THE USE OF WIND ASSIST TECHNOLOGY ON TWO CONTRASTING ROUTE CASE STUDIES

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ABSTRACT

The performance and application of wind assist technologies has become an increasingly popular topic of discussion in recent times, but the actual performance expected in real life operational conditions remains clouded and unclear. This paper describes a performance prediction software package designed specifically to asses wind assist and wind propulsion technologies, and then goes on to compare the relative performance of three selected wind assist technologies. The Dyna rig, the Flettner Rotor, and the Active Towing Kite, are compared over two very different routes, using an aframax tanker as a case study vessel.

Keywords: Kite, Flettner Rotor, Dyna Rig, Wind Assist, Weather

1. INTRODUCTION

In the last three decades global emissions from the shipping industry have more than doubled (International Energy Agency 2011). In 2011 the International Maritime Organisation (IMO) published their regulations on the efficiency of new builds which drew considerable attention to the need to adopt low carbon technologies in order to meet the tough targets set (Bazari & Longva 2011). While the list of potential technologies which intend to increase efficiency, or lower the consumption of fossil fuels is extensive, it is likely that in order to meet these targets the use of fossil fuels will need to be substantially reduced or substituted by alternative forms of propulsive power.

A part of this growing attention on reducing fossil fuel use has turned to wind power, which has all the desirable characteristics of being clean, free, abundant, and in unlimited supply. Wind has driven seaborne trade and transportation since the very first days mankind took to the seas and in fact has only fallen out of favour in the very recent history. Towards the end of the 19th century the reliability and speed of higher density energy sources; first coal, and later diesel took over. Since then wind power has been relegated to largely recreational use only.

This study focuses on technologies described by the term ‘Wind Assist’, which can be distinguished from ‘Wind Propulsion’ by its intended operational profile. Wind assist technologies are expected to operate at, or close too, conventional ship speeds and will therefore spend far more time at higher ratios of ship speed to wind speed and lower apparent wind angles than a ship powered exclusively by the wind.

Despite the growing levels of interest, performance figures published for wind assist technologies vary wildly; a situation often not helped by the ambitious claims of concept designs from many with a potential stake in the industry. Any well-proportioned wind assist technology will be capable of supplying close to 100% of a ships total power requirements given optimal conditions - But the question remains: just how often do those optimal conditions occur, and what are the tradeoffs outside this region?

This study seeks to address this question by presenting technology models for different three wind assist technologies in order to compare their potential for power savings. The technologies chosen are those considered to have the most future potential by the authors: the Flettner Rotor, Dyna Rig, and Active Towing Kite.

In order to contextualise the results of the technology models two routes are chosen for consideration, and the performance of each technology is assessed over multiple simulation voyages across a 30 year timespan in order to draw attention to the link between the technologies and their environment. The routes selected are Lagos (Nigeria) to Barcelona (Spain) and Los Angeles (USA) to Chiba (Japan)

2. METHODOLOGY

2.1 VOYAGE SIMULATION

2.1 (a) Ship

An Afromax Tanker was chosen as the reference vessel for this study because of the availability of route data Lu(2015). The ship is approximately 250m and operates on a variety of routes across the globe but due to confidentiality agreements further details of the ships particulars are not able to be shared. The design speed for the ship is 15knots, but given the focus on reducing fuel consumption expected of any ship considering the potential of wind assist technology a slow steaming margin of 20% is applied and the ship is assumed to operate at a constant speed of 12knots throughout the voyage.

2.1 (b) Route

From the noon reports available two voyages have been selected representing two typical but highly contrasting routes over which to assess the potential impact of wind assist technologies. The voyages are described as a sequence of longitude and Latitude coordinates recorded each day of the voyage and intermediary points are inferred between these to allow a higher resolution in the analysis. For each route around 50 waypoints in total are used. To allow a direct comparison speed has been averages over both voyages and no attempt has been made to optimise these routes either through course or speed changes to account for the weather conditions experienced, or the presence of wind assist technologies.

