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P3_12 The Age of Sail

Michael McNally, Allen Phong, Robert Pierce, Thomas Searle

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

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Abstract

The maximum speed of a cargo ship powered entirely by wind is examined and found to be around 50% of wind speed, evaluating to between 5 and 8 knots. Available solar power is also examined as a comparison and shown to give an increase in speed. It is shown to be feasible to power a ship with renewable power but only if speed is a minimal concern.

Introduction

In 2007, international shipping carried around 8 billion tons of cargo, as compared to 28 million tons carried by air freight[1]. CO2 emissions from international shipping are poorly measured as they do not fall under the regulations of the Kyoto protocol on carbon emissions. To get a sense of the scale of the issue, it is worth noting that in 2003, emissions from ships leaving Dutch ports stood at 43 million tons of carbon[2]. It is clear that in order to achieve a sustainable economy worldwide, shipping must become more efficient. This paper will examine the feasibility of powering a large container ship with a wind turbine or with solar power.

Cargo Ships

One of the largest classes of cargo ship in the world is the Maersk E-Class, capable of carrying over 10000 tons of cargo. Ships of this class are 397m long, 56m across the beam, and with a depth below the waterline of around 15.5m[3] (dependent on loading.) The drag coefficient for a ship hull can be safely assumed to be around 0.01 without too much consideration of the shape of the hull[4].

Wind Resource

As a resource, wind is readily available around the world's oceans, except for in a few bands around the equatorial doldrums and the tropics of Cancer and Capricorn. Average wind-speeds suitable for power generation range from less than $5ms^{-1}$ to over $8ms^{-1}$, and these wind speeds are common over the open ocean[5]. Power generated by a turbine of diameter D, can be estimated from the Carlin formula for the power generated by a Rayleigh-Betz turbine.

$$P_w = \rho_A (\tfrac{2}{3}D)^2 U^3 \text{ (1)[6]}$$

This formula gives the average power (P_w) generated from an average wind speed of U, where ρ_A is the density of the air; it assumes a Rayleigh distribution of speeds around the average and incorporates the Betz limit of 16/27 for turbine efficiency[6].

Speed Calculation

In order to calculate the maximum possible speed achievable, the power available from wind can be equated to the power used in motion through the water:

$$P_w = F_D . v \text{ (2)}$$

where v is the ship velocity and F_D is the drag force. Drag force can be calculated from:

$$F_D = \tfrac{1}{2}\rho_w v^2 C_D A \text{ (3)}$$

where A is the cross sectional area of the ship below the waterline, ρ_w is the density of water and C_D is the drag coefficient of the hull.

Before calculating the velocity of the ship it is worth noting that the direction of the wind and the air resistance of the ship have been neglected. Whilst these are not negligible factors, they will cancel each other out to some extent: when the wind is blowing against the direction of travel of the ship, it opposes the motion, but also the average wind speed powering the ship is increased (U_{Total} = U+v); when the wind blows behind the ship it complements the motion, but the average wind speed powering the ship is decreased (U_{Total} = U-v).

Substituting (1) and (3) into equation (2) and solving for v leads to:

$$v = \left(\frac{2\rho_A(\frac{2}{3}D)^2}{\rho_W C_D A}\right)^{\frac{1}{3}} U \quad (4)$$

Assuming a 40m diameter turbine, which could comfortably fit on the Emma Maersk, a cross-sectional area of 56x15.5=868m^2, and a drag coefficient of 0.01 as mentioned above, equation (4) can be rewritten as:

$$v = 0.55U$$

From the average wind speeds outlined above, this would result in speeds of 2.5 – 4ms^{-1}, which evaluates as between 5 and 8 knots[7].

Comparison with Solar Power

The power available from sunlight at the earth's surface is around 1kWm^{-2}[8] and current silicon solar cell technology can convert sunlight with an efficiency of around 20%[9]. Assuming complete coverage of the ship's surface, giving an area of around 20000m^2, leads to generated power of 4MW. Halving this, as there is only sunlight available for half of the time, and substituting this into equation (2) gives a maximum velocity of around 5.5ms^{-1}, corresponding to 11 knots.

Conclusion

The Emma Maersk has a top speed of around 25 knots, and it has been shown that renewable cannot match this. However, given the problems with emissions from conventional sea freight outlined in the introduction, there is a strong case for replacing some of the worldwide sea transport with some form of solar or wind powered ship, for ships which transport non-perishable cargo.

References

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