Deutsches Zentrum für Luft- und Raumfahrt
Institut für Maritime Energiesysteme

WIND ASSISTED SHIP PROPULSION: EXPLORING TECHNOLOGIES, WING SAIL ASSESSMENT PROCEDURE, AND VLGC CASE STUDY

DESIRAE MINNETT

BRIGHT OKPEKE

SÖREN EHLERS

Technische Universität Hamburg
Universidade da Coruña
Università degli studi di Napoli Federico II
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This thesis has been approved in partial fulfillment of the requirements for the **double degree,** issued by the **University of Naples Federico II** and the **University of A Coruña**:

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1.0 Abstract

A literature review of Wind Assisted Ship Propulsion methods is presented, along with an assessment procedure for wing sails and its thorough application in a case study. The assessment procedure conducted utilizes XFOIL to obtain a lift coefficient and drag coefficient, MARIN’s Blue Route application is used for obtaining wind data, finally MATLAB is utilized for calculations.

The assessment procedure calculations focus on power, energy, fuel tonnage required, fuel tonnage saved, fuel volume required, and finical analysis including money saved, Net Present Value, and Simple Payback Period. These calculations are completed for a variety of fuels including combustion of High Sulphur Fuel Oil, Very Low Sulphur Fuel Oil, Liquified Natural Gas, Liquid Hydrogen, and Liquid Ammonia. In addition, the use of fuel cells is considered for Liquid Hydrogen, and Liquid Ammonia.

The assessment procedure is deemed successful, the percent savings from the sail array mirrors that from literature very closely. The fuel savings results show 19% at 10 knots, 8% at 16 knots and 2% at 20 knots for the round trip from Hamburg, Germany to Walvis Bay, Namibia. During the literature review wing sails showed an average fuel oil consumption savings of 10%. More specifically up to 22% savings were observed at low speeds. On a more comparable journey from Cape Lopez, Gabon to Point Tucker Canada fuel oil consumption was reduced to 8.8% which is in line with 8.0% estimated during the case study on the round trip from Hamburg to Walvis Bay.

2.0 Table of Contents

3.0 List of Acronyms

AoA - Angle of Attack
AWA - Apparent Wind Angle
AWS - Apparent Wind Speed
CAPEX - Capital Expenditure
DWT - Deadweight Tonnage
HSFO - High Sulfur Fuel Oil
IMO - International Maritime Organization
LPG - Liquefied Petroleum Gas
LNH3 - Liquified Ammonia
LH2 - Liquified Hydrogen
LNG - Liquified Natural Gas
MCR - Maximum Continuous Rating
NACA - National Advisory Committee for Aeronautics
NPV - Net Present Value
OPEX - Operational Expenditure
SPP - Simple Payback Period
TWA - True Wind Angle
TWS - True Wind Speed
VLGC - Very Large Gas Carrier
VLSFO - Very Low Sulfur Fuel Oil
WASP - Wind Assisted Ship Propulsion

4.0 List of Figures

5.0 Introduction

The following thesis will detail a literature review of WASP methods along with a proposed assessment procedure for evaluating the performance, fuel consumption and economics of wing sails. A Case study will then implement the proposed assessment procedure, existing literature will be referenced to validate results. As ever-increasing attention is turned on carbon emissions and creative ways to reduce them, could WASP be a part of the solution?

5.1 Problem Statement

With constantly variable wind conditions evaluating the performance of a wing sail accurately can be very challenging, there is a desire to propose a procedure capable of accurately assessing the role that wing sails ply in a vessel.

5.2 Aim of Research

The aim of the research is to propose an assessment method which evaluates the wing sails, effectively within the range of published literature and has relatively low computational costs.

5.3 Research Questions

- How does the inclusion of wing sails affect fuel consumption?
- How much power can be generated from wing sails on particular route?
- How to determine the optimal angle of attack?
- How can wind data be used to?
- How does number of sails effect fuel savings?
- How does vessel speed effect fuel savings?

5.4 Scope

The scope of the thesis will cover modern day commercial applications for WASP methods. A focus will be placed on rigid sails, soft sails, rotors, and suction wings. A literature review will encompass the technological overview and emissions reduction resulting from different WASP technologies. An assessment method will be developed to evaluate wing sails in terms of performance, fuel consumption/emissions reduction, and economics. Other fuels will also be considered

6.0 WASP Literature Review

The following section will provide an overview and brief description of the main approaches to WASP. These methods include soft sails, rigid sails, rotors and suction wings. Although there may be other novel or emerging methods available literature best covers the aforementioned methods, kite sails pose risk to crew and they fall outside of the scope of interest for this thesis.

6.1 WASP; Overview of Methods

6.1.1 Rigid Sails

Figure 1: Shown above are some of the first commercial examples of rigid sails in use. On the left is the JAMDA sails and on the right the MV Ashington which is outfitted with the Walker WingSail.

Rigid sails are the oldest and most proven rendition of WASP in commercial ships. Figure 1 shows two early examples which were fitted in the 1980’s in an effort to save fuel. The JAMDA example was fitted in Japan and the Walker WingSail was fitted in the UK. Due to this storied history rigid sails are rather mature and correspond to lower technical risk than other alternatives [1]. This is due to simplified geometry and the lack of a sophisticated control system, although rigid sails are not without their disadvantages.

First is the additional capital expenditure which is not insignificant on larger vessels which often feature multiple sails for maximum benefit. On top of this initial expense rigid sails also require ongoing maintenance resulting from exposure to the harsh marine environment. These sails may also present safety concerns and increase the workload on the crew. The addition of the sails also presents additional weight and this will result in a lower net tonnage and cargo carrying capabilities. Perhaps the largest drawback is the potential for interference with cargo operations which can complicate logistics, resulting in reduced overall efficiency.

The benefits of rigid sails are mainly in their ability to reduce fuel consumption and cut emissions, this will be addressed in further detail in a later section [2]. The incentive for implementation of this technology is increased as fuel oil prices increase. This further shows the importance of IMO measures aimed at curbing emissions by gradual penalization of carbon emissions to provide financial motivation for green innovation.

6.1.2 Rigid Sails

Figure 2: Shown above are two examples of soft sails, on the left is the Ecoliner concept rendering from Dykstra while on the left is the Black Pearl sailing vessel which was delivered by Oceanco in 2016. Both vessels feature a Dynarig setup.

Soft sails are newer than rigid sails in their modern application but are based on traditional sails. These types of sails have recently seen a significant amount of development and innovation. Soft sails work on the same principals as rigid sails but feature lighter, non-rigid materials to save weight. Additionally, this weight reduction results in smaller actuators needed for the control system to ensure maximum benefit is achieved through the sails.

The innovative control systems utilized ensure that much of the sail control is automated including the rotation of the mast, freestanding square rigs and the duplex rigs [1]. Perhaps the most popular of soft sails is the DynaRig pictured in Figure 2 which is highly self-sustainable and although having a lower drag coefficient then suction sails the larger sail area can make up for this and provide similar performance [1]. Some other innovative soft sails include Fastrigs, Delta wingsails, and the Pinta-Rig.

6.1.3 Rotors

Figure 3: Shown above is the E-SHIP 1 which is a general cargo ship utilizing Flettner rotors. This particular ship is used for transporting wind turbine components.

Rotor sails, also commonly known as Feltner rotors utilize a rotating cylinder to induce the magnus effect and provide additional thrust. The direction of the thrust force depends on the apparent wind direction and the direction of rotation with thrust being produced perpendicular to the apparent wind vector [1]. For clarification see Figure 4 below [1].

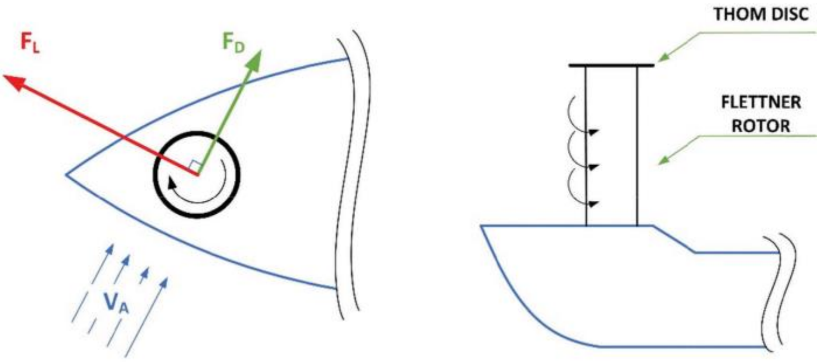


Figure 4: The Magnus effect is illustrated above with the apparent wind speed (V_a), the drag force (F_d) and the thrust or lift force(F_l). On the right the components of the rotor are labeled.

Flettner rotors have a long history with the first rotors being installed on an American ship the Backau in 1925. Flettner rotors were proven technically feasible but due to low fuel oil costs they were not installed again until recently.

6.1.4 Suction Wings

Figure 5: the FRISIAN SEA utilizes two Flatrack suction wings

Suction wings utilize airfoils the produce lift in the same manner as an aircraft. Similarly, to how aircraft work the suction wings chord thickness and shape can be optimized to increase lift and decrease drag. This facilitates a strong a strong lift effect while minimizing energy loses due to drag. A Freebody diagram shown in Figure 6 illustrates the force components on a suction wing.

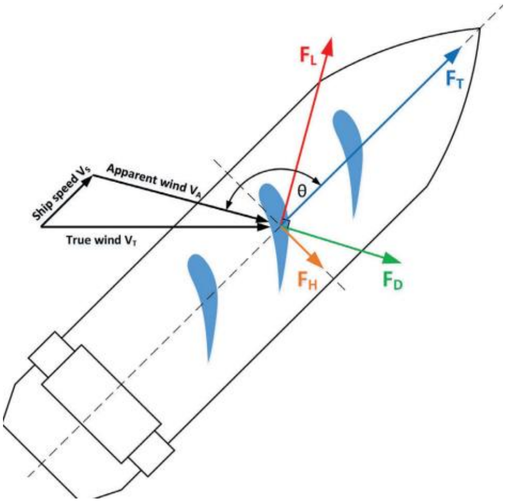


Figure 6:The freebody diagram [1] illustrates the thrust force (F_t), drift force (F_h), lift force (F_l), drag force (F_d), and θ which is the angle between apparent wind and the ships longitudinal reference plane.

The wing sail is also rotatable on the z axis which keeps the system in the most optimum position. It is suggested that wing sails are kept as small as possible in terms of their lift maximized. There has been a significant amount of recent development with wing sails and they often combine multiple design aspects from other methods such as soft sails.

6.2 Emission Reduction: WASP Contributions

The following section will quantify the approximate fuel savings and emissions reduction resulting from the incorporation of various WASP technologies. This is a part of the literature review and a focus will be placed on previous works surrounding bulkers and tankers.

6.2.1 Rigid Sails

First the reduction in fuel oil consumption is determined for a bulker through extensive analysis in a PHD thesis titled “Aerodynamic analysis of segment rigid sails and estimation of propulsive power from sail array on large powered ship” by Gregory Mark Atkinson [3]. Chapter 7 summarizes the work to conclude the estimated fuel oil consumption savings for an eco-ship concept fitted with a rigid sail array. The process involved a performance analysis of the sail array, ship details, voyage profiles, wind conditions and probability, sail array power profile, voyage analysis and finally fuel oil consumption reduction from the sails.

Particulars	
Segment Rigid Sails	14 Sails
Length Overall	240 m
Breadth	45 m
Draft	18 m
Deadweight Tonnage	102,000 t

Figure 7: Shown above is the rigid sail concept and key ship particulars

The fuel oil consumption reduction was calculated for different voyages based on a percentage of power from the sail array divided by the power of the main engine(s), multiplied by the fuel oil consumption of the main engine(s). This is shown by the following equation:

$$FOCR = \left(\frac{P_{SA}}{P_{ME}}\right) FOC$$

Where,

$$FOCR = Fuel\ Oil\ Consumption\ Reduction$$

$$P_{SA} = Power\ of\ Sail\ Array$$

$$P_{ME} = Power\ of\ Main\ Engines$$

$$FOC = Fuel\ Oil\ Consumption$$

Three separate voyages were used as case studies to evaluate the thrust generated by the sail array and the subsequent fuel oil consumption. The first voyage includes two ports of call, two sailings of 6 days each and a day of transit. The ship operates at 16 knots while which amounts to 70-75% of MCR and at 12 knots which amounts to 50% MCR. Headwinds are assumed to be present 50% of the time with modest wind speeds ranging from 8 to 20 knots, this case is supposed to represent a more unfavorable scenario for the use of a sail array. This resulted in 1.3% of the total required propulsive power being produced for stage 1 while in stage two 2.6% of the total required propulsive power was produced. This resulted in an overall voyage fuel oil consumption reduction of 1.7% or 7.2 tonnes.

Next, more favorable wind conditions are simulated, with the second voyage still based on two ports of call but this time with 16 days at an “eco speed” of 12 knots and 1 transit day. This time headwinds are assumed on 62.5% of the journey but still only light winds are expected ranging from 5 to 2 knots. Stage 1 performed better but once again proved to be unfavorable to the sail array resulting in 2% of the total required propulsion power being produced. For stage 2 with more favorable conditions the results showed the sail array producing 5.9% of the total required propulsion power. Throughout the journey this resulted in an overall voyage fuel oil consumption reduction of 4.1% or 15 tonnes.

The last voyage scenario provides more favorable conditions and provides a more compelling case for the sail array. During the first stage the sails generated nearly 10.5% of the required propulsion power, a whopping 19% of the required propulsion power was produced in the best conditions with the ship traveling at 5 knots and an apparent wind speed of 22kn. During stage 2 the sails generated 4.8% of the required propulsion power. Overall this resulted in a fuel oil consumption reduction over the entire journey of 7.7% of 27.4 tonnes.

To conclude when utilizing rigid sails, it is reasonable to expect between 1.5-8.0% fuel oil consumption reduction depending on how ideal the conditions are.

6.2.2 Soft Sails

Next the expected emissions reductions from soft sails will be quantified from the literature. The focus is placed on the DynaRig system as this is the most widely used form of soft sails with multiple concepts and integration on existing vessels. The DynaRig system was evaluated and compared against a baseline, Flettner rotor and wing sail [4]. Depending on the vessel and analysis results the DynaRig may contribute significant fuel and operational costs savings. Surplus proposed a 3000 DWT zeros emissions coastal sailing vessel concept which utilized multiple sources of alternative fuels, including the DynaRig which produces 60% of the total required thrust [4]. In another study Dykstra Naval Architects conducted a design study on an 8000 DWT multi-purpose cargo vessel called the Ecoliner [5]. This study utilized CFD and route planning weather data to conclude that at the design speed of 12 knots up to 35% fuel savings and 22% lower operational costs can be expected [4].

A case study of an Aframax oil tanker was completed to compare the results of the various WASP methods. Since this case study also provides results for the Flettner rotor and suction wings they will be outlined in the following sections.

Particulars

DynaRig: Area	1000 m^2
Length Overall	250 m
Breadth	40 m
Draft	14 m

Figure 8: Shown above is a similar vessel [6] to the Aframax oil tanker used in the case study, the exact vessel was not provided due to confidentiality agreements. The ship particulars and DynaRig specifications are shown on the right [4].

For the first route between Cape Lopez in Gabon to Point Tupper in Canada the reference case required 966.7 tonnes of fuel while 912.6 tonnes of fuel was required when outfitted with the DynaRig [4]. This yielded a savings of 54.1 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 5.6%. The second route between Angra dos Reis in Brazil and Rotterdam in the Netherlands resulted in 1162.1 tonnes of fuel consumption in the reference case and 1113.7 tonnes of fuel consumption when outfitted with the DynaRig [4]. This yielded a savings of 48.4 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 4.2%. This shows significant improvement with the inclusion of a DynaRig in the vessels design.

6.2.3 Rotors

The Flettner Rotor is at the forefront of various research and case studies when exploring the feasibility and performance of various WASP methods. In a study completed by Traut et al of a 5500 DWT cargo ship with 3 Flettner rotors installed with a diameter of 4 m and height of 27 m over 50% of the required thrust was developed [7]. The 10500 DWT cargo ship Enercon E-Ship 1 came into service in 2010 and was fitted with 4 25 m high, 4 m diameter rotors. On the route from Emden to Portugal fuel consumption decreased by up to 22.9% when compared with data in which only the main engines where used for propulsion power, it was concluded that in general savings of up to 15% can be consistently expected [8].

The results for the Flettner rotor of the case study of an Aframax oil tanker was completed to compare the results of the various WASP methods.

Particulars	
Flettner Rotor: Area	509 m^2
Flettner Rotor: Area	108 m^2 (projected)
Flettner Rotor: RPM	600
Flettner Rotor: Height	18 m
Flettner Rotor: Diameter	3 m (cylinder)
Flettner Rotor: Diameter	6 m (top disc)
Length Overall	250 m
Breadth	40 m
Draft	14 m

Figure 9: Shown above is a similar vessel [6] to the Aframax oil tanker used in the case study, the exact vessel was not provided due to confidentiality agreements. The ship particulars and Flettner Rotor specifications are shown on the right.

For the first route between Cape Lopez in Gabon to Point Tupper in Canada the reference case required 966.7 tonnes of fuel while 880.6 tonnes of fuel was required when outfitted with the Flettner rotor [4]. This yielded a savings of 86.1 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 8.9%. The second route between Angra dos Reis in Brazil and Rotterdam in the Netherlands resulted in 1162.1 tonnes of fuel consumption in the reference case and 1086.6 tonnes of fuel consumption when outfitted with the Flettner rotor [4]. This yielded a savings of 75.5 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 6.5%. In this case study the inclusion of a single Feltner rotor amidships showed remarkable results.

6.2.4 Suction Wings

Suction wings/wing sails like Flettner rotors are at the forefront of late research into different WASP technologies. They are particularly appealing because the lift created by the airfoil can be significant while they lack constantly moving like the Flettner rotor, instead the angle of attack may only be changed intermittently by rotating the mast. The WingShip project proposed a rigid wing sail concept where a 50000 DWT product carrier was selected as aa case study ship, a velocity prediction program was developed to predict the speed, drift and rudder angles for wind directions, wind speeds, and propeller loadings. The results of this case study in an area with strong winds showed promising results with fuel savings in the range of 10%, it should be noted that as vessel speed increases and wind speed decreases the case for a suction wing becomes less clear as performance degrades. Another concept studied was the 180000 DWT bulk carrier UT Wind Challenger, an energy prediction program was developed to estimate the operational performance. Once again very promising results were shown on a voyage between Yokohama in Japan and Seattle Washington up to 22% fuel oil consumption savings were calculated under constant speed.

The results for the wing sail of the case study of an Aframax oil tanker was completed to compare the results of the various WASP methods.

Particulars	
Wing sail: Area	1000 m^2
Wing sail: Height	50 m
Wing sail: Cord	20 m
Length Overall	250 m
Breadth	40 m
Draft	14 m

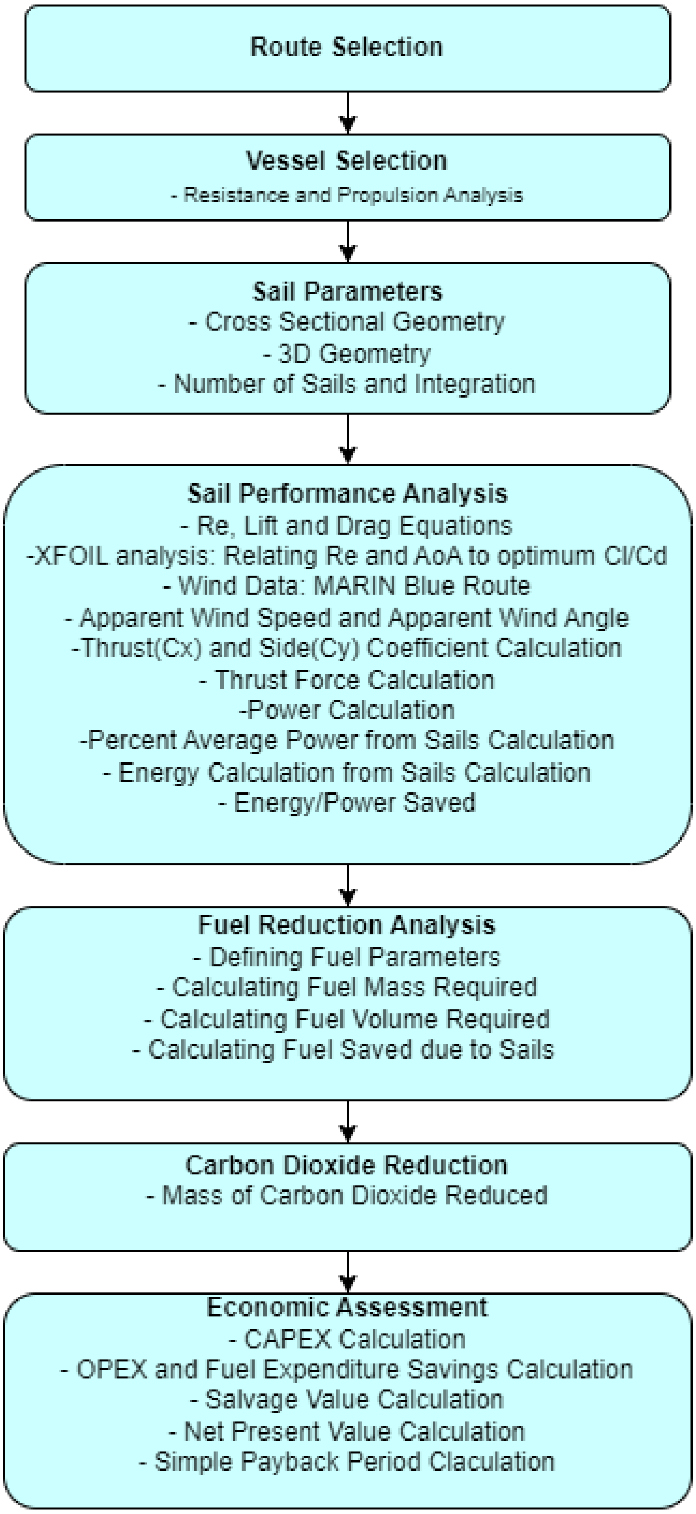
Figure 10: Shown above is a similar vessel [6] to the Aframax oil tanker used in the case study, the exact vessel was not provided due to confidentiality agreements. The ship particulars and wing sail specifications are shown on the right, the total sail area was made the same as the DynaRig example [4].

For the first route between Cape Lopez in Gabon to Point Tupper in Canada the reference case required 966.7 tonnes of fuel while 881.5 tonnes of fuel was required when outfitted with the wing sail [4]. This yielded a savings of 85.2 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 8.8%. The second route between Angra dos Reis in Brazil and Rotterdam in the Netherlands resulted in 1162.1 tonnes of fuel consumption in the reference case and 1091.5 tonnes of fuel consumption when outfitted with the Flettner rotor [4]. This yielded a savings of 70.6 tonnes of fuel oil, corresponding to a fuel oil consumption reduction of 6.1%. In this case study the inclusion of a single wing sail showed remarkable results, only trailing the Flettner rotor marginally.

7.0 WASP Assessment Procedure for Wing Sails

The following section will outline an assessment method for wing sails, see the flow chart below for a summary of the assessment procedure proposed.

7.1 Assessment Procedure Flow Chart



7.2 Route Selection

The first step in holistically assessing the inclusion of wing sail(s) on a vessel is understanding the route. It is important to consider a realistic routing trajectory which considers how to leverage prevailing winds. Taking full advantage of favorable wind conditions is key in order to make a significant difference in fuel consumption and a reduction in emissions.

7.3 Vessel Selection

When selecting the vessel, it is important to have a thorough understanding of the requirements under which the vessel will operate. It is important to note that wing sails are highly situational and function best when equipped on a slow vessel operating in areas with high winds. It is also extremely important to consider how sightlines are affected and if open deck space is required. The requirements of easy access to the deck makes the application of wing sails challenging on a cargo vessel but ideal for a tanker.

7.3.1 Resistance and Propulsion Analysis

The Holtrop method is recommended for an initial start point when conducting a resistance and propulsion analysis on a vessel. The method is a statistical regression of model tests mostly conducted at MARIN, In total 334 models were tested against full scale trials [9]. The total resistance may be approximated as follows:

$$R_{total} = R_F(1+k) + R_W + R_B + RTR + RAPP + RA \text{ [9]}$$

Where,

$$R_F = ITTC\ flat\ plate\ frictional\ resistance$$

$$R_W = wave\ making\ resistance$$

$$R_B = bulbous\ bow\ resistance$$

$$R_{TR} = transom\ immersion\ resistance$$

$$R_{APP} = appendage\ resistance$$

$$R_A = model\ ship\ correlation\ resistance$$

Next, effective power can be calculated by multiplying the total resistance and the vessel speed.

$$P_E = \frac{R_{Total}}{V_{ship}}\ [9]$$

Finally, the propulsive power can be obtained by dividing the effective power by the propeller efficiency.

$$P_P = \frac{P_E}{\eta_{prop}}\ [9]$$

7.4 Sail Parameter Definition

The following section will outline the process for defining the sail geometry.

7.4.1 Cross Section Geometry

The cross-sectional geometry can be either designed from scratch and tested using wind tunnel testing, CFD, or other panel codes. A National Advisory Committee for Aeronautics (NACA) series may be used more conveniently as extensive tests may have been conducted before hand which can make the design process much easier. See below for further guidance on airfoil geometry.

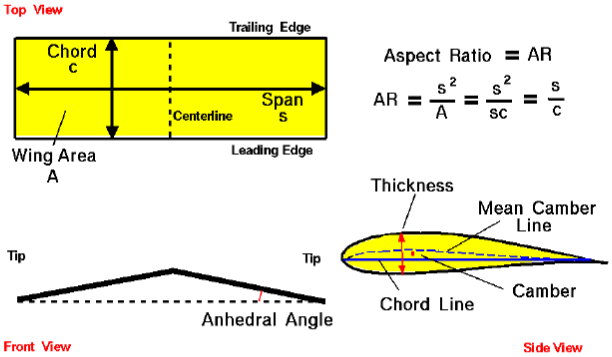


Figure 11: Cross sectional air foil geometry [10]

7.4.2 3-Dimensional Geometry

3D dimensions are highly project dependent, but the following geometry must be constrained.

- Chord

- Height
- Mast thickness
- Deck clearance

7.4.3 Sail number and integration

In terms of sail integration, it is imperative to consider vessel sight lines and crew operations on deck. Wing sails are able to rotate 360° and it is important that at no point is it possible for the sail to come into contact with crew members or other deck equipment. It is also important to consider that the sails are adequately spaced apart in order to ensure that each sail has good inflow characteristics and interference between sails is reduced. It is generally best to place the sails as far apart as possible.

7.5 Sail Performance Analysis

The next section makes up the majority of the assessment procedure with a definite focus placed on the performance of the sail array. The calculations determine or play a direct role with regards to total energy produced, average power, fuel reduction, CO_2 reduction

7.5.1 R_e, Lift and Drag Equations

The Reynolds number, lift and drag equations underpin a significant position of the rest of the analysis. The Reynolds number is used to model the effects of viscosity on turbulence. For this type of analysis, the apparent wind speed will vary widely and this will affect the Reynolds number.

$$R_e = \frac{\rho V D}{\mu}$$

Where,

$$\rho = fluid\ density$$

$$V = fluid\ velocity$$

$$D = chord\ length$$

$$\mu = \ dynamic\ viscosity$$

The lift and drag force form the basis of the power and energy equations encountered later. The biggest challenge is accurately modeling C_l and C_d.

$$F_{Lift} = \frac{1}{2} C_l \rho v^2 A \text{ [11]}$$

$$F_{Drag} = \frac{1}{2} C_d \rho v^2 A \text{ [11]}$$

7.5.2 XFOIL Analysis: Relating Re and AoA to optimum Cl/Cd

With rapidly changing wind speeds it is important to operate the sails in the most optimum path relative to the apparent wind angle. One crucial component to this is the AoA. The most optimum angle of attack is generally when the lift to drag ratio is maximized. There are lots of ways to determine this such as wind tunnel testing or CFD but the challenge is balancing computational costs with accuracy.

Since wing sails generally have a cross section of an airfoil it is recommended to use XFOIL to run a number of simulations at varying angles of attack and wind speeds to determine the ideal angle of attack for each wind speed. XFOIL is an iterative panel based numerical method used to model the flow of fluids around objects. The domain is discretized into flat panels before a vortex lattice is applied to model the viscous effects.

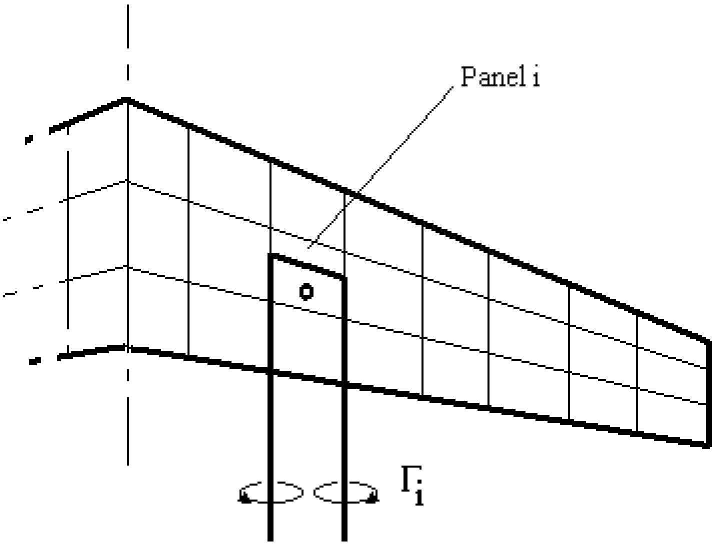


Figure 12: Illustration of Vortex Lattice Method Discretization [12]

7.5.3 Wind Data: MARIN Blue Route

Obtaining useable and accurate wind data is challenging and the key factor in determining the success of the sail performance analysis. For this purpose it is recommended to utilize MARIN Blue Route software which allows for the automatic plotting of the course while accounting for heading.

Year round 1989-2019 ERA-5 data is available and downloadable as True Wind Speed (TWS) and True Wind Angle (TWA). The data comes in form of a cumulative probability matrix which outputs the percentage of time in which a specific TWS from 1-25 m/s and TWA from 0-355° is present along a chosen journey. The application will provide an apparent wind polar but note that only true wind statistics are downloadable.

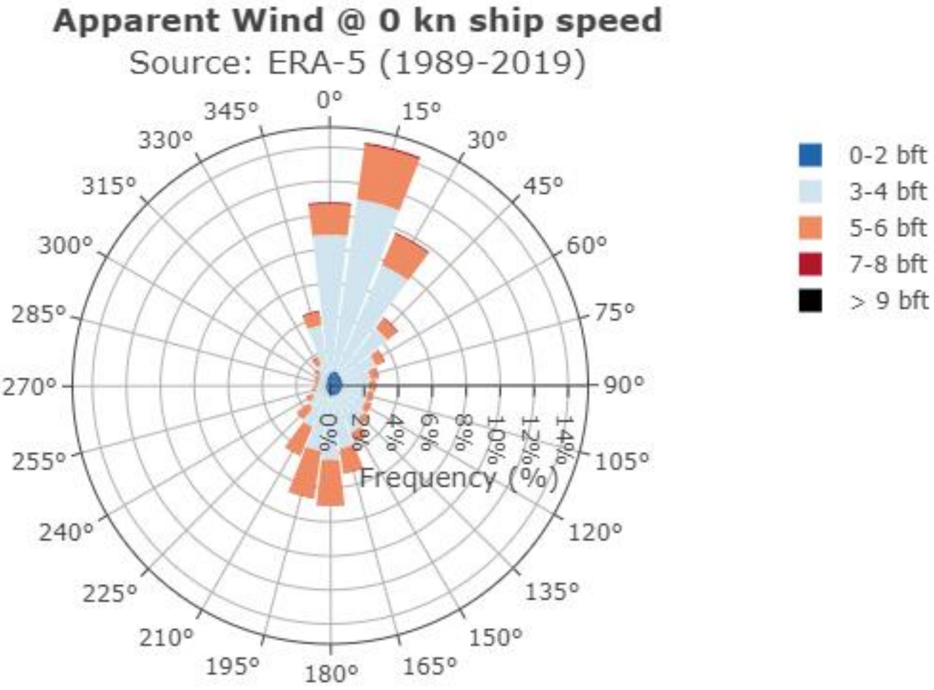


Figure 13: MARIN Blue Route Data for TWS and TWA [13]

7.5.4 Wind Calculation: AWA and AWS

Now that TWS and TWA is obtained from the previous step this matrix must be converted into Apparent Wind Speed (AWS) and Apparent Wind Angle (AWA), see the equations below.

$$AWS = \sqrt{V_{ship}^2 + TWS^2 - 2\left(V_{ship}\right)(TWS)(\cos(TWA))}\ [14]$$

$$AWA = arcTan\left(\frac{TWS * \sin(TWA)}{V_{ship} + (TWS)(\cos(\mathrm{TWA}))}\right)\ [14]$$

7.5.5 Thrust and Side Force Coefficient Calculation

The thrust (Cx) and side (Cy) force coefficients should be calculated in a matrix format with many different coefficients depend on wind speed and angle. The side force coefficient could be used for automatic course correction as a part of the wing sails control system but that is beyond the scope of the thesis.

$$Cx = C_L \sin(AWA) - C_d \cos(AWA) \ [3]$$

$$C_y = C_L \cos(AWA) - C_d \sin(AWA) \ [3]$$

Cx should be set to 0 in some conditions, such as when the apparent wind angle is coming directly towards the bow, also there must be an upper wind limit where Cs is 0. Assigning Cx to 0 fir these circumstances is intended to mimic how wing sails are operated in practice.

