ULYSSES – the ultra slow ship of the future

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Summary

The EU-project ULYSSES: *Ultra Slow Ships* is currently in progress. ULYSSES' main objective is to develop ship design concepts, which should be able to meet the 2020 and 2050 emissions' targets. The fact that slow steaming saves fuel is well known and commonly used. History shows that reducing service speed of ships has been a common strategy when charter rates were low and/or the fuel oil prices were high. Slow steaming can be economically sound strategy, but also can be a potential problem, especially when sailing in crowded area with large traffic, dangerous areas infested by pirates or in adverse weather conditions. The main aspect is to determine whether the available propulsion power will be sufficient to enable a safe sailing of the ship. Since slow steaming also is ideal to be combined with different kind of wind propulsors such as kites, Flettner rotors or sails, the needed power installed on board can be very low to just ensure calm water operations. In the present paper these issues are illuminated.

Introduction

Maritime industry has already taken steps on the way to reduce CO2 emissions and pollution, but pressure is increasing for the industry to make greater improvements in the fight against climate change. Therefore, if the marine industry is going to meet the targets of CO2 reduction (IMO 2009a) for 2020 by 30%, and for 2050 by 80% compared to 1990 levels, drastic improvement of the energy efficiency of existing ships and newbuildings needs to be achieved. Currently no system or technical innovation to be installed onboard guarantees that at current logistic chain setup, shipping will be able to meet these targets.

If we are to consider that 60% of CO2 emissions come from the bulk cargo transport, simple inspiration to solve the target problem can be found in pipelines due to their very high-energy efficiency. From that point of view, it would be very good to transport everything by pipeline. However, there are obviously some practical issues with such a scenario, e.g. political. Ships, on the other hand, are much more flexible, have a lower capital cost, which is also distributed over many more stakeholders, can cross vast distances, and have much better network security, e.g. if one ship is out of service the remaining ships still operate. So the challenge is to make ships with efficiency close to that of pipelines.

Almost a trivial solution would be to simulate a pipeline cargo flow, by significantly slowing the ships down and possibly creating a line of ships, figuratively speaking 'bow to stern', moving from A to B. We will show in the continuation of this paper that such a solution is viable, and not only in terms of the emissions, but also related to ship economics. To further explore the capabilities and challenges of such a solution an EU FP7 project *ULYSSES: Ultra*

Slow Ships (www.ultraslowships.org) is currently in progress. ULYSSES' main objective is to develop ship design concepts, which should be able to meet the 2020 and 2050 emissions' targets.

In this paper we will thus introduce the economics, environmental impact and safety of ships operating at ultra slow speeds, as well as the advantages of alternative propulsion concepts such as wind.

Economical soundness of slow steaming

The fact that slow steaming saves fuel is well known and commonly used. History shows that reducing service speed of ships has been a common strategy when charter rates were low and/or the fuel oil prices were high. The reason is simple: the power needed to propel the ship increases roughly with the speed in the power of three. The figure below shows a possible relationship speed-power for a 40 000 DWT tanker. This ship, designed for 16 knots, could reduce the fuel consumption in the order of 50% by reducing its speed by only 3 knots, from 16 down to 13 knots. Going down to 10 knots means a power reduction of approximately 80 %. In the case of wind propulsion, instead of focusing at delivered power, one must also consider the resistance of the ship (see figure below). Going from 16 knots down to 13 knots indicates a decrease in resistance by approx. 40 % and further down to 10 knots approx. 65 %.

