine configuration, but the 20 knot wind exceeded the test requirements.

The table above shows the secondary parameters, for all the extra data points. All days it remains around 50% pitch. This means, that if the external variables, ship condition and auxiliary power stayed the same, the data points should be relatively close together.

Table 24. Secondary Parameters: Trail Examination

Date	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW]		Propulsion Power [KW]	
dd/mm	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	PS	SB
11/Oct				592		112		51				70	3150		500		2250
19/Oct				592		112		52				68	3060		460		2250
20/Oct				592		112		53				70	3150		470		2300
22/Oct				592		112		50				66	2970		440		2200
22/Oct				592		112		45				63	2835		465		2000
23/Oct				592		112		52				71	3195		460		2300
25/Oct	592			592	112	112	58	52	57			56	5085	170	270	2100	1900
26/Oct	592				112		55		68				3060	445		2200	
27/Oct		592			112		55			69			3105	430		2000	
28/Oct		592			112		50			68			3060	420		2000	
28/Oct		592			112		49			68			3060	420		2000	
31/Oct	592				112		53		60				2700	420		2000	

Table 25. Fuel Consumption: Trail Examination

Date	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (20 min)	
	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)
dd/mm	Litres start	Litres end	Litres start	Litres end	L	L
11/Oct			483765	483988		223
19/Oct			519893	520112		219
20/Oct			533434	533656		222
22/Oct			562305	562519		214
22/Oct			567836	568037		201
23/Oct			579252	579477		225
25/Oct	538116	538324	579501	579686	208	185
26/Oct	556581	556830			249	
27/Oct	575845	576076			231	
28/Oct	588222	588445			223	
28/Oct	590536	590760			224	
31/Oct	642018	642242			224	

Table 26. Density Correction

Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)
[°C]		[kg/m3]		Given by fuel supplier	Portside (no.1)	Starboard (no.2)	TOTAL
Portside (no.1)	Starboard (no.2)				kg/h	kg/h	[kg/h]
	34,9		816,57	0,00064		546,28	546,28
	33,2		817,47			537,08	537,08
	33,1		817,52			544,47	544,47
	33,6		817,25			524,68	524,68
	33,6		817,25			492,80	492,80
	33		818,10			552,22	552,22
27,2	32,3	820,64	817,94		512,08	453,96	966,04
24,7		821,97			614,01		614,01
24,8		821,91			569,59		569,59
24,3		822,18			550,04		550,04
23,4		822,65			552,82		552,82
22		823,39			553,32		553,32

Table 27. Fuel Effectivity

Date	FO Consumption (Calculated)	Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
dd/mm	[kg/h]	kg/nm	[kts]
11/Oct	546,2826904	**62,1**	8,8
19/Oct	537,0751221	**58,4**	9,2
20/Oct	544,4675698	**58,5**	9,3
22/Oct	524,6771974	**60,3**	8,7
22/Oct	492,8042836	**62,4**	7,9
23/Oct	552,2182776	**63,5**	8,7
25/Oct	966,0386136	**89,4**	10,8
26/Oct	614,0081263	71,4	8,6
27/Oct	569,5853132	71,2	8
28/Oct	550,0364804	68,8	8
28/Oct	552,823159	69,1	8
31/Oct	553,3211658	**62,9**	8,8