7.5.6 Thrust Force Calculation

The thrust force equation closely mimics the lift and drag force equations, it should be noted that the side force is obtained by replacing C_x with C_y

$$F_{sail} = \frac{1}{2}(C_x)(\rho)(AWS)^2(A) \ [3]$$

7.5.7 Power and Energy Calculation

Power can now be calculated by multiplying the sail force by the ships speed, although still in matrix form the power calculation can be summed depending on the probability maintenance and time to calculate the average power vs speed.

$$P_{sail} = (F_{sail})(V_{ship}) \ [3]$$
$$P_{sails} = (n_{sails})(F_{sail})\big(V_{ship}\big)$$
$$P_{\%(from\ sails)} = \frac{P_{sails}}{P_{Propulsion\ Analysis}}$$

Where,

$$P_{sail} = Sail\ Power$$
$$V_{ship} = Ship\ Speed$$
$$P_{\%(from\ sails)} = Percent\ Power\ Generated\ from\ Sails$$

The total energy required is found by taking the sum of instantaneous power multiplied by time spent in a condition on a given journey,

$$E_{sails} = (P_{sails})(Time)$$
$$Time = \frac{Distance_{route}}{V_{ship}}$$

$$E_{\%(saved/from\ sails)} = \frac{E_{sails}}{E_{propulsion}}(100)$$

7.6 Fuel Reduction

With the total percentage of power/energy coming from sails and the total required energy fuel parameters can be determined

7.6.1 Fuel Parameter Definition

Different fuels have different properties which can make a direct comparison difficult, for any fuels of interest it is recommended to define the density, specific energy, CO2 per tonne, cost, and chemical to mechanical conversion efficiency. It is important to accurately account for realistic storage conditions such as hydrogens need to be chilled and pressurized as an example.

7.6.2 Fuel Mass Required

The fuel mass required can now be obtained by dividing the previously calculated Energy journey by specific energy and efficiency.

$$Mass\ Required = \frac{Energy_{journey}}{(Specific\ Energy)(\eta_{Chemical \to mechanical})}$$

7.6.3 Fuel Volume Needed

The volume required for the fuel is an important factor to consider since mass does not paint the full picture. Volume is calculated as the fuel mass required divided by the fuels density.

$$Volume\ Fuel\ Required = \frac{Mass\ Fuel\ Required}{Fuel\ Density}$$

7.6.4 Fuel Mass Saved

The fuel mass saved is obtained by multiplying the fuel mass by the energy saved from the sails s shown by the following equation:

$$Mass\ Fuel\ Saved = (Mass\ Fuel\ Required)(\ Energy_{\%(saved/from\ sails)})$$

7.7 CO₂ Reduction

The CO_2 reduction is calculated by multiplying the fuel mass saved by the CO_2 rating of the fuel of interest, see the below equation:

$$CO_2(Reduction) = (Mass\ Fuel\ Saved)\left(\frac{tCO2}{t}\right)$$

7.8 Economic Assessment

The following section will provide procedure for conducting a basic economic assessment for feasibility.

7.8.1 Money Saved Per Journey

The amount of money saved on a given journey is calculated by multiplying the fuel mass saved by the cost of a given fuel.

$$€_{saved} = (Mass\ Fuel\ Saved)\left(\frac{€}{Mass\ unit}\right)$$

7.8.2 CAPEX

The capital expenditure (CAPEX) is defined as the sum of all upfront. This is highly project dependent but generally will consist of the cost required to design, construct, install, and train crew on the sail array. The number of sails must be considered in the construction and installation costs.

$$\sum_{CAPEX} = R\&D + (n_{sails})(Construction) + (n_{sails})(Installation) + Training\ [15]$$

7.8.3 OPEX and Fuel Expenditure Savings

The operational expenditure (OPEX) refers to the ongoing yearly costs associated with conducting maintenance and repairs on the sail array while the fuel expenditure savings should be calculated based on a specific fuel for a specific route and number of trips per year. For ongoing maintenance and repairs it may be assumed that 10% of the initial construction and installation costs are spent annually.

$$\sum_{OPEX} = (10\%)\big((n_{sails})(Construction)(n_{sails})(Installation)\big)\ [15]$$

$$\sum_{Fuel\ expenditure\ savings} = (n_{trips\ annually})(€_{saved\ per\ trip})\ [15]$$

Where,

$$€_{saved\ per\ trip} = (mass_{fuel\ saved})\left(\frac{€_{fuel\ cost}}{mass_{fuel}}\right)$$

7.8.4 Salvage Value

The salvage value is the recovered costs associated with the sail array when the vessel goes to scrap. This can assume to be 30% of the initial construction costs of the sail array at the vessels end of life.

$$\sum_{Salvage} = (30\%)((n_{sails})(Construction))\ [15]$$

7.8.5 NPV Calculation

The Net Present Value (NPV) calculation is used to assign an economic value to the sail array in the present moment without regard for inflation or other factors. A positive NPV indicates a possible financial case for investment. The NPV calculation takes into account initial costs, annuities which are the sum of net annual costs to net profits, service life, and finally recovered initial costs.

$$NPV = -Inital\ Cost + S_{years}(Annuites) + Salvage\ Value\ [15]$$

$$NPV = -\sum_{CAPEX} + \ S_{years}\left(\sum_{Fuel\ expenditure\ savings} - \sum_{OPEX}\right) + \sum_{Salvage}$$

7.8.6 SPP Calculation

The Simple Payback Period (SPP) is the useful for understanding how long the sail array will take to pay for itself. SPP is calculated by dividing the initial costs by the annuity.

$$SPP = \frac{Inital\ Cost}{Annuity}\ [15]$$

Take Aways: Understanding KPI’s

Some Key Performance Indicators (KPI’s) which may be obtained by following the proposed assessment the includes an understanding of the best angle of attack to optimize thrust at varying AWS and AWA. The procedure may be used to optimize a vessels speed for the maximum power coming from sails. The procedure is also useful for comparing the performance, emissions reductions, and financial savings of different fuels in combination with wing sails.

Additionally, the fuel mass, volume, CO_2 emissions, and financial savings can be applied to wide3 variety of circumstances. These parameters can be calculated for one-time trips, journeys. Annual mission profiles and even in terms of service life to further understand the complex interaction of how additional costs balance with fuel and emissions savings to potentially save money.

The NPV calculation provides an instantaneous look into the financial case for investment and is useful when comparing fuels. Perhaps even more powerful is the SPP which can be used to quickly understand how quickly an investment such as a sail array would take to pay off financially.

8.0 WASP Case Study

The following section will outline the WASP case study for an ammonia/LPG tanker on the routes from Hamburg, Germany to Walvis Bay, Nambia. Originally an additional route was considered instead a decision was made to focus on a one way and return trip for one route.

8.1 Route Selection

Based on recent industry activity a liquefied petroleum gas (LPG) dual-fuel very large LPG / liquefied ammonia gas (NH3) carrier (VLGC) from Kawasaki Heavy Industries has been chosen for a case study.

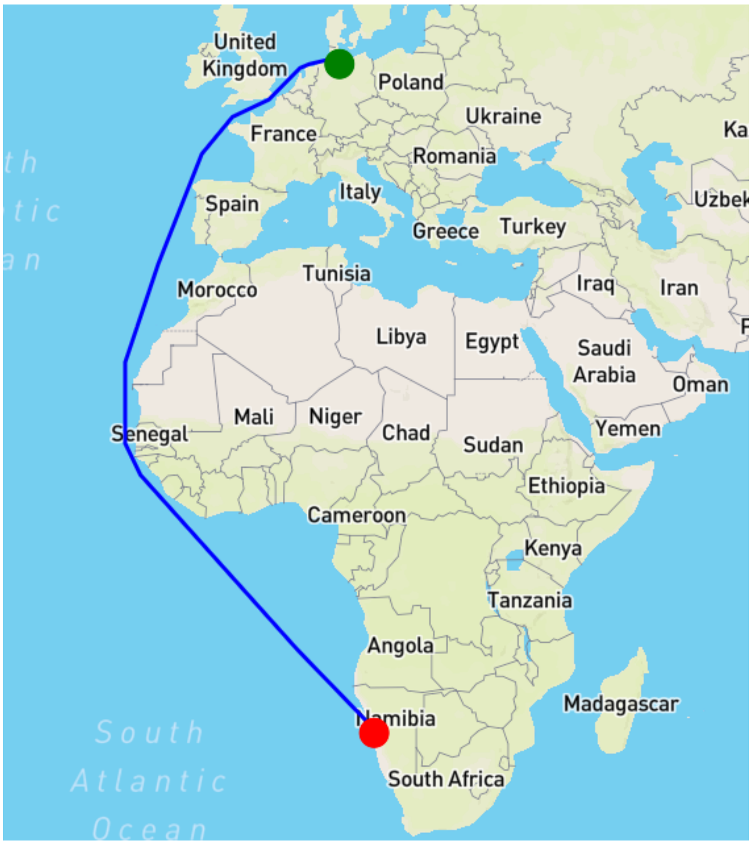


Figure 14: Route 1 from Hamburg, Germany to Walvis Bay, Nambia

Figure 15: Route 2 originally considered from Hamburg, Germany to Valparaiso, Chile

Due to time constraints only Hamburg to Walvis Bay, Walvis Bay to Hamburg, and Hamburg to Walvis Bay round trip was considered.

8.2 Vessel Selection

Based on recent industry activity a liquefied petroleum gas (LPG) dual-fuel very large LPG / liquefied ammonia gas (NH3) carrier (VLGC) from Kawasaki Heavy Industries has been chosen for a case study [16] . The vessel is not yet built and will be constructed by KHI Sakaide Works shipyard with delivery set for 2024 [17] .

Particulars

Length Overall	230 m
Breadth (moulded)	37.20 m
Depth (moulded)	21.90 m
Summer Draft (molded)	11.65 m
Tank Capacity	86,700 m^3

Figure 16: Shown above is a VLGC from Kawasaki Heavy industries [16] with particulars as outlined by NKK website [17].

8.2.1 Hull and Superstructure

To save time and since this thesis does not focus on the design aspect of the VLGC a model was obtained from GrabCAD [18] as a starting point. This model was scaled to meet the previously outlined particulars. The Hull required a complete rebuild in order to generate a workable surface which was fair and completely closed.

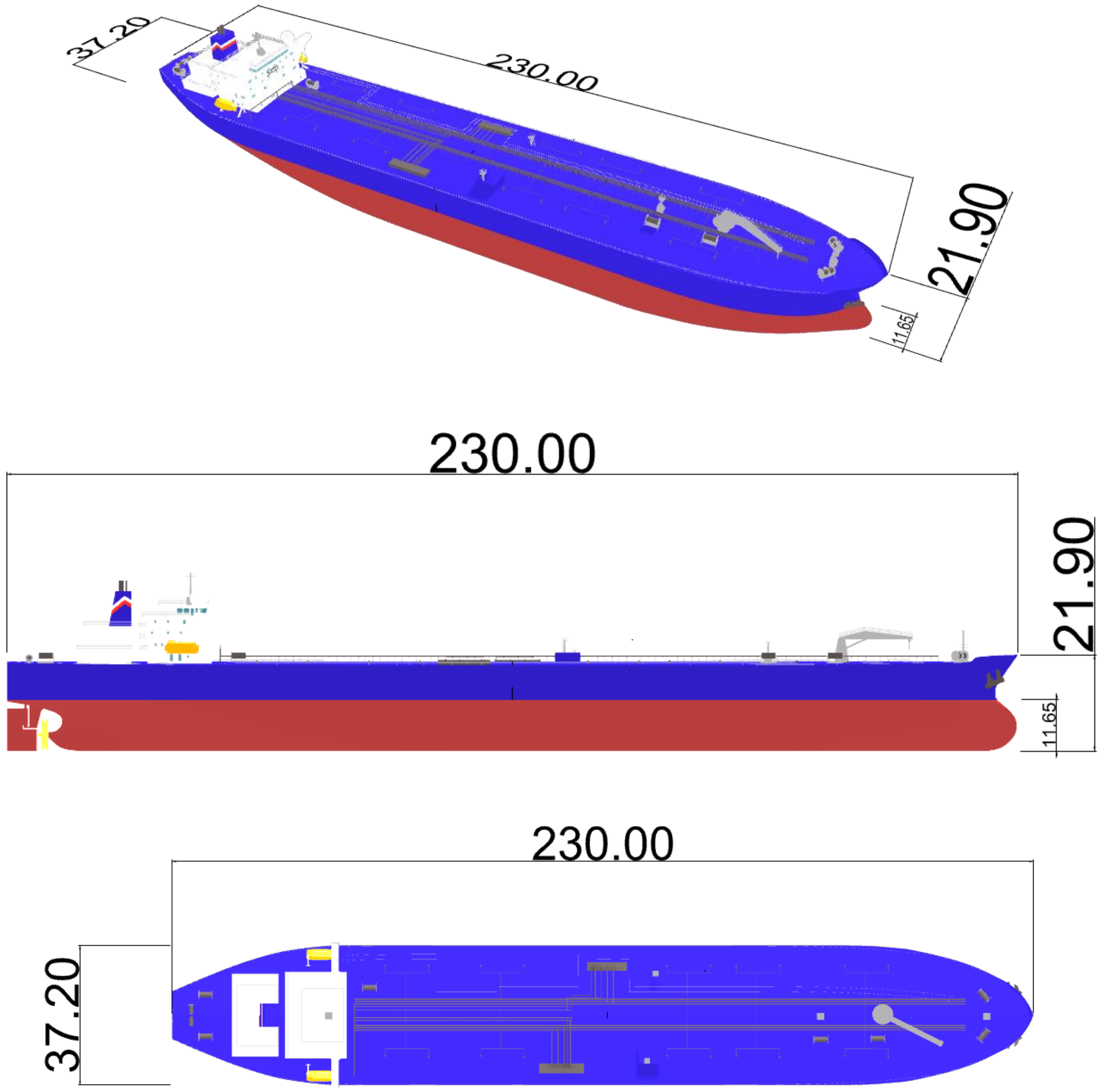
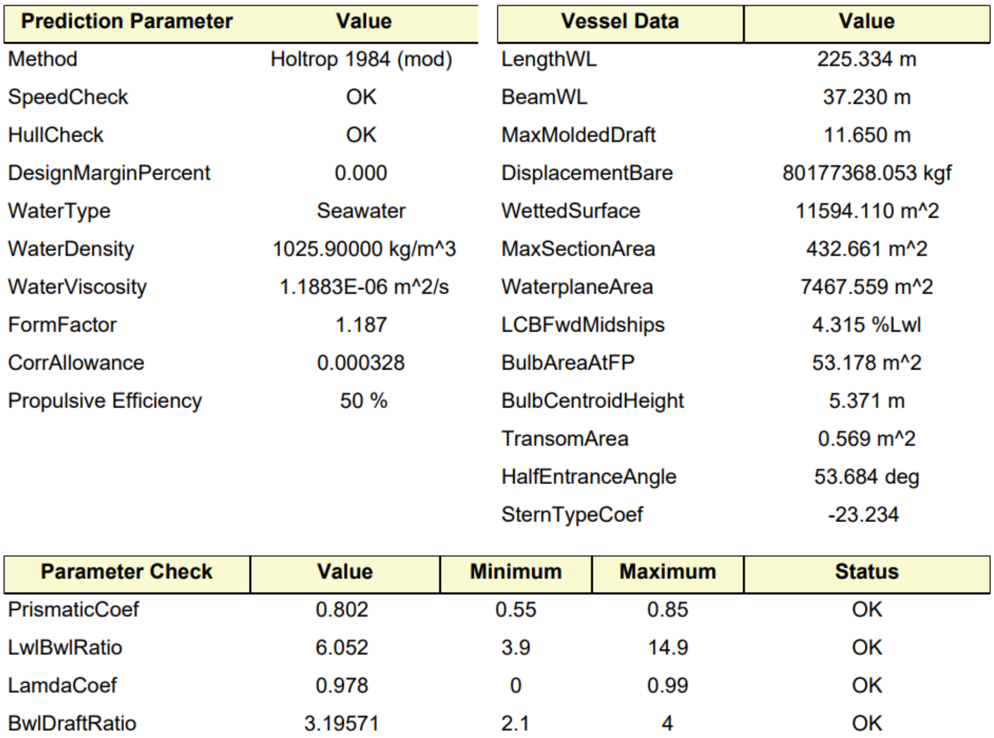


Figure 17: Shown above are rendered images in Rhino, created by scaling the base model according to the desired main particulars illustrated with dimensions in m.

8.2.2 Resistance and Propulsion

The Holtrop method was utilized to generate resistance and propulsion data for the ship model in Orca3D. This required a well-made model to ensure accuracy and validity to the software calculation. See the full analysis in 12.1 Appendix: Resistance and Propulsion Analysis

The purpose of this analysis is to provide resistance and powering data in determining how much thrust is required and therefore how much fuel the inclusion of wing sails can offset.



Prediction Parameter	Value
Method	Holtrop 1984 (mod)
SpeedCheck	OK
HullCheck	OK
DesignMarginPercent	0.000
WaterType	Seawater
WaterDensity	1025.90000 kg/m^3
WaterViscosity	1.1883E-06 m^2/s
FormFactor	1.187
CorrAllowance	0.000328
Propulsive Efficiency	50 %

Vessel Data	Value
LengthWL	225.334 m
BeamWL	37.230 m
MaxMoldedDraft	11.650 m
DisplacementBare	80177368.053 kgf
WettedSurface	11594.110 m^2
MaxSectionArea	432.661 m^2
WaterplaneArea	7467.559 m^2
LCBFwdMidships	4.315 %Lwl
BulbAreaAtFP	53.178 m^2
BulbCentroidHeight	5.371 m
TransomArea	0.569 m^2
HalfEntranceAngle	53.684 deg
SternTypeCoef	-23.234

Parameter Check	Value	Minimum	Maximum	Status
PrismaticCoef	0.802	0.55	0.85	OK
LwlBwlRatio	6.052	3.9	14.9	OK
LamdaCoef	0.978	0	0.99	OK
BwlDraftRatio	3.19571	2.1	4	OK

Figure 18: Parameters used in Orca3D to perform a Holtrop resistance and propulsion analysis.

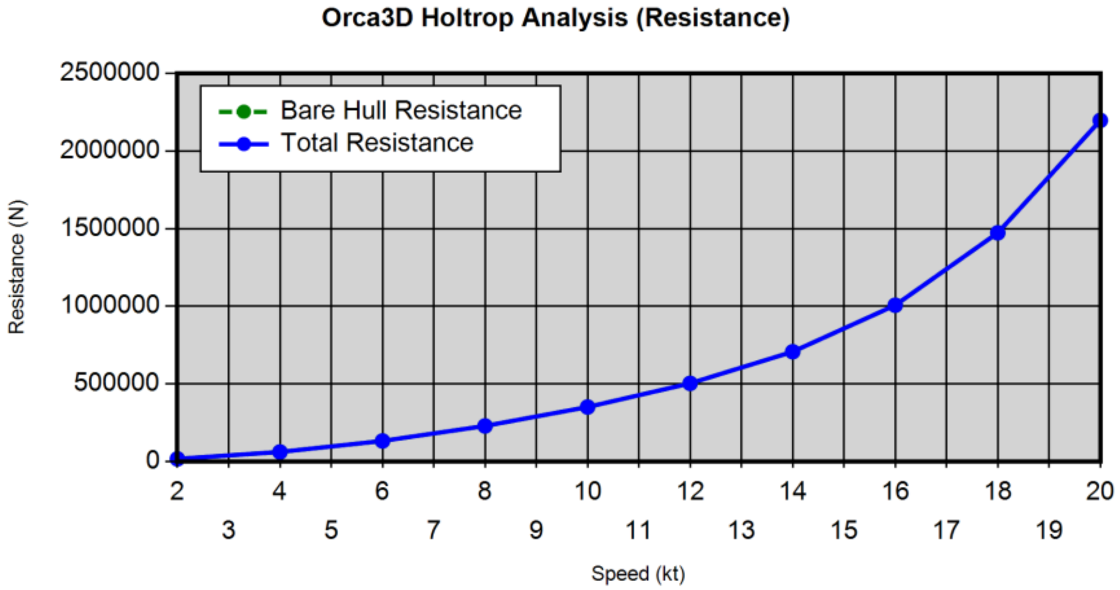


Figure 19: Resistance vs speed curve resulting from the Holtrop method from speeds of 2-20 knots.

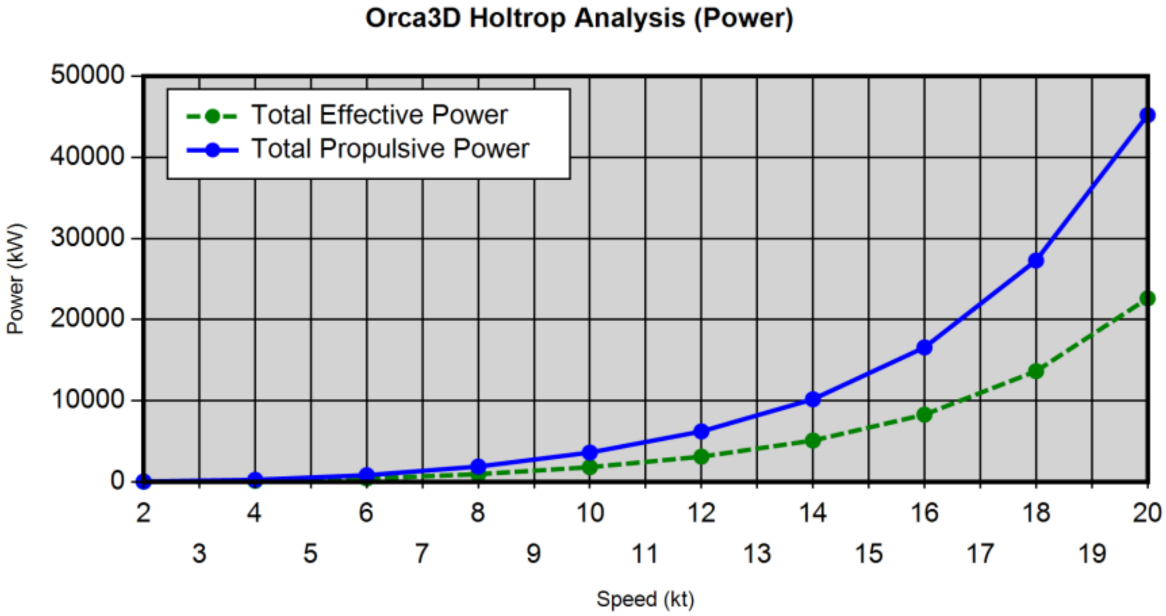


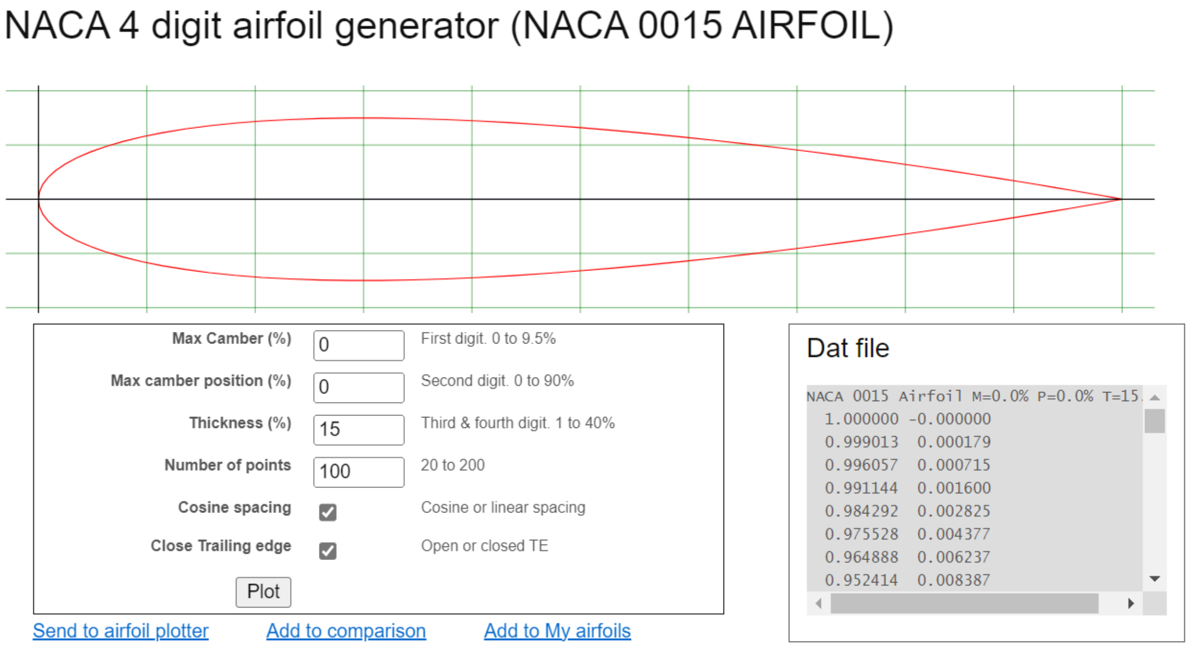
Figure 20: Required power vs speed highlighting the effective power in green and the propulsive power in blue after respective power loss factors have been considered.

8.3 Sail Parameter Definition

To best align with DLR interests a rigid wing sail with a NACAA 0015 profile of a height of 56 m and chord length of 14 m has been chosen.

8.3.1 Cross Sectional Geometry

The foil cross section was generated using on online tool which generates cross sections according to the max camber as a percentage, max camber position as a percentage, thickness as a percentage and the number of points. The max camber position, thickness and number of points. A csv file was created using the points calculated from the online tool.



NACA 4 digit airfoil generator (NACA 0015 AIRFOIL)

Max Camber (%)	0	First digit. 0 to 9.5%
Max camber position (%)	0	Second digit. 0 to 90%
Thickness (%)	15	Third & fourth digit. 1 to 40%
Number of points	100	20 to 200
Cosine spacing	☑	Cosine or linear spacing
Close Trailing edge	☑	Open or closed TE

```
NACA 0015 Airfoil M=0.0% P=0.0% T=15.
 1.000000 -0.000000
 0.999013  0.000179
 0.996057  0.000715
 0.991144  0.001600
 0.984292  0.002825
 0.975528  0.004377
 0.964888  0.006237
 0.952414  0.008387
```

Figure 21: The NACA 0015 profile as generated using Airfoil Tools [19].

8.3.2 3-Dimensional Geometry

In order to generate the sail geometry to profile was imported into Rhino, scaled to a chord length of 14 m and extruded to a height of 56 m. A mast of 1.6m in diameter was extruded to a height of 61.5 m to provide 5.5 m of clearance to ensure clearance of items on the deck.

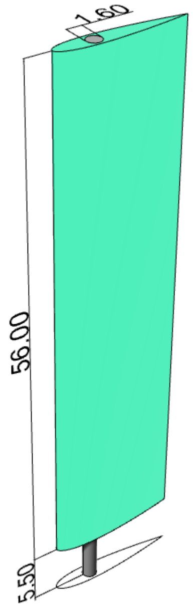


Figure 22: The wing sail assembly is shown above with a chord length of 14 m and height of 56 m. The mast features a diameter of 1.6m and mast height of 61.5 m.

8.3.3 Sail Integration

3 of these sails are to be placed on the vessel's centerline with one amidships and the other 2 equidistance apart.

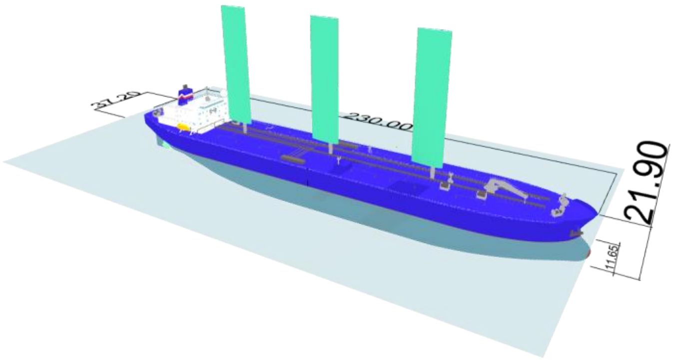


Figure 23: VLGC tanker model with 3 of the same wing sails installed, the wing sails have been installed at midships at offset by 50 meters on each side.

8.4 Sail Performance Analysis

Now that the geometry is defined it is possible to move forward and estimate the thrust and drag which will be generated. XFOIL is used to optimize the angle of attack at different wind speeds and calculate drag and lift coefficients. XFOIL is a design tool particularly well suited for sub sonic air foils low Reynolds number (but not too low)

8.4.1 Reynolds Number

First the Reynolds must be calculated, this must be completed for a variety of wind speeds, in our case from 1-50 knots. Shown below is an example calculation at 20 knots:

$$R_e = \frac{\rho V D}{\mu} = \frac{\left(\left(1.292\,\frac{kg}{m^3}\right)\left(10.289\,\frac{m}{s}\right)(14\,m)\right)}{1.328x10^{-5}\,\frac{m^2}{s}} = 1.40x10^7$$

Where,

$$\rho = fluid\ density = 1.292\,\frac{kg}{m^3}\ (STP, 0^{\circ}\ and\ 1\ atm)\ [20]$$

$$V = Relative\ wind\ speed = 20\ knots\ (used\ for\ an\ example) = \ 10.289\,\frac{m}{s}$$

$$D = Chord\ length = 14\ m$$

$$\mu = \ dynamic\ viscosity = 1.328\,\frac{m^2}{s}\ (STP, 0^{\circ}\ and\ 1\ atm)\ [21]$$

8.4.2 Lift Force

The lift force must first provide the positive portion of thrust which allows for fuel savings when a vessel is fitted with a sail array.

$$F_{L(1\ sail)} = \frac{1}{2}\rho v^2 A C_L$$

$$F_{L(all\ sails)} = n_{sails}\left(\frac{1}{2}\right)\rho v^2 A C_L$$

Where,

$$n_{sails} = number\ of\ sails = 3$$

$$\rho = fluid\ density = 1.292\,\frac{kg}{m^3}\ (STP, 0^{\circ}C\ at\ 1\ atm)\ [20]$$

$$v = apparent\ wind\ speed\ (changes)$$

$$A = sail\ area = 1600m^2$$

$$C_l = \ lift\ coefficent\ (changes\ with\ Re\ and\ AoA)$$

8.4.3 Drag Force

The drag force must be included when calculating the thrust as it reduces the effective lift, and it would not be accurate to exclude the drag component.

$$F_{D(1\ sail)} \ = \frac{1}{2}\rho v^2 A C_D$$

$$F_{D(all\ sails)} \ = n_{sails}\left(\frac{1}{2}\right)\ \rho v^2 A C_D$$

Where,

$$n_{sails} = number\ of\ sails = 3$$

$$\rho = fluid\ density = 1.292\frac{kg}{m^3}\ (STP, 0^{\circ}C\ at\ 1\ atm)\ [20]$$

$$v = apparent\ wind\ speed\ (changes)$$

$$A = sail\ area = 1600m^2$$

$$C_d = \ lift\ coefficent\ (changes\ with\ Re\ and\ AoA)$$

8.4.4 XFOIL Analysis: Relating Re and AoA to optimum C_d/C_d

XFOIL was used in order to determine the drag and lift coefficients of the wing sail which has a NACA 0015 profile.