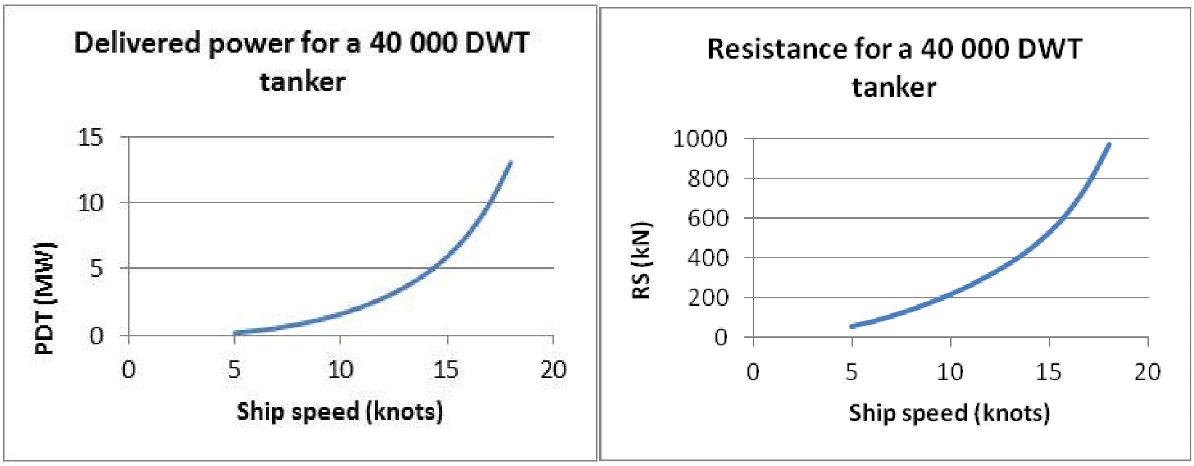

Figure 1 and 2 showing a possible power-speed and resistance –speed relation for a 40 000 DWT HANDYMax tanker

Claus Gronborg, head of crude at Maersk Tankers, explained that they have managed to reduce their operating costs to one half by slowing their VLCC tankers to 8.5 knots. In this particular case, bunker costs are in value of about 85% of all voyage costs. Reducing speed from standard service speeds (14-16 knots) to 8.5 knots, they have managed to save about 50% in bunker costs on the ballast leg and have removed 400 000 USD on the bunker bill for a standard round voyage. Maersk decreased engine load by 10%, what equivalents to 50% of service speed, all with approval of their two engine manufactures, Wärtsilä and MAN B&W and only required a few precautions.

Klanac *et al.* (2010, 2011) developed a simplified economical model and argued that slow steaming is economically and environmentally sound strategy. The economic model follows the assumption of the economic equilibrium, in which stakeholders will tend to through a period of time equally share the benefits of an economic behaviour as much as possible. The very fact made it possible to determine the optimal ship service speed that results in equal amount of benefits for the owner and charterer for any given market condition. Application of the model to the AFRAMax- and VLCC-sized tankers, 100’000DWT and 300’000DWT respectively, resulted with the finding that both stakeholders will enjoy a bigger joint benefit for slow steaming ship than ship operating at standard service speed at the current market conditions.

In Figure 3, we can see the optimal speeds determined for modern AFRAMax and VLCC tankers for the average bunker prices of 2011, while Figure 4 presents the link between the optimal speed and freight rates.

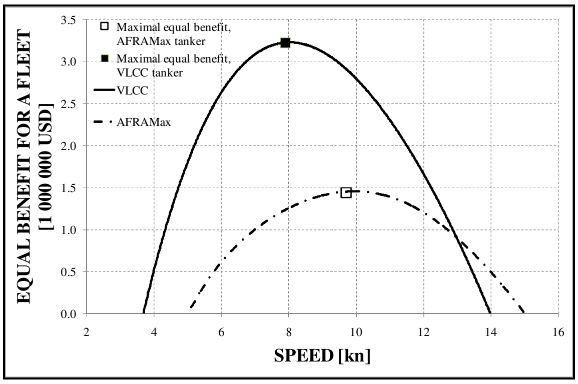

Figure 3. Comparison between the values of AFRAMax and VLCC tanker equal benefits of owner and charterer. Dots indicate “optimal speed” (Klanac *et al.* 2011)