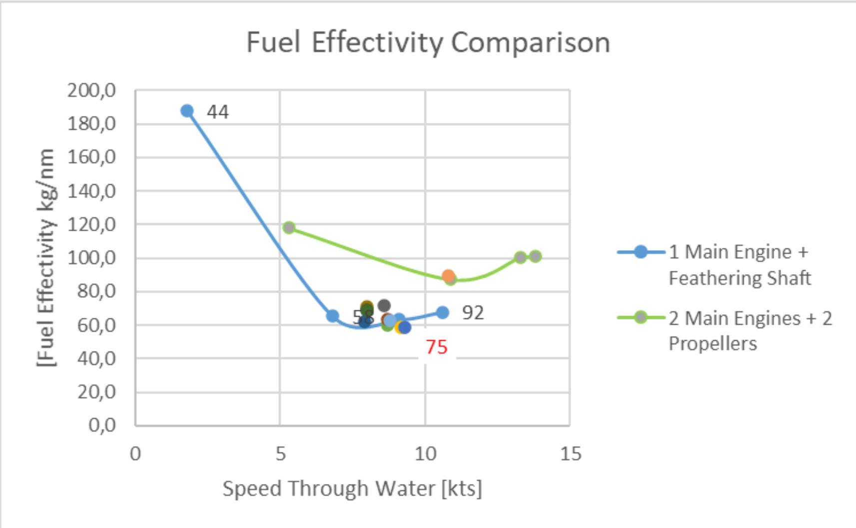


Figure 16. Fuel Effectivity Comparison showing all extra Data Points

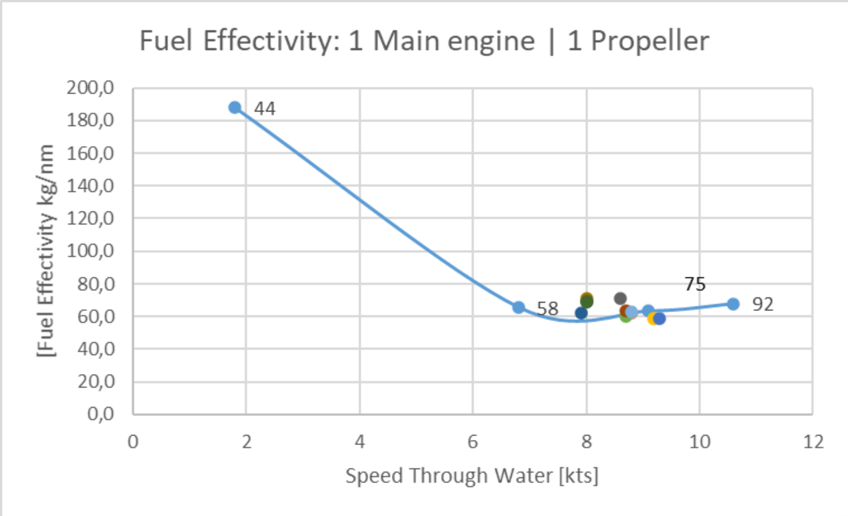


Figure 17. Final Trial Examination: 1 Main Engine 1 | 1 Propeller

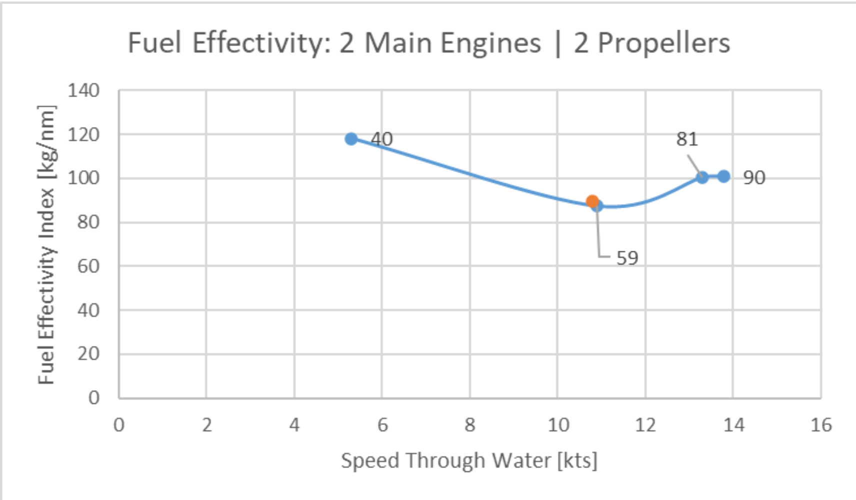


Figure 18. Final Trail Examination: 2 Main Engines | 2 Propellers

Before filtering out the data using the test requirements it showed quite some difference to the first test day. However, there were quite a few days where the test requirements were exceeded. Removing them all for the one-engine configuration provided the following figure.

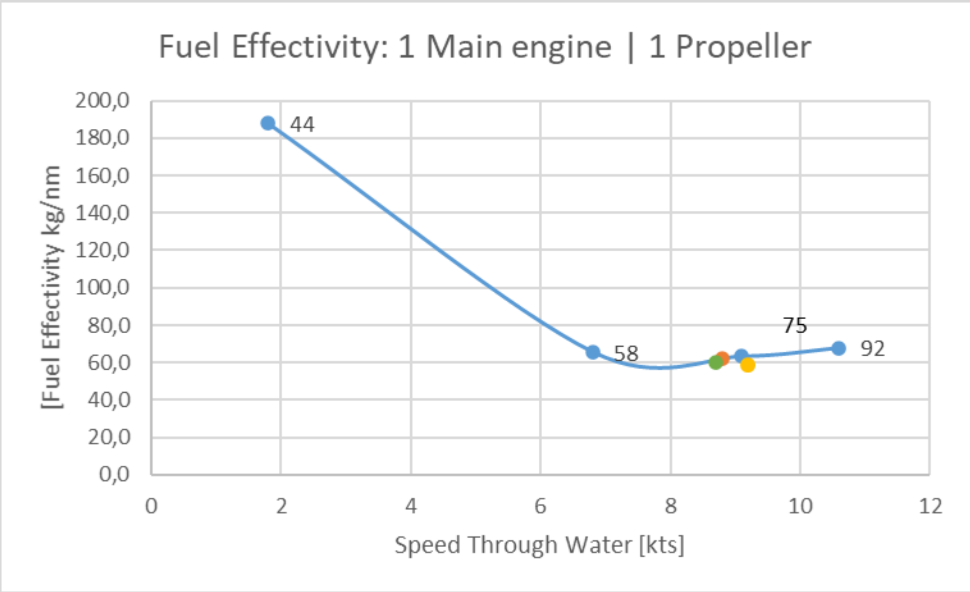


Figure 19. Fuel Effectivity Figures Meeting Trial Criteria

Now the figures lay much closer together as was expected. To check the maximum error from the first test individual error bars were used.