XFOIL iteratively converges on a solution for drag and lift coefficients for a sequence of angle of attack at a given Reynolds number. Since it is not feasible to run CFD simulations for so many angles of attack and Reynolds number conditions XFOIL is used to determine to optimal operating conditions for the wing sail cross section. The optimal angle of attack is calculated by determine the best lift to drag ratio. This will be constrained by the ships heading and relative wind heading.

$$\frac{L}{D} = \frac{C_l}{C_d}\,[11]$$

For a given simulation XFOIL produces a polar plot consisting of 3 graphs. The first plot is the lift coefficient (C_l) vs the drag coefficient (C_d) multiplied by 10^4. The ideal lift and drag ratio for a given condition may be found by drawing a straight line from the origin up the y axis and rotating it until the line first touches.

The second plot is combination of the lift curve plot and the moment polar vs angle of attack. This plot provides a wealth of data including where the angle of attack of zero lift is, the linear region where the lift slope may be obtained, the maximum lift coefficient, angle of attack where stall occurs and the nature of stall. For the moment coefficient the plot is flipped so that negative values are shown as positive and ice-versa. This is to illustrate that negative values are good as in aircraft design a negative moment coefficient will provide a pitch down moment. This means a disturbance which causes a pitch up will induce a downward pitch which for aircraft design is an important condition for inherently stability.

The third and final plots shows where on the normalized cord the flow transitions from laminar to turbulent flow for a given lift coefficient. The coefficient of lift is on the y-axis for all 3 plots, exclusive of the moment coefficient. The x axis shows the location on the normalized chord. Two lines are used in order to represent the upper and lower surface

Since a Cl and Cd are calculated for each speed and Reynolds number and XFOIL's plotter is not intuitive the raw data was exported for use in excel so that Cl and Cd data can be matched to calculated to total thrust force which can be converted into power savings over the ships journey. See Figure 24 for an example of the polar plots exported by XFOIL.

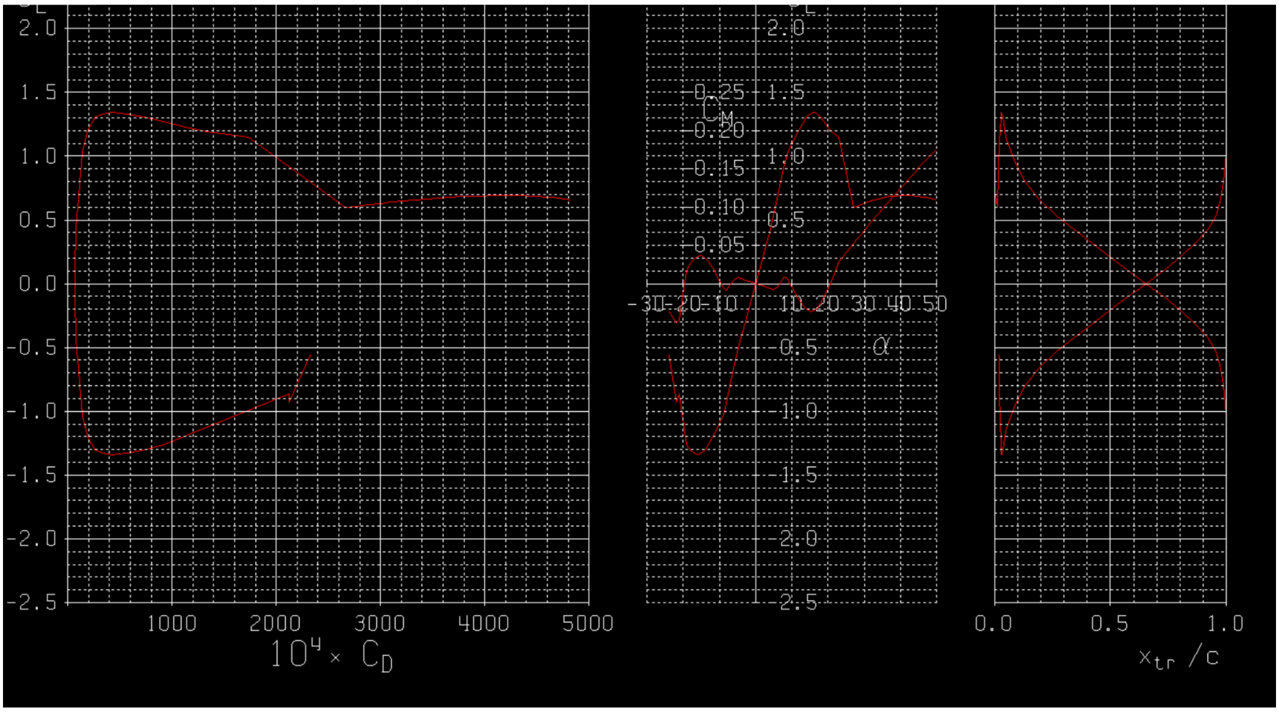


Figure 24: The polar plot from XFOIL is shown above, the contrast makes the image difficult to see and the y labels are cut off, these reasons are why excel was used to store the data from each of these plots for each wind speed.

The raw data from XFOIL was exported for further analysis and is available in the appendix section. Figure 25-Figure 28 contain the results of the XFOIL analysis and the subsequent Cd and Cl values used later when calculating the thrust.

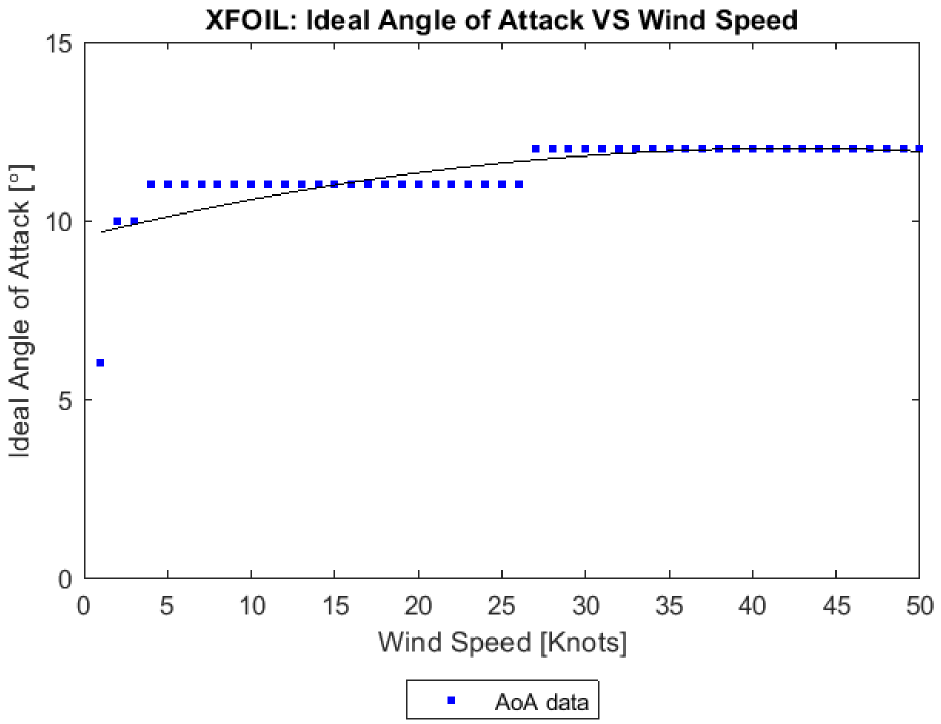


Figure 25: The resulting ideal angle of attack is plotted against the apparent wind speed, notice that as the speed increases the optimal angle shifts from 10, 11, 12 degrees at speeds of approximately 2,4, and 10 knots respectively. The initial point of 6 degrees AoA at 1 knot is unreliable.

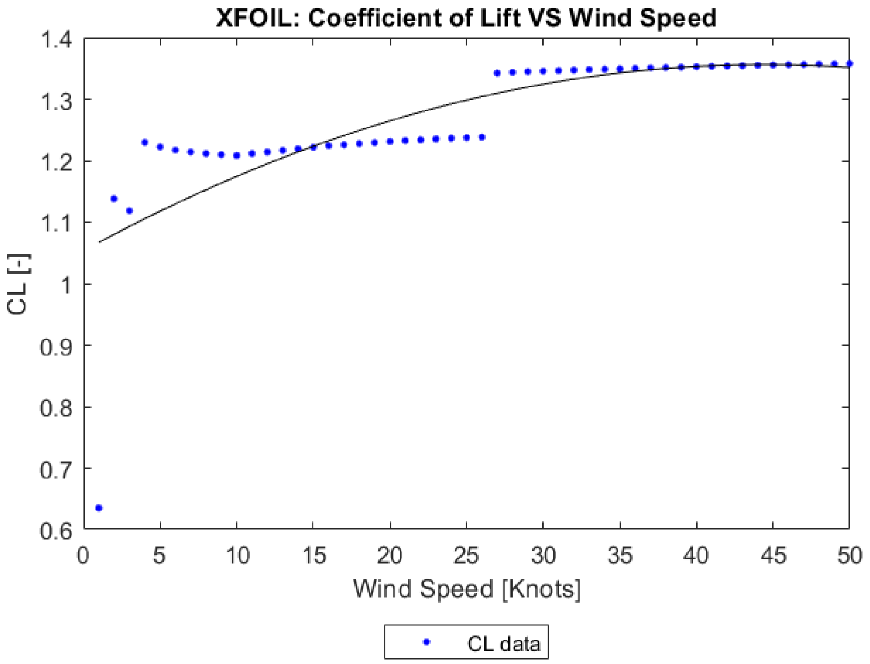


Figure 26:The lift coefficient (Cl) is plotted against the wind speed, the first Cl is very low which makes sense for 1 knot overall. However the starting Cl is taken as 1.14 at 2 knots and gradually increases to 1.36 at 50 knots with significant changes to accompany the aforementioned increase in angle of attack.

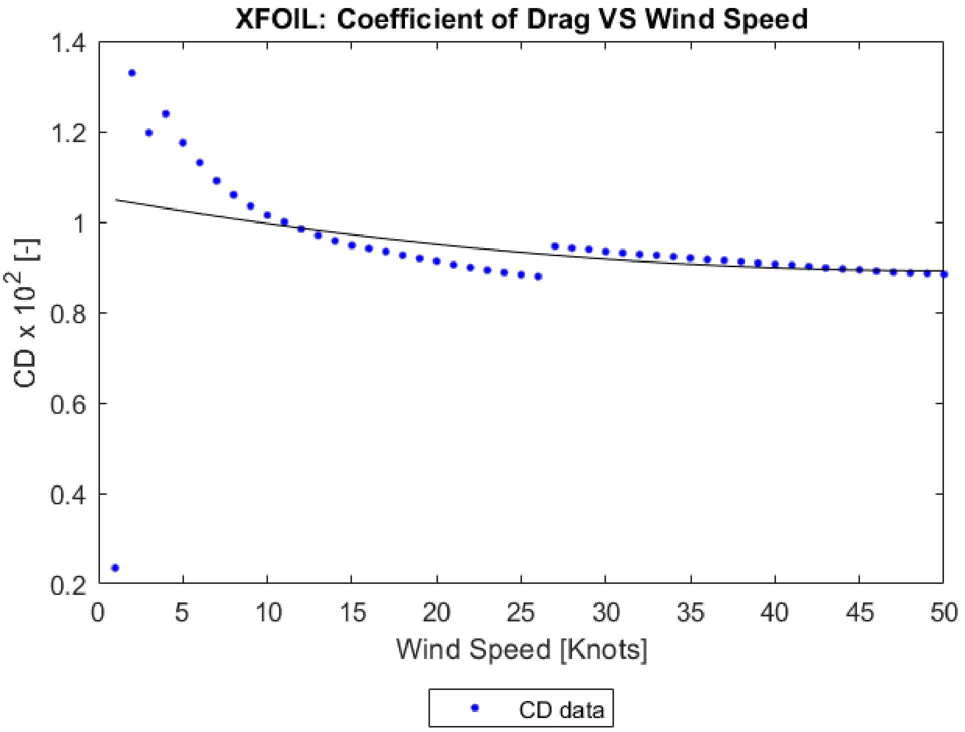


Figure 27: The drag coefficient (Cd) is plotted against wind speed, notice the discontinuities as this shows a higher drag is produced which is expected with an increase in angle of attack.

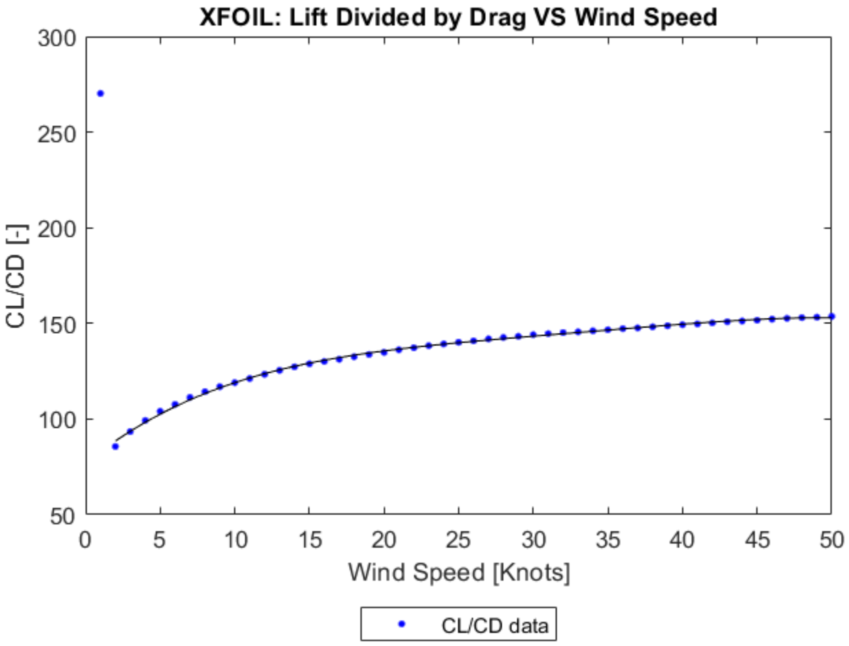


Figure 28: XFOIL: The optimum Cd/Cl is plotted against an apparent wind speed of 1-50 knots. Notice the first point is showing an unreasonably high Cd/Cl of 270, this is due to XFOIL struggling to produce valid results at such a low Reynolds number. This is ignored and 2 knots is taken as the start point with a value of 85, eventually increasing to around 150 at 50 knots.

8.4.5 Wind Data: Using Marine Blue Route

Forecasting or modeling the wind conditions along a shipping route proves to be an especially difficult process when used to estimate to flow of air around a sail array. Not only the wind conditions change constantly but additional complications from course changes will change the Apparent Wind Angle (AWA). In order to make an approximation, a method is to use True Wind Speed (TWS) and True Wind Direction (TWD) data which is collected from AIS receivers located on shore. The data was gathered using MARIN Blue Route tool which is based on ERA-5 data collected from 1989-2019, the data was tailored to each of the routes selected and was collected for each direction.

$$AWS = \sqrt{V_{ship}^2 + TWS^2 - 2\left(V_{ship}\right)(TWS)(\cos(TWA))}\ [14]$$

$$AWA = arcTan\left(\frac{TWS * \sin(TWA)}{V_{ship} + (TWS)(\cos(\mathrm{TWA}))}\right)\ [14]$$

Where,

$$AWS = Apparent\ Wind\ Speed$$

$$AWA = Apparent\ Wind\ Speed$$

$$V_{ship} = Speed\ Speed$$

$$TWS = \ True\ Wind\ Speed$$

$$TWA = True\ Wind\ Angle$$

MARIN Blue Route data was obtained in the form of a wind matrix with column headers being TWA and row headers indicating TWS in m/s. The AWS and AWA was calculated for 1800 combinations of TWA from 0 to 355° and 1-25 m/s TWS. This matrix is key in obtaining subsequent calculations.

8.4.6 Thrust and Side Force Coefficient Calculation

Similarly, to the wind matrix the thrust coefficient (Cx) and side force coefficient (Cy) are calculated for each of the 1800 combinations of TWA from 0 to 355° and 1-25 m/s TWS. This matrix is not represented in any figures, but it is required for obtaining the thrust force calculation, the side force is not used but it could be used in the future to automate course correction via the rudder. Cx and Cl are found with the following equations.

$$Cx = C_L \sin(AWA) - C_d \cos(AWA)\ \ [3]$$

$$C_y = C_L \cos(AWA) - C_d \sin(AWA)\ \ [3]$$

Where,

$$Cx = thrust\ coefficent$$

$$Cy = side\ force\ coefficent$$

$$Cx = 0 \quad for \quad AWA < 30, \qquad AWA > 330, \qquad and\ AWS > 35\ knots$$

Cx is set to 0 between 330 and 30 degrees to account for how wing sails are used in practice. The wing sails would be feathered and not producing any thrust from these wind angles, also 35 knots has been set as the upper limit for the sail this is why power produced by the sail array may decrease at higher speeds as the AWS increases above the 35 knots threshold

8.4.7 Thrust Force Calculation

The thrust force is calculated using a very similar equation to lift or drag force but instead with the thrust coefficient used. This was also completed as a matrix in the same fashion as AWS, AWA. The average sail thrust was also plotted VS vessel speed for each leg of the journey from Hamburg to Walvis Bay, Walvis Bay to Hamburg, and Hamburg to Walvis Bay including return.

$$F_{sail} = \frac{1}{2}(C_x)(\rho)(AWS)^2(A)\ [3]$$

Where,

$$F_{sail} = force\ from\ sail$$

$$C_X = thrust\ coefficent$$

$$\rho = air\ density$$

$$AWS = Apparent\ Wind\ Speed$$

$$A = sail\ area$$

8.4.8 Power and Energy Calculation

The power is calculated by multiplying the sail force by the vessel speed, this was completed for the wind matrix and the average power found throughout the journey. The percentage of power obtained from the sails was also plotted, see the following equation and subsections for results.

$$P_{sail} = (F_{sail})(V_{ship})\ [3]$$
$$P_{sails} = (n_{sails})(F_{sail})(V_{ship})$$

$$P_{\%(from\ sails)} = \frac{P_{sails}}{P_{Propulsion\ Analysis}}$$

Where,

$$P_{sail} = Sail\ Power$$

$$V_{ship} = Ship\ Speed$$

$$P_{\%(from\ sails)} = Percent\ Power\ Generated\ from\ Sails$$

The total energy was obtained via matrix manipulation in MATLAB (see 12.5 Appendix: MATLAB Code for more info), each entry in the power matrix was multiplied by total time required for the journey which was in turn multiplied by the probability matrix. Each entry in the energy matrix was summed before being converted back to power in order to obtain the average power at varying speeds.

$$E_{sails} = (P_{sails})(Time)$$

$$Time = \frac{Distance_{route}}{V_{ship}}$$

$$E_{\%(saved/from\ sails\ )} = \frac{E_{sails}}{E_{propulsion}}(100)$$

8.4.8.1 Hamburg to Walvis Bay

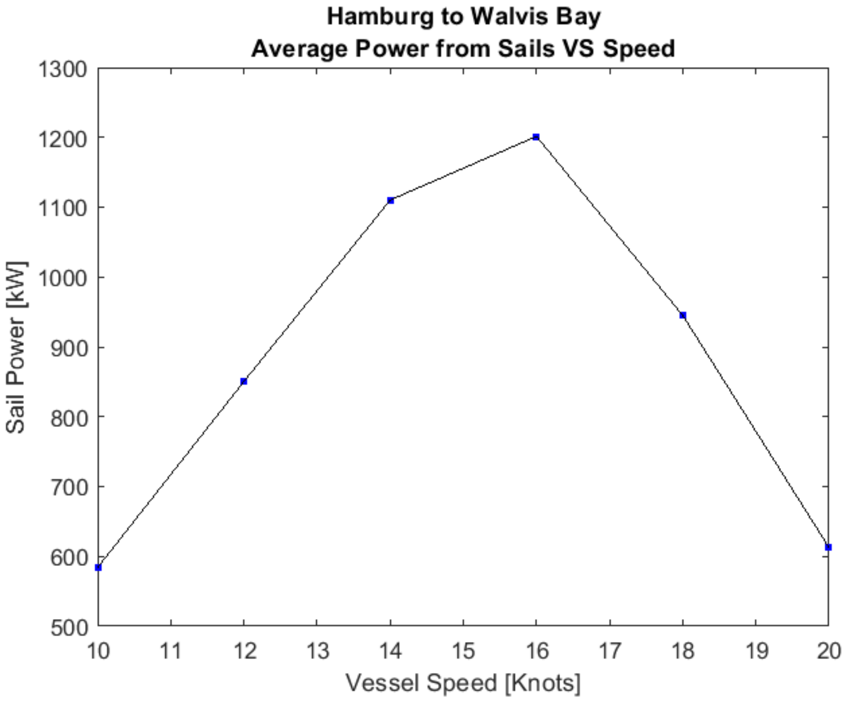


Figure 29: The average power generated by the sails is shown vs the vessel speed. The lowest overall power is generated at 10 knots with a result of around 600 kw while the highest average power is generated at the design speed of 16 knots with a power of around 1200 kw. The power quickly falls off from there decreasing to just over 600 kw, this decrease is due to the AWS exceeding the limit of 35 knots which results in a decrease in power.

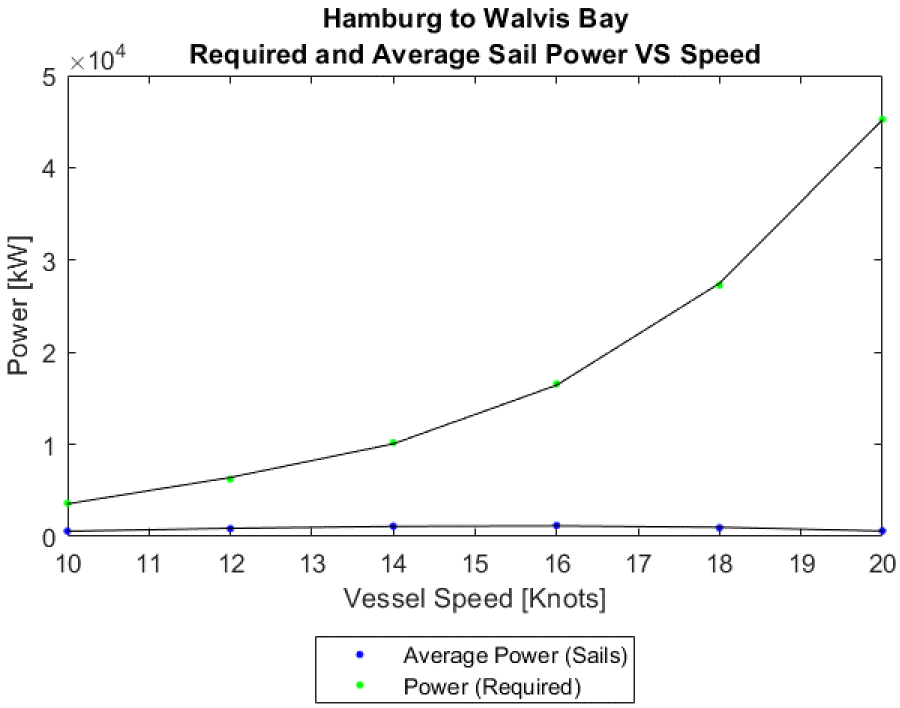


Figure 30: For context the propulsive power from the Holtrop resistance and propulsion analysis is shown in blue with the power generated from sails shown in green.

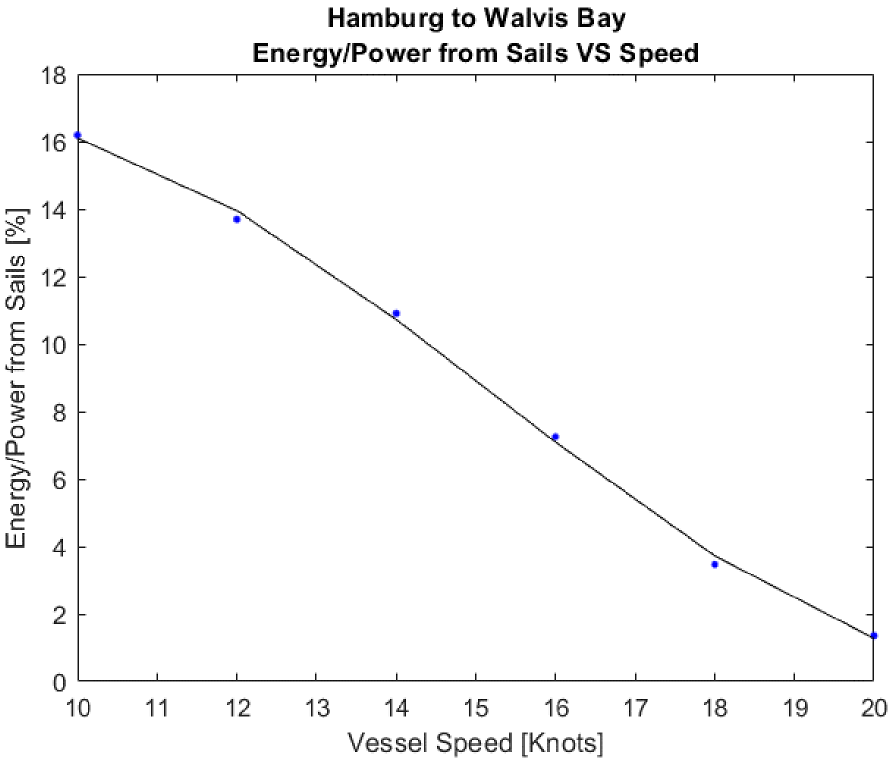


Figure 31: Shown is the percent power or wind energy generated throughout the journey. At 10 knots the highest savings are shown at approximately 16% while this steadily decreases to less than 2% at 20 knots. At the design speed of 16 knots approximately 8% savings are observed.

8.4.8.2 Walvis Bay to Hamburg

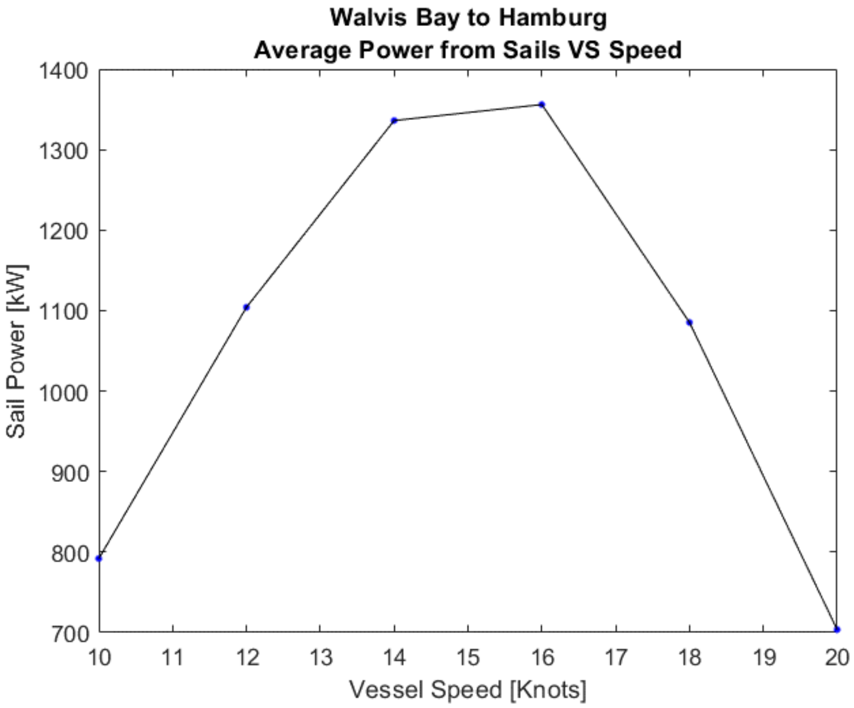


Figure 32: The average power generated by the sails is shown vs the vessel speed. The lowest overall power is generated at 20 knots with a result of around 700 kw while the highest average power is generated at the design

speed of 16 knots with a power of around 1350 kw. The power quickly falls off from there, this decrease is due to the AWS exceeding the limit of 35 knots which results in a decrease in power.

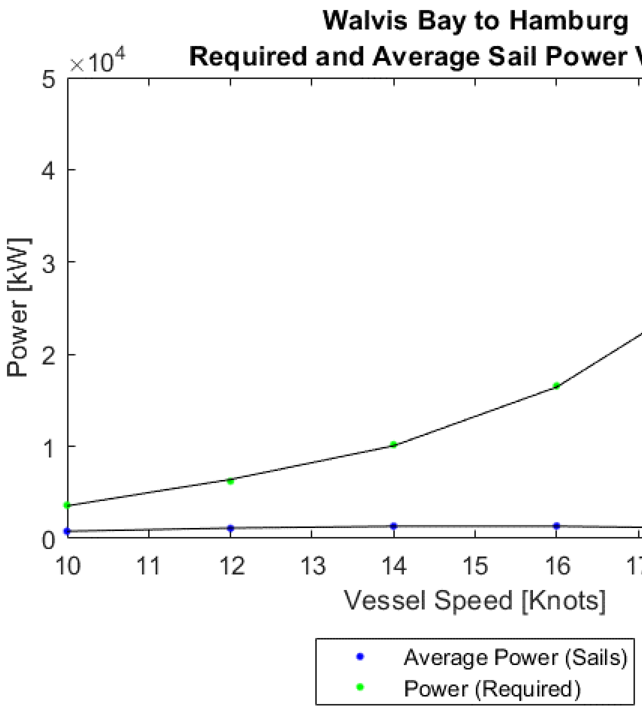


Figure 33: For context the propulsive power from the Holtrop resistance and propulsion analysis is shown in blue with the power generated from sails shown in green.

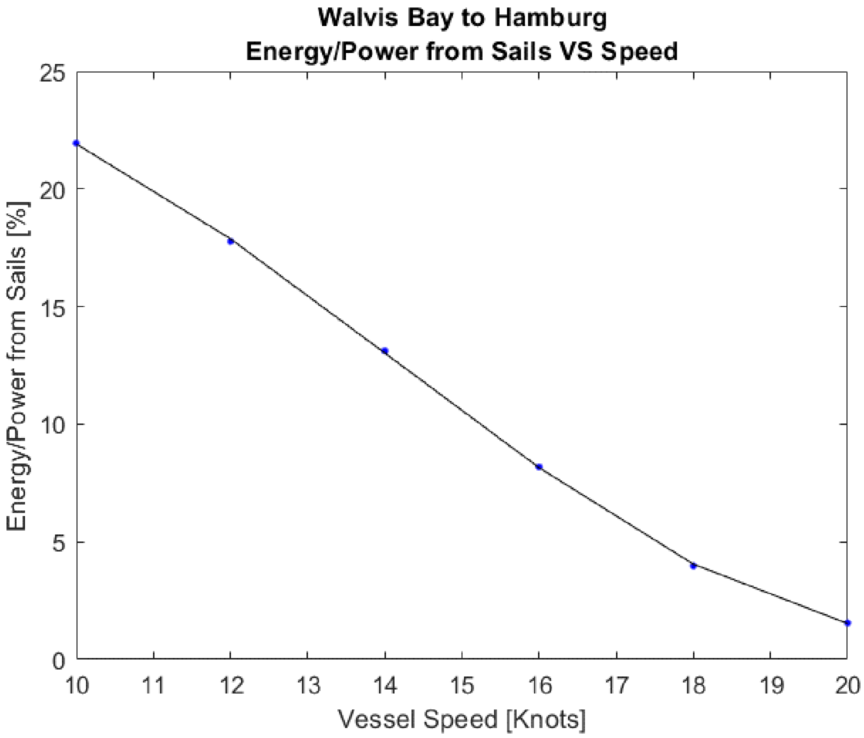


Figure 34: Shown is the percent power or wind energy generated throughout the journey. At 10 knots the highest savings are shown at approximately 22% while this steadily decreases to less than 3% at 20 knots. At the design speed of 16 knots approximately 8% savings are observed.