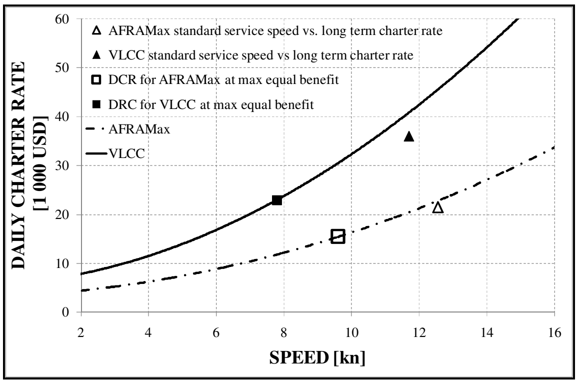

Figure 4. Comparison between the daily charter rates at equal benefits for owner and charterer for AFRAMax and VLCC tanker, Ref [14], interpolated curves. (Klanac *et al.* 2011)

Environmental impact

Given the CO2 on the emissions data obtained from the manufacturer for the same two ships slow steaming results in a significant positive ecological impact. As it can be seen from Figure 5, if ship service speed is reduced to 12 knots, CO2 emission reduction will be in value of 25% of those at present day. If speed is reduced to 6 knots, the amount of reduction will be more than 85% on a fleet level. For the AFRAMax tanker, as it can be seen from Figure 6, if we reduce the ship service speed just by one third, to 10 knots, CO2 emission reduction will be more than 80% of those at standard speed. If we reduce speed to 5 knots, the amount of reduction will be more than 95%.

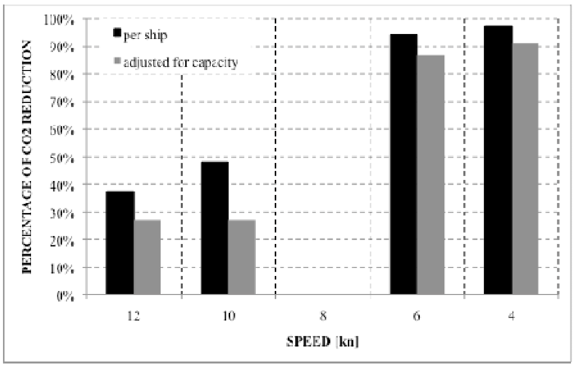

Figure 5. Annual VLCC CO2 exhaust reduction, function of ships speed and adjusted to fit the same cargo capacity per unit time.

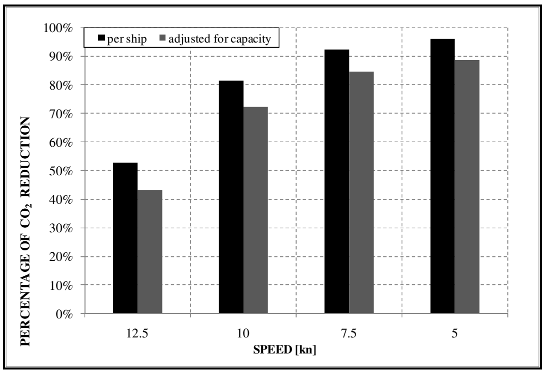

Figure 6. Annual AFRAMax CO2 exhaust reduction, function of ships speed and adjusted to fit the same cargo capacity per unit time.

IMO (2009b) recently implemented the EEDI, or the energy efficiency design index), to be conceived as a mandatory newbuilding standard. EEDI for a ship represents the basic energy efficiency of a design. The fundamental principle is that the emission index expresses the ratio between the amount of emission and the benefit that is generated, expressed as a transport work capacity. The EEDI is defined for a ship under specified conditions (e.g., engine load, draught, wind, waves, etc.) in relation to the nominal transport work rate. The unit for EEDI is grams of CO2 per capacity-mile, where "capacity" is an expression of the cargo-carrying capacity relevant to the cargo that the ship is designed to carry. It is applied here to capture more holistic aspect of ship speed reduction. Figure 7 shows EEDI comparison for different speeds for the VLCC and AFRAMax tanker taken into consideration.