Table 1 - Details for routes studied

Coastal Route:	Lagos (Nigeria) – Barcelona (Spain)	3776nm
Ocean:	Los Angeles (USA) – Chiba (Japan	4646nm

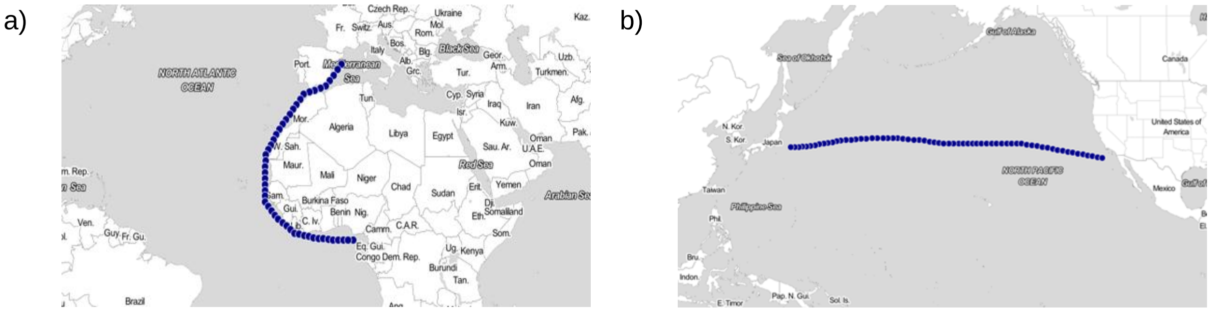

Figure 1 – Maps showing voyage track for a) Coastal Route, and b) Ocean Route

2.1 (c) Weather

The European Centre for Medium range Weather Forecasting (ECMWF) continuously reanalyses its archived meteorological observations using its modern forecasting systems. The ERA-INTERIM project is the latest step in this process and provides a global atmospheric reanalysis archive spanning from 1979 to the present day, as described in (Dee et al. 2011). The data is made available in gridded binary (GRIB) data format at approximately 80km spatial resolution, and with 60 atmospheric levels. For this study 36 years worth of wind speed and direction data at a 10m reference height has been downloaded for the simulation of historic voyages.

Voyage dates are selected at random and simulation voyages were run a total of 1000 times for each route in order to gather a complete historical picture of the weather conditions expected. The statistical distribution and mean trends for each route are presented below.