8.4.8.3 Hamburg to Walvis Bay Round Trip

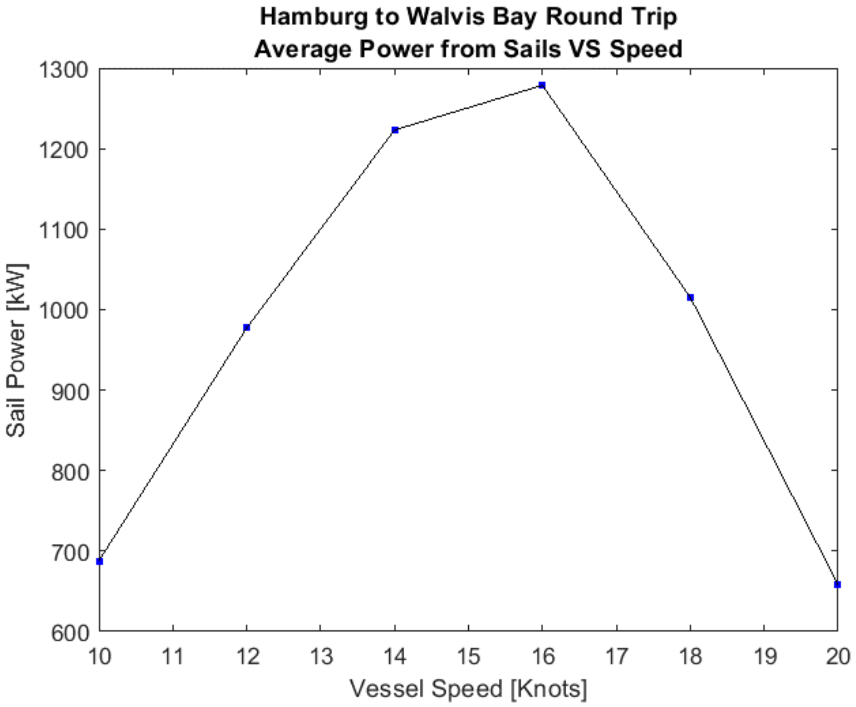


Figure 35: The average power generated by the sails is shown vs the vessel speed. The lowest overall power is generated at 20 knots with a result of around 700 kw while the highest average power is generated at the design

speed of 16 knots with a power of around 1275 kw. The power quickly falls off from there, this decrease is due to the AWS exceeding the limit of 35 knots which results in a decrease in power.

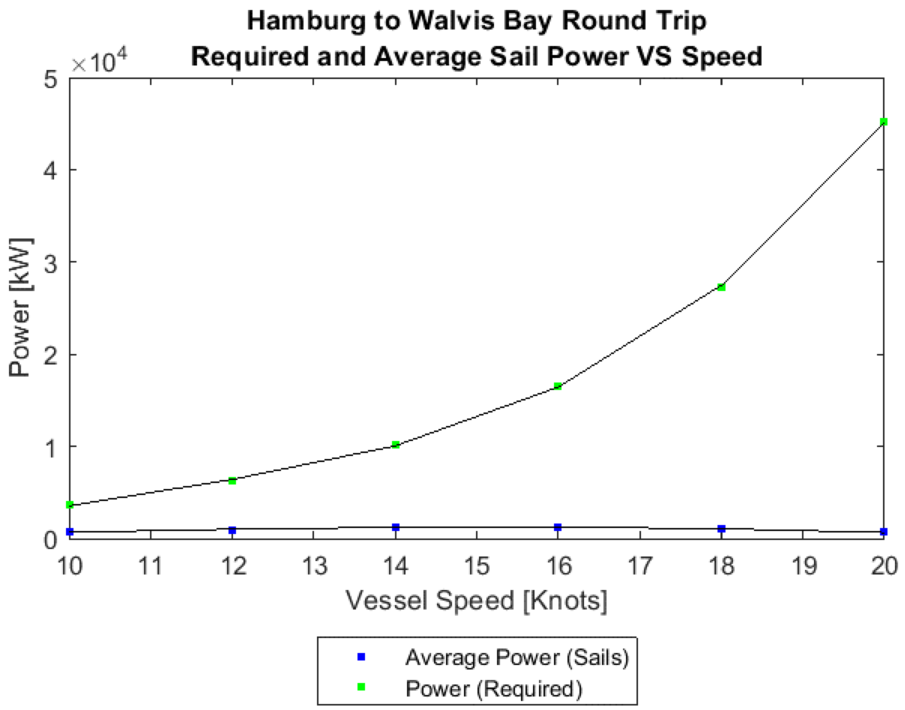


Figure 36: For context the propulsive power from the Holtrop resistance and propulsion analysis is shown in blue with the power generated from sails shown in green.

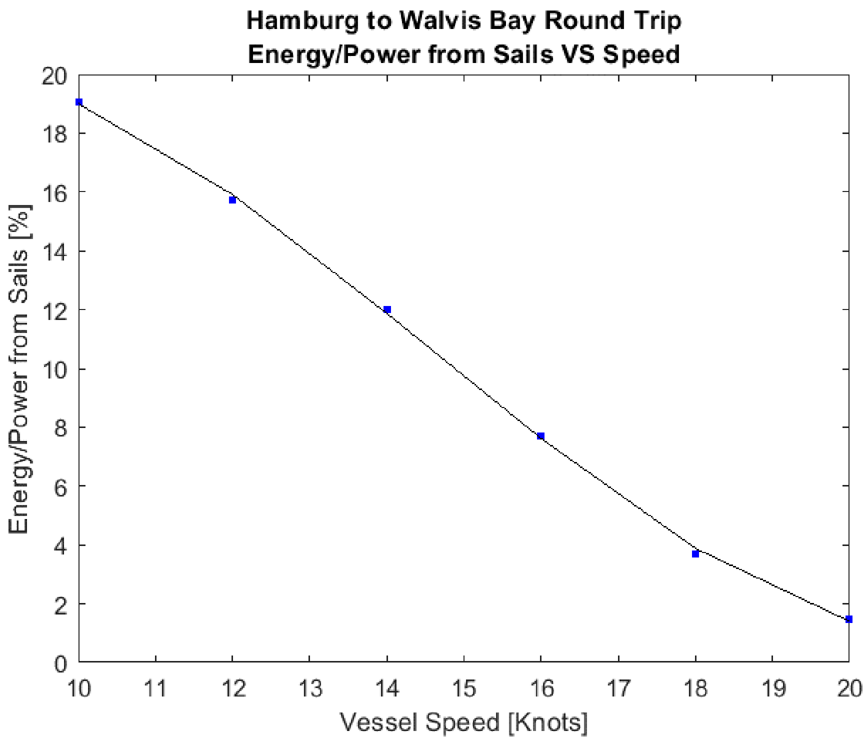


Figure 37: Shown is the percent power or wind energy generated throughout the journey. At 10 knots the highest savings are shown at approximately 19% while this steadily decreases to less than 2% at 20 knots. At the design speed of 16 knots approximately 8% savings are observed.

8.5 Fuel Calculations

The following subsection will detail various calculations related to fuel consumption for each leg of the Journey. This will include fuel parameter definitions, calculation of needed fuel, calculation of volume needed, and fuel mass saved.

8.5.1 Fuel Parameter Definition

Fuel parameters were collected from various sources to facilitate calculations relating to fuel. Information was collected on High Sulfur Fuel Oil(HSFO), Very Low Sulfur Fuel Oil(VLSFO), Liquified Natural Gas(LNG), Liquid Hydrogen(LH$_2$) and Liquid Ammonia(LNH$_3$). In particular density, specific energy, CO$_2$ per tonne, cost, and chemical to mechanical conversion efficiency was recorded.

Table 1 – Fuel Parameters

Fuel	Density [kg/m^3]	Specific Energy [J/t]	t-CO_2/t [-]	η Chem→Mech	Cost [€/tonne]	Source
HSFO	970	44.2×10^6	2.90	50%	440	[22] [23]
VLSFO	890	43.2×10^6	2.80	50%	534	[22] [23]
LNG	510	55.0×10^6	2.75	60%	2312	[24] [23]
LH_2	71	142.0×10^6	0 (green)	25%(comb) 60%(FC)	2648	[24]
LNH_2	700	22.8×10^6	0 (green)	25%(comb) 60%(FC)	2584	[24]

Green hydrogen and ammonia were assumed, as such there are no calculations surrounding their emissions of carbon dioxide.

8.5.2 Fuel Mass Required

The fuel mass required in tons was calculated by dividing the sum of the energy required throughout each leg of the journeys between Hamburg and Walvis Bay, along with Hamburg to Valparaiso and their respective round trips. The equation used is shown below:

$$Mass\ Required = \frac{Energy_{journey}}{(Specific\ Energy)(\eta_{Chemical \rightarrow mechanical})}$$

The required mass was calculated for each fuel and depended highly on the velocity as this greatly affected the total energy required throughout the journey. η is referred to as chemical to mechanical because combustion is considered for all fuels in addition to fuel cells for hydrogen and ammonia.

8.5.2.1 Hamburg to Walvis Bay

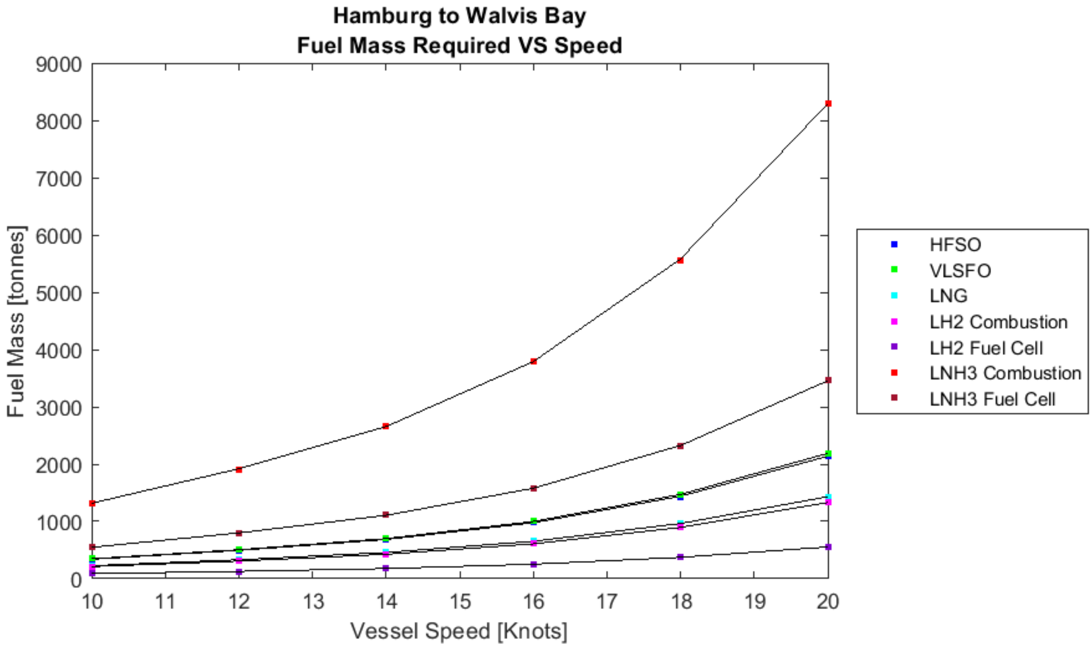


Figure 38: Shown is the fuel required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 977 tonnes for HFSO shown in blue; 1000 tonnes for VLSFO shown in green, 654 tonnes for LNG shown in cyan, 608 tonnes for LH_2 combusted shown in magenta, 253 tonnes for LH_2 utilizing fuel cells shown in purple, 3789 tonnes for LNH_3 combusted shown in bright red, and 1579 tonnes for LNH_3 utilizing fuel cells shown in dark red.

8.5.2.2 Walvis Bay to Hamburg

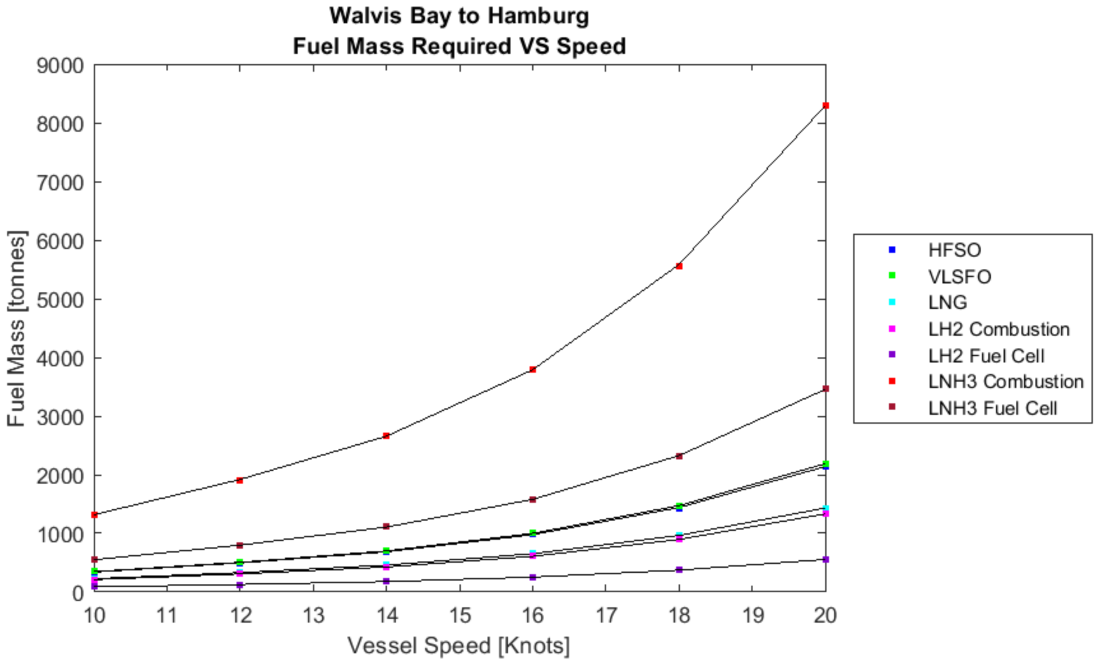


Figure 39: Shown is the fuel required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 977 tonnes for HFSO shown in blue; 1000 tonnes for VLSFO shown in green, 654 tonnes for LNG shown in cyan, 608 tonnes for LH_2 combusted shown in magenta, 253 tonnes for LH_2 utilizing fuel cells shown in purple, 3789 tonnes for LNH_3 combusted shown in bright red, and 1579 tonnes for LNH_3 utilizing fuel cells shown in dark red.

8.5.2.3 Hamburg to Walvis Bay Round Trip

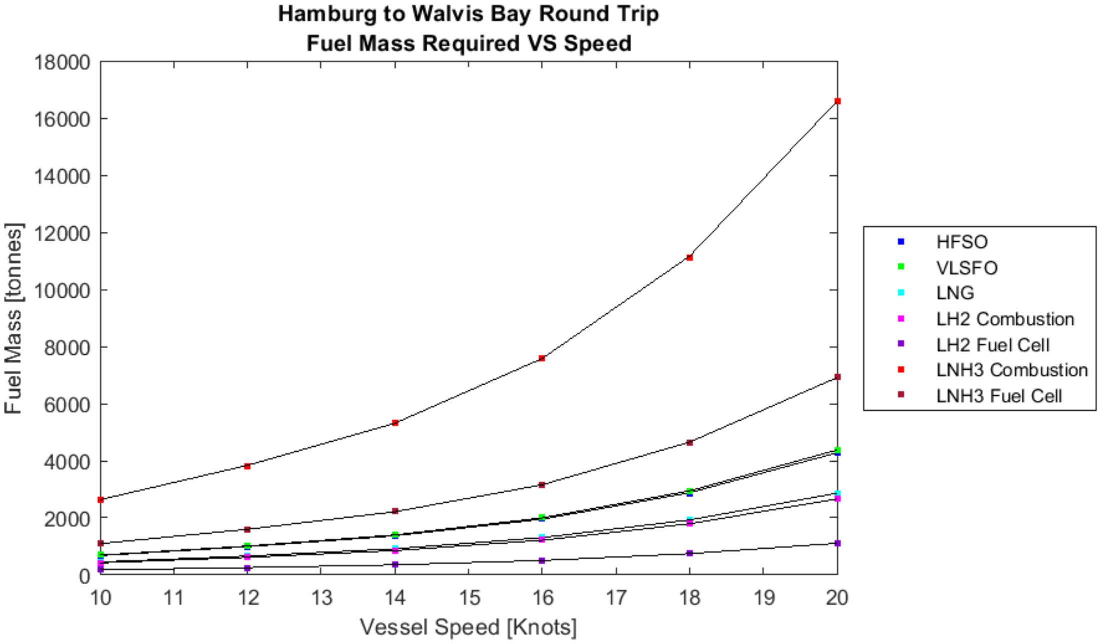


Figure 40: Shown is the fuel required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 1954 tonnes for HFSO shown in blue; 2000 tonnes for VLSFO shown in green, 654 tonnes for LNG shown in cyan, 1216 tonnes for LH_2 combusted shown in magenta, 506 tonnes for LH_2 utilizing fuel cells shown in purple, 7578 tonnes for LNH_3 combusted shown in bright red, and 3158 tonnes for LNH_3 utilizing fuel cells shown in dark red.

8.5.3 Fuel Volume Required

The fuel volume required in cubic meters was calculated by dividing the sum of the fuel required by the fuel density throughout each leg of the journey between Hamburg and Walvis Bay, including a respective round trip. The equation used is shown below:

$$Volume\ Required = \frac{Mass\ Required}{Fuel\ Density}$$

The required volume was calculated for each fuel and depended highly on the velocity as this greatly affected the total energy required throughout the journey. Knowing the volume is useful when planning tank volumes and preparing tank plans. This also helps understand the full strengths and weaknesses of different fuels, rather than considering mass exclusively.

8.5.3.1 Hamburg to Walvis Bay

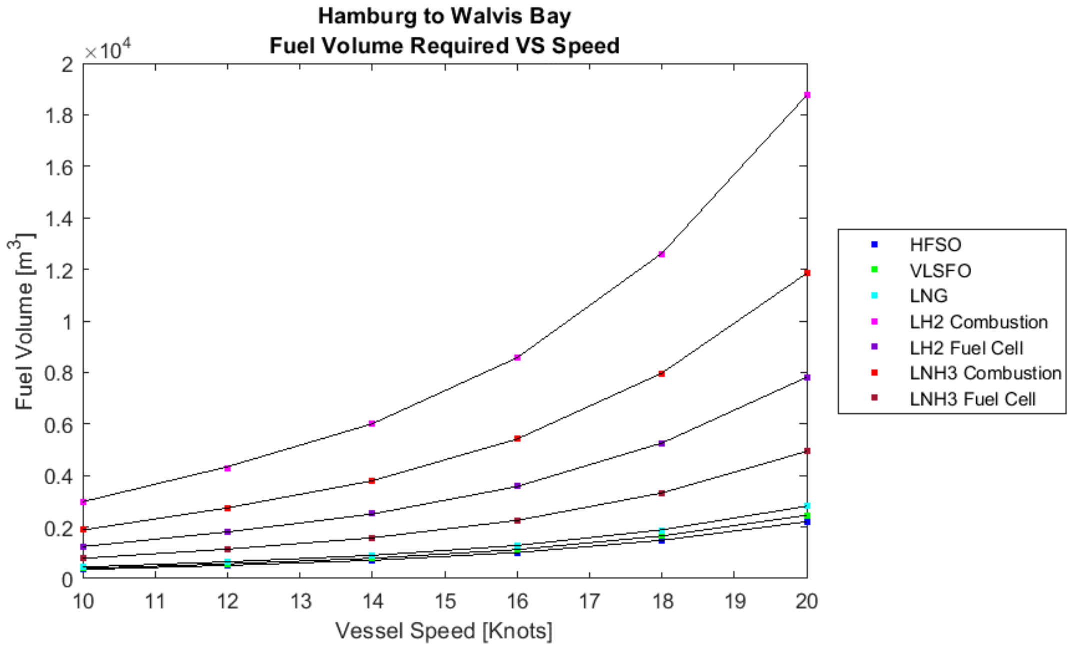


Figure 41: Shown is the fuel volume required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 1007 m^3 for HFSO shown in blue; 1123 m^3 for VLSFO shown in green, 1283 m^3 for LNG shown in cyan, 8569 m^3 for LH_2 combusted shown in magenta, 3570 m^3 for LH_2 utilizing fuel cells shown in purple, 5413 m^3 for LNH_3 combusted shown in bright red, and 2255 m^3 for LNH_3 utilizing fuel cells shown in dark red.

8.5.3.2 Walvis Bay to Hamburg

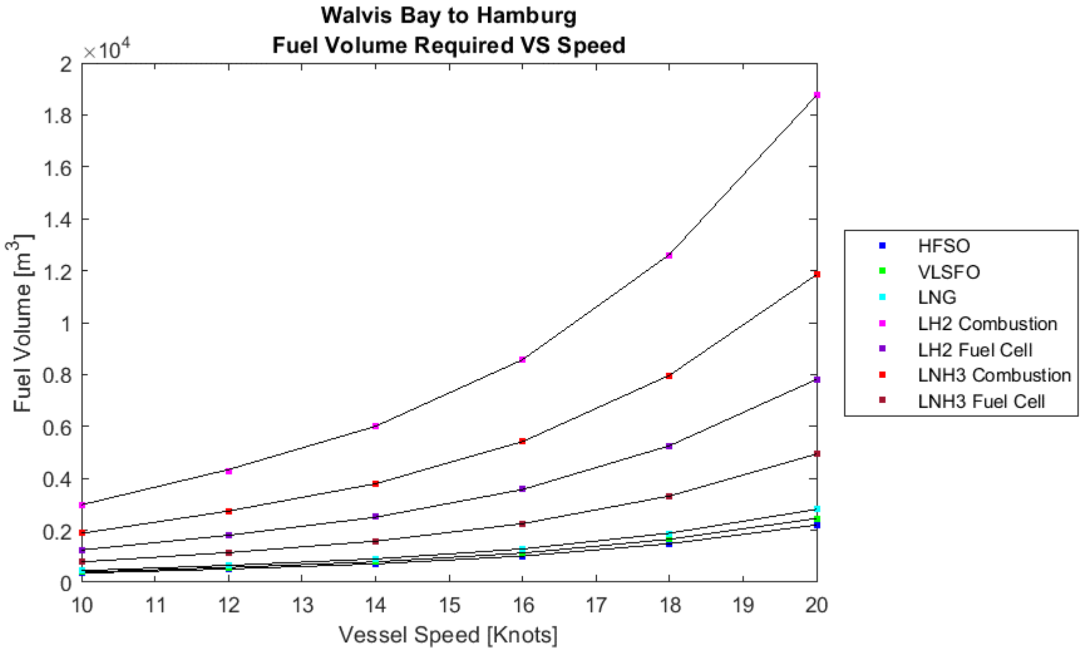


Figure 42: Shown is the fuel volume required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 1007 m^3 for HFSO shown in blue; 1123 m^3 for VLSFO shown in green, 1283 m^3 for LNG shown in cyan, 8569 m^3 for LH_2 combusted shown in magenta, 3570 m^3 for LH_2 utilizing fuel cells shown in purple, 5413 m^3 for LNH_3 combusted shown in bright red, and 2255 m^3 for LNH_3 utilizing fuel cells shown in dark red.

8.5.3.3 Hamburg to Walvis Bay Round Trip

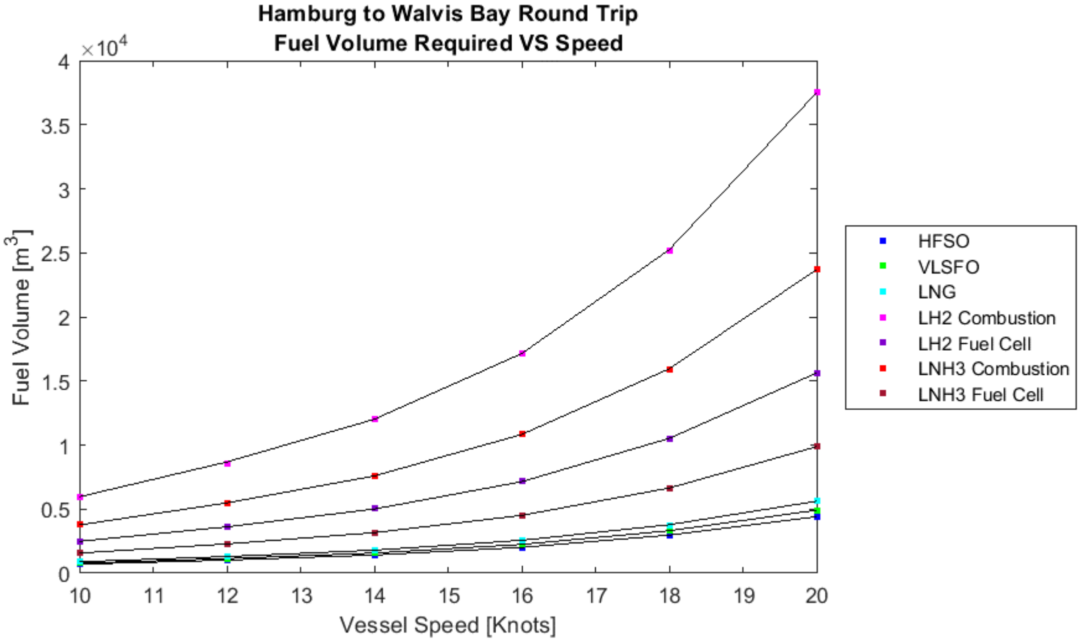


Figure 43: Shown is the fuel volume required vs vessel speed, at the design speed of 16 knots the following fuel volume is required; 2015 m^3 for HFSO shown in blue; 2247 m^3 for VLSFO shown in green, 2567 m^3 for LNG shown in cyan, 17138 m^3 for LH_2 combusted shown in magenta, 7140 m^3 for LH_2 utilizing fuel cells shown in purple, 10826 m^3 for LNH_3 combusted shown in bright red, and 4510 m^3 for LNH_3 utilizing fuel cells shown in dark red.

8.5.4 Fuel Mass Saved

The fuel mass saved is calculated by multiplying the required fuel mass by the percent of required energy generated by sails. This is calculated for each leg of the journey between Hamburg and Walvis Bay, including a respective round trip. The equation used is shown below:

$$Mass\ Saved = (Mass\ Required)(\ Energy_{\%(saved/from\ sails\ )})$$

The annual fuel mass saved is found by multiplying the mass saved during round trips with the number of annual trips. Similarly, the fuel mass savings are obtained by multiplying the annual mass by the service life of the vessel. The number of annual trips is calculated based on each round-trip distance assuming 250 days of transit operation per year, the service life of the vessel is assumed to be 30 years.

8.5.4.1 Hamburg to Walvis Bay

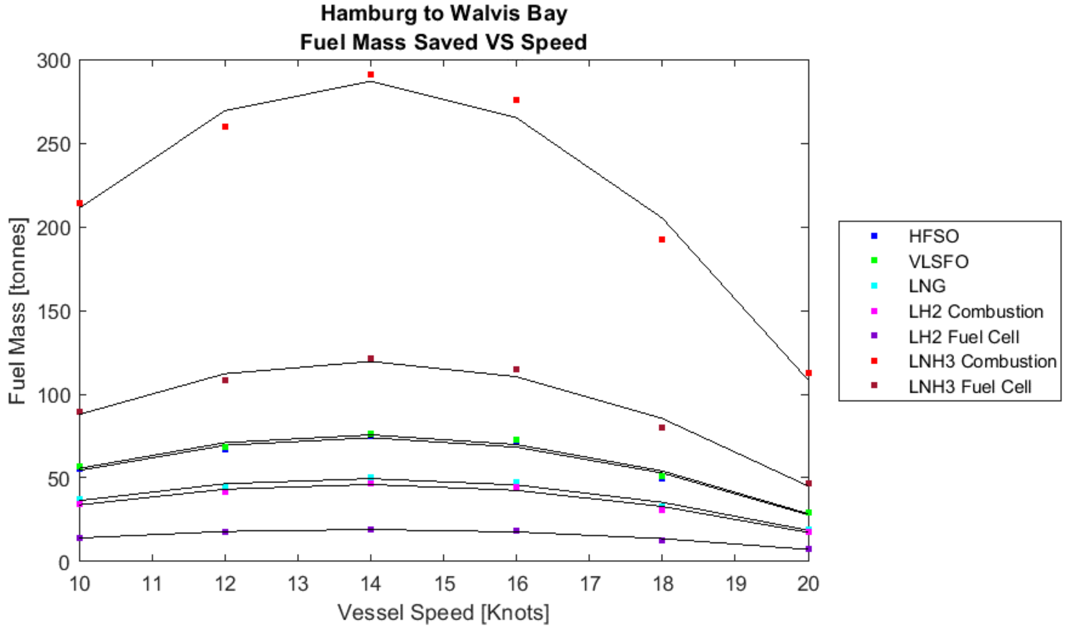


Figure 44: Shown is the fuel mass saved vs vessel speed, at the design speed of 16 knots the following fuel mass is saved; 70 tonnes for HFSO shown in blue; 73 tonnes for VLSFO shown in green, 47 tonnes for LNG shown in cyan, 43 tonnes for LH_2 combusted shown in magenta, 18 tonnes for LH_2 utilizing fuel cells shown in purple, 275 tonnes for LNH_3 combusted shown in bright red, and 115 tonnes for LNH_3 utilizing fuel cells shown in dark red.