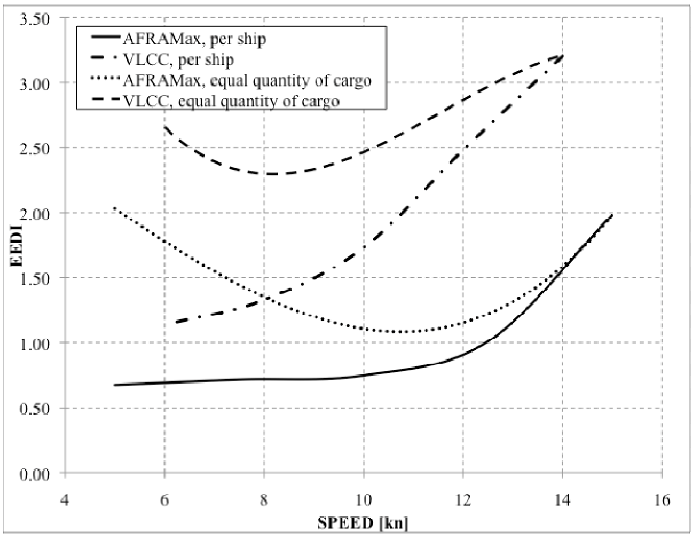

Figure 7. Comparison between EEDI's for AFRAMax and VLCC tanker

It is not a surprise that the slow steaming VLCC and AFRAMax have smaller EEDI's. However, if adjusted for the same transport capacity per unit time, the EEDI for the VLCC is minimal for the ship operating at 8 knots, and at about 11 knots for the AFRAMax. This means that on the fleet level addition of more ships to make up for the lost capacity will reduce the efficiency of the system. Nevertheless, the ecological efficiency will be still better than for a ship operating at standard speed.

Slow steaming – addressing potential safety issue

Slow steaming can be economically sound strategy, but also can be a potential problem, especially when sailing in crowded area with large traffic, dangerous areas infested by pirates or in adverse weather conditions. There are a lot of areas such as the English Channel, where the traffic ways are crossed due to heavy shore-to-shore communication. Avoiding ship-to-ship collisions could be a real problem with slow steaming ships. Additional problems deal with navigation in rough weather conditions, since their service speed is relatively small, and they possibly could not avoid developing storms. The effect of bad weather is either to slow down the ship for a given power absorption, unless an additional input of power to the propeller is produced in order to maintain the same ship speed, to a certain extent. The limitations are given by the propeller(s) adaptation and efficiency, and the main engine torque limitation, for a given resistance.

To maintain ship's operability, there should be an accurate calculation of a minimum main power, or the installation of an additional power storage unit on board, which can be used in these extreme situations.

Consideration of a minimum main propulsion power for a super slow ship

In order to address the above mentioned potential hazards to which a super slow ship could be exposed in the future, it is necessary to determine criteria based on scenarios exploited by the project. The main aspect is to determine whether the available propulsion power will be sufficient to enable a safe sailing of the ship. Therefore it was of an important interest to consider the on-going work by the IMO, through the MEPC. The International Association of Class Society (IACS) proposed and was mandated by the Assembly to elaborate criteria to assess a minimum safety level in propulsion power, considering that the availability of propulsion is the basis of the safety principle. A ship with an insufficient propulsion power will not make her way through harsh stormy weather, and eventually will be pushed to the shore by lack of manoeuvrability and sea keeping capability. She will not be able to escape due to the action of the waves on the hull and the wind on the above water surfaces and structure.

Standards for manoeuvrability in adverse condition

Today, the only existing standards for ship manoeuvrability are for calm water, ie MSC.137(76) and MSC/Circ.1053. There are no existing international standards for manoeuvring in adverse conditions. Some class rules are requesting a minimum speed of 7 knots in BF 5, but this is limited to some additional notations.