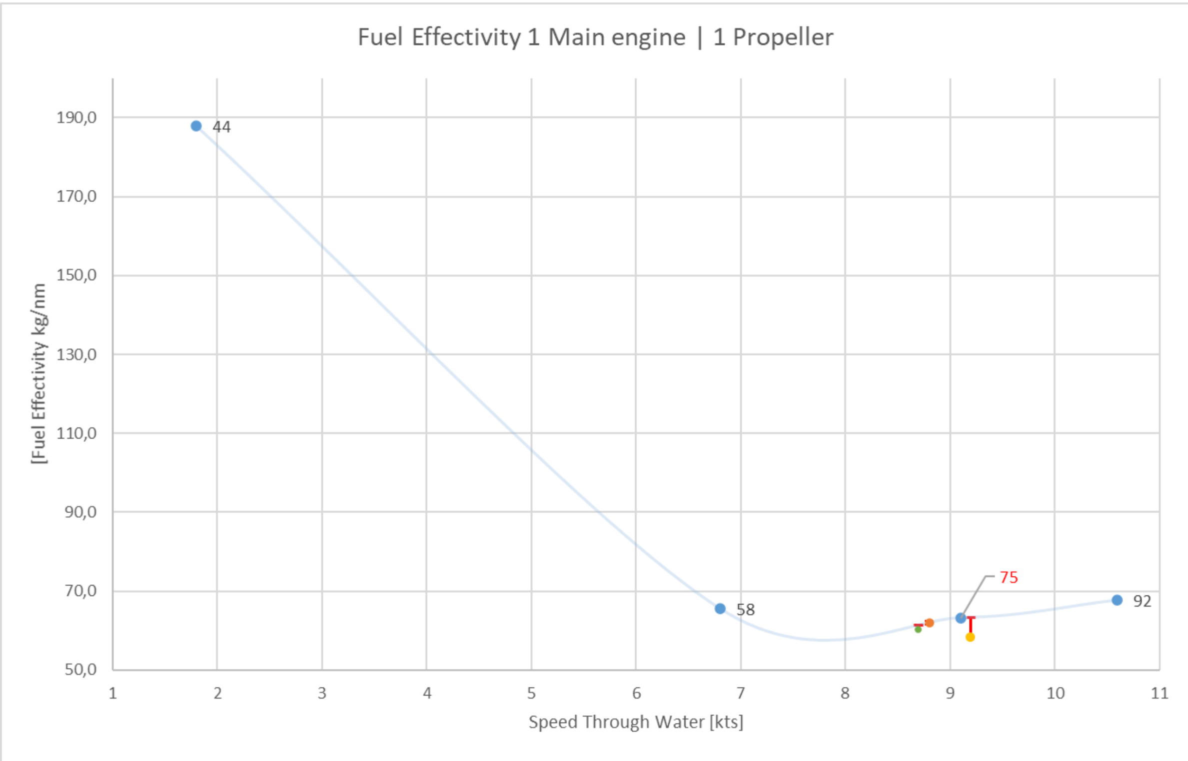


Figure 20. Trial Errors Meeting Test Requirements

For the two-engine configuration there was only one extra data point taken, though unfortunately the test requirements for wind strength were exceeded that day.

Fault 1 [%]	Fault 2 [%]	Fault 3 [%]
1	0,5	5

Table 28. Maximum Deviation from intial Trial Data

Finally this showed a 5% deviation from the initial trial with the one-engine configuration.

5. Discussion

5.1 Test Conditions

Wind can add significant drag to a ship and cause it to slow down or speed up noticeably. Because of this, it also effects efficiency and with it the fuel effectivity. For this reason trial requirements called for a maximum wind speed, set at 4 Beaufort or 11 knots. In the first trial the wind restrictions were exceeded. The trial was run anyway, because the planned time to take the test was coming to an end. During the second configuration it lowered to 6 knots, well within the requirements. The goal of this test was to compare propulsion configurations and find which one was most efficient at what point. This is does put the validity of the results into question.

Sea state was good and within the test requirements. When comparing the first test to the subsequent single data points that met the requirements the difference was small. Though the following could also have been of influence.

5.2 Rudder Deviation

While testing the first configuration, the 5 degree maximum rudder deviation was exceeded. Limits were set on this, because rudder actions cause the rudder to experience more drag. This does again question the validity of the results. While testing the second configuration, with one engine, the rudder continually holds a five degree angle. The reason for the large rudder angles is that the rudder was damaged before the trial took place. This ship uses an extra flap on the trailing end of its' rudder for increased maneuverability and efficiency. While on a anchor handling job this flap was knocked out of zero position, where it got jammed. This was unfortunate as it puts the results into question. Crew stated to noticeably have lost speed over this. It should be noted that the rudder got repaired immediately a few days after the first trial. Unfavorable conditions for the test followed days after, due to weather, traffic and course changes. Extra datasets were taken after the repair. Less drag was experienced during these measurements.

5.3 Amount of Measurements

For every study the amount of data is important to the validity of its' results. To get a good average a certain amount of data is needed, so one can see how what the spread looks like and how much datapoints are needed to assess the outcome. For this test five load points were chosen. Because of the amount of variables involved this seems a bit superficial. To get a more accurate result the goal was to perform the same configuration four times. Some play in load was allowed and this would have caused a more precise result with data points over the whole load and speed range. To still get an indication of how precise the test requirements allowed the results to be more single datapoints were gathered during the remaining days on board, over a great variety in conditions.

The trials were originally meant to include another datapoint at 20% engine load, though the vessel would not get up to speed. This led to the decision to go on testing from the 40% engine load mark. Likely, it already took that engine load to spin the propeller at zero percent pitch. Also shaft generator load was part of this.

5.4 Accuracy Main Parameters

In a research where the main parameters are fuel consumption and speed, it should be made sure that those parameters have a high resolution. As was shown in the results with the data gotten, the worst case scenario presents a possible error of 10%. At this point, it did not change the answer to which configuration is most efficient at what speed. Though it could be, when other configurations are to be tested.

For the next test, the procedure could be updated to include a longer time to record fuel consumption. Then, reading the miles traveled could give a more accurate result.

5.6 Auxiliary Power Demand on Shaft Generator

For these trials the choice was made to run the auxiliary power on the main engines through the shaft generator. It was done because it does benefit the overall efficiency and fuel effectiveness positively and it is also how the ship is normally operated. This does pose another issue.

The electrical power demand on a ship can be relatively stable, though it does go up and down significantly when big machinery is operated. Doing more measurements would have provided a sound average. Though because the amount of measurements was fairly low, there were some differences in auxiliary power demands during the trials that possibly impacted the results notably. At one point the difference in auxiliary power demand reached 100 kW's, when the power going to the propeller shaft was 2420 kW was going to the shaft. This was a 4% difference of power going to the shaft, a noteworthy difference.