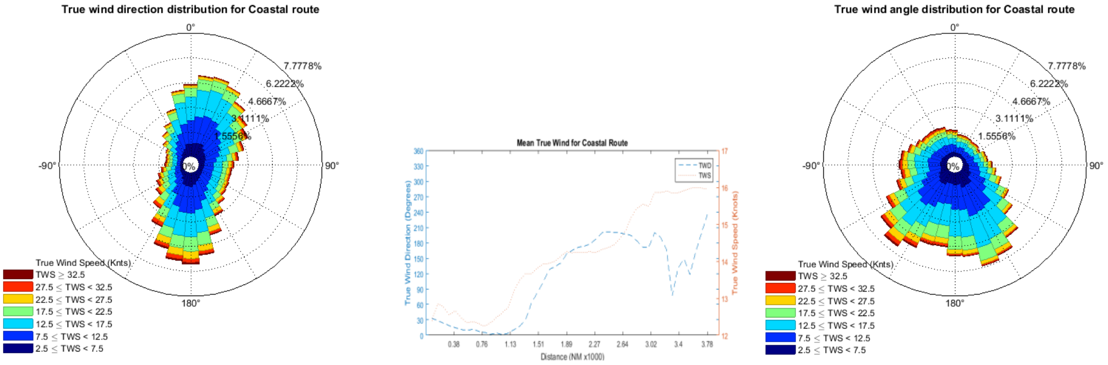

Figure 2 - Wind Statistics for Coastal Route

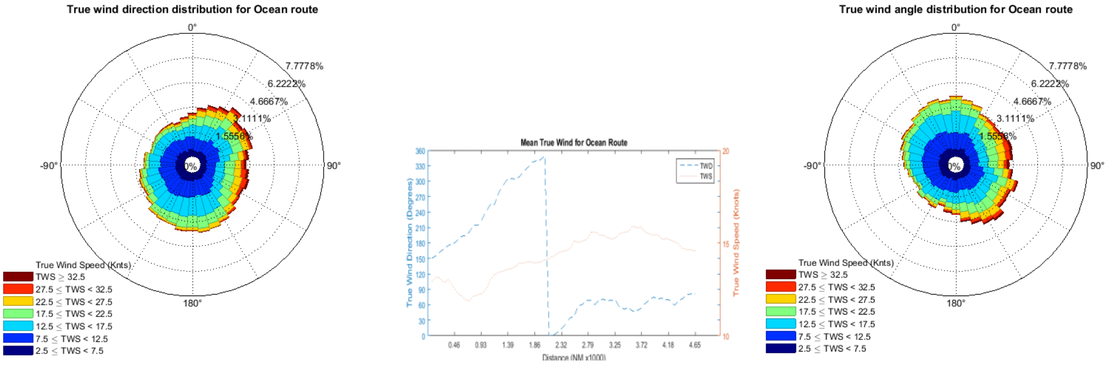

Figure 3 - Wind Statistics for Ocean Route

Due to the similarity of true wind angles for the outbound and return routes (essentially a 180° flip) only the outbound results for true wind angle are shown here.

Given the differing nature of the routes selected, their similarity in average true wind speed (TWS) is surprising – 14.12knots for the coastal route and 14.25knots for the ocean route. This figure agrees closely with the global average for ice free seas of 14.38knots established by (Kent et al. 1012). The difference in true wind direction (TWD) is more marked. The coastal route demonstrates a significant bias towards prevailing winds from astern of the ship on the outward voyage, and conversely on the bow for the return leg. The nature of this route mirrors that of the trade winds which in the eastern Atlantic are south westerly in the southern hemisphere, and north easterly in the northern hemisphere. The Ocean route demonstrates a more balanced wind direction profile. The trade winds in the northern pacific are generally easterly but due to the more northerly latitude of this route some circulation is expected.

2.2 SHIP PERFORMANCE PREDICTION

In order to assess the question of performance a velocity prediction program (VPP) names WASPP (Wind Assisted Ship Performance Prediction) has been developed with wind assist technologies and motor sailing specifically in mind. The program follows conventional sailing yacht VPP practice as described by (Philpott et al. 1993), the overriding principle of which is the conservation of Newtons second law: “For any body which is not accelerating the sum of forces in each coordinate direction and the sum of moments around each coordinate axis must be zero”. WASSP is essentially a 4 degrees of freedom balance model. For a given combination of input parameters it calculates the aerodynamic and hydrodynamic forces and moments, and solves to find the equilibrium condition where surge, sway, roll and yaw are balanced. Input variables are TWS, TWA, and either engine RPM, or ship speed depending on whether speed or power is desired as an output. The program is then free to select values for heel, leeway and rudder angle, along with either engine RPM or desired ship speed (depending on input parameters). Additional variables are also available for each wind assist technology – for example rotational speed in the case of the flettner rotor. In many cases multiple solutions are possible, which all respect the governing law of balance. In these cases the solution can be optimised for maximum speed, minimum fuel consumption, or some combination of both. For this study desired speed is a fixed input and the solution is found for minimum fuel consumption.

Bare hull calm water resistance is obtained using (Holtrop 1984) The additional drag due to heel is approximated via a change in wetted surface area as it is assumed that for small heel angles viscous resistance is largely unaffected. Drag due to leeway is included in the form of hydrodynamic coefficients from the testing of British Bombardier as described in (Journee & Clarke 2005) and used in (Naaijen et al. 2006). Drag due to rudder angle is calculated along with standard aerofoil theory assuming a NACA0018 section. Finally aerodynamic drag of the topsides and superstructure is calculated according to (Blendermann 1994) to find the total resistance of the ship.