In the IACS initiative, it was decided to opt for a solution which would facilitate an early implementation of the regulation for minimum power requirement. Two assessments methods have been proposed, a comprehensive one, which remains complex, costly, and of a long term process, and a said simplified assessment, which has the advantage to be short and give early conclusion, but for which special care must be taken to not misinterpret the results. To discriminate the two methods, some assumption has been made.

Typically, it is assumed, in a simplified approach, that the dimensioning criterion for a minimum power is the minimum advance speed in waves. This assumption is fairly correct for ships with low Froude Numbers, and low ratio of above-water lateral area to total lateral area, typical for bulk carriers and oil tankers. Those two types of ship which are central to the ULYSSES project are less subject to mitigation of their manoeuvring capability in strong gale force winds.

Methods of added resistance in waves estimation for a typical ship

To calculate the propulsion power for a ship, the resistance and the total propulsive efficiency have to be determined with the highest possible accuracy. As empirical methods are normally used for these calculations, it is worthwhile at least to know the accuracy of the different elements in the calculation procedures such that the propulsive power can be predicted in combination with an estimate of the uncertainty of the result. The option, used in ULYSSES, is to estimate the total resistance by a full scale prediction method. However, for calculation of added resistance due to waves in adverse conditions, the scope of available options is much restricted. The possibilities to use tank test is relatively expensive, and must be repeated for case by case study. There are empirical formulae, but whilst they are of a commercial restricted access, and also they are usually addressing large scope of different types of ship, thus being too general to be accurate enough for such a task. The other way is to use estimation methods which are based on use of data base for standard series hull forms for which main parameters have been varied. Regarding the calculation methods, when based on linear potential theory, are generally underestimating the added resistance when compared against model tests. CFD calculation for estimation of added resistance in waves in adverse conditions is to be used whilst subject to controversy for this specific usage.

Safety requirements in ULYSSES

In ULYSSES, the case of a super slow ship is addressed. The vessel will be fitted with non conventional propulsion systems. As developed further, alternative propulsion systems such as wind sails, kites will be combined with derated diesel engine. Furthermore, the hull efficiency will be optimised for slow speed. Therefore there is a need to ensure that the performances optimization in calm water at slow speed will not detriment the hull capability to sail safely in adverse conditions with high waves and wind.

For the 2020 ship design, an extended simulation will be carried out to ensure that the ship can be safely operated in severe weather conditions, based on the above detailed criteria. An indication of the magnitude of minimum required power to be able to handle the ship in severe conditions will be produced.

The project is also revisiting the wave and fatigue loads and hull strength requirements to establish a specific hull structure update.

Going beyond, the manoeuvrability criteria, established above, through this undergoing work, is extended to approaches, port operations, directional stability and crash stop requirements.

Slow steaming – ideal for wind propulsion

The wind propulsors to be investigated in the Ulysses project are kites, Flettner rotors and suction sails. In this paper the kites and rotors will be discussed.

To investigate the use of wind propulsion on a ship, the wind speed and also wind direction is of course necessary to define. A typical mean wind velocity used for the North Atlantic is 8 m/s or roughly 16 knots. For a 40’000 DWT tanker we can easily understand that not much fuel can be saved if the ship should maintain the service speed of 16 knots by using wind propulsion. In head wind and sea our wind propulsors will not be in use. In following wind and sea the resulting (apparent) wind speed will be zero. Having a wind coming from side, there is a possibility to get some wind thrust from the rotor. If we assume for this ship three rotors with the diameter of 4 m and height 24 m (aspect ratio 6), there is a possibility that we could get a wind thrust of approx. 100 kN. This force represents the increase in resistance going from 15 to 16 knots, a difference in power of about 30 %. So if we could sail in beam winds all the time the fuel savings with these rotors could be in the order of 30 %, however, in practice it will be much lower. If we will not practice weather routing this beneficial wind direction across the North Atlantic is not very common.