One option was to calculate out the fuel consumption of the shaft generator, though the efficiency figures on the shaft generator were too limited.

5.7 Humidity

Humidity does have a significant effect on engine efficiency, which is why it is normally noted when testing for engine performance, or during the speed trial. On this ship there was no equipment to measure this, so this was not noted.

5.8 Previous Research Comparison

Previous research on the matter was found. Though, this was not wholly comparable. For the two-engine configuration, electrical power generation was left out. Still the fuel effectivity did not present the expected difference. This could be due to a number of factors. The displacement was 23.6% higher and the fuel used was still heavy fuel oil, which also affects the data. Also it could be that the current test procedures are not stringent enough. Further control variable data would be needed. Hull and prop fouling could have been an influencing factor, as this data was missing. For the current test it was six months since the last dry dock.

The one-engine configuration showed more comparable figures, indicating that the current procedure may have been stringent enough. This was only when the weather control variables were remarked as negligible. Though, there were only two of such datapoints and the remaining control variables were missing.

6. Conclusion & Recommendations

The goal of this thesis was to find the answer to which of the possible propulsion configurations on board the ALP STRIKER would be most economic at any given speed. To help answer this, sub-questions were formulated. These were answered by ways of desk research and combining the research found into a new test procedure. This way the lowest fuel consumption per mile traveled through the water could be found.

To assess the validity of the found data, the resolution of the main parameters was investigated, showing the final possible impact on the fuel effectivity figures. This showed a maximum error of 10% in at lower speeds. Significant, though at higher speed this became negligible. Seeing as there was no other configuration to be compared to at such speeds, it did not have an influence of the end result for this research.

Control variables including external variables and ship condition, were noted and assessed for possible influence on the test data. Set test procedures were exceeded, as wind was 2 knots higher than required. The maximum rudder action was also exceeded. This was due to damage on the rudder on the previous job. The damage was resolved and the rudder deflection was back to normal. Then the individual datapoints were taken on the following voyage. These also showed slightly better fuel effectivity figures, probably due to the decrease in rudder drag.

Previous fuel consumption data was used to be compared to the data currently found. This showed only partial comparability, due to different generation of electrical power and limited control variable information.

Finally, more individual data points were taken for the remaining part of the test window. This added to current test data and gave an indication to its' validity.

The following conclusion is only applicable to the vessel when the ship condition is as following:

- Draft of 7.2m forward and 6.8m aft
- Auxiliary power demand of around 500 kilowatts
- Fuel with a heat value of 43.02 MJ/kg
- Hull and propeller cleaned six months earlier

As the final graph showed, the one-engine configuration was most economic when the required speed was within 10.6 knots. After, the two-engine configuration became most effective.

Other configurations could still be more efficient. Especially the three-engine configuration is missing. When other configurations are to be tested, these should be tested again. Either by adding individual datapoints in the same way as was currently done, or by full tests. Individual datapoints can be added easily and should not interfere with normal ship operations. This way the individual datapoints should provide a more reliable chart over time. By adjusting the filtering procedure for control variables, the exact effect of those can be made more visible and a more stringent procedure can be established.

Another way to make further research much easier is to use the system installed. By using the flow meters going to the main engines individually, and setting up the fuel profiles correctly, the fuel efficiency module of the K-Chief program can be used as is immediately shows the current fuel consumption per mile traveled. Using this could provide much faster way to make a good graph and test the various setups, especially important when towing. It could then also be compared to previous results and indicate the need for hull or drive system maintenance. Unfortunately this system was out of order during the test period.

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Attachment 1: Speed Trail Test Sheet

BRIDGE Date:

Efficiency Test Sheet: 1 Engine | 1 Propeller |2 Shaft Generators | Combinator Mode

Load of ME	Draft FWD/AFT	Displ.	Start time	Weather	Ambient Pressure / Temperature	Relative Humidity	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Blade Angle [%]	
%	[m]	[t]	UTC		[Bar]/[°C]	[%]	[m]	[deg]	[sec]	[m]	[deg]	[sec]	[deg]	[kts]	[deg]	[m/s]	[m]	PS	SB	PS	SB
20																					
40																					
60																					
80																					
95																					

Test requirements: *****During the whole test all the test requirements are to be met*****

Instructions:

To find an optimal drivetrain configuration for each speed this test is performed with several configurations. Most importantly shall be noted how much fuel consumption the ship has with certain main engine load points and corresponding pitch (blade angle). The other factors recorded are all factors of influence.

The test shall be conducted by going through each of the main engine load points. Try to stay within 5 percent of the load requested in the first row of the table. Once the speed has stabilized, the engine crew is to be notified. They will collect the remaining data including the *actual load*. Once they have collected all data, they will call the bridge to move to the following load point on the list. This will continue till all the load points are filled in.

Efficiency Test Sheet: 1 Engine | 1 Propeller | 2 Shaft Generators| Constant Speed

Load of ME	FO Consumption ME (Read once over 20 minutes)				Fuel Temperature (at flowmeter)		Fuel density at 15°C $\rho_{15°C}$	Volume Correction Factor	Heat Value	Air after Charge Air Cooler (average)	Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	Portside (no.1)		Starboard (no.2)		[°C]		[kg/m3]	Given by fuel supplier	kJ/kg	[°C]	[kts]	[kts]
	Liters start	Liters end	Liters start	Liters end	Portside (no.1)	Starboard (no. 2)						
20												
40												
60								0,000645				
80												
95												

Load of ME	FO Consumption Calculated	Main Engine Speed [RPM]				Propeller Speed [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW] (average)		Propulsion Power [KW]	
%	[m3/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	PS	SB
20																		
40																		
60																		
80																		
95																		

Instructions:

The fuel oil consumption for the main engines is measured at the booster modules 1 and 2. At module no. 1 the portside consumption is measured. Module no.2 starboard consumption is measured. When the speed and other parameters have stabilized, the bridge will request the engine room crew to take a their readings. Once the engine room crew has the data, the bridge is to be informed. Then the pitch is to be altered till the next load point is reached and speed has stabilized. This is repeated till the data from all setpoints has been filled in.