2.2 (a) Dyna Rig (Sails)

Sails in various forms have powered sea trade for most of its history. The Dyna Rig configuration has been selected for this study as the most promising configuration for modern applications. Very much the modern square rigger, the sails are easily handled and loads are kept manageable by breaking the sailplan up into many small sails set between horizontal yards, typically on multiple masts. The whole system can be fully automated, and unlike square riggers of old the whole system can be operated by a single crew member from the safety of the bridge (Occasional maintenance trips aside!). This configuration has been proven at full scale on the private super yacht ‘Maltese Falcon’ and its potential in the commercial sector has been extensively studied with the B9 Shipping project claiming up to 60% of the thrust for a 3000dwt coastal cargo ship (Surplus 2011) and the Ecoliner concept also anticipating significant savings (Dykstra Naval Architects 2013).

Dyna Rigs provide a number of advantages: Because each sail can be removed individually they are highly adaptable and their performance is fairly balanced across a range of wind speeds and angles. With the sails removed the masts and yards alone provide relatively low aerodynamic drag and construction and sail handling technology is well proven in the leisure market (albeit at a smaller scale than discussed here). Compared to the other technologies however, there is a high level of complexity and many individual failure points which may hamper reliability. Cost is expected to be high and maintenance will require specialist skills. A major limiting factor in the application of dyna rigs is the deck space consumed, although the sails themselves can be raised above the working deck height the masts and yards will provide a significant hindrance dockside operations and cranes in particular.

Drive force from the rig is computed as per a conventional VPP. Lift and drag coefficients used are the result of wind tunnel testing completed in the Wolfson unit and described in (Grech La Rosa 2012). The coefficients include the effect of multi-mast interaction and since the configuration tested is close to that described here the results are expected to be comparable. A reefing system is employed in strong winds similar to a conventional VPP but the usual FLAT and TWIST parameters are ignored as it is not believed they can be achieved effectively with this rig configuration. While the loading and safety factors involved in such a rig are not fully understood, In the absence of other knowledge an upper wind limit of 35knots has been set at which point the rig is fully reefed and all sails are removed.

A total sail area of 8446m2 split between 4 masts is selected, in line with existing studies, and scaled to the ships size.

Figure 4 - The Ecoliner Concept (www.dykstra-na.nl)

2.2 (b) Flettner Rotor (Rotor)

Flettner rotors are named for their inventor Anton Flettner, who pioneered their use in the early 1920s. The concept came back into light during the fuel crisis in the 1980s but failed to prove sufficiently attractive to take hold as fuel prices dropped once more. In today’s financial and regulatory climate many are turning their attention back to Rotors as a potential solution. In 2010 the 10,000dwt ‘E-Ship 1’ launched, fitted with four Flettner rotors and claiming a 25% increase in fuel efficiency (Enercon 2013) and recently the ‘M/V Estraden’, a 9741dwt Ro-Ro cargo vessel was retrofitted with a single 18m high rotor.

The Rotor consists of a slender vertical cylinder which is rotated by a motor. This rotation created a low pressure region normal to the apparent wind flowing over the cylinder due to the Magnus effect – The same effect which makes a ball curve through the air when given the right amount of spin. Rotating cylinders have been repeatedly shown in wind tunnel, CFD and full scale testing to be capable of generating significantly higher lift coefficients than conventional sails, and therefore can be far smaller in area for the same force provided.

Flettner Rotors occupy far less deck space than sails and are significantly simpler in their construction, being less prone to damage and mechanical failure. Maintenance routines will be dominated by the engines and bearing systems, therefore requiring skillsets already on board. While telescoping and folding systems have been proposed, the only practical means of control and tuning of the rotor after construction is by varying its rotational speed. There is no reefing or removal possible in high winds so adverse performance should be expected in these scenarios. Ship motions and practical issues such as docking may be limiting factors but are outside the scope of this study.