8.5.4.2 Walvis Bay to Hamburg

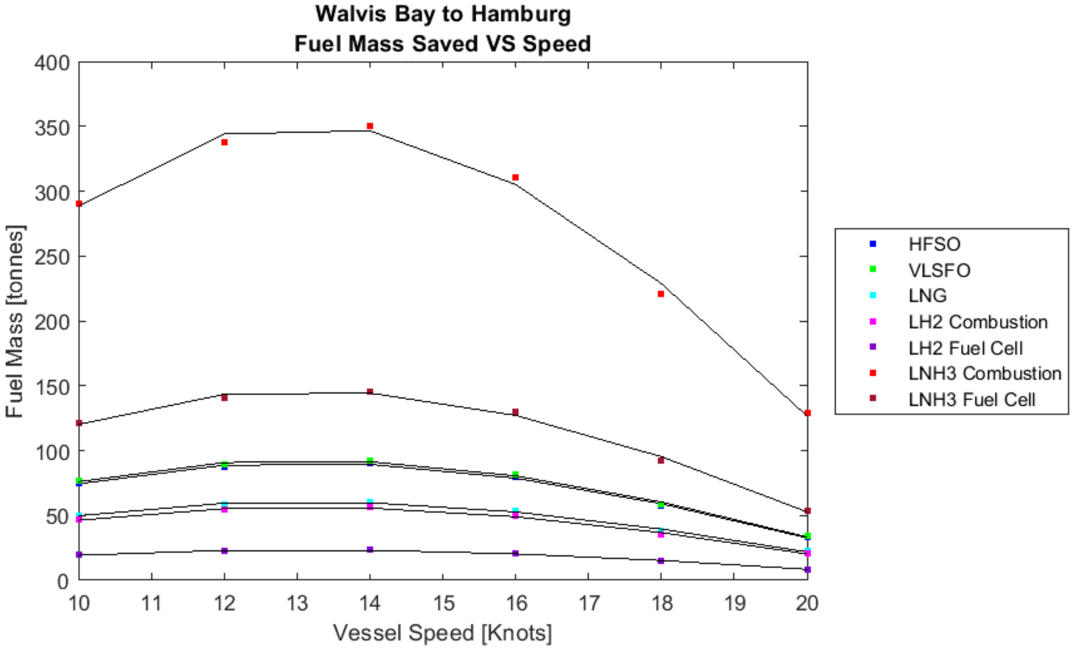


Figure 45: Shown is the fuel mass saved vs vessel speed, at the design speed of 16 knots the following fuel mass is saved; 79 tonnes for HFSO shown in blue; 81 tonnes for VLSFO shown in green, 54 tonnes for LNG shown in cyan, 49 tonnes for LH_2 combusted shown in magenta, 20 tonnes for LH_2 utilizing fuel cells shown in purple, 311 tonnes for LNH_3 combusted shown in bright red, and 130 tonnes for LNH_3 utilizing fuel cells shown in dark red.Hamburg to Walvis Bay Round Trip

8.5.4.3 Hamburg to Walvis Bay Round Trip

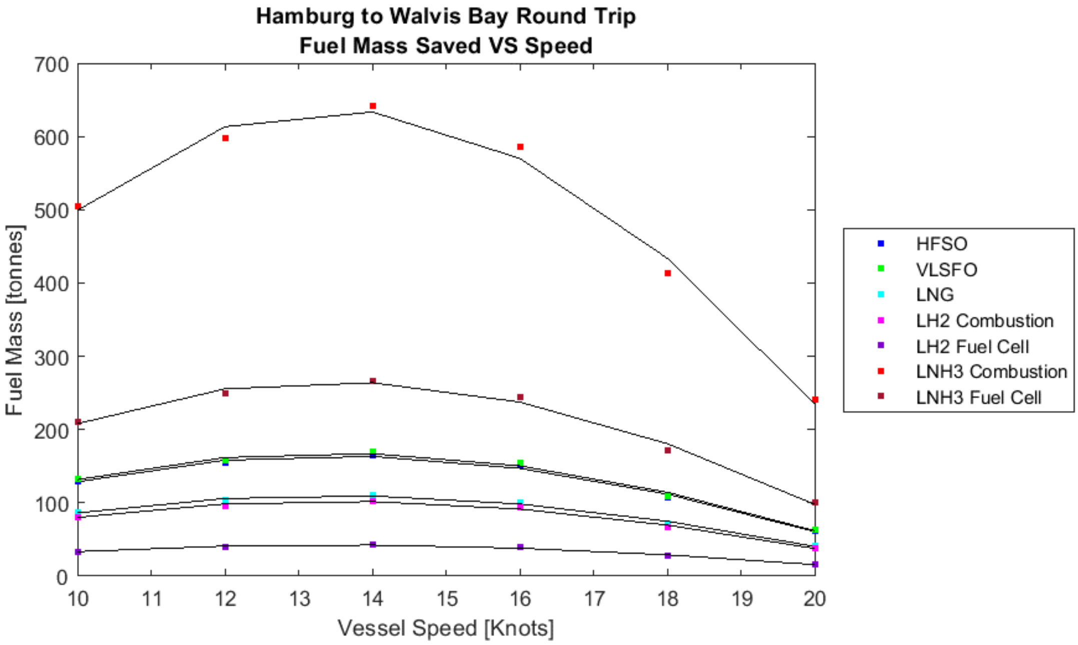


Figure 46: Shown is the fuel mass saved vs vessel speed, at the design speed of 16 knots the following fuel mass is saved; 150 tonnes for HFSO shown in blue; 155 tonnes for VLSFO shown in green, 101 tonnes for LNG shown in cyan, 92 tonnes for LH_2 combusted shown in magenta, 38 tonnes for LH_2 utilizing fuel cells shown in purple, 586 tonnes for LNH_3 combusted shown in bright red, and 244 tonnes for LNH_3 utilizing fuel cells shown in dark red.Hamburg to Walvis Bay Round Trip

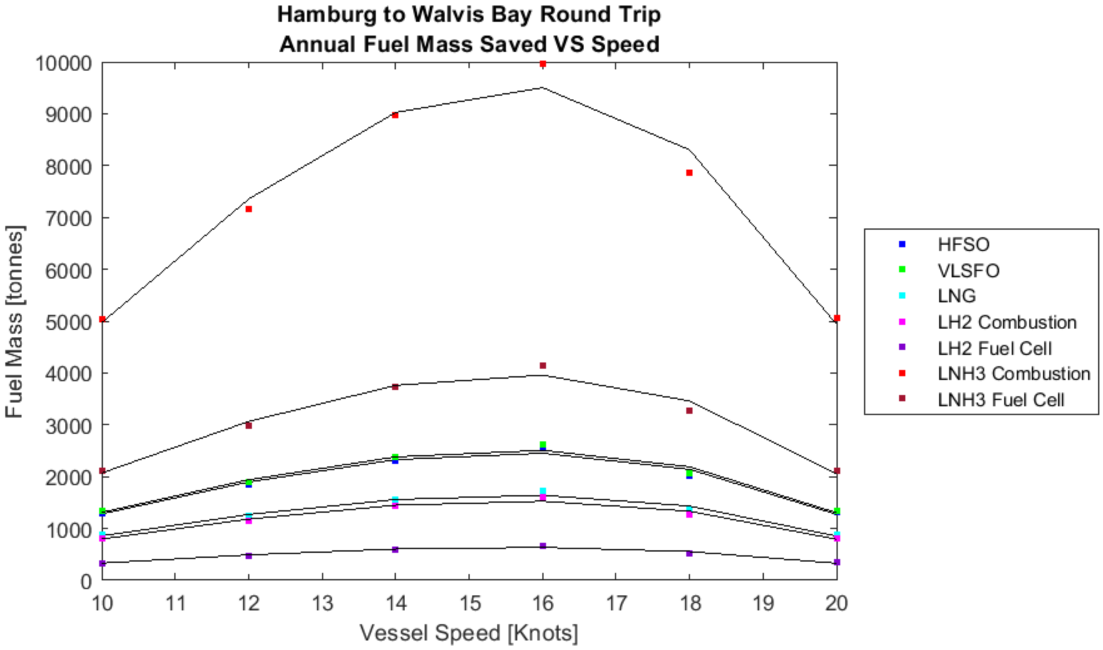


Figure 47: Shown is the fuel mass saved vs vessel speed for 17 annual trips at the design speed of 16 knots the following fuel mass is saved; 2571 tonnes for HFSO shown in blue; 2631 tonnes for VLSFO shown in green, 1721 tonnes for LNG shown in cyan, 1600 tonnes for LH_2 combusted shown in magenta, 667 tonnes for LH_2 utilizing

fuel cells shown in purple, 9969 tonnes for LNH₃ combusted shown in bright red, and 4154 tonnes for LNH₃ utilizing fuel cells shown in dark red.Hamburg to Walvis Bay Round Trip

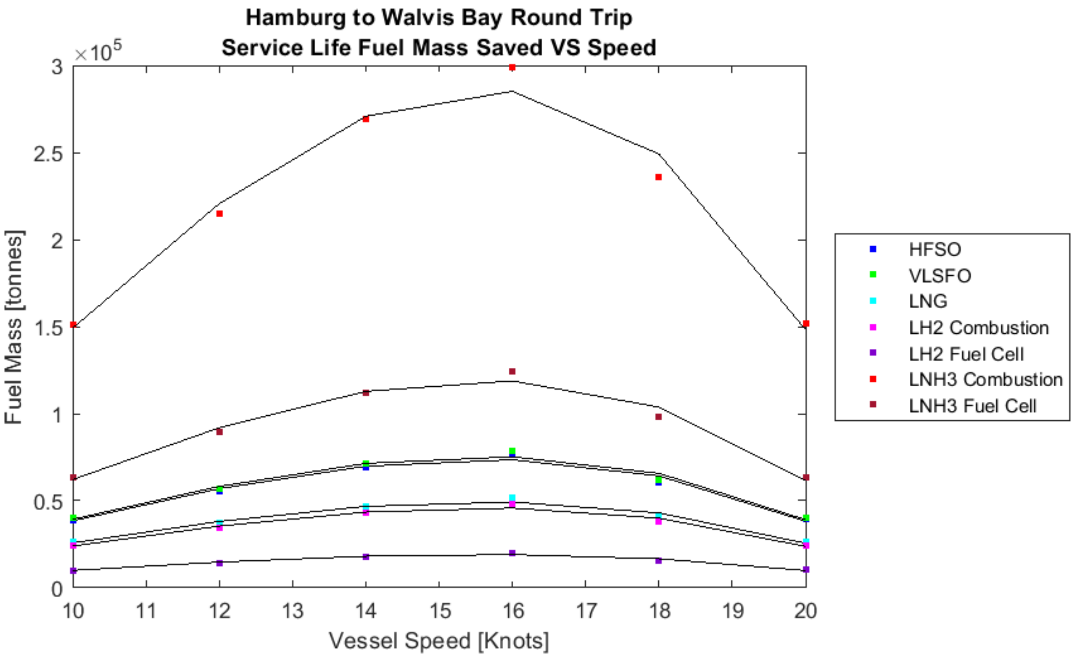


Figure 48: Shown is the fuel mass saved vs vessel speed for 17 annual trips with a service life of 30 years at the design speed of 16 knots the following fuel mass is saved; 77135 tonnes for HFSO shown in blue; 78920 tonnes for VLSFO shown in green, 51657 tonnes for LNG shown in cyan, 48019 tonnes for LH_2 combusted shown in magenta, 20008 tonnes for LH_2 utilizing fuel cells shown in purple, 299067 tonnes for LNH_3 combusted shown in bright red, and 124611 tonnes for LNH_3 utilizing fuel cells shown in dark red.

8.6 CO_2 Reduction

The carbon dioxide reduction is calculated per trip in addition to being calculated in terms of annually and service life for the round-trip journey. The reduction in CO_2 is calculated by multiplying the fuel mass saved by the respective CO_2 emissions per tonne.

$$CO_2(Reduction) = (MassNeeded)\left(\frac{tCO2}{t}\right)$$

This is completed for HFSO, VLSFO, and LNG while the other fuels are all assumed to come from green sources.

8.6.1.1 Hamburg to Walvis Bay

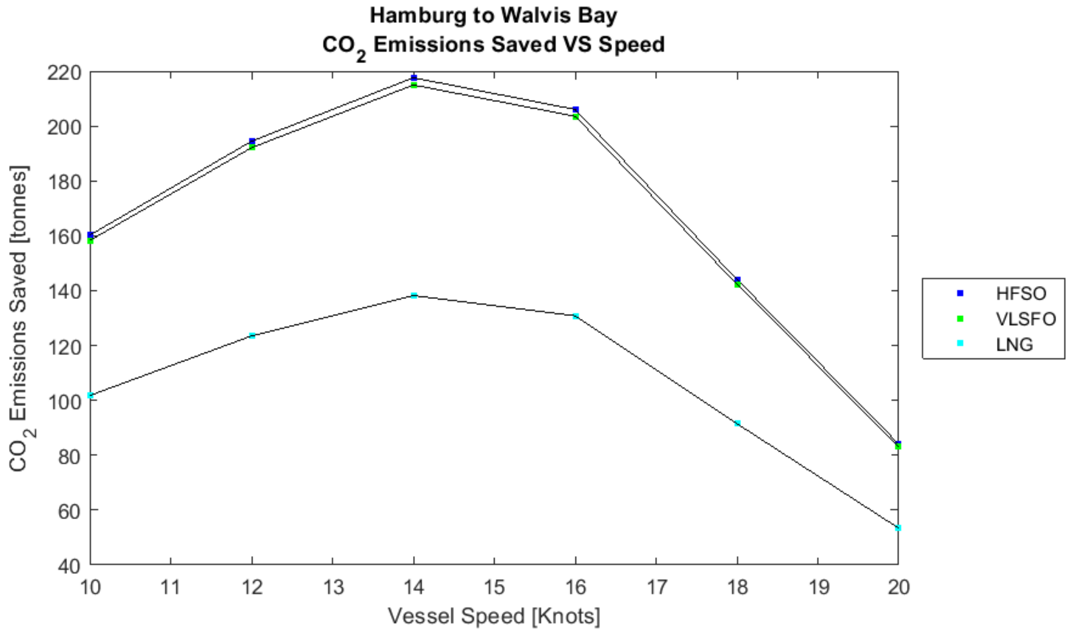


Figure 49: Shown is the CO_2 saved vs vessel speed, at the design speed of 16 16 knots the following CO_2 is saved; 206 tonnes for HFSO shown in blue; 203 tonnes for VLSFO shown in green, and 131 tonnes for LNG shown in cyan.

8.6.1.2 Walvis Bay to Hamburg

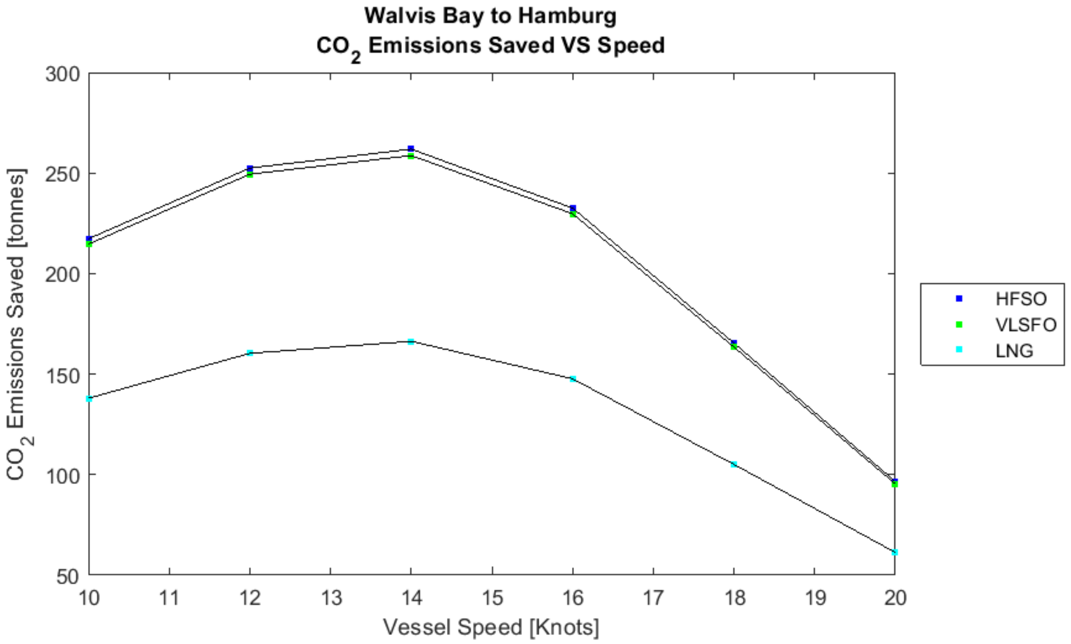


Figure 50: Shown is the CO_2 saved vs vessel speed, at the design speed of 16 knots the following CO_2 is saved; 232 tonnes for HFSO shown in blue; 230 tonnes for VLSFO shown in green, and 148 tonnes for LNG shown in cyan.

8.6.1.3 Hamburg to Walvis Bay Round Trip

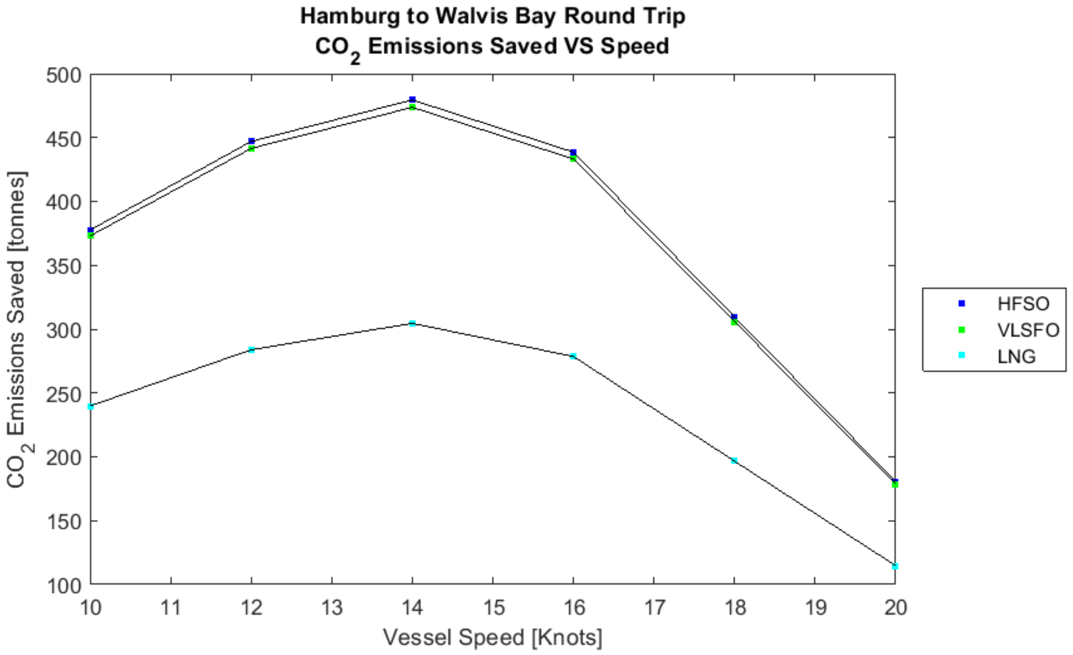


Figure 51: Shown is the CO_2 saved vs vessel speed, at the design speed of 16 knots the following CO_2 is saved; 438 tonnes for HFSO shown in blue; 433 tonnes for VLSFO shown in green, and 278 tonnes for LNG shown in cyan.

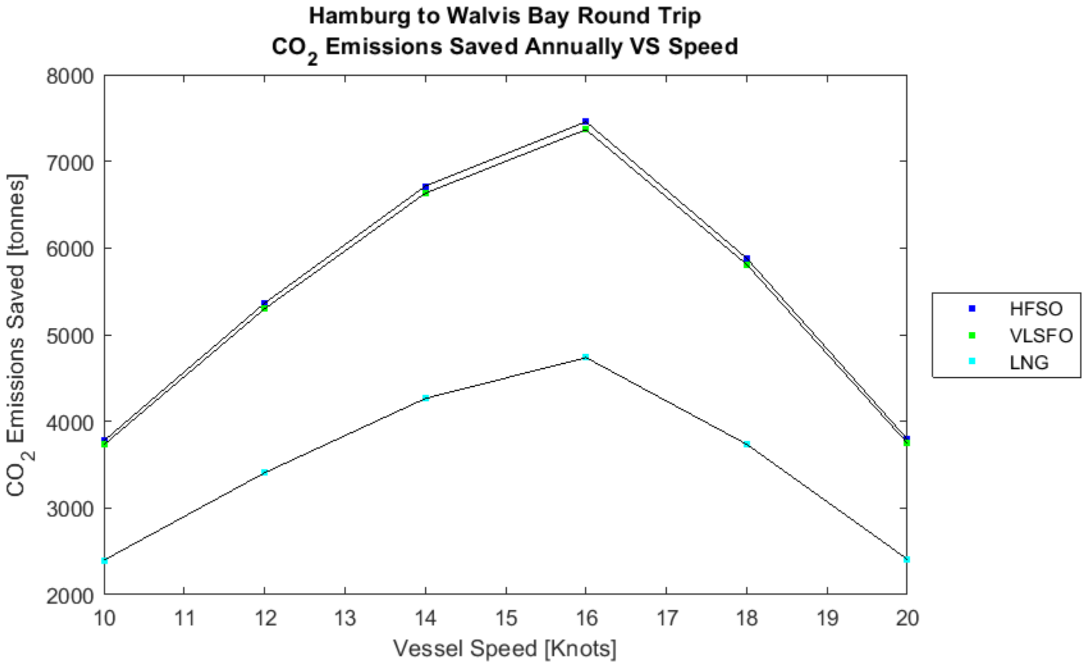


Figure 52: Shown is the fuel mass saved vs vessel speed for 17 annual trips at the design speed of 16 knots the following CO_2 is saved; 7456 tonnes for HFSO shown in blue; 7365 tonnes for VLSFO shown in green, and 4735 tonnes for LNG shown in cyan.

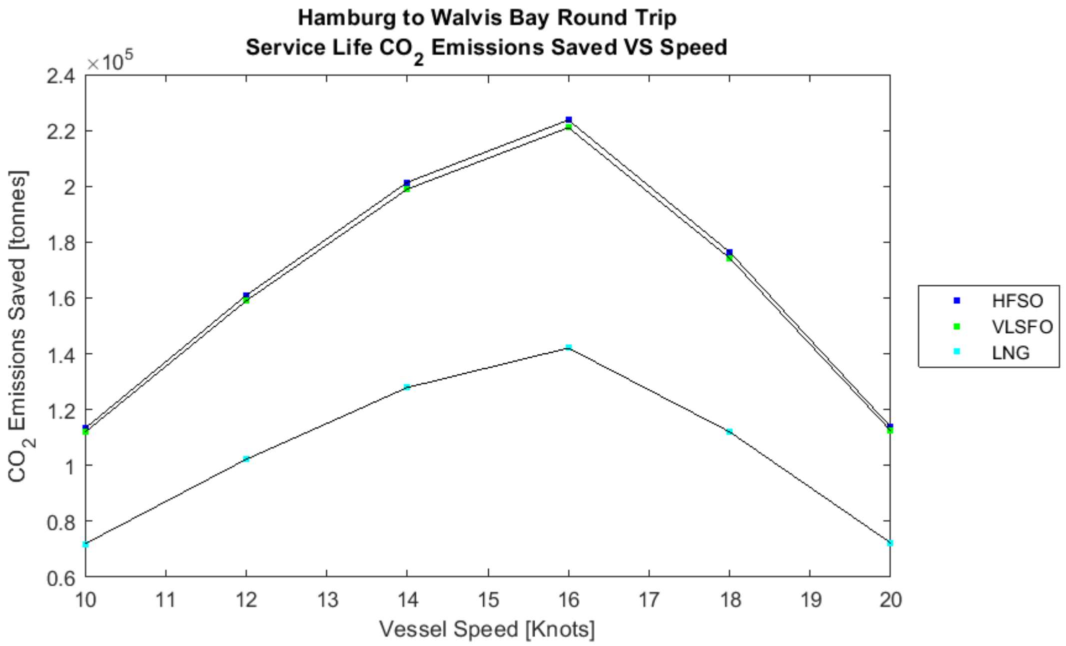


Figure 53: Shown is the fuel mass saved vs vessel speed for 17 annual trips with a service life of 30 years at the design speed of 16 knots the following CO_2 is saved; 232 tonnes for HFSO shown in blue; 230 tonnes for VLSFO shown in green, and 148 tonnes for LNG shown in cyan.

8.7 Economic Assessment

The following subsection will detail the process for determining the amount of money saved per trip throughout all legs of the journey. For the round trips the amount of money saved will be provided on the basis of annually and over the vessels service life. An NPV and SPP calculation is also completed to paint a clear economic picture.

8.7.1 Fuel Cost Savings

The amount saved per trip can be calculated by multiplying the fuel mass saved by the cost of the fuel per unit mass. The equation follows:

$$€_{saved} = (Mass\ Saved)(Fuel\ Cost)$$

8.7.1.1 Hamburg to Walvis Bay

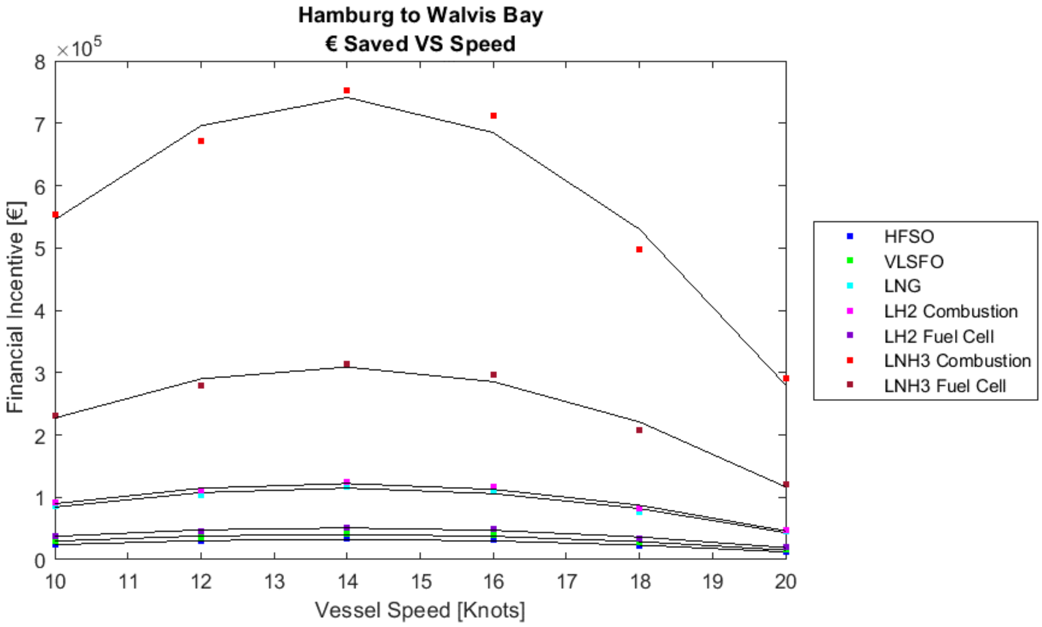


Figure 54: Shown is the euros saved vs vessel speed, at the design speed of 16 knots the following amount is saved; €30035 for HFSO shown in blue; €37375 for VLSFO shown in green, €105856 for LNG shown in cyan, €117115 for LH_2 combusted shown in magenta, €48814 for LH_2 utilizing fuel cells shown in purple, €711851 for LNH_3 combusted shown in bright red, and €296604 for LNH_3 utilizing fuel cells shown in dark red.

8.7.1.2 Walvis Bay to Hamburg

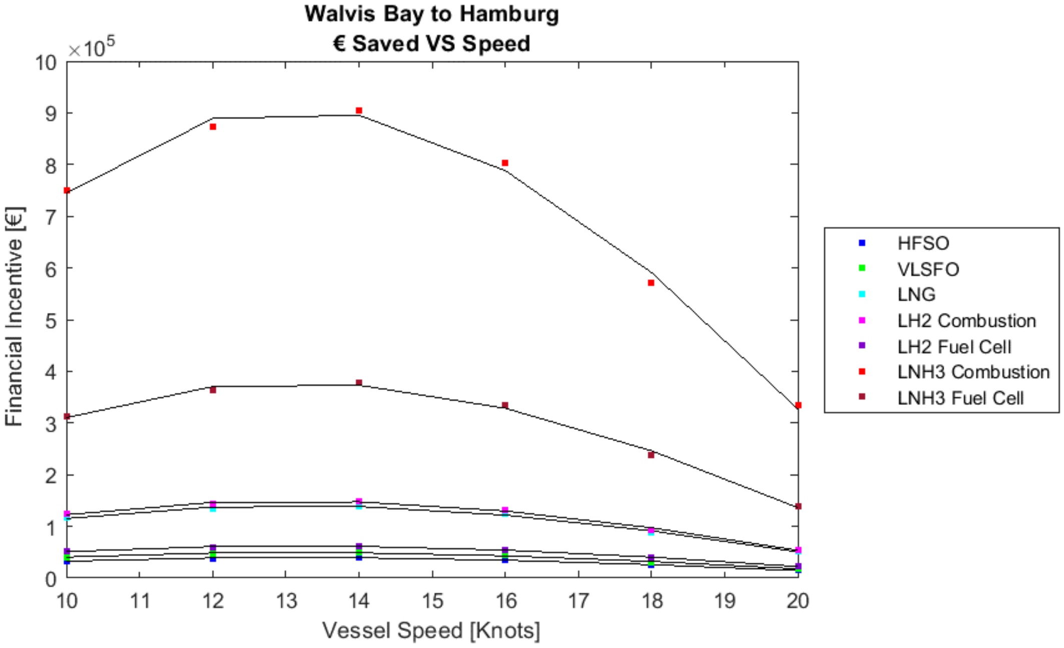


Figure 55: Shown is the euros saved vs vessel speed, at the design speed of 16 knots the following amount is saved; €33578 for HFSO shown in blue; €43026 for VLSFO shown in green, €121867 for LNG shown in cyan, €132226 for LH_2 combusted shown in magenta, €54067 for LH_2 utilizing fuel cells shown in purple, €803424 for LNH_3 combusted shown in bright red, and €334670 for LNH_3 utilizing fuel cells shown in dark red.

8.7.1.3 Hamburg to Walvis Bay Round Trip

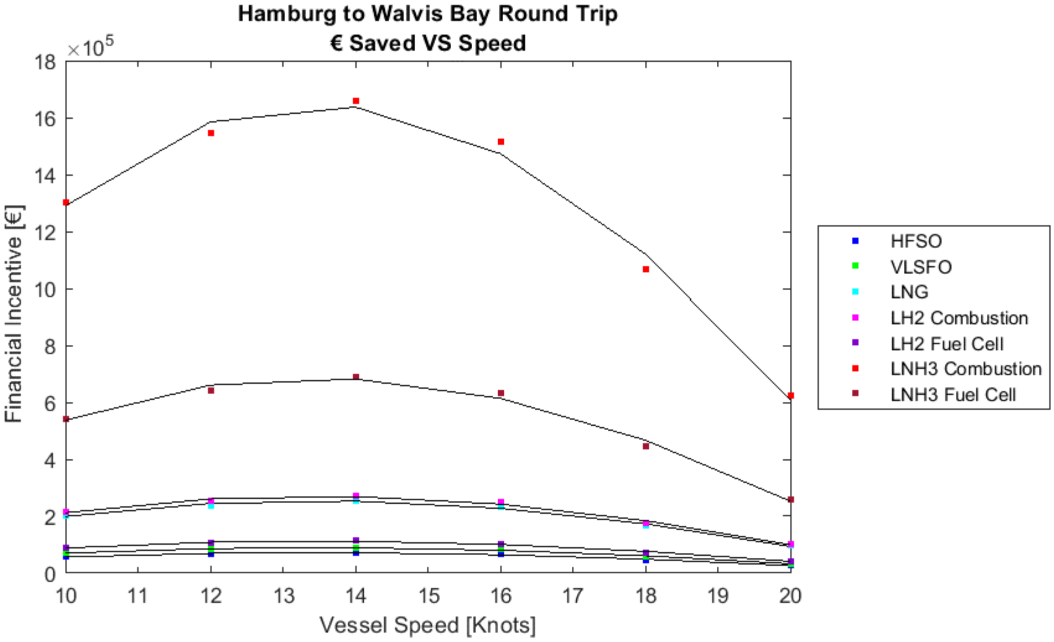


Figure 56: Shown is the euros saved vs vessel speed, at the design speed of 16 knots the following amount is saved; €64613 for HFSO shown in blue; €80402 for VLSFO shown in green, €227723 for LNG shown in cyan,

€242474 for LH_2 combusted shown in magenta, €101031 for LH_2 utilizing fuel cells shown in purple, €1515280 for LNH_3 combusted shown in bright red, and €631365 for LNH_3 utilizing fuel cells shown in dark red.