All the following points are to be checked off, otherwise the data is not valid.

- **Waves** and **swell** should not exceed the height of ± 1.5m, according to the following formula:

$$H_{wave} \leq 1.5 * \sqrt{\frac{L_{pp}}{100}}$$

- **Wind** should remain under 11 knots or 4 Beaufort
- Areas with large **variations in current** are to be **avoided**
- **Shaft generator loads** to be kept **constant**
- **Time to stabilize condition** (load and speed)
  At least 10 minutes should be taken after the data has stabilized before it is collected. Total stabilization time varies with the amount of engines running.
- **No course changes**
- **No trim changes**
  Trim also has an effect on propeller efficiency, therefore no ballast water should be displaced.
- **No draft changes**
  A change in draft changes the resistance of the vessel and there the speed and consumption. Again the fuel used should not affect the draft enough to be sufficient.
- **Minimum water dept** should be should be met, satisfying both of the following formulas:

  $h_{min} = 2 * \sqrt{B * T}$ and $h_{min} = 2 * \frac{v_s^2}{g}$
- **Load reduction** should not be activated so keep the load under 95 percent. Load reduction will vary pitch and the data will be unusable.
- **Amount of measurements**
  For each drivetrain configuration at least four data points have to be taken across the range 10-25, 25-50, 50-75, 75-100 percent load of the main engines.
- The **same type of fuel** is to be used. Different quality of fuel impacts engine fuel consumption and will influence the results.
- **Rudder actions** should be **minimized** by checking proper controller settings and rudder angles are not to exceed 5 degrees.

Attachment 2: Data Processing

ALP Speed trials

3 Main Engines + 2 Propellers

Load of ME	Draft FWD/AFT	Displ.	Start time	Weather	Ambient Pressure / Temperature	Relative Humidity	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Run time		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	[m]	[t]	UTC		[Bar]/[°C]	[%]	[m]	[deg]	[sec]	[m]	[deg]	[sec]	[deg]	[kts]	[deg]	[m/s]	[m]	PS	SB	[min	[sec]	[kts]	[kts]
20																							10
40	8.2 / 7.8	9822	09:55	good			1			1,5	1,5	1,5	180	0,7	30	0,36	3600	+2 / -2	+2 / -2	4	12	14	13,4
60	8.3 / 7.7	9822	10:07	good			1			1,5	1,5	1,5	180	0,7	30	0,36	3600	+3 / -3	+3 / -3	3	35	16,7	16,2
80	8.4 / 7.6	9822	10:19	good			1			1,5	1,5	1,5	180	0,7	30	0,36	3600	+4 / -4	+4 / -4	3	25	17,2	16,9
95	8.4 / 7.6	9822	10:30	good			1			1,5	1,5	1,5	180	0,7	30	0,36	3600	+4 / -4	+4 / -4	3	20	17,9	17,5

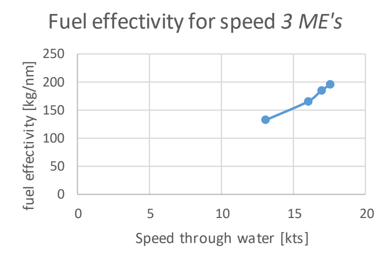
Load of ME	FO Consumption (Read)	FO Consumption (Calculated)	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW]		Auxiliary Consumption	Propulsion Power [KW]		Fuel Effectivity (Calculated)
%	[m3/h]	[kg/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	[kg/h]	PS	SB	kg/nm
20	1,2	960																			96
40	2,099	1540,0363	592	592	592	592	112	112	70	71								0	3200	3600	114,9280821
60	3,189	2339,7693	592	592	592	592	112	112	86	87								0	5400	5570	144,4302037
80	3,707	2719,8259	592	592	592	592	112	112	91	92								0	6340	6700	160,9364438
95	4,06	2978,822	592	592	592	592	112	112	96	97								0	7500	8180	170,2184

Normally fuel effectivity can be directly read from K-chief and is calculated using fuel consumption from the flow meters from the main engines. However the readout currently gives an uncertain fault. The system is also set up into thinking it is using HFO, while in reality taking in MGO, using different data in the proces.

Correctionfactor	1,02
T(at flowmeter)	80
$\rho_{15°C}$ [kg/m3]	800
ρ_{fuel} [kg/m3]	733,7
Fuel Heat Value	

Possibly to be noted
- Prop efficiency
- Engine efficiency
- Fuel efficiency [g/kWh]

Test results



ER list

Load of ME	1. FO Consumption ME (Read over 1 minute)				2. FO Consumption ME (Read over 1 minute)				Fuel Temperature (at flowmeter)		Fuel density at 15°C $\rho_{15°C}$	Fuel Correctionfactor
%	Portside (no.1)		Starboard (no.2)		Portside (no.1)		Starboard (no.2)		[°C]		[kg/m3]	Given by fuel supplier
	Litres start	Litres end	Litres start	Litres end	Litres start	Litres end	Litres start	Litres end	Portside (no.1)	Starboard (no.2)		
20												
40												
60												
80												
95												