If the ship speed is lowered the kite will be a very interesting alternative especially in following wind. If we still assume wind speed of 8 m/s but look at an ultra slow speed of 7 knots we will have the possibility to use a kite in following and probably beam winds. Then it can be assumed that a wind thrust of at least 100 kN can be achieved. For this ship it is in the order of the resistance of the ship at 7 knots, i.e. the main engine can be turned off! Still our three rotors can also produce a thrust in the order of 100 kN in beam winds.

Higher winds – higher speeds

Perhaps 7 knots is not the optimum speed from economical and logistic point of views. One can also assume that in practice wind propulsors will only be used when there is a significant wind speed! As mentioned above, when heading against the wind it is assumed that rotors will be folded and of course the kite is down. This is also to be the case if the wind is weak. On the other hand, having a wind speed of 12 m/s the situation looks very different. The reason is also simple. Wind forces increases with wind speed in square. Going from 8 to 12 m/s gives more than twice the wind force. At this wind speed we can assume that a kite can produce a thrust of at least 200 kN in following winds and nearly that much up to beam wind. However, around beam wind the three rotors will also produce around 200 kN, so we can assume that with a combination of these two wind propulsors a thrust high enough for the majority of wind directions to reach a speed of about 10 knots can be achieved without using the main engine. The idea in the Ulysses project is, however, not to design a sailing ship but to use wind propulsors to reduce the fuel consumption. If 10 knots is used as design speed, the fuel reduction for the main engine will be between 0 and 100 % in the wind speed range from 0 to 12 m/s in most headings. As stated above at 8 m/s wind speed our fuel saving will be roughly 50 % for beneficial wind directions. If we assume that these wind directions occur half of the time we will get a relation power-wind speed for the design speed 10 knots according to the figure below. In these simplified calculations the power increase needed when heading wind and waves are neglected. Taken this into account would have lifted the mean curves some 5-10 %.

If the design speed of 16 knots is kept we are only able to benefit from the rotors. Perhaps the power consumption can be reduced by 30 %, but only a fraction of the time, perhaps 15 %. The figure below shows how the needed power would vary under the above given assumptions. ‘Mean power’ means the power needed if the ship is sailing in different headings as described above. With the same approach the ‘mean fuel’ needed per nautical mile is calculated to give a comparison between 16 and 10 knots. It is here assumed a fuel consumption of 180 g/kW. Just to reduce the speed from 16 to 10 knots the fuel consumption is reduced from nearly 90 kg/nm down to about 30 kg/nm. Using wind propulsion at 16 knots could give us a fuel reduction up to 10 %, while the same figure at 10 knots is about 50 %.