4 rotors are fitted for this study, with the total area falling in line with existing ships and preceeding studies where possible. Each is a plain cylinder 39.4m high and 6.4m diameter with no end plate or thom disks fitted. The spin ratio (the ratio between the rotational speed of the cylinder and the velocity of the incoming air flow) is allowed to vary within a range of 0 to 8 but typically falls within a range of around 3.5 which is in line with other studies (Traut et al. 2014)

Lift and Drag Coefficients are a function of the spin ratio, and are obtained from experimental studies completed by (Prandtl & Betz 1932) and adjusted for aspect ratio. Lift and drag forces on the cylinder are calculated as per a conventional sail rig.

Flettner Rotors differ from the other technologies considered here in that they require a constant power input in order to generate lift. While sails and kites have an energy cost associated with their deployment and retrieval, they require only trivial amounts of power in their control systems to continue to operate. The lift generated by Rotors on the other hand is a function of the speed of their rotation and therefore there are additional losses to be considered. For this study the additional power required is included as a reduction in the power generated.

Figure 5 - The Enercon Eship1 (www.7seasvessels.com)

2.2 (c) Kite

The study of kites for marine propulsion dates back to the mid 1980s (Wellicome et al 1984) and (Duckworth 1985) and relative to the other technologies discussed a relatively large amount of full scale testing has taken place, pioneered in a large part by the company Skysails, with a number of ships currently operating with the technology claiming 16-23% savings (Brabeck et al. 2013).

Kites have a number of features which differentiate their performance and application from sails and rotors. By their very nature they operate at altitude and therefore fly in stronger and more stable winds than those experienced at deck level. Furthermore they can be flown dynamically and have the ability to generate their own apparent wind, further increasing the thrust available. Their installation takes up limited deck space, away from the main working area and is well suited to retrofit. While a small launching tower is required, air draft is not typically affected and due to the low centre of gravity of the system and attachment point of the kite towing cable at deck level, stability is not affected and resulting heeling moment is low.

Kite onset velocity and the resulting towing force is calculated by the zero mass model as first described by (Wellicome & Wilkinson S 1984) and later validated against experimental data by (Dadd et al. 2010) and (Guisnel 2013). The model neglects the mass of the kite and lines; which means dynamic effects can be ignored during flight.

The force generated by the kite is given as the vector sum of the lift and drag forces for any given kite velocity. If this force vector is not in line with the direction of the kite cable then the kite will either accelerate or decelerate until an equilibrium condition is reached. Using this principle it can be shown that kite angular velocity can be determined directly as a function of angular position and by solving for this equilibrium condition, we can calculate the velocity, and therefore the force generated for any given point along the kites trajectory. The mean force generated by the kite is then calculated as a time average over the trajectory and the thrust is calculated as a component of this in the direction of ship travel.

Since line length is constant the kite trajectory can be plotted on a sphere. The kite trajectory is described by a figure of 8 on the surface of this sphere and parameterised as described in (Dadd et al. 2011). No attempt is made during this study to optimise the trajectory of the kite, but the position of the kite within the flight envelope, as well as the rotation of the main trajectory axis is optimised for each condition.

A kite area of 640m2 is chosen with a Line length of 300m. This is slightly smaller than might be expected for a ship of this size, but the increased mass that comes with area poses a hard limit on kite size. This is investigated by (Bles et al. 2012) but the limits of the materials involved are outside the scope of this study . Further work is needed to establish the tradeoffs involved in increasing size, but in the absence of this: 640m2 is the largest kite currently offered by the market leaders (Skysails 2010) so was chosen as a suitable compromise.

A further issue exists which is that while kites are able to generate their own apparent wind dynamically, they cannot be launched or retrieved in very light winds. In the absence of available data a lower wind band of 7.5knots was selected in line with anecdotal reports and experience from the leisure kite industry. 35knots was selected as the upper wind band. In both cases the apparent wind experienced by the ship is used, not that experienced by the kite as it is assumed the trajectory can be altered and onset velocity reduced to keep forces within a safe and manageable level when in flight. Outside of this operating wind band the kite is simply removed.