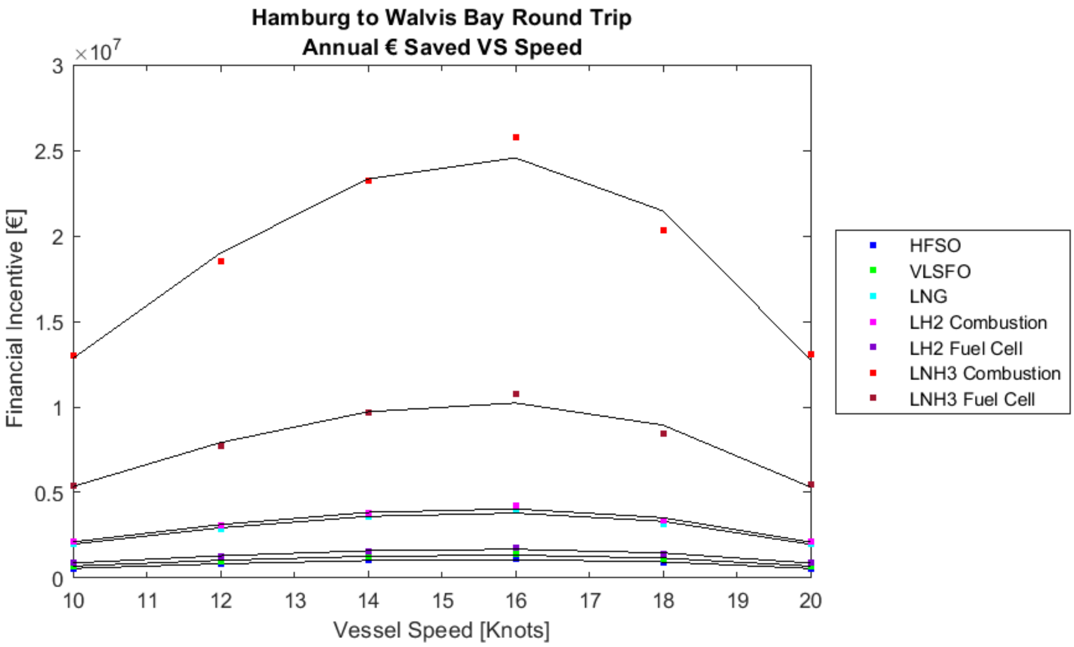


Figure 57: Shown is the euros saved vs vessel speed, at the design speed of 16 knots the following amount is saved; €1076950 for HFSO shown in blue; €1340130 for VLSFO shown in green, €3795630 for LNG shown in cyan, €4239460 for LH_2 combusted shown in magenta, €1766440 for LH_2 utilizing fuel cells shown in purple, €25759700 for LNH_3 combusted shown in bright red, and €10733200 for LNH_3 utilizing fuel cells shown in dark red

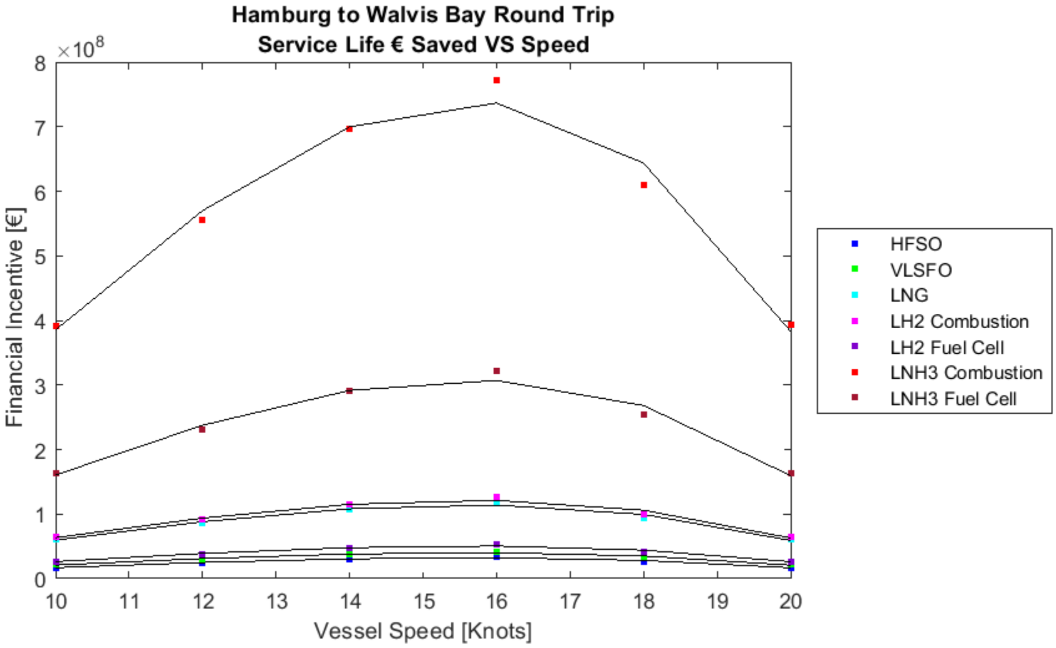


Figure 58: Shown is the euros saved vs vessel speed, at the design speed of 16 knots the following amount is saved; €23208600 for HFSO shown in blue; €40203900 for VLSFO shown in green, €121245000 for LNG shown in cyan, €127184000 for LH_2 combusted shown in magenta, €52993300 for LH_2 utilizing fuel cells shown in purple, €772790000 for LNH_3 combusted shown in bright red, and €321996000 for LNH_3 utilizing fuel cells shown in dark red

8.7.2 CAPEX

The capital expenditure (CAPEX) consists of all initial costs. It is difficult to obtain exact figures for the development, construction, installation and training costs. Literature has been consulted as an example and this serves the basis for where CAPEX costs come from [25].

$$\sum_{CAPEX} = (n_{sails})R\&D + (n_{sails})(Construction) + (n_{sails})(Installation) + Training \ [15]$$

Where,

$$R\&D = (30\%)(Construction)$$

$$Construction = (Projected\ Area)\left(\frac{€3500}{m^2}\right)$$

$$Installation = (20\%)(Construction)$$

$$Training = (20\%)(R\&D)$$

$$n_{sails} = 3$$

8.7.3 OPEX and Fuel Expenditure Savings

The sum of the operating expenditure and fuel expenditure savings determine the annuity. For simplicity the operating costs are assumed to be 10% of construction and installation costs annually. The fuel expenditure savings have been previously calculated but nonetheless the equation is shown below.

$$\sum_{OPEX} = (10\%)\big((n_{sails})(Construction) + (n_{sails})(Installation)\big) \ [15]$$

$$\sum_{Fuel\ expenditure\ savings} = (n_{trips\ annually})(€_{saved\ per\ trip}) \ [15]$$

8.7.4 Salvage Value

The final component required for an NPV calculation is the salvage value which is the amount received for the sail array when the vessel is scrapped. For simplicity sake this is assumed to be 30% of the construction costs.

$$\sum_{Salvage} = (30\%)((n_{sails})(Construction)) \ [15]$$

8.7.5 NPV Calculation

With the CAPEX, OPEX, fuel expenditure savings, and salvage value the only thing missing is the service life of the vessel over which to calculate annuities. For consistency the service life of the vessel is assumed to be 30 years. An NPV calculation is completed for the round trip at different vessel speeds for all of the selected fuels

$$NPV = -Inital\ Cost + S_{years}(Annuites) + Salvage\ Value\ [15]$$

In this case,

$$NPV = -\sum_{CAPEX} + S_{years}\left(\sum_{Fuel\ expenditure\ savings} - \sum_{OPEX}\right) + \sum_{Salvage}$$

8.7.5.1 Hamburg to Walvis Bay Round Trip

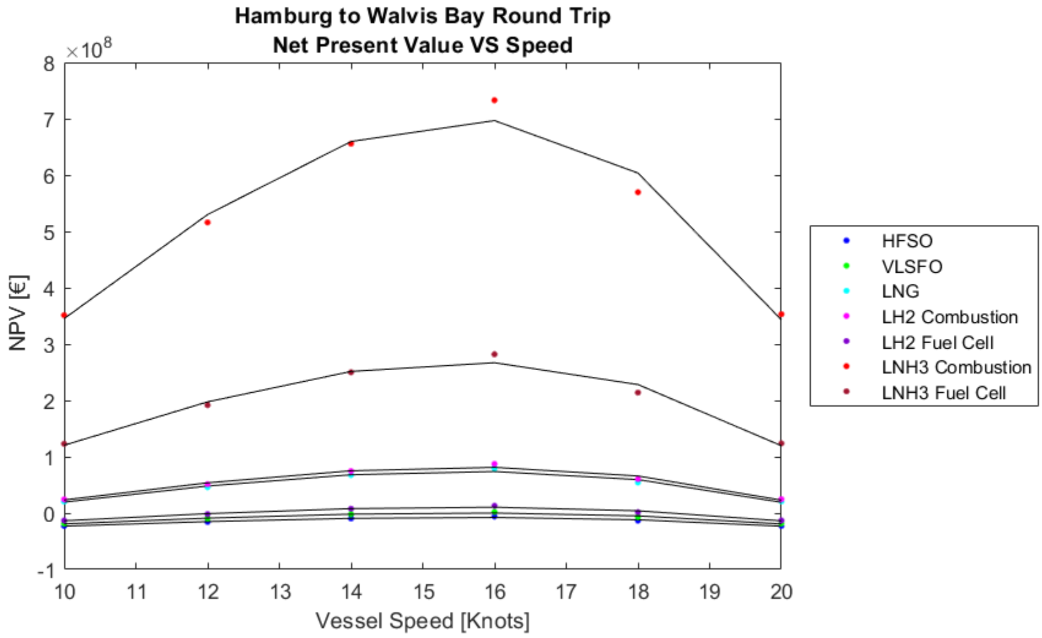


Figure 59: Shown is the NPV vs vessel speed, at the design speed of 16 knots the following NPV are; –€7,698,900 for HFSO shown in blue; €196,340 for VLSFO shown in green, €79,439,200 for LNG shown in cyan, €87,176,300 for LH_2 combusted shown in magenta, €12,985,800 for LH_2 utilizing fuel cells shown in purple, €732,783,000 for LNH_3 combusted shown in bright red, and €281,988,000 for LNH_3 utilizing fuel cells shown in dark red

8.7.6 SPP Calculation

The Simple Payback Period (SPP) divides the initial costs, or in this case the CAPEX by annuities or in this case the sum of annual fuel expenditure savings and operational expenses. This allows for the determination of how long the investment will take to be paid back and if it is a wise decision, complex factors such as inflation or changing fuel prices are not accounted for.

$$SPP = \frac{Inital\ Cost}{Annuity}\ [15]$$

8.7.6.1 Hamburg to Walvis Bay Round Trip

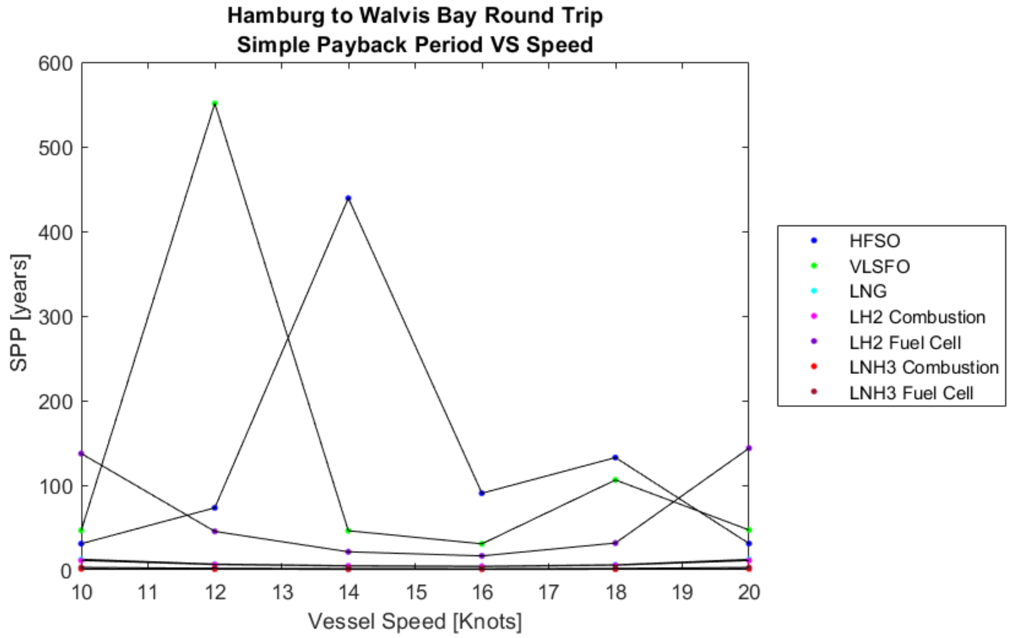


Figure 60: Shown is the SPP vs vessel speed, at the design speed of 16 knots the following SPP are; $90\ years$ *for HFSO shown in blue;* 30 years *for VLSFO shown in green,* 4.3 years *for LNG shown in cyan,* 4.0 years *for* LH_2 *combusted shown in magenta,* $16.5\ years$ *for* LH_2 *utilizing fuel cells shown in purple,* 0.5 years *for* LNH_3 *combusted shown in bright red, and* 1.3 years *for* LNH_3 *utilizing fuel cells shown in dark red*

9.0 Conclusions

In conclusion a literature review of WASP methods has been presented, along with an assessment procedure for wing sails and its thorough application in a case study. The assessment procedure involved selection of a route, vessel and sail array parameters. Next a performance analysis is conducted using a combination of XFOIL (see 11.2 Appendix: XFOIL Data) to obtain C_l and C_d, along with MARIN's Blue Route application for sourcing wind data (see 11.3 Appendix: Wind Data Hamburg to Walvis Bay and 11.4 Appendix: Wind Data Walvis Bay to Hamburg), finally MATLAB is utilized (see Appendix: MATLAB Code) to complete a number of calculations and generate plots.

The MATLAB calculations focus on power, energy, fuel mass required, fuel mass saved, fuel volume required, NPV, and SPP. It is important to consider both mass and volume when evaluating differing fuels. For instance, when comparing LNG and VLFSO one might be tempted to chose LNG on the fact alone that it requires only 654 tonnes of fuel while VLFSO requires 2000 tonnes of fuel on the round trip at 16knots. However, things become less clear when comparing LNG with a required volume of 2567 m^3 to VLFSO with a required volume of 2247 m^3.

Another possible question is weather 16 knots is a good design speed to maximize the sail array. In terms of fuel mass saved and CO_2 emissions saved 14 knots appears to be a clear winner. For HFSO, VLFSO and LNG this translates to CO_2 savings of 438, 433, and 278 tonnes respectively at 16 knots while total CO_2 savings are 475, 464, and 300 tonnes respectively.

Things get a little more interesting when comparing average power though, during the round trip traveling at 16 knots illicit an average power from the sail array of 1275 kW while at 14 knots this drops to 1200 Kw. However, looking at power as a percentage of power the lower speeds actually come out on top again. At 10 knots 19% of propulsion power is generated by the sails on the round trip while it dips to 8% of the power at 16 knots and down to a measly 2% at 20 knots. This can be explained by multiple factors, first and foremost is that required propulsive power increases exponentially with displacement ships and although the sail power also increases in absolute terms it does not increases proportionally with the required propulsive power (see section 8.4.8.3 Hamburg to Walvis Bay Round Trip). Another factor is that as the ship speed increases so does the AWS and as this occurs a higher percentage of the wind speed violates the upper limit leading to a 0 thrust coefficient and reduction in power produced by the sails.

Between the conflicting pros and cons of 14 vs 16 knots it is useful to look towards the NPV and SPP to determine objectively which operational speed is better. Both the NPV and SPP paint a clear picture that financially 16 knots is a better investment speed to operate at as this clearly shows the highest NPV point and the lowest SPP. For context the NPV and SPP values are listed alongside respective fuels at 16 knots. [Fuel;NPV;SPP],[HFSO; €7,698,900;90yr], [VLSFO; €196,340;30yr],[LNG; €79,439,200;4.3yr], [LH_2; €87,176,300;4.0yr],[LH_2FC;€12,985,800;16.5yr], [LNH_3; €732,783,000;0.5yr],[LNH_3FC; €281,988,000;1,3yr],

Perhaps ironically the fuels with the highest NPV and lowest SPP are the most expensive, so although theoretically scoring the best. Using these fuels for propulsion would be an expensive endeavor as the savings would only be around 8% while payment is still required for the other 92% of fuel that would have been purchased anyways. Even though HFSO scored the worst it would still be the cheapest. Perhaps it would be more useful to approach these conundrums with a clear goal of either wanting to be low on emissions or wanting to spend the least amount of money. Otherwise, LNG appears to strike a solid balance between having low SPP of 4.3 years which is well within the vessels service life while offering a NPV of €79,439,200

In conclusion the assessment procedure is successful, the percent savings mirror that of the literature very closely from 19% at 10 knots to 2% at 20 knots and 8% at 16 knots. These figures appear well within the range of possibility, during the literature review wing sails showed the an average fuel oil consumption savings of 10%. More specifically up to 22% savings were observed at low speeds. On a more comparable journey from Cape Lopez, Gabon to Point Tucker Canada fuel oil consumption was reduced to 8.8%.

10.0 Recommendations and Limitations

The following points are some recommendations and limitations:

- In the future It is recommended to run an initial XFOIL analysis to identify a smaller range of angles over which to run simulations for optimal AoA. XFOIL output over 3000 entries of data as each speed involved 60 simulations.
- Utilize CFD to validate the results, if resources allow wind tunnel testing could also be useful to gauge sail performance.
- Further work should be completed to understand to structural and stability implications of installing an array of wing sails.
- The MATLAB program ended up being over 2000 lines of code, given it does output 36 figures. However, there is definitely room for further optimization by reworking loops.
- Future work could involve creating a program to automatically correct course with the rudder depending on the side force generated from sails.
- Future work could involve evaluating the effect of sails on propeller efficiency when loaded.
- The costing data should also be improved in future iterations as obtaining this data on short notice proved to be difficult.

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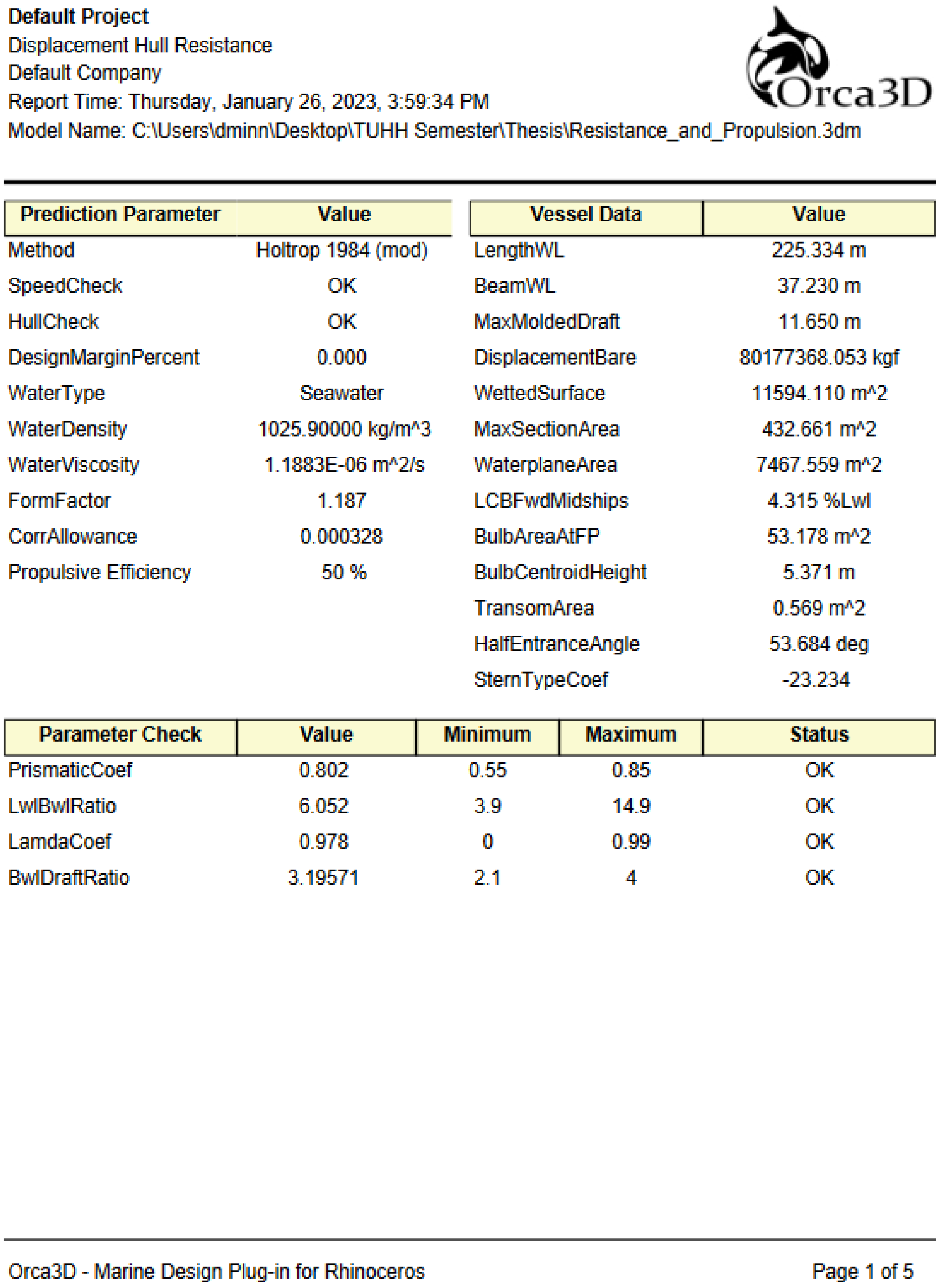
12.0 Appendices

12.1 Appendix: Resistance and Propulsion Analysis



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Displacement Hull Resistance
Default Company
Report Time: Thursday, January 26, 2023, 3:59:34 PM
Model Name: C:\Users\dminn\Desktop\TUHH Semester\Thesis\Resistance_and_Propulsion.3dm

Prediction Parameter	Value
Method	Holtrop 1984 (mod)
SpeedCheck	OK
HullCheck	OK
DesignMarginPercent	0.000
WaterType	Seawater
WaterDensity	1025.90000 kg/m^3
WaterViscosity	1.1883E-06 m^2/s
FormFactor	1.187
CorrAllowance	0.000328
Propulsive Efficiency	50 %

Vessel Data	Value
LengthWL	225.334 m
BeamWL	37.230 m
MaxMoldedDraft	11.650 m
DisplacementBare	80177368.053 kgf
WettedSurface	11594.110 m^2
MaxSectionArea	432.661 m^2
WaterplaneArea	7467.559 m^2
LCBFwdMidships	4.315 %Lwl
BulbAreaAtFP	53.178 m^2
BulbCentroidHeight	5.371 m
TransomArea	0.569 m^2
HalfEntranceAngle	53.684 deg
SternTypeCoef	-23.234

Parameter Check	Value	Minimum	Maximum	Status
PrismaticCoef	0.802	0.55	0.85	OK
LwlBwlRatio	6.052	3.9	14.9	OK
LamdaCoef	0.978	0	0.99	OK
BwlDraftRatio	3.19571	2.1	4	OK

Orca3D - Marine Design Plug-in for Rhinoceros

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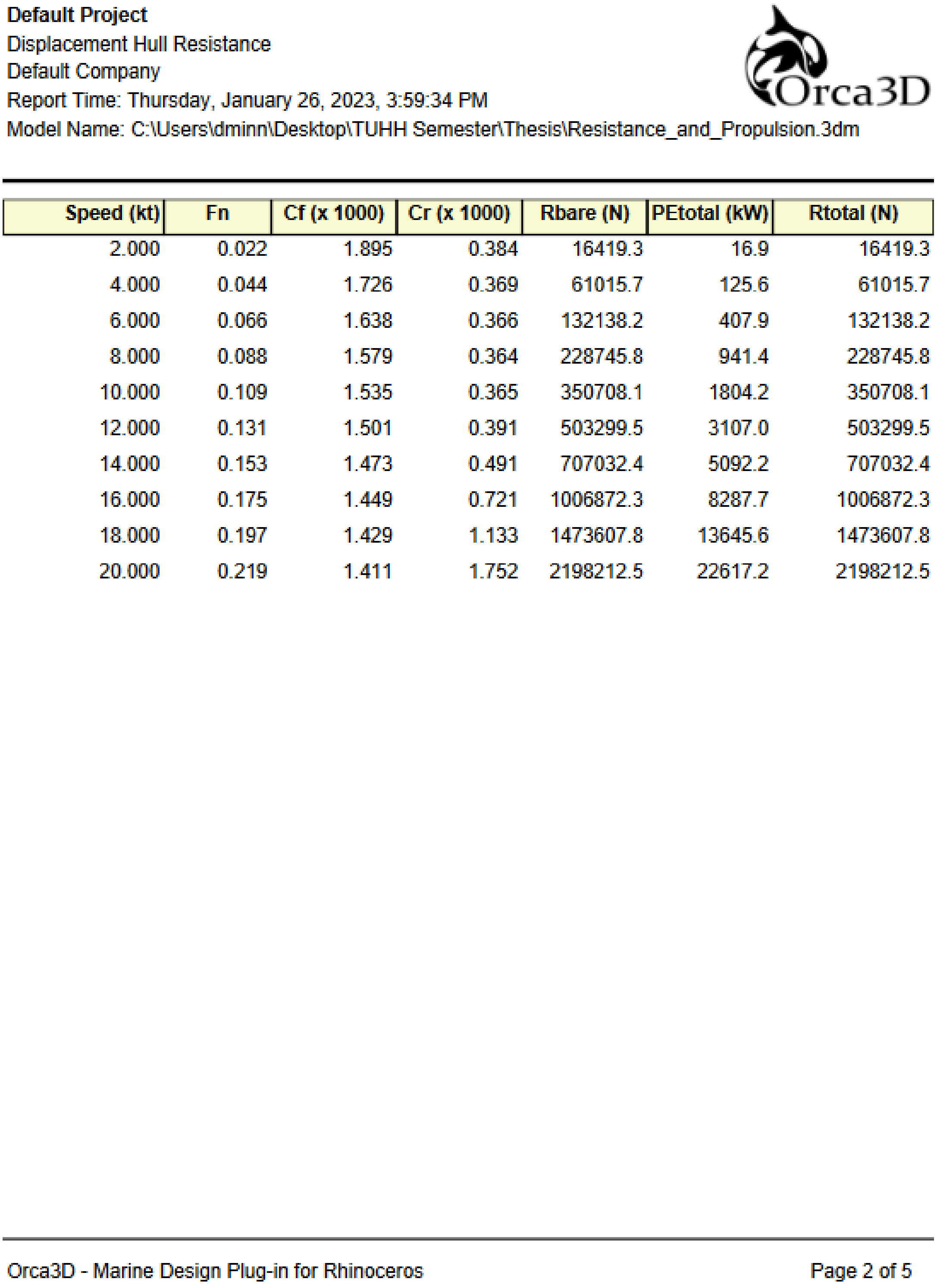

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Report Time: Thursday, January 26, 2023, 3:59:34 PM
Model Name: C:\Users\dminn\Desktop\TUHH Semester\Thesis\Resistance_and_Propulsion.3dm

Speed (kt)	Fn	Cf (x 1000)	Cr (x 1000)	Rbare (N)	PEtotal (kW)	Rtotal (N)
2.000	0.022	1.895	0.384	16419.3	16.9	16419.3
4.000	0.044	1.726	0.369	61015.7	125.6	61015.7
6.000	0.066	1.638	0.366	132138.2	407.9	132138.2
8.000	0.088	1.579	0.364	228745.8	941.4	228745.8
10.000	0.109	1.535	0.365	350708.1	1804.2	350708.1
12.000	0.131	1.501	0.391	503299.5	3107.0	503299.5
14.000	0.153	1.473	0.491	707032.4	5092.2	707032.4
16.000	0.175	1.449	0.721	1006872.3	8287.7	1006872.3
18.000	0.197	1.429	1.133	1473607.8	13645.6	1473607.8
20.000	0.219	1.411	1.752	2198212.5	22617.2	2198212.5

Orca3D - Marine Design Plug-in for Rhinoceros

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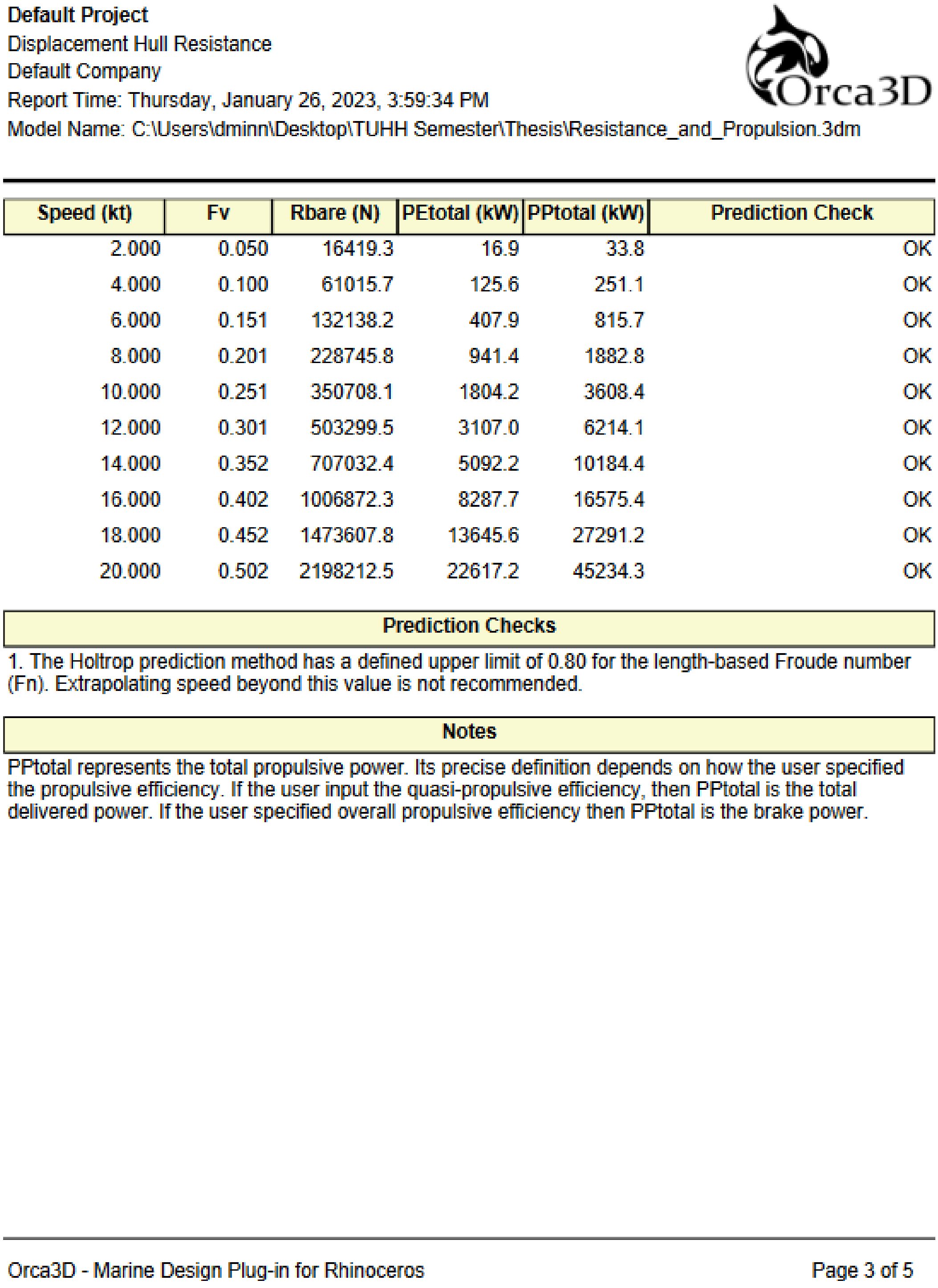

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Default Company
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Model Name: C:\Users\dminn\Desktop\TUHH Semester\Thesis\Resistance_and_Propulsion.3dm

Speed (kt)	Fv	Rbare (N)	PEtotal (kW)	PPtotal (kW)	Prediction Check
2.000	0.050	16419.3	16.9	33.8	OK
4.000	0.100	61015.7	125.6	251.1	OK
6.000	0.151	132138.2	407.9	815.7	OK
8.000	0.201	228745.8	941.4	1882.8	OK
10.000	0.251	350708.1	1804.2	3608.4	OK
12.000	0.301	503299.5	3107.0	6214.1	OK
14.000	0.352	707032.4	5092.2	10184.4	OK
16.000	0.402	1006872.3	8287.7	16575.4	OK
18.000	0.452	1473607.8	13645.6	27291.2	OK
20.000	0.502	2198212.5	22617.2	45234.3	OK

Prediction Checks

1. The Holtrop prediction method has a defined upper limit of 0.80 for the length-based Froude number (Fn). Extrapolating speed beyond this value is not recommended.

Notes

PPtotal represents the total propulsive power. Its precise definition depends on how the user specified the propulsive efficiency. If the user input the quasi-propulsive efficiency, then PPtotal is the total delivered power. If the user specified overall propulsive efficiency then PPtotal is the brake power.