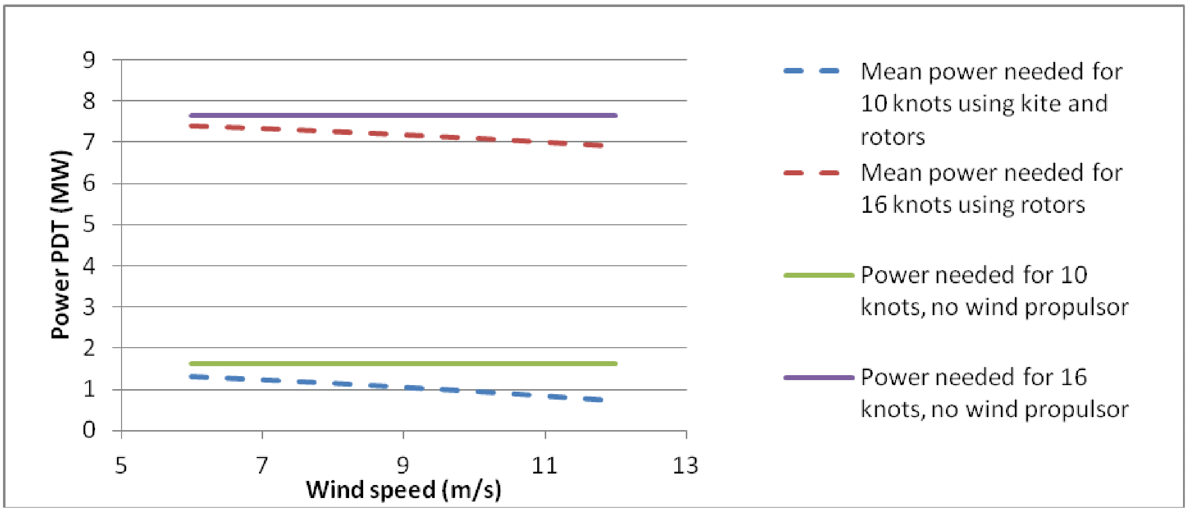

Figure 8. Power needed for design speed 10 and 16 knots respectively with and without wind propulsors.

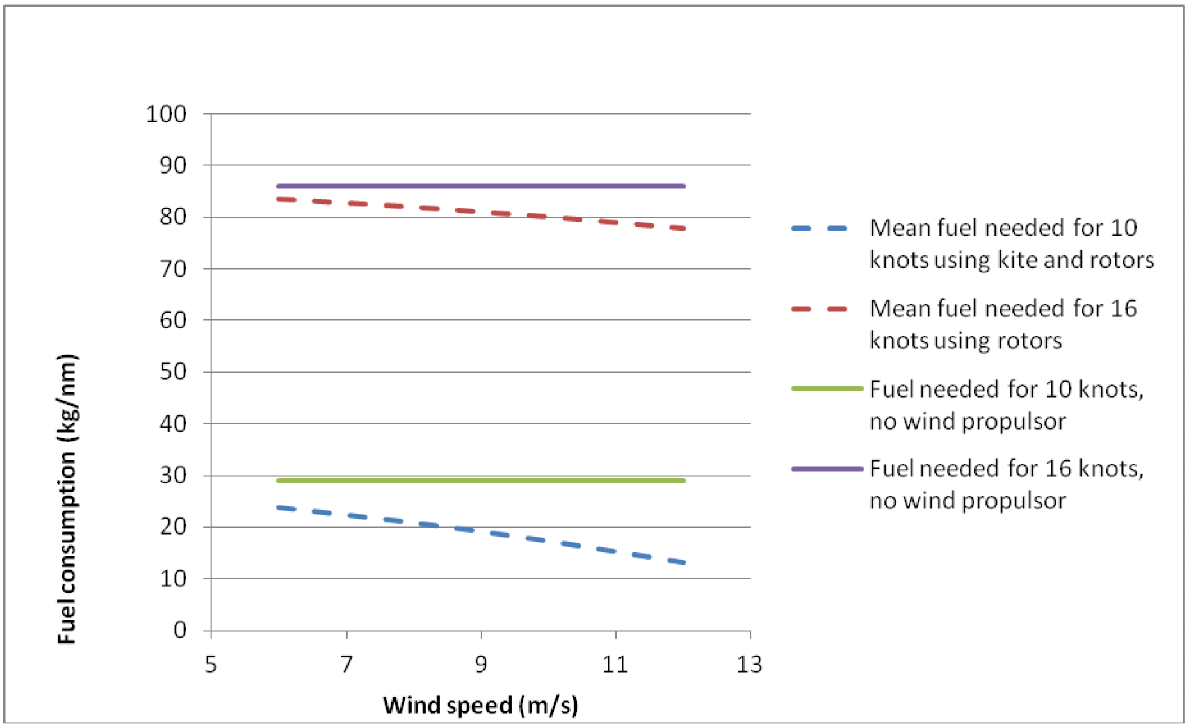

Figure 9. Fuel needed for design speed 10 and 16 knots respectively with and without wind propulsors.

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