Figure 6 - A towing kite in action (www.skysails.info)

2.3 PERFORMANCE PREDICTION OUTPUT

Presented below are the outputs from the VPP for each technology, presented in the form of polar diagrams. The diagrams show TWA on the radial axis and thrust generated on the Y axis, for a range of TWS from 5 to 30 knots. These results indicate that the Rotors specified for this case study vessel significantly outperform the other technologies, regularly supplying 100% of the ships required power and being throttled back in their output. The performance of the kite for downwind angles greater than 150degrees is surprising as this is traditionally an area where actively flow kites are expected to perform well. Further work is needed to identify the cause of this anomaly.

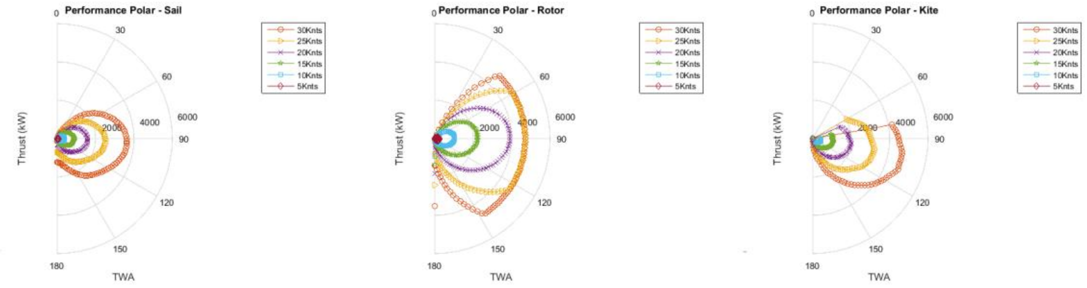

Figure 7 - Performance polar plots showing thrust generated over a range of true wind angles and speeds for each technology

Plotted below is the same information plotted in an alternative form, this time showing fuel consumption for each condition. Results are presented as a percentage of fuel consumption with 100% taken as the baseline ship with no wind assist technology fitted, and 0% indicating that no additional engine use is required at all to achieve the ships propulsion requirements. It can be seen from these results that there is in fact a slight increase in fuel consumption for the sails and particularly the rotors in headwind conditions due to the additional drag. Kites are unaffected by this drawback as they can be fully stowed in such conditions.

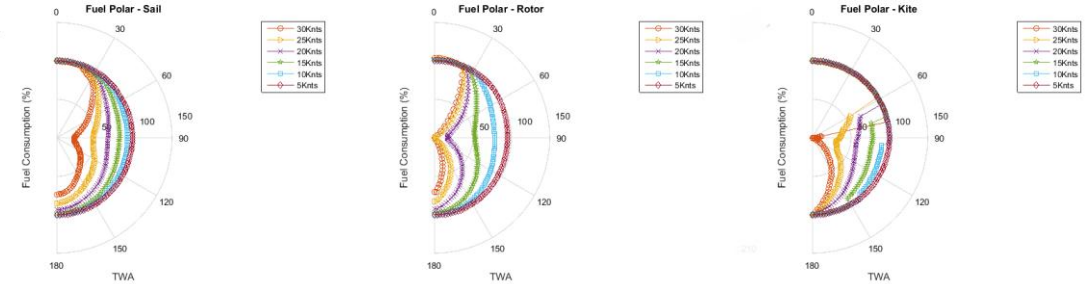

Figure 8 - Fuel polar plots showing fuel consumption as a percentage for a range of true wind angles and speeds where 100% is the fuel consumption in calm water with no wind assist technology fitted

3. RESULTS AND DISCUSSION

The results presented below show fuel consumption as a percentage of fuel consumption with 100% taken as the baseline ship with no wind assist technology fitted, and 0% indicating that no additional engine use is required at all to achieve the ships propulsion requirements. The X axis shows distance travelled along the voyage and the performance over the duration of every single simulation is plotted along with an average figure for each point on the route taken over the full time history of the route.