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Default Project
Displacement Hull Resistance
Default Company
Report Time: Thursday, January 26, 2023, 3:59:34 PM
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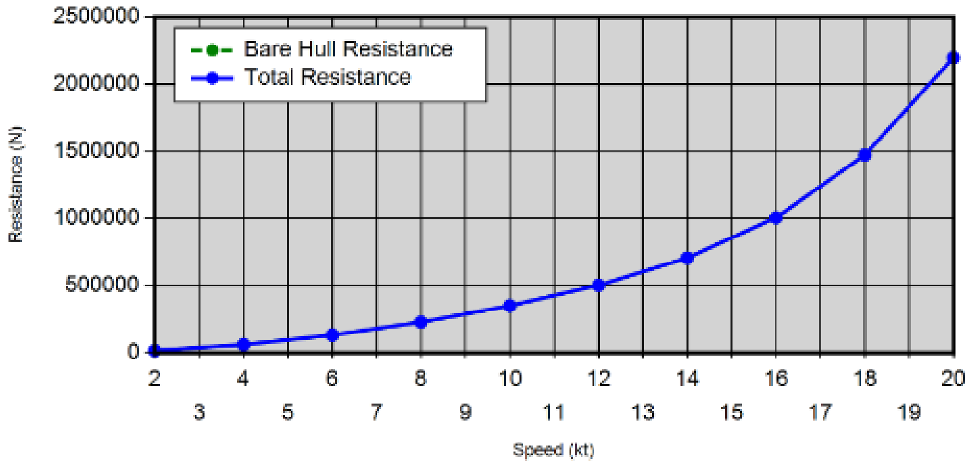
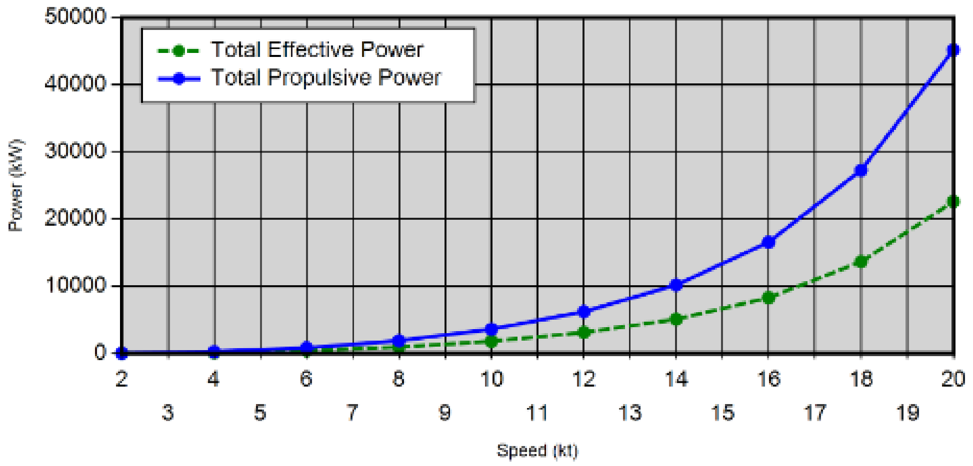
Orca3D Holtrop Analysis (Resistance)



Orca3D Holtrop Analysis (Power)



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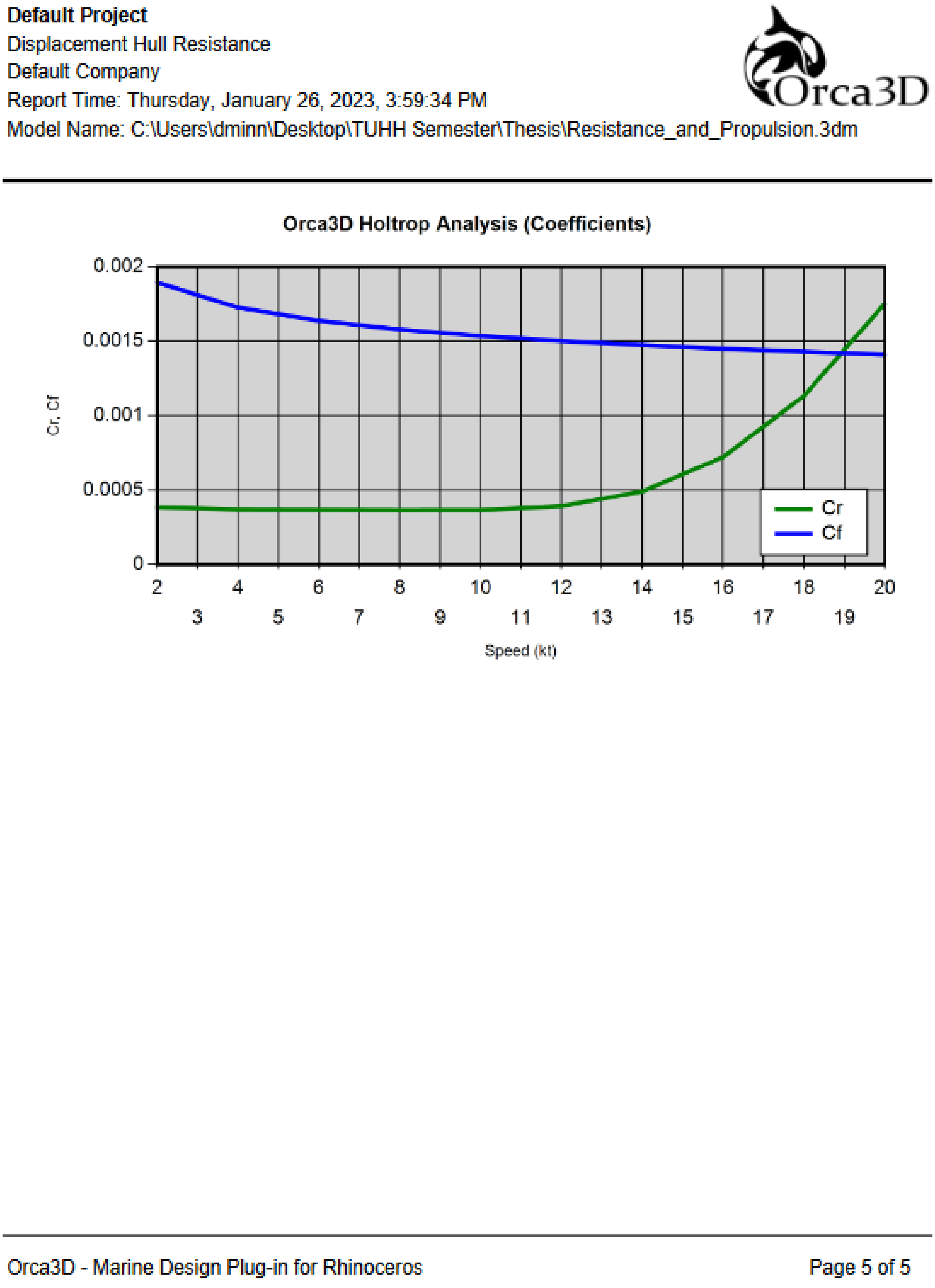

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Orca3D Holtrop Analysis (Coefficients)

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12.2 Appendix: XFOIL Data

Speed_Kn	m	Re	alpha	CL	CD	CDp	CM	Top_Xtr	Bot_Xtr	Cl_over_cD
1	0.5	695461.159	0	0	0.00154	-0.00339	0	0.642	0.6422	0
1	0.5	695461.159	-1	-0.1057	0.00156	-0.00337	-0.0016	0.7182	0.565	67.75641026
1	0.5	695461.159	-2	-0.2113	0.0016	-0.00333	-0.0032	0.7914	0.4887	132.0625
1	0.5	695461.159	-3	-0.3159	0.00169	-0.00327	-0.005	0.8555	0.4123	186.9230769
1	0.5	695461.159	-4	-0.4187	0.00184	-0.00324	-0.0071	0.9084	0.3364	227.5543478
1	0.5	695461.159	-5	-0.5199	0.00207	-0.00322	-0.0094	0.9492	0.2627	251.1594203
1	0.5	695461.159	-6	-0.6352	0.00242	-0.00315	-0.0081	0.9731	0.1915	262.4793388
1	0.5	695461.159	-7	-0.7674	0.00294	-0.0029	-0.0025	0.9849	0.1313	261.0204082
1	0.5	695461.159	-8	-0.898	0.00362	-0.00241	0.003	0.9948	0.0916	248.0662983
1	0.5	695461.159	-9	-1.0005	0.00453	-0.00159	0.0032	1	0.0695	220.8609272
1	0.5	695461.159	-10	-1.0519	0.00554	-0.00054	-0.0072	1	0.0585	189.8736462
1	0.5	695461.159	-11	-1.0991	0.00685	0.00083	-0.0177	1	0.0503	160.4525547
1	0.5	695461.159	-12	-1.1402	0.00849	0.00259	-0.0272	1	0.0442	134.2991755
1	0.5	695461.159	-13	-1.1768	0.01108	0.00539	-0.0343	1	0.0397	106.2093863

1	0.5	695461.159	-14	-1.1949	0.01609	0.01069	-0.0395	1	0.0362	74.26351771
1	0.5	695461.159	-15	-1.1843	0.02639	0.02128	-0.0417	1	0.0337	44.87684729
1	0.5	695461.159	-16	-1.1688	0.04049	0.03579	-0.041	1	0.0319	28.86638676
1	0.5	695461.159	-17	-1.1259	0.06015	0.05582	-0.0379	1	0.0306	18.71820449
1	0.5	695461.159	-18	-1.0704	0.08166	0.07764	-0.0328	1	0.0293	13.10800882
1	0.5	695461.159	-19	-1.0214	0.10112	0.09751	-0.0262	1	0.0283	10.10087025
1	0.5	695461.159	-20	-0.5797	0.17241	0.17035	0.0105	1	0.0252	3.362333971
1	0.5	695461.159	-21	-0.6451	0.17027	0.16819	0.0115	1	0.0253	3.788688553
1	0.5	695461.159	-22	-0.726	0.16586	0.1637	0.0106	1	0.0248	4.377185578
1	0.5	695461.159	-25	-0.5709	0.24496	0.24308	0.0426	1	0.0173	2.330584585
1	0.5	695461.159	-28	-0.608	0.27886	0.27708	0.059	1	0.0129	2.18030553
1	0.5	695461.159	-29	-0.6219	0.2883	0.28655	0.0644	1	0.0115	2.157127992
1	0.5	695461.159	-30	-0.6305	0.30153	0.29982	0.0701	1	0.0103	2.091002554
1	0.5	695461.159	1	0.1057	0.00155	-0.00338	0.0016	0.565	0.7181	68.19354839
1	0.5	695461.159	2	0.2113	0.00159	-0.00335	0.0031	0.4883	0.7912	132.8930818
1	0.5	695461.159	3	0.3159	0.00166	-0.0033	0.005	0.4121	0.8556	190.3012048

1	0.5	695461.159	4	0.4187	0.0018	-0.00328	0.0071	0.3364	0.9083	232.6111111
1	0.5	695461.159	5	0.5198	0.00201	-0.00327	0.0094	0.2626	0.949	258.6069652
1	0.5	695461.159	6	0.635	0.00235	-0.00322	0.0081	0.1915	0.9731	270.212766
1	0.5	695461.159	7	0.7672	0.00285	-0.00299	0.0025	0.1314	0.9849	269.1929825
1	0.5	695461.159	8	0.8978	0.00351	-0.00251	-0.003	0.0916	0.9949	255.7834758
1	0.5	695461.159	9	0.9999	0.00441	-0.0017	-0.0031	0.0694	1	226.7346939
1	0.5	695461.159	10	1.0512	0.0054	-0.00067	0.0073	0.0585	1	194.6666667
1	0.5	695461.159	11	1.0987	0.00671	0.00068	0.0177	0.0503	1	163.7406855
1	0.5	695461.159	12	1.1399	0.00834	0.00244	0.0272	0.0442	1	136.6786571
1	0.5	695461.159	13	1.1765	0.01092	0.00524	0.0342	0.0397	1	107.7380952
1	0.5	695461.159	14	1.1953	0.01592	0.01053	0.0393	0.0362	1	75.08165829
1	0.5	695461.159	15	1.1845	0.02626	0.02115	0.0415	0.0337	1	45.10662605
1	0.5	695461.159	16	1.1693	0.04034	0.03564	0.0408	0.032	1	28.986118
1	0.5	695461.159	17	1.1262	0.06003	0.0557	0.0377	0.0305	1	18.76061969
1	0.5	695461.159	18	1.07	0.08154	0.07753	0.0327	0.0293	1	13.12239392
1	0.5	695461.159	19	1.0208	0.10097	0.09736	0.0261	0.0283	1	10.10993364

Cont… If you would like the file feel free to email me: dminnett@mun.ca

12.3 Appendix: Wind Data Hamburg to Walvis Bay

β↓ / v→	0	1	2	3	4	5	6	7	8
0	0.000276	0.000691	0.001478	0.002822	0.004892	0.006971	0.007369	0.00551	0.003003
5	0.000287	0.000732	0.001622	0.003227	0.005749	0.008249	0.008683	0.006492	0.003625
10	0.000298	0.000772	0.001741	0.003516	0.00628	0.00889	0.009231	0.006989	0.004193
15	0.000306	0.000805	0.001819	0.003648	0.006393	0.008802	0.008984	0.006965	0.004581
20	0.000312	0.000822	0.001845	0.003613	0.006091	0.008069	0.008066	0.00637	0.004457
25	0.000316	0.000828	0.001821	0.003424	0.005477	0.006921	0.006721	0.005288	0.003729
30	0.000319	0.000826	0.001758	0.003122	0.004682	0.005609	0.005254	0.004034	0.002748
35	0.000321	0.000819	0.00167	0.002766	0.00386	0.004373	0.003944	0.002923	0.001886
40	0.000323	0.00081	0.001583	0.002448	0.003178	0.003406	0.00295	0.002093	0.001278
45	0.000324	0.000802	0.001514	0.002212	0.002692	0.002734	0.002272	0.001547	0.000916
50	0.000324	0.000796	0.001459	0.002029	0.002332	0.002253	0.001804	0.001204	0.000721
55	0.000329	0.000793	0.001407	0.001873	0.002048	0.001887	0.001465	0.00098	0.000612
60	0.000334	0.000791	0.001365	0.001749	0.001826	0.00161	0.001224	0.00083	0.000541
65	0.000336	0.000789	0.001338	0.001659	0.001658	0.001406	0.001053	0.000726	0.000491
70	0.000336	0.000785	0.001314	0.001591	0.001538	0.001264	0.000933	0.000655	0.000459
75	0.000334	0.000775	0.001287	0.001537	0.001456	0.001172	0.000857	0.000609	0.000436
80	0.000334	0.000771	0.001272	0.001506	0.001406	0.001116	0.000814	0.000579	0.000415
85	0.000336	0.000769	0.001266	0.001492	0.001381	0.001086	0.000787	0.000559	0.000398
90	0.000335	0.000765	0.001257	0.001479	0.001365	0.001067	0.000767	0.000541	0.000384
95	0.000332	0.000759	0.001247	0.001468	0.001354	0.001053	0.000748	0.000521	0.000372
100	0.000331	0.000755	0.001238	0.001463	0.001355	0.001047	0.000734	0.000506	0.000361
105	0.000328	0.000749	0.001233	0.001468	0.001365	0.001049	0.00073	0.000502	0.000353

110	0.000322	0.000739	0.001229	0.00148	0.001382	0.001061	0.000736	0.000504	0.000352
115	0.000319	0.000727	0.001218	0.001484	0.001403	0.001088	0.000758	0.000516	0.000358
120	0.000318	0.000716	0.001203	0.001484	0.001429	0.001129	0.000796	0.000542	0.000374
125	0.000316	0.000711	0.001198	0.001494	0.001468	0.001187	0.000849	0.000579	0.000395
130	0.000313	0.00071	0.001206	0.001518	0.001523	0.001265	0.000921	0.000629	0.000422
135	0.00031	0.000707	0.001213	0.00155	0.001592	0.00136	0.001014	0.000701	0.000465
140	0.000304	0.000696	0.001211	0.001584	0.00167	0.001472	0.001137	0.000806	0.000536
145	0.000298	0.000685	0.001209	0.001613	0.001748	0.001606	0.001299	0.00095	0.000643
150	0.000293	0.000674	0.001203	0.001632	0.001822	0.001755	0.001492	0.001135	0.000789
155	0.000289	0.00066	0.001184	0.001638	0.001891	0.001914	0.00172	0.001369	0.000983
160	0.000284	0.000644	0.001159	0.001636	0.001959	0.00209	0.002008	0.001701	0.001277
165	0.000278	0.000628	0.001132	0.001624	0.002017	0.002279	0.002359	0.002161	0.001723
170	0.000272	0.000611	0.001103	0.001605	0.002058	0.002449	0.002717	0.002683	0.002287
175	0.000265	0.000593	0.00107	0.001571	0.002067	0.00257	0.00301	0.003159	0.002863
180	0.000256	0.000569	0.001022	0.001513	0.002037	0.002619	0.003194	0.003504	0.003309
185	0.00025	0.000544	0.000963	0.001432	0.001964	0.002584	0.003238	0.003658	0.003538
190	0.000245	0.000519	0.000902	0.001331	0.001844	0.002462	0.00313	0.003607	0.003566
195	0.000239	0.000492	0.000839	0.001222	0.00169	0.002272	0.002904	0.003374	0.003392
200	0.00023	0.000467	0.000778	0.00111	0.001519	0.002034	0.002593	0.003001	0.003023
205	0.000221	0.000444	0.000718	0.000995	0.001339	0.001771	0.00223	0.002549	0.002539
210	0.000213	0.000417	0.000658	0.000888	0.001168	0.001514	0.001867	0.002089	0.002045
215	0.000207	0.000392	0.000605	0.000799	0.001021	0.001284	0.001539	0.001673	0.001603
220	0.000203	0.000373	0.000561	0.000722	0.000895	0.001092	0.001266	0.00133	0.001236

225	0.000197	0.000355	0.000524	0.000653	0.000784	0.000934	0.001051	0.001065	0.00095
230	0.000189	0.000337	0.000491	0.000596	0.000695	0.000807	0.000883	0.000867	0.000744
235	0.000185	0.000323	0.000462	0.000553	0.000628	0.000706	0.00075	0.000719	0.000596
240	0.000181	0.000311	0.000437	0.000514	0.000575	0.000627	0.000648	0.000605	0.000487
245	0.000176	0.000301	0.000414	0.000477	0.000524	0.000563	0.00057	0.000515	0.000403
250	0.000175	0.000294	0.000397	0.000446	0.000479	0.000504	0.000497	0.000439	0.000338
255	0.000173	0.000288	0.000384	0.000426	0.000447	0.000453	0.000432	0.000373	0.000284
260	0.000169	0.000282	0.000374	0.000412	0.000424	0.000417	0.000383	0.00032	0.000238
265	0.000169	0.000278	0.000366	0.000397	0.000403	0.000389	0.000347	0.000282	0.000207
270	0.000171	0.000278	0.00036	0.000385	0.000386	0.000367	0.000323	0.000258	0.00019
275	0.000171	0.000276	0.000357	0.00038	0.000376	0.000354	0.000308	0.000245	0.000182
280	0.000168	0.000275	0.000358	0.00038	0.000372	0.000346	0.000298	0.000238	0.00018
285	0.000167	0.000276	0.00036	0.000381	0.000371	0.000341	0.000293	0.000236	0.00018
290	0.000168	0.000279	0.000364	0.000385	0.000372	0.00034	0.000293	0.000239	0.000184
295	0.000169	0.000282	0.000369	0.00039	0.000377	0.000343	0.000298	0.000247	0.000194
300	0.000171	0.000289	0.000378	0.000399	0.000385	0.000352	0.000307	0.000258	0.000206
305	0.000175	0.000299	0.000393	0.000414	0.000398	0.000363	0.000319	0.000271	0.000219
310	0.000181	0.000312	0.000416	0.000441	0.000421	0.000378	0.000329	0.000283	0.000235
315	0.000189	0.000332	0.000451	0.000482	0.000455	0.000402	0.000346	0.000298	0.000255
320	0.000197	0.000354	0.000496	0.000539	0.000508	0.000445	0.000377	0.000321	0.000279
325	0.000204	0.000381	0.000556	0.000625	0.000599	0.00052	0.00043	0.000357	0.000305
330	0.000211	0.000413	0.000632	0.000749	0.000753	0.000664	0.000534	0.000419	0.000341
335	0.00022	0.000448	0.000723	0.000922	0.001008	0.00095	0.000766	0.000559	0.000412

340	0.000231	0.00049	0.000836	0.001164	0.001421	0.001479	0.001262	0.000894	0.00058
345	0.000246	0.000538	0.000972	0.001489	0.002038	0.002371	0.002198	0.001581	0.000936
350	0.000258	0.000588	0.001132	0.001895	0.002874	0.003688	0.003674	0.002712	0.001532
355	0.000265	0.000642	0.00131	0.002358	0.003873	0.005324	0.005541	0.004145	0.002283

9	10	11	12	13	14	15	16	17	18
0.001374	0.000674	0.00041	0.000284	0.000202	0.000142	9.53E-05	5.75E-05	3.22E-05	1.83E-05
0.001767	0.000914	0.000542	0.000349	0.000232	0.000154	9.81E-05	5.77E-05	3.26E-05	1.84E-05
0.002341	0.001358	0.000811	0.000482	0.000286	0.000172	0.000101	5.63E-05	3.16E-05	1.81E-05
0.00291	0.001826	0.001082	0.000601	0.000325	0.000179	0.0001	5.53E-05	3.08E-05	1.77E-05
0.003	0.001895	0.00108	0.000568	0.000295	0.000162	9.40E-05	5.41E-05	3.00E-05	1.66E-05
0.002472	0.001492	0.000809	0.000418	0.000226	0.000134	8.47E-05	5.11E-05	2.79E-05	1.45E-05
0.001716	0.000972	0.000519	0.000288	0.000177	0.000117	7.77E-05	4.77E-05	2.60E-05	1.32E-05
0.001099	0.000605	0.000348	0.000225	0.000157	0.00011	7.42E-05	4.50E-05	2.49E-05	1.29E-05
0.000721	0.000419	0.000277	0.000202	0.000148	0.000105	7.04E-05	4.23E-05	2.32E-05	1.20E-05
0.000532	0.000344	0.000252	0.00019	0.00014	9.83E-05	6.50E-05	3.91E-05	2.13E-05	1.09E-05
0.000447	0.000313	0.000237	0.000178	0.000131	9.16E-05	5.99E-05	3.61E-05	1.99E-05	1.01E-05
0.000403	0.000293	0.000222	0.000166	0.000121	8.51E-05	5.58E-05	3.34E-05	1.85E-05	9.19E-06
0.000372	0.000276	0.000209	0.000154	0.000112	7.90E-05	5.20E-05	3.11E-05	1.69E-05	8.27E-06
0.000347	0.00026	0.000198	0.000146	0.000106	7.36E-05	4.73E-05	2.81E-05	1.56E-05	8.01E-06
0.000331	0.000248	0.000188	0.000139	0.0001	6.79E-05	4.26E-05	2.53E-05	1.44E-05	7.84E-06
0.000318	0.000238	0.000179	0.000132	9.35E-05	6.15E-05	3.85E-05	2.32E-05	1.32E-05	7.11E-06
0.000304	0.000227	0.00017	0.000123	8.56E-05	5.61E-05	3.55E-05	2.17E-05	1.24E-05	6.57E-06
0.000289	0.000217	0.000161	0.000114	7.92E-05	5.34E-05	3.42E-05	2.07E-05	1.19E-05	6.30E-06

0.000278	0.000207	0.000152	0.000107	7.53E-05	5.16E-05	3.28E-05	1.95E-05	1.09E-05	5.70E-06
0.000273	0.0002	0.000145	0.000102	7.17E-05	4.80E-05	3.00E-05	1.77E-05	9.75E-06	4.99E-06
0.000266	0.000195	0.00014	9.87E-05	6.84E-05	4.48E-05	2.74E-05	1.58E-05	8.51E-06	4.29E-06
0.000258	0.000191	0.000137	9.68E-05	6.64E-05	4.33E-05	2.61E-05	1.46E-05	7.72E-06	3.75E-06
0.000255	0.000189	0.000137	9.67E-05	6.54E-05	4.22E-05	2.53E-05	1.45E-05	7.71E-06	3.51E-06
0.000258	0.00019	0.000139	9.78E-05	6.50E-05	4.06E-05	2.42E-05	1.44E-05	7.69E-06	3.19E-06
0.000267	0.000194	0.00014	9.82E-05	6.39E-05	3.91E-05	2.30E-05	1.34E-05	6.85E-06	2.62E-06
0.000278	0.000198	0.000141	9.71E-05	6.20E-05	3.83E-05	2.26E-05	1.20E-05	5.57E-06	2.08E-06
0.000288	0.000201	0.00014	9.58E-05	6.18E-05	3.88E-05	2.23E-05	1.08E-05	4.68E-06	1.77E-06
0.000307	0.000209	0.000143	9.64E-05	6.31E-05	3.99E-05	2.21E-05	9.97E-06	4.15E-06	1.59E-06
0.000347	0.000228	0.000152	9.95E-05	6.43E-05	4.01E-05	2.17E-05	9.31E-06	3.52E-06	1.37E-06
0.000416	0.000266	0.00017	0.000109	6.75E-05	4.03E-05	2.12E-05	8.90E-06	2.98E-06	1.06E-06
0.000518	0.000333	0.000211	0.00013	7.57E-05	4.25E-05	2.16E-05	9.01E-06	2.98E-06	9.27E-07
0.000666	0.00044	0.000283	0.000169	9.25E-05	4.82E-05	2.33E-05	9.64E-06	3.52E-06	1.11E-06
0.000891	0.000599	0.000387	0.000231	0.000124	6.00E-05	2.68E-05	1.08E-05	4.08E-06	1.28E-06
0.001233	0.00082	0.000515	0.000303	0.000161	7.46E-05	3.11E-05	1.20E-05	4.44E-06	1.30E-06
0.001695	0.001112	0.000658	0.000361	0.000182	8.25E-05	3.35E-05	1.30E-05	4.95E-06	1.43E-06
0.002202	0.001423	0.000786	0.000392	0.000185	8.36E-05	3.50E-05	1.37E-05	5.21E-06	1.51E-06
0.002599	0.001649	0.000858	0.0004	0.000183	8.37E-05	3.61E-05	1.38E-05	4.68E-06	1.27E-06
0.002811	0.001768	0.00089	0.000398	0.000179	8.11E-05	3.46E-05	1.26E-05	3.79E-06	9.45E-07
0.002888	0.001838	0.000916	0.000393	0.000168	7.41E-05	3.08E-05	1.07E-05	2.88E-06	6.45E-07
0.002814	0.001836	0.000924	0.000383	0.000154	6.52E-05	2.64E-05	8.96E-06	2.14E-06	3.65E-07
0.002544	0.001707	0.000883	0.000363	0.000138	5.52E-05	2.13E-05	7.07E-06	1.70E-06	2.43E-07

0.002144	0.001476	0.000791	0.00033	0.000121	4.61E-05	1.69E-05	5.39E-06	1.37E-06	2.26E-07
0.001722	0.001207	0.000669	0.00029	0.000108	4.08E-05	1.50E-05	4.75E-06	1.23E-06	2.77E-07
0.001337	0.000941	0.000535	0.000245	9.72E-05	3.84E-05	1.50E-05	4.95E-06	1.32E-06	3.63E-07
0.001004	0.000699	0.000406	0.000197	8.59E-05	3.74E-05	1.58E-05	5.53E-06	1.62E-06	4.54E-07
0.00074	0.000503	0.000298	0.000156	7.62E-05	3.76E-05	1.77E-05	6.88E-06	2.30E-06	7.07E-07
0.000551	0.000362	0.000219	0.000124	6.59E-05	3.57E-05	1.90E-05	8.15E-06	2.87E-06	9.21E-07
0.000423	0.000269	0.000163	9.41E-05	5.10E-05	2.80E-05	1.57E-05	7.04E-06	2.40E-06	7.30E-07
0.000334	0.000206	0.000121	6.74E-05	3.48E-05	1.77E-05	9.37E-06	4.06E-06	1.30E-06	3.37E-07
0.000271	0.000162	9.06E-05	4.73E-05	2.30E-05	1.05E-05	4.77E-06	1.93E-06	5.91E-07	1.34E-07
0.000223	0.000131	7.07E-05	3.53E-05	1.66E-05	7.16E-06	3.04E-06	1.20E-06	4.24E-07	1.57E-07
0.000186	0.000108	5.78E-05	2.92E-05	1.40E-05	6.24E-06	2.69E-06	1.10E-06	4.89E-07	2.00E-07
0.000156	9.20E-05	5.03E-05	2.63E-05	1.31E-05	5.98E-06	2.60E-06	1.15E-06	4.95E-07	1.62E-07
0.000137	8.32E-05	4.73E-05	2.57E-05	1.30E-05	6.07E-06	2.75E-06	1.26E-06	4.46E-07	1.17E-07
0.00013	8.20E-05	4.86E-05	2.72E-05	1.41E-05	6.91E-06	3.36E-06	1.61E-06	6.23E-07	1.87E-07
0.000128	8.40E-05	5.15E-05	3.01E-05	1.62E-05	8.11E-06	4.10E-06	2.07E-06	9.73E-07	3.59E-07
0.000129	8.61E-05	5.37E-05	3.25E-05	1.85E-05	9.72E-06	4.91E-06	2.38E-06	1.11E-06	4.28E-07
0.000131	8.94E-05	5.70E-05	3.48E-05	2.08E-05	1.16E-05	5.84E-06	2.84E-06	1.25E-06	4.20E-07
0.000136	9.58E-05	6.30E-05	3.94E-05	2.41E-05	1.39E-05	7.38E-06	3.93E-06	1.86E-06	6.78E-07
0.000146	0.000105	7.19E-05	4.73E-05	3.01E-05	1.77E-05	9.64E-06	5.19E-06	2.66E-06	1.20E-06
0.000157	0.000117	8.40E-05	5.81E-05	3.79E-05	2.26E-05	1.25E-05	6.65E-06	3.46E-06	1.76E-06
0.000172	0.000133	9.91E-05	6.98E-05	4.61E-05	2.80E-05	1.62E-05	8.66E-06	4.35E-06	2.31E-06
0.00019	0.000152	0.000115	8.12E-05	5.39E-05	3.37E-05	2.03E-05	1.10E-05	5.42E-06	2.90E-06
0.000212	0.00017	0.00013	9.32E-05	6.25E-05	4.02E-05	2.49E-05	1.39E-05	6.95E-06	3.58E-06

0.000236	0.00019	0.000148	0.000108	7.32E-05	4.80E-05	3.03E-05	1.74E-05	8.81E-06	4.23E-06
0.000259	0.000212	0.000168	0.000124	8.64E-05	5.77E-05	3.66E-05	2.11E-05	1.05E-05	4.87E-06
0.000287	0.000237	0.000189	0.000143	0.000102	6.91E-05	4.41E-05	2.53E-05	1.25E-05	6.10E-06
0.000326	0.000267	0.000214	0.000165	0.00012	8.25E-05	5.25E-05	3.02E-05	1.57E-05	8.17E-06
0.000399	0.000304	0.000242	0.000189	0.000141	9.72E-05	6.16E-05	3.60E-05	1.95E-05	1.03E-05
0.000543	0.000363	0.000275	0.000215	0.000161	0.000112	7.22E-05	4.31E-05	2.35E-05	1.23E-05
0.000776	0.000446	0.000313	0.000239	0.000178	0.000124	8.24E-05	5.00E-05	2.74E-05	1.48E-05
0.001064	0.000544	0.000354	0.000259	0.000189	0.000134	9.02E-05	5.48E-05	3.03E-05	1.71E-05

19	20	21	22	23	24	25
9.85E-06	4.88E-06	2.05E-06	6.30E-07	2.35E-07	1.45E-07	0
1.00E-05	5.02E-06	2.11E-06	7.11E-07	2.64E-07	1.35E-07	0
1.01E-05	5.09E-06	2.14E-06	8.14E-07	2.79E-07	9.09E-08	0
9.77E-06	4.71E-06	1.96E-06	8.17E-07	2.75E-07	5.20E-08	0
8.66E-06	3.86E-06	1.55E-06	6.73E-07	2.58E-07	5.23E-08	0
7.20E-06	3.27E-06	1.31E-06	5.43E-07	2.56E-07	7.00E-08	0
6.33E-06	2.93E-06	1.24E-06	5.28E-07	2.62E-07	8.80E-08	0
5.94E-06	2.54E-06	1.13E-06	5.04E-07	1.98E-07	7.98E-08	0
5.46E-06	2.24E-06	1.00E-06	4.41E-07	1.29E-07	6.74E-08	0
5.00E-06	2.08E-06	8.79E-07	3.99E-07	1.22E-07	6.64E-08	0
4.61E-06	2.01E-06	8.99E-07	4.04E-07	1.07E-07	8.24E-08	0
4.12E-06	2.02E-06	1.05E-06	4.11E-07	8.80E-08	8.86E-08	0
3.92E-06	2.12E-06	1.04E-06	3.26E-07	8.54E-08	5.69E-08	0
4.10E-06	2.20E-06	9.44E-07	2.60E-07	9.16E-08	3.17E-08	0