Attachment 3: Ship Particulars

309mt Bollard Pull

DP II Anchor Handling Salvage Tug

ALP STRIKER

General Data

Callsign	PDDI
Flag	The Netherlands
Port of registry	Rotterdam
IMO number	9737230
Year built	2017 - NSR Niigata, hull N-0081
Design	Ulstein SX 157
Classification	DNV+ 1A1 Offshore Service Vessel+, Anchorhandling, Towing, E0, SF, Iceclass 1B, Fifi II, Tmon, Bis, Dynpos-Autr, Naut-OSV(A), Clean design, Comf-V(3), BWM-T, Recyclable
DP II	ERN 99, 99, 98, 77
Bollard pull	309,6 mt cont.
Maximum speed	19,0 knots
Service speed	12,6 knots

Main Dimensions

Length o.a.	88,90 m
Length b.p.	83,40 m
Beam o.a.	21,00 m
Depth to maindeck	9,50 m
Max. draught	8,50 m
Deadweight	4.250 mt
Gross tonnage	5.901 mt
Nett. tonnage	1.771 mt
Cargo deck area	550 sqm
Deck load	10 mt / sqm max.
Chain locker capacity	2 x 255,6 cbm

Towing / Anchor Handling

Towing winch	Rolls Royce mod. SL400-3T 1st speed: 401 mt @ 0-13 m / sec
Brake holding load	675 mt towing drum's 1st layer 675 mt AH drum's 1st layer
Drums	3 x 86 mm x 2.510 m steel wire
Control	Remote controlled from bridge
Cable lifters	2 x 76 mm
Tow wires	1 x 2.000 m x 86 mm on main tow winch 1 x 2.000 m x 86 mm on secondary tow winch 1 x 2.000 m x 86 mm on storage reel
Storage reels	1 x 2 compartments 2.630 & 620 m 86 mm wire 1 x 3 compartments 1.115 m 86 mm wire each
Fibre rope	Dismountable storage drum, max. capacity 7.200 m x 203 mm
Stern roller	650 mt SWL, 5,50 m length / 4,00 m diameter
Gog winches	2 x Rolls Royce - 30 mt pull @ 0-12 m / min
Capstans	2 x hydraulic - 13,2 mt pull @ 0-10 m / min
Tugger winch	1 x Rolls Royce - 15 mt pull @ 0-30 m / min
Towing pins	4 x Karmoy 300 mt SWL
Karm forks	2 x Karmoy 600 mt SWL, various inserts
Pop-up pins	2 x 300 mt SWL

Tank Capacities

Ballast water	3.184 cbm
Fresh water	308 cbm
Marine Gas Oil	301 cbm
Heavy Fuel Oil / Marine Gas Oil	3.184 cbm

Machinery

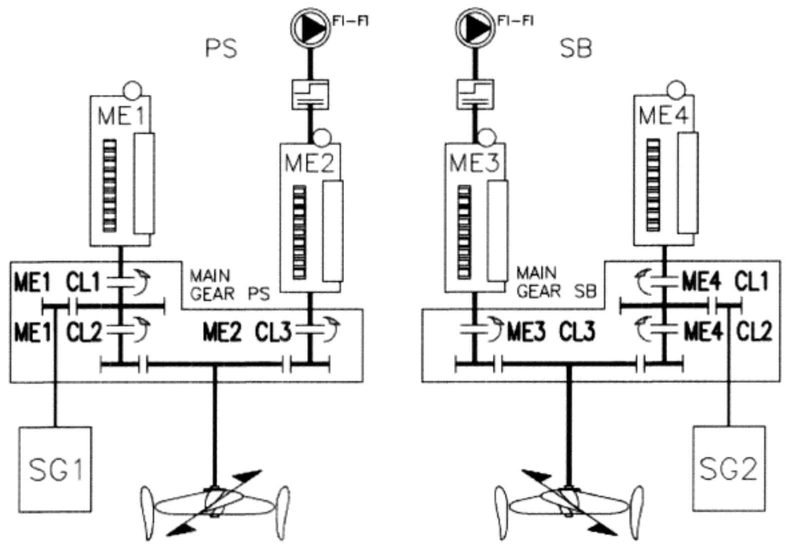
Main engines	18.000 kW / 600 rpm 4 x 4.500 kW MAK 9M32C
Propellers	2 x CPP 5.000 mm in nozzle
Rudders	High performance Becker rudders
Bow thrusters	2 x 1.500 kW @ 228 rpm tunnel thrusters
Stern thrusters	2 x 1.050 kW @ 316 rpm tunnel thrusters
Generators	3 x 940 ekW, 60Hz auxiliary generators 1 x 200 ekW, 60Hz emergency generator 2 x 3.150 ekW, 60Hz shaft generators driven from main reduction gear

Accommodation

Total capacity	35 persons
Cabins	Single berth 25 Double berth 5
Hospital	Single berth

Attachment 4: Drivetrain Overview ALP Striker

Propulsion System Over View



Main Engine
MaK 9M32C
4500kW/600rpm
4 sets

Gera Box
RENK
2 input/1 output
With 1 PTO
2 sets

Propulsion
CAT Propulsion
Output: 9000kW
5000mm dia
2 sets

Fixed Nozzle
Damen Optima
2 sets

PS
ME1 Clutch1 : PTO
ME1 Clutch2 : ME1 Motor Clutch
ME2 Clutch3 : ME2 Motor Clutch

SB
ME4 Clutch1 : PTO
ME4 Clutch2 : ME4 Motor Clutch
ME3 Clutch3 : ME3 Motor Clutch