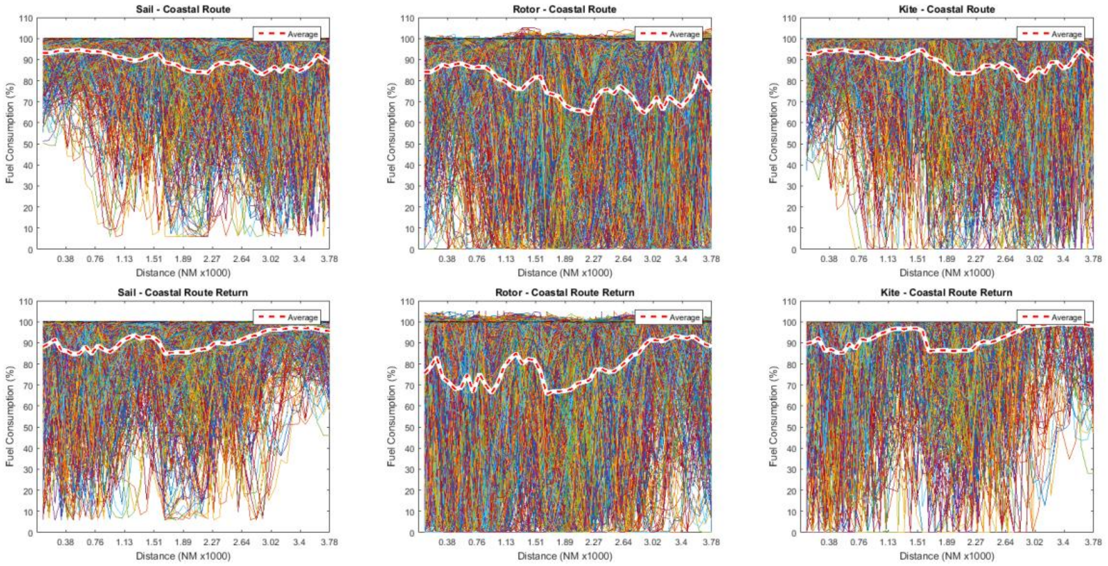

Figure 9 - Fuel savings for the Coastal route - both outward bound and return, and for each technology. Every voyage simulated is plotted, along with an average for all voyages. 100% is the fuel consumption in calm water with no wind assist technology fitted.