Attachment 5: Trial Results two main engines

ALP Speed trials

alp maritime services

2 Main Engines + 2 Propellers 11/Oct

Load of ME	Draft FWD/AFT	Displ.	Start time	Weather	Ambient Pressure / Temperature	Relative Humidity	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	[m]	[t]	UTC		[Bar]/[°C]	[%]	[m]	[deg]	[sec]	[m]	[deg]	[sec]	[deg]	[kts]	[deg]	[kts]	[m]	PS	SB	[kts]	[kts]
20																					
40	7,2 / 6,8	7949,5	08:25		1015 /22		0,8	21	3	0,5	1	5	71	0,5	43	14	2672	5	5	5	5,3
60	7,2 / 6,8	7949,5	08:55		1015 /24		0,8	21	3	0,5	1	5	71	0,5	45	13	3060	5	5	10,6	10,9
80	7,2 / 6,8	7949,5	09:24		1015 /26		0,8	21	3	0,5	1	5	71	0,5	51	14	3500	5	5	12,9	13,3
95	7,2 / 6,8	7949,5	09:55		1015 /29		0,8	21	3	0,5	1	5	71	0,5	58	14	4100	5	5	13,1	13,8

Load of ME	FO Consumption (Calculated)	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [kW]		Total Aux Power Demand [kW]	Propulsion Power [kW]		Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
%	[kg/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total [kW]	PS	SB	PS + SB	PS	SB	kg/nm	[kts]
20																					
40	625,8421408	592			592	112	112	27	17	38			40	3510	168	272	440	1100	1100	118,1	5,3
60	952,0591679	592			592	112	112	59	53	59			59	5310	168	280	448	1920	2100	87,3	10,9
80	1334,811405	592			592	112	112	69	72	81			81	7290	176	256	432	3000	3130	100,4	13,3
95	1391,359001	592			592	112	112	73	73	73			90	7335	175	297	472	3300	3100	100,8	13,8

Load of ME	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (Read over 20 minutes)		Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)
%	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)	[°C]		[kg/m3]		Given by fuel supplier	Portside (no.1)	Starboard (no.2)	TOTAL
	Litres start	Litres end	Litres start	Litres end	L	L	Portside (no.1)	Starboard (no.2)				[kg/h]	[kg/h]	[kg/h]
20														
40	528748	528879	478558	478682	131	124	30,7	33,4	818,7892992	817,3601	0,0006	321,7841946	304,0579462	625,8421408
60	528996	529202	478790	478972	206	182	30,7	34,2	818,7892992	816,9366		506,0117869	446,047381	952,0591679
80	529335	529619	479095	479355	284	260	30,9	34	818,6834304	817,0425		697,5182827	637,2931219	1334,811405
95	529762	530044	479500	479785	282	285	31	33,5	818,630496	817,3071		692,5613996	698,7976013	1391,359001

Attachment 6: Trial Results One Main Engine

ALP Speed trials

1 Main Engine + Feathering Shaft

11/Oct

Load of ME	Draft FWD/AFT	Displ.	Start time	Weather	Ambient Pressure / Temperature	Relative Humidity	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)
%	[m]	[t]	UTC		[Bar]/[°C]	[%]	[m]	[deg]	[sec]	[m]	[deg]	[sec]	[deg]	[kts]	[deg]	[kts]	[m]	PS	SB	[kts]	[kts]
20																					
40	7,2 / 6,8	7949,5	10:33		1015 /29		0,8	21	3	0,5	1	5	71	0,5	49	11,5	3500	10	10	1,4	1,8
60			11:10		1015 / 30		0,8	21	3	0,5	1	5	71	0,5	54	11	3500	8	8	6,1	6,8
80			11:40		1015 / 30		0,8	21	3	0,5	1	5	71	0,4	51	7	3440	7	7	8,4	9,1
95			12:10		1015 / 30		0,8	21	3	0,5	1	5	71	0,4	51	6	3440	7	7	10	10,6

Load of ME		FO Consumption (Calculated)	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW]		Auxiliary Consumption	Propulsion Power [KW]		Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
%		[kg/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	[kg/h]	PS	SB	kg/nm	[kts]
20																		0				
40		338,2336653				592		112		5				44	1980		526	0		526	187,9	1,8
60		445,9606744				592		112		35				58	2610		520	0		520	65,6	6,8
80		575,7537059				592		112		54				75	3375		536	0		536	63,3	9,1
95		718,0872672				592		112		65				92	4140		547	0		547	67,7	10,6

Load of ME	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (Read over 20 minutes)		Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)
	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)	[°C]					Portside (no.1)	Starboard (no.2)	TOTAL
%	Litres start	Litres end	Litres start	Litres end	L	L	Portside (no.1)	Starboard (no.2)	[kg/m3]		Given by fuel supplier	[kg/h]	[kg/h]	[kg/h]
20														
40			479974	480112		138		34,1	835,0402	816,9895	0,0006		338,2336653	338,2336653
60			480211	480393		182		34,5	835,0402	816,7778			445,9606744	445,9606744
80			480482	480717		235		34,7	835,0402	816,6719			575,7537059	575,7537059
95			480969	481262		293		34,2	835,0402	816,9366			718,0872672	718,0872672