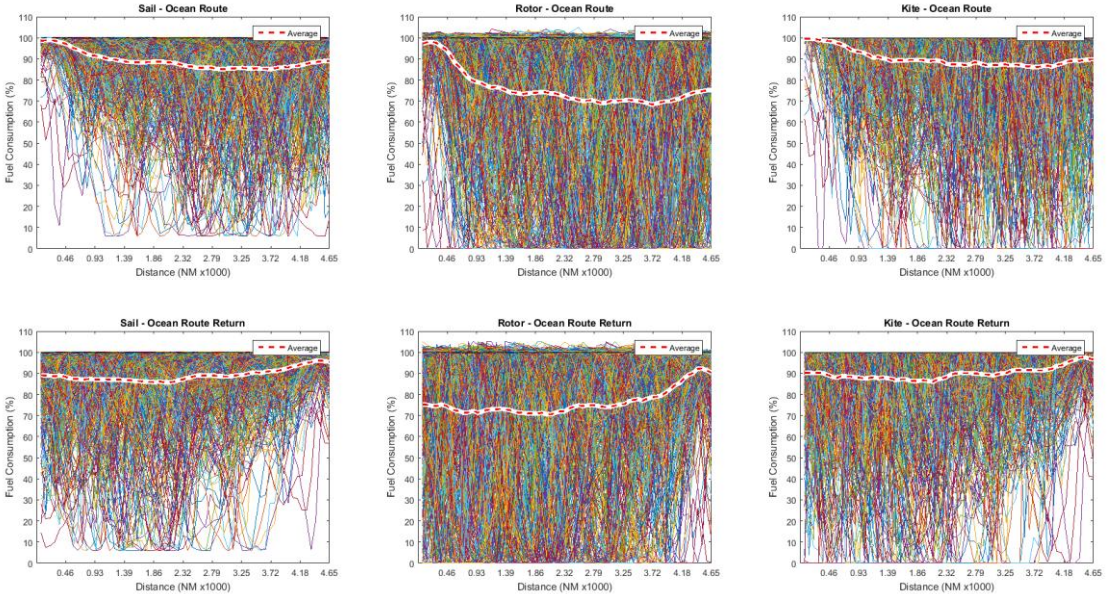

Figure 10 - Fuel savings for the Ocean route - both outward bound and return, and for each technology. Every voyage simulated is plotted, along with an average for all voyages. 100% is the fuel consumption in calm water with no wind assist technology fitted.

These results demonstrate the extreme variability in wind power and highlight the need to evaluate its effects over multiple voyages and over an extended time period. The so called ‘1000 year storm’, the worst conditions expected in 1000 years, is often referenced in safety discussions. For 1000 voyages over the past 36 years it can be seen that there is a clear trend that for some sections of the route, or specifically some geographic areas, the full performance potential of each technology is never reached.

It is worth drawing attention to the fact that the sails never quite achieve full 100% drive force. This is because the upper wind limit of 35knots is reached and the sails are fully removed to prevent damage before they are able to generate sufficient thrust. Due to the relative rarity of these wind speeds it is not thought that this will have a significant impact on the results, nonetheless further investigation should be carried out to investigate the performance and safety factors involved at this upper limit. It can also be seen that the rotor suffers significantly more than the dyna rig in the case of adverse conditions. Further research into the drag of these technologies in ‘bare poles’ conditions is needed to verify this apparent trend.

4. CONCLUSIONS

It can be seen from the table below that the average fuel saving across both routes is 10.5% for the Dyna Rig, 23.2% for the Flettner Rotor, and 9.5% for the Kite. While it has been shown that each technology is able to supply significant proportions of the ships propulsion power demand in ideal conditions, assessment over a significant timeframe and two very different operational regions have shown the figures for this case study vessel fall someway short of other studies and many manufacturer claims. It is suggested that this may be a function of the ships size – being significantly larger than previously considered but further work is needed to assess the impact of this.

Table 2 - Average results and comparisons of fuel saved for each route and technology

	Dyna Rig (Sail)		
Route	Coastal	Ocean	δ(Ocean - Coastal)
Out	10.8%	11.0%	0.2%
Return	9.4%	10.8%	1.5%
MEAN(Return, Out)	10.1%	10.9%	
δ(Return - Out)	-1.4%	-0.2%	

	Flettner Rotor (Rotor)		
Route	Coastal	Ocean	δ(Ocean - Coastal)
Out	23.8%	24.1%	0.3%
Return	21.3%	23.8%	2.5%
MEAN(Return, Out)	22.5%	24.0%	
δ(Return - Out)	-2.5%	-0.3%	

	Kite		
Route	Coastal	Ocean	δ(Ocean - Coastal)
Out	10.7%	9.8%	-0.9%
Return	7.3%	10.0%	2.7%
MEAN(Return, Out)	9.0%	9.9%	
δ(Return - Out)	-3.4%	0.2%	

The performance for each technology over both routes is remarkably similar, and it is proposed that the similarity in average TWS between the routes outweighs the TWD variation in terms of the performance demonstrated.

For all technologies there is a significantly greater variation in the out and return routes for the coastal voyage. It is suggested that this is due to the upwind/downwind bias that can be seen from the wind distribution charts in Figure 2 - Wind Statistics for Coastal Route

It is clear that for the cases presented here the Flettner Rotor significantly outperforms the other technologies, however the importance of sizing cannot be underestimated when assessing wind assist technologies. While every attempt has been made to ensure the technologies presented here all fall in line with previous examples found in the literature, and follow real life ships wherever possible no attempt has been made to optimise the size of the technologies selected. Further considerations including structural design, motions, purchase and maintenance costing are also outside the scope of this paper and it is suggested that future work should be directed in this area.

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