Attachment 7: Fault Check

FAULT CHECK

1 Main Engine + Feathering Shaft

Date	Draft FWD/AFT	Displ.	Start time	Weather	Ambient Pressure / Temperature	Course	Wave	Wave Direction (Relative)	Wave Period	Swell	Swell Direction (Relative)	Swell Period	Current (Relative)		Wind (Relative)		Water Depth	Rudder Deviation [deg]		Average Speed Over Ground (SOG)	Average Speed Through Water (STW)	
dd/mm	[m]	[t]	UTC		[Bar]/[°C]	[deg]	[m]	[deg]	[sec]	[m]	[deg]	[sec]	[deg]	[kts]	[deg]	[kts]	[m]	PS	SB	[kts]	[kts]	
11/Oct	7,5/7,1	7949,5					NIL			NIL					180	3,5				8,9	8,8	
19/Oct	7,5/7,1		19:30	P. cloudy	1.021 / 20	300	0,5	0	2	0,5	30PS	4	0	0,2	50PS	8	2000	1	1	9,2	9,2	
20/Oct	7,0/6,45	7934	16:11	P. cloudy	1019 / 21	272	0,8	157PS	4	0,2	42PS	4	47PS	0,5	157PS	23	300	1	1	8,9	9,3	
22/Oct	6,5/7,2		11:55		1012 / 26		0,3	210	2	0,9	130	5	130	0,5	154	8	2700	1	1	8,5	8,7	
22/Oct	6,5/7,2		21:15		1015 / 21	255	0,4	55SB	2	0,6	165PS	0,6	20PS	0,6	20PS	14	2100	1	1	7,8	7,9	
23/Oct	6,5/7,2		07:55	**P. cloudy**	1021 / 20	270	0,8	0	4	1	45PS	5		0,6	5SB	18	2075	1	1	8,2	8,7	
25/Oct	7,7/7,4	8874	14:23		1020 / 19	270	1,2	20PS	3	1,2	50PS	7	0	2,1	0	20	320	2	2	8,5	10,8	2 engines
26/Oct	7,7/7,4				1022 / 22	345	0,7	15SB	4	4,1	75PS	13	120PS	0,3	10	6	1200	5	5	8,8	8,6	
27/Oct	7,6/7,3	8740	17:08		1015 / 16	359	3,3	134PS	5	3	44PS	12	46SB	0,2	134PS	24	3000	5	5	8,2	8	
28/Oct	7,6/7,3		11:00		1020 / 16	23	1,2	138PS	5	6,1	88PS	16	92SB	0,3	123PS	21	1500	8	8	8,1	8	
28/Oct	7,6/7,3		14:23		1020 / 16	25	2,5	180	8	7	85	16	70SB	0,1	145PS	18	1400	8	8	8,1	8	
31/Oct	7,6/7,3		19:00		1013 / 14	45	1,4	160SB	5	0,8	135SB	6	135PS	0,8	145PS	29	28	5	5	7,9	8,8	

Date		FO Consumption (Calculated)	Main Engine RPM				CPP [RPM]		Blade Angle [%]		Main Engine output [%]					Auxiliary Power Demand [KW]		Auxiliary Consumption	Propulsion Power [KW]		Fuel Effectivity (Calculated)	Average Speed Through Water (STW)
dd/mm		[kg/h]	ME1	ME2	ME3	ME4	PS	SB	PS	SB	ME1	ME2	ME3	ME4	Total	PS	SB	[kg/h]	PS	SB	kg/nm	[kts]
11/Oct		546,2826904				592		112		51				70	3150		500	0		2250	**62,1**	8,8
19/Oct		537,0751221				592		112		52				68	3060		460	0		2250	**58,4**	9,2
20/Oct		544,4675698				592		112		53				70	3150		470	0		2300	**58,5**	9,3
22/Oct		524,6771974				592		112		50				66	2970		440	0		2200	**60,3**	8,7
22/Oct		492,8042836				592		112		45				63	2835		465	0		2000	**62,4**	7,9
23/Oct		552,2182776				592		112		52				71	3195		460			2300	**63,5**	8,7
25/Oct		966,0386136	592			592	112	112	58	52	57			56	5085	170	270		2100	1900	**89,4**	10,8
26/Oct		614,0081263	592				112		55		68				3060	445			2200		71,4	8,6
27/Oct		569,5853132		592			112		55			69			3105	430			2000		71,2	8
28/Oct		550,0364804		592			112		50			68			3060	420			2000		68,8	8
28/Oct		552,823159		592			112		49			68			3060	420			2000		69,1	8
31/Oct		553,3211658	592				112		53		60				2700	420			2000		**62,9**	8,8

Date	1. FO Counter Booster Module (Read over 20 min)				2. FO Consumption ME (20 min)		Fuel Temperature (at flowmeter)		Actual Fuel Density		Fuel Correctionfactor	2. FO Consumption ME		FO Consumption (Calculated)	
dd/mm	Portside (no.1)		Starboard (no.2)		Portside (no.1)	Starboard (no.2)	[°C]		[kg/m3]		Given by fuel supplier	Portside (no.1)	Starboard (no.2)	TOTAL	
	Litres start	Litres end	Litres start	Litres end	L	L	Portside (no.1)	Starboard (no.2)				kg/h	kg/h	[kg/h]	
11/Oct			483765	483988		223		34,9		816,5661	0,00064		546,2826904	546,2826904	
19/Oct			519893	520112		219		33,2		817,4659			537,0751221	537,0751221	
20/Oct			533434	533656		222		33,1		817,5189			544,4675698	544,4675698	
22/Oct			562305	562519		214		33,6		817,2542			524,6771974	524,6771974	
22/Oct			567836	568037		201		33,6		817,2542			492,8042836	492,8042836	
23/Oct			579252	579477		225		33		818,1012			552,2182776	552,2182776	
25/Oct	538116	538324	579501	579686	208	185	27,2	32,3	820,642	817,9423		512,08061	453,9580036	966,0386136	2 engines on
26/Oct	556581	556830			249		24,7		821,9654			614,0081263		614,0081263	
27/Oct	575845	576076			231		24,8		821,9124			569,5853132		569,5853132	
28/Oct	588222	588445			223		24,3		822,1771			550,0364804		550,0364804	
28/Oct	590536	590760			224		23,4		822,6535			552,823159		552,823159	
31/Oct	642018	642242			224		22		823,3946			553,3211658		553,3211658	