4.11E-06	2.14E-06	8.98E-07	2.72E-07	1.11E-07	5.82E-08	0
3.68E-06	1.93E-06	8.43E-07	2.91E-07	1.57E-07	1.32E-07	0
3.15E-06	1.54E-06	6.89E-07	2.90E-07	1.87E-07	1.56E-07	0
2.85E-06	1.21E-06	5.06E-07	2.19E-07	1.21E-07	8.41E-08	0
2.64E-06	1.13E-06	4.67E-07	1.61E-07	6.18E-08	4.51E-08	0
2.32E-06	1.03E-06	4.77E-07	1.73E-07	6.25E-08	5.43E-08	0
1.88E-06	7.72E-07	3.99E-07	1.79E-07	4.71E-08	2.98E-08	0
1.53E-06	5.50E-07	2.67E-07	1.18E-07	1.73E-08	5.23E-09	0
1.40E-06	5.12E-07	1.88E-07	5.00E-08	2.62E-09	2.39E-08	0
1.23E-06	5.14E-07	1.87E-07	4.06E-08	1.24E-08	5.40E-08	0
9.27E-07	3.99E-07	1.71E-07	6.21E-08	3.57E-08	5.82E-08	0
6.73E-07	2.61E-07	1.35E-07	7.59E-08	4.38E-08	4.64E-08	0
5.45E-07	1.90E-07	1.07E-07	6.61E-08	2.81E-08	2.26E-08	0
4.95E-07	1.55E-07	8.21E-08	4.25E-08	9.16E-09	2.94E-09	0
4.66E-07	1.40E-07	7.36E-08	2.81E-08	1.31E-09	9.81E-10	0
4.14E-07	1.46E-07	8.21E-08	2.58E-08	5.89E-09	1.77E-08	0
3.09E-07	1.08E-07	6.67E-08	2.03E-08	1.18E-08	3.53E-08	0
2.43E-07	4.81E-08	3.66E-08	1.37E-08	7.20E-09	2.16E-08	0
2.18E-07	2.35E-08	1.60E-08	7.20E-09	9.81E-10	2.94E-09	0
2.06E-07	3.73E-08	1.37E-08	9.81E-10	0	0	0
2.22E-07	5.43E-08	2.35E-08	0	0	0	0
1.82E-07	2.98E-08	1.44E-08	0	0	0	0
1.28E-07	4.58E-09	1.96E-09	0	0	0	0

1.45E-07	1.21E-08	6.54E-10	3.27E-10	0	0	0
1.40E-07	2.94E-08	1.18E-08	5.89E-09	0	0	0
6.38E-08	2.62E-08	2.35E-08	1.18E-08	0	0	0
1.44E-08	9.16E-09	1.44E-08	7.20E-09	0	0	0
2.52E-08	1.31E-09	1.96E-09	9.81E-10	0	0	0
6.08E-08	5.89E-09	0	0	0	0	0
8.73E-08	1.18E-08	0	0	0	0	0
8.70E-08	7.20E-09	0	0	0	0	0
1.03E-07	9.81E-10	0	0	0	0	0
1.25E-07	0	0	0	0	0	0
9.42E-08	0	0	0	0	0	0
3.57E-08	0	0	0	0	0	0
2.29E-08	9.81E-10	3.27E-10	0	0	0	0
5.92E-08	1.77E-08	5.89E-09	0	0	0	0
7.56E-08	3.60E-08	1.21E-08	0	0	0	0
6.12E-08	3.34E-08	1.31E-08	0	0	0	0
4.84E-08	2.75E-08	1.31E-08	0	0	0	0
5.95E-08	3.24E-08	1.31E-08	0	0	0	0
1.04E-07	4.38E-08	1.31E-08	0	0	0	0
1.29E-07	4.71E-08	1.37E-08	6.54E-10	3.27E-10	0	0
1.51E-07	7.26E-08	2.52E-08	1.18E-08	5.89E-09	0	0
3.13E-07	1.53E-07	4.28E-08	2.35E-08	1.18E-08	0	0
5.60E-07	2.20E-07	4.58E-08	1.50E-08	7.52E-09	0	0

7.75E-07	2.46E-07	4.87E-08	1.44E-08	6.87E-09	0	0
1.05E-06	3.50E-07	1.02E-07	3.70E-08	1.18E-08	1.31E-09	0
1.46E-06	5.91E-07	2.21E-07	6.93E-08	7.52E-09	2.35E-08	0
1.83E-06	7.82E-07	3.18E-07	1.13E-07	8.83E-09	4.78E-08	0
1.95E-06	8.00E-07	3.23E-07	1.47E-07	4.78E-08	4.06E-08	0
2.25E-06	9.02E-07	3.41E-07	1.75E-07	9.09E-08	2.78E-08	0
3.09E-06	1.28E-06	5.01E-07	2.17E-07	9.22E-08	2.06E-08	0
4.16E-06	1.80E-06	7.28E-07	2.44E-07	8.77E-08	2.16E-08	0
5.17E-06	2.30E-06	9.59E-07	3.29E-07	1.15E-07	5.82E-08	0
6.23E-06	2.77E-06	1.20E-06	4.94E-07	1.64E-07	1.52E-07	0
7.73E-06	3.49E-06	1.50E-06	5.95E-07	2.04E-07	2.28E-07	0
9.18E-06	4.39E-06	1.85E-06	6.09E-07	2.21E-07	1.95E-07	0

12.4 Appendix: Wind Data Walvis Bay to Hamburg

β↓ / v→	0	1	2	3	4	5	6	7	8
0	0.000238	0.00052	0.000914	0.001336	0.001808	0.002335	0.002843	0.003163	0.003086
5	0.000231	0.000494	0.00086	0.001268	0.001757	0.002341	0.002933	0.003326	0.003273
10	0.000224	0.00047	0.000808	0.001193	0.001676	0.002275	0.002904	0.003331	0.003278
15	0.000219	0.000449	0.000762	0.001117	0.001567	0.002135	0.002742	0.003149	0.003086
20	0.000213	0.00043	0.000719	0.001037	0.001438	0.001951	0.002495	0.002844	0.002775
25	0.000204	0.000409	0.000672	0.000952	0.001301	0.001745	0.002212	0.002499	0.002422
30	0.000195	0.000383	0.000621	0.000866	0.001161	0.001531	0.001919	0.002142	0.002046
35	0.000189	0.000362	0.000575	0.000786	0.001029	0.001327	0.001631	0.001784	0.001662
40	0.000188	0.000348	0.000538	0.000716	0.000912	0.001147	0.001374	0.001462	0.001318
45	0.000186	0.000337	0.000506	0.000651	0.000808	0.000995	0.001162	0.001196	0.001035
50	0.000182	0.000324	0.000476	0.000595	0.000721	0.000871	0.000988	0.000979	0.00081
55	0.000178	0.000312	0.000449	0.000549	0.000653	0.000771	0.000848	0.000808	0.000644
60	0.000175	0.000303	0.000425	0.000508	0.000594	0.000687	0.000734	0.000677	0.000523
65	0.000174	0.000296	0.000404	0.000473	0.000542	0.000611	0.000634	0.00057	0.000432
70	0.000172	0.000288	0.000387	0.000445	0.000498	0.000543	0.000546	0.000481	0.000361
75	0.000169	0.000281	0.000373	0.000422	0.000461	0.000485	0.000474	0.000409	0.000306
80	0.000167	0.000277	0.000361	0.000403	0.000432	0.00044	0.000415	0.00035	0.000259
85	0.000167	0.000274	0.000352	0.000387	0.000407	0.000403	0.000368	0.000301	0.000222
90	0.000166	0.000271	0.000345	0.000372	0.000384	0.000373	0.000334	0.000269	0.000199
95	0.000164	0.000267	0.000341	0.000363	0.000367	0.000354	0.000314	0.000253	0.000189
100	0.000164	0.000266	0.000339	0.00036	0.00036	0.000342	0.000302	0.000245	0.000186
105	0.000166	0.000269	0.000341	0.000359	0.000356	0.000335	0.000296	0.000243	0.000187

110	0.000167	0.000272	0.000345	0.000361	0.000355	0.000332	0.000294	0.000245	0.000191
115	0.000167	0.000275	0.000353	0.000368	0.000357	0.000333	0.000297	0.000251	0.0002
120	0.00017	0.000283	0.000364	0.000378	0.000364	0.000338	0.000303	0.00026	0.000212
125	0.000176	0.000294	0.000379	0.000392	0.000375	0.000345	0.00031	0.00027	0.000226
130	0.000182	0.000309	0.000401	0.000416	0.000394	0.000358	0.00032	0.000283	0.000242
135	0.000187	0.000327	0.000434	0.000456	0.000431	0.000385	0.000339	0.0003	0.000264
140	0.000193	0.000348	0.000479	0.000515	0.000487	0.000429	0.00037	0.000326	0.000291
145	0.0002	0.000372	0.000539	0.000602	0.000577	0.000503	0.000422	0.000363	0.000321
150	0.000206	0.000402	0.000615	0.000726	0.000726	0.000641	0.000522	0.000423	0.000361
155	0.000215	0.000438	0.000706	0.000895	0.000967	0.0009	0.000731	0.000551	0.000426
160	0.000228	0.000481	0.000817	0.001127	0.001348	0.001372	0.001162	0.000836	0.000565
165	0.000241	0.000529	0.000954	0.001441	0.001919	0.002165	0.001964	0.001407	0.00085
170	0.000251	0.00058	0.001115	0.001839	0.002712	0.003363	0.003256	0.002365	0.001337
175	0.000261	0.000633	0.00129	0.002302	0.003703	0.004942	0.005007	0.003674	0.002001
180	0.000271	0.000684	0.001465	0.002785	0.004771	0.006673	0.006925	0.005107	0.002763
185	0.000281	0.000726	0.001617	0.003216	0.005714	0.008152	0.008534	0.006374	0.003591
190	0.000292	0.000766	0.001737	0.003526	0.00633	0.009005	0.009415	0.007213	0.004409
195	0.000302	0.000798	0.001812	0.003667	0.006487	0.009038	0.009372	0.007391	0.004912
200	0.00031	0.000815	0.001832	0.003621	0.006181	0.008319	0.008474	0.006785	0.004731
205	0.000316	0.000821	0.001802	0.003412	0.005533	0.007111	0.007019	0.005565	0.00389
210	0.000317	0.000817	0.001735	0.003097	0.004712	0.005733	0.005423	0.004165	0.002818
215	0.000317	0.000807	0.001642	0.002745	0.00389	0.004452	0.004011	0.002948	0.001895
220	0.000318	0.000798	0.001559	0.00244	0.003213	0.003444	0.002942	0.002062	0.001265

225	0.000319	0.000794	0.001507	0.002226	0.002729	0.002748	0.002237	0.001509	0.000908
230	0.000322	0.000795	0.00147	0.002062	0.00237	0.002261	0.001779	0.001184	0.000724
235	0.000325	0.000795	0.001427	0.001914	0.002079	0.001887	0.001453	0.000979	0.000625
240	0.000331	0.000792	0.001388	0.001793	0.001851	0.001607	0.00122	0.000839	0.000559
245	0.000337	0.000795	0.001367	0.001706	0.001685	0.001408	0.001057	0.00074	0.000509
250	0.000338	0.000796	0.001351	0.001644	0.001571	0.001275	0.000946	0.000673	0.000477
255	0.000334	0.000789	0.001329	0.001595	0.001496	0.00119	0.000875	0.000631	0.000458
260	0.000332	0.000783	0.001314	0.001566	0.001453	0.001141	0.000833	0.000603	0.000442
265	0.000332	0.000782	0.001309	0.001555	0.001434	0.001115	0.000807	0.000582	0.000426
270	0.000332	0.00078	0.001307	0.001552	0.001425	0.001098	0.000784	0.000561	0.00041
275	0.000331	0.000776	0.001302	0.001548	0.001419	0.001086	0.000764	0.000539	0.000392
280	0.00033	0.00077	0.001293	0.001545	0.001423	0.001086	0.000754	0.000522	0.000377
285	0.000327	0.000762	0.001284	0.001548	0.001435	0.001092	0.000751	0.000515	0.000367
290	0.000322	0.000751	0.001275	0.001553	0.001449	0.001104	0.000758	0.000516	0.000365
295	0.000318	0.000737	0.001256	0.001548	0.001468	0.001132	0.000779	0.000528	0.000369
300	0.000315	0.00072	0.00123	0.00154	0.001492	0.001171	0.000817	0.000553	0.000381
305	0.000308	0.000706	0.001214	0.00154	0.001524	0.00123	0.000879	0.000598	0.000406
310	0.000301	0.000697	0.001207	0.001546	0.001568	0.001315	0.000973	0.000672	0.00045
315	0.000297	0.000687	0.001198	0.001557	0.001622	0.001417	0.001097	0.000784	0.000526
320	0.000293	0.000673	0.001183	0.001566	0.001678	0.001531	0.001251	0.000941	0.00065
325	0.000289	0.00066	0.001166	0.001566	0.001729	0.001655	0.001431	0.001136	0.000823
330	0.000284	0.000647	0.001144	0.001555	0.001765	0.00177	0.001624	0.001366	0.001042
335	0.000276	0.000627	0.00111	0.001531	0.001785	0.001869	0.001819	0.001629	0.001313

340	0.000269	0.000604	0.001069	0.001497	0.001803	0.00197	0.002024	0.00193	0.001661
345	0.000264	0.000586	0.001031	0.001462	0.00182	0.002081	0.00225	0.002275	0.002081
350	0.000256	0.000568	0.000998	0.001429	0.001832	0.002191	0.002481	0.002616	0.002485
355	0.000245	0.000545	0.000961	0.001389	0.00183	0.00228	0.002684	0.002913	0.002811

9	10	11	12	13	14	15	16	17	18
0.002528	0.001681	0.00091	0.000429	0.000195	8.88E-05	3.80E-05	1.43E-05	4.57E-06	1.16E-06
0.00267	0.001749	0.000922	0.000415	0.00018	8.12E-05	3.51E-05	1.27E-05	3.80E-06	8.69E-07
0.002657	0.001719	0.000884	0.000383	0.000159	6.89E-05	2.88E-05	1.01E-05	2.99E-06	7.10E-07
0.002489	0.001606	0.000823	0.000353	0.000142	5.82E-05	2.34E-05	7.96E-06	2.29E-06	6.24E-07
0.002251	0.001479	0.000778	0.000338	0.000132	5.03E-05	1.91E-05	6.18E-06	1.65E-06	4.74E-07
0.001976	0.001326	0.000716	0.000315	0.000119	4.24E-05	1.48E-05	4.41E-06	1.12E-06	3.10E-07
0.001653	0.001109	0.000603	0.000268	0.000101	3.47E-05	1.17E-05	3.45E-06	8.88E-07	2.32E-07
0.001307	0.000856	0.000461	0.00021	8.30E-05	2.99E-05	1.05E-05	3.32E-06	9.01E-07	2.12E-07
0.000993	0.000626	0.000335	0.000159	6.91E-05	2.84E-05	1.07E-05	3.54E-06	9.90E-07	2.17E-07
0.000742	0.000452	0.000247	0.000126	6.10E-05	2.84E-05	1.18E-05	3.93E-06	1.08E-06	2.63E-07
0.000559	0.000337	0.000191	0.000105	5.60E-05	2.86E-05	1.31E-05	4.63E-06	1.33E-06	4.08E-07
0.000434	0.000264	0.000155	9.02E-05	5.05E-05	2.75E-05	1.38E-05	5.42E-06	1.72E-06	5.49E-07
0.000348	0.000214	0.000128	7.52E-05	4.19E-05	2.29E-05	1.19E-05	5.01E-06	1.68E-06	4.92E-07
0.000284	0.000175	0.000105	5.95E-05	3.15E-05	1.63E-05	7.99E-06	3.27E-06	1.08E-06	2.95E-07
0.000237	0.000146	8.59E-05	4.69E-05	2.34E-05	1.11E-05	5.00E-06	1.91E-06	5.80E-07	1.66E-07
0.000202	0.000124	7.25E-05	3.92E-05	1.89E-05	8.45E-06	3.75E-06	1.55E-06	5.48E-07	2.04E-07
0.000172	0.000106	6.26E-05	3.44E-05	1.71E-05	7.75E-06	3.50E-06	1.67E-06	7.40E-07	2.86E-07
0.000149	9.38E-05	5.64E-05	3.18E-05	1.64E-05	7.77E-06	3.66E-06	1.83E-06	8.17E-07	2.74E-07

0.000137	8.85E-05	5.48E-05	3.19E-05	1.68E-05	8.12E-06	3.97E-06	1.91E-06	8.41E-07	2.92E-07
0.000133	8.83E-05	5.59E-05	3.32E-05	1.82E-05	9.25E-06	4.70E-06	2.28E-06	1.03E-06	4.12E-07
0.000135	9.22E-05	5.93E-05	3.57E-05	2.04E-05	1.11E-05	5.79E-06	2.84E-06	1.19E-06	4.59E-07
0.000139	9.76E-05	6.40E-05	3.94E-05	2.35E-05	1.32E-05	6.93E-06	3.44E-06	1.38E-06	4.75E-07
0.000143	0.000103	6.92E-05	4.39E-05	2.68E-05	1.53E-05	8.26E-06	4.45E-06	2.09E-06	7.58E-07
0.000152	0.000111	7.72E-05	5.05E-05	3.11E-05	1.80E-05	1.00E-05	5.61E-06	2.96E-06	1.27E-06
0.000166	0.000125	8.93E-05	6.07E-05	3.81E-05	2.25E-05	1.28E-05	6.80E-06	3.45E-06	1.71E-06
0.000182	0.000142	0.000106	7.45E-05	4.80E-05	2.92E-05	1.71E-05	8.91E-06	4.23E-06	2.18E-06
0.000202	0.000163	0.000126	8.95E-05	5.89E-05	3.71E-05	2.24E-05	1.21E-05	6.04E-06	3.03E-06
0.000226	0.000185	0.000143	0.000103	7.05E-05	4.57E-05	2.78E-05	1.50E-05	7.75E-06	3.91E-06
0.000252	0.000207	0.000161	0.000118	8.27E-05	5.48E-05	3.33E-05	1.77E-05	8.95E-06	4.55E-06
0.00028	0.000232	0.000182	0.000135	9.46E-05	6.37E-05	3.96E-05	2.17E-05	1.09E-05	5.45E-06
0.000312	0.000261	0.000207	0.000154	0.000109	7.40E-05	4.68E-05	2.62E-05	1.33E-05	6.57E-06
0.00035	0.000291	0.000234	0.000177	0.000127	8.66E-05	5.47E-05	3.03E-05	1.52E-05	7.68E-06
0.000409	0.000324	0.000259	0.0002	0.000146	9.94E-05	6.20E-05	3.45E-05	1.76E-05	9.18E-06
0.000518	0.000366	0.000285	0.000222	0.000164	0.000111	6.95E-05	3.98E-05	2.13E-05	1.13E-05
0.000697	0.000424	0.000312	0.000242	0.000179	0.000123	7.91E-05	4.71E-05	2.57E-05	1.36E-05
0.000942	0.000503	0.000344	0.00026	0.000191	0.000134	9.02E-05	5.48E-05	2.96E-05	1.60E-05
0.001276	0.000646	0.000408	0.00029	0.000207	0.000146	9.91E-05	6.00E-05	3.23E-05	1.79E-05
0.001793	0.000954	0.000572	0.000368	0.000241	0.000161	0.000105	6.16E-05	3.32E-05	1.85E-05
0.002512	0.001466	0.000864	0.000505	0.000296	0.000179	0.000108	6.09E-05	3.26E-05	1.83E-05
0.003109	0.001918	0.001108	0.000604	0.000327	0.000184	0.000106	5.92E-05	3.19E-05	1.81E-05
0.003119	0.001919	0.00107	0.00056	0.000297	0.000168	9.92E-05	5.73E-05	3.13E-05	1.75E-05

0.002523	0.001488	0.000799	0.00042	0.000237	0.000146	9.20E-05	5.54E-05	3.04E-05	1.62E-05
0.001739	0.000975	0.000524	0.000301	0.000194	0.000131	8.69E-05	5.36E-05	2.97E-05	1.53E-05
0.00111	0.000617	0.000362	0.000242	0.000174	0.000123	8.23E-05	5.11E-05	2.86E-05	1.48E-05
0.00073	0.000437	0.000294	0.000219	0.000164	0.000116	7.74E-05	4.76E-05	2.67E-05	1.39E-05
0.000546	0.000364	0.000268	0.000205	0.000154	0.00011	7.34E-05	4.51E-05	2.50E-05	1.27E-05
0.000466	0.000336	0.000256	0.000195	0.000146	0.000105	7.10E-05	4.36E-05	2.40E-05	1.20E-05
0.000424	0.000318	0.000246	0.000186	0.000138	9.98E-05	6.81E-05	4.16E-05	2.27E-05	1.16E-05
0.000393	0.0003	0.000234	0.000177	0.00013	9.32E-05	6.33E-05	3.86E-05	2.13E-05	1.11E-05
0.000367	0.000282	0.000221	0.000167	0.000121	8.66E-05	5.78E-05	3.53E-05	1.99E-05	1.04E-05
0.000352	0.000271	0.000209	0.000157	0.000114	8.00E-05	5.28E-05	3.20E-05	1.81E-05	9.62E-06
0.000342	0.000261	0.000199	0.000148	0.000106	7.36E-05	4.80E-05	2.86E-05	1.61E-05	8.57E-06
0.00033	0.00025	0.000189	0.000139	9.80E-05	6.66E-05	4.31E-05	2.58E-05	1.46E-05	7.70E-06
0.000317	0.000239	0.000179	0.000128	8.89E-05	6.04E-05	3.92E-05	2.39E-05	1.35E-05	7.13E-06
0.000306	0.000232	0.000171	0.00012	8.31E-05	5.70E-05	3.70E-05	2.27E-05	1.29E-05	6.68E-06
0.000295	0.000224	0.000165	0.000115	7.95E-05	5.40E-05	3.49E-05	2.13E-05	1.23E-05	6.40E-06
0.000283	0.000214	0.000157	0.000111	7.64E-05	5.07E-05	3.23E-05	1.96E-05	1.12E-05	6.03E-06
0.000272	0.000203	0.000149	0.000107	7.47E-05	4.88E-05	3.03E-05	1.81E-05	1.01E-05	5.28E-06
0.000267	0.000199	0.000146	0.000105	7.30E-05	4.76E-05	2.91E-05	1.72E-05	9.26E-06	4.45E-06
0.000269	0.0002	0.000146	0.000103	7.02E-05	4.55E-05	2.78E-05	1.63E-05	8.52E-06	3.84E-06
0.000275	0.000202	0.000146	0.000101	6.69E-05	4.32E-05	2.65E-05	1.51E-05	7.50E-06	3.20E-06
0.000286	0.000205	0.000146	9.92E-05	6.43E-05	4.13E-05	2.53E-05	1.35E-05	6.14E-06	2.47E-06
0.000305	0.00021	0.000146	9.81E-05	6.28E-05	3.97E-05	2.36E-05	1.19E-05	5.08E-06	2.04E-06
0.000342	0.000224	0.000149	9.81E-05	6.29E-05	3.91E-05	2.25E-05	1.11E-05	4.81E-06	1.93E-06

0.000417	0.000258	0.00016	0.000102	6.50E-05	3.99E-05	2.25E-05	1.11E-05	4.69E-06	1.78E-06
0.000542	0.000326	0.000188	0.000113	6.92E-05	4.12E-05	2.27E-05	1.07E-05	4.22E-06	1.53E-06
0.000719	0.000445	0.00025	0.000138	7.76E-05	4.35E-05	2.29E-05	1.01E-05	3.81E-06	1.33E-06
0.000955	0.000618	0.000352	0.000185	9.58E-05	4.95E-05	2.40E-05	1.01E-05	3.90E-06	1.34E-06
0.001272	0.000848	0.00049	0.000258	0.00013	6.17E-05	2.73E-05	1.08E-05	4.12E-06	1.37E-06
0.001666	0.001126	0.000646	0.000339	0.000169	7.69E-05	3.15E-05	1.17E-05	4.22E-06	1.31E-06
0.002041	0.001387	0.000782	0.0004	0.000195	8.67E-05	3.45E-05	1.29E-05	4.66E-06	1.39E-06
0.002317	0.001565	0.000867	0.000426	0.000202	8.99E-05	3.68E-05	1.41E-05	4.98E-06	1.40E-06

19	20	21	22	23	24	25
1.76E-07	4.48E-08	2.49E-08	5.89E-09	0	0	0
1.01E-07	4.48E-08	3.63E-08	1.18E-08	0	0	0
5.95E-08	2.91E-08	2.29E-08	7.85E-09	0	0	0
7.52E-08	2.65E-08	2.65E-08	1.28E-08	0	0	0
8.83E-08	3.11E-08	4.71E-08	2.35E-08	0	0	0
6.90E-08	2.16E-08	2.88E-08	1.44E-08	0	0	0
5.95E-08	1.96E-08	3.92E-09	1.96E-09	0	0	0
5.23E-08	1.90E-08	0	0	0	0	0
3.63E-08	8.18E-09	0	0	0	0	0
4.58E-08	9.81E-10	0	0	0	0	0
7.95E-08	0	0	0	0	0	0
8.90E-08	0	0	0	0	0	0
6.25E-08	0	0	0	0	0	0
3.73E-08	3.27E-10	0	0	0	0	0

4.58E-08	5.89E-09	0	0	0	0	0
8.01E-08	1.21E-08	0	0	0	0	0
1.00E-07	1.31E-08	0	0	0	0	0
8.18E-08	1.37E-08	3.27E-10	0	0	0	0
7.10E-08	2.55E-08	5.89E-09	0	0	0	0
1.31E-07	4.97E-08	1.21E-08	0	0	0	0
2.04E-07	7.46E-08	1.34E-08	6.54E-10	3.27E-10	0	0
2.12E-07	7.88E-08	1.93E-08	1.18E-08	5.89E-09	0	0
2.53E-07	8.80E-08	3.17E-08	2.42E-08	1.21E-08	0	0
4.48E-07	1.57E-07	5.00E-08	2.62E-08	1.31E-08	0	0
7.48E-07	2.54E-07	6.54E-08	2.65E-08	1.34E-08	3.27E-10	0
1.08E-06	3.90E-07	1.04E-07	3.34E-08	1.93E-08	5.89E-09	0
1.47E-06	6.09E-07	2.04E-07	6.25E-08	3.07E-08	1.18E-08	0
1.85E-06	8.09E-07	2.99E-07	9.91E-08	3.24E-08	7.20E-09	0
2.12E-06	8.80E-07	3.12E-07	1.09E-07	2.68E-08	9.81E-10	0
2.51E-06	9.74E-07	2.87E-07	9.13E-08	2.16E-08	3.27E-10	0
3.18E-06	1.31E-06	4.03E-07	1.30E-07	3.89E-08	7.52E-09	0
3.87E-06	1.69E-06	6.16E-07	2.30E-07	8.70E-08	4.32E-08	0
4.56E-06	1.92E-06	7.25E-07	3.28E-07	1.52E-07	1.04E-07	0
5.65E-06	2.40E-06	9.32E-07	4.87E-07	2.43E-07	1.50E-07	0
7.07E-06	3.24E-06	1.34E-06	6.48E-07	2.92E-07	1.55E-07	0
8.62E-06	4.00E-06	1.62E-06	6.65E-07	2.61E-07	1.29E-07	0
9.81E-06	4.40E-06	1.67E-06	6.23E-07	2.42E-07	1.20E-07	0

1.01E-05	4.57E-06	1.83E-06	7.16E-07	3.04E-07	1.39E-07	0
1.01E-05	4.91E-06	2.15E-06	8.49E-07	3.42E-07	1.25E-07	0
1.01E-05	5.05E-06	2.16E-06	7.80E-07	2.55E-07	9.16E-08	0
9.49E-06	4.48E-06	1.75E-06	6.36E-07	1.88E-07	9.65E-08	0
8.54E-06	3.81E-06	1.41E-06	5.71E-07	2.13E-07	1.03E-07	0
7.79E-06	3.41E-06	1.29E-06	5.74E-07	2.62E-07	9.32E-08	0
7.23E-06	3.18E-06	1.36E-06	6.71E-07	2.99E-07	8.44E-08	0
6.58E-06	3.08E-06	1.52E-06	7.10E-07	2.53E-07	5.69E-08	0
5.92E-06	2.99E-06	1.54E-06	6.34E-07	1.77E-07	5.07E-08	0
5.71E-06	2.97E-06	1.45E-06	5.81E-07	1.70E-07	1.16E-07	0
5.86E-06	2.98E-06	1.33E-06	5.36E-07	1.85E-07	1.78E-07	0
5.69E-06	2.81E-06	1.16E-06	4.26E-07	1.54E-07	1.58E-07	0
5.25E-06	2.53E-06	1.02E-06	3.28E-07	1.10E-07	9.35E-08	0
4.74E-06	2.27E-06	9.82E-07	2.96E-07	8.24E-08	4.58E-08	0
4.12E-06	2.02E-06	9.48E-07	2.78E-07	8.05E-08	3.43E-08	0
3.74E-06	1.86E-06	8.53E-07	2.80E-07	1.12E-07	4.35E-08	0
3.55E-06	1.68E-06	7.33E-07	2.78E-07	1.15E-07	3.99E-08	0
3.14E-06	1.42E-06	6.26E-07	2.25E-07	6.77E-08	3.76E-08	0
2.84E-06	1.32E-06	6.20E-07	2.00E-07	6.02E-08	1.02E-07	0
2.79E-06	1.31E-06	6.24E-07	2.09E-07	7.95E-08	1.51E-07	0
2.54E-06	1.16E-06	4.82E-07	1.52E-07	5.63E-08	8.93E-08	0
2.06E-06	9.16E-07	3.37E-07	9.98E-08	3.53E-08	4.61E-08	0
1.65E-06	7.50E-07	3.13E-07	9.71E-08	2.68E-08	5.43E-08	0

1.32E-06	6.36E-07	2.94E-07	9.91E-08	2.13E-08	2.98E-08	0
1.02E-06	4.85E-07	2.40E-07	1.13E-07	3.04E-08	3.92E-09	0
8.04E-07	3.08E-07	1.59E-07	9.26E-08	2.62E-08	0	0
6.68E-07	1.70E-07	7.20E-08	4.06E-08	9.16E-09	0	0
5.73E-07	1.35E-07	4.87E-08	1.60E-08	1.64E-09	1.96E-09	0
5.07E-07	1.45E-07	6.15E-08	1.31E-08	1.18E-08	3.53E-08	0
4.05E-07	9.75E-08	4.78E-08	1.31E-08	2.35E-08	7.06E-08	0
3.12E-07	4.09E-08	2.85E-08	1.28E-08	1.44E-08	4.32E-08	0
2.50E-07	2.16E-08	1.44E-08	7.20E-09	1.96E-09	5.89E-09	0
2.21E-07	2.03E-08	2.29E-09	9.81E-10	0	0	0
2.43E-07	3.11E-08	5.89E-09	0	0	0	0
2.34E-07	3.86E-08	1.28E-08	3.27E-10	0	0	0

12.5 Appendix: MATLAB Code

```matlab
clear
clc
close all

vAnalysis = [10 12 14 16 18 20]; % [knots] - speeds for iteration

%% Prealocate variable sizes for loop
% Hamburg -> Walvis Bay
E_req_total_H2WB = zeros(size(vAnalysis));
E_sails_sum_H2WB = zeros(size(vAnalysis));
P_avg_H2WB = zeros(size(vAnalysis));
E_saved_H2WB = zeros(size(vAnalysis));

HFSO_mass_H2WB = zeros(size(vAnalysis));
VLSFO_mass_H2WB = zeros(size(vAnalysis));
LNG_mass_H2WB = zeros(size(vAnalysis));
LH2_mass_H2WB = zeros(size(vAnalysis));
LH2_mass_FC_H2WB = zeros(size(vAnalysis));
LNH3_mass_H2WB = zeros(size(vAnalysis));
LNH3_mass_FC_H2WB = zeros(size(vAnalysis));

HFSO_vol_H2WB = zeros(size(vAnalysis));
VLSFO_vol_H2WB = zeros(size(vAnalysis));
LNG_vol_H2WB = zeros(size(vAnalysis));
LH2_vol_H2WB = zeros(size(vAnalysis));
LH2_vol_FC_H2WB = zeros(size(vAnalysis));
LNH3_vol_H2WB = zeros(size(vAnalysis));
LNH3_vol_FC_H2WB = zeros(size(vAnalysis));

HFSO_mass_saved_H2WB = zeros(size(vAnalysis));
VLSFO_mass_saved_H2WB = zeros(size(vAnalysis));
LNG_mass_saved_H2WB = zeros(size(vAnalysis));
LH2_mass_saved_H2WB = zeros(size(vAnalysis));
LH2_mass_saved_FC_H2WB = zeros(size(vAnalysis));
LNH3_mass_saved_H2WB = zeros(size(vAnalysis));
LNH3_mass_saved_FC_H2WB = zeros(size(vAnalysis));

HFSO_CO2_saved_H2WB = zeros(size(vAnalysis));
VLSFO_CO2_saved_H2WB = zeros(size(vAnalysis));
LNG_CO2_saved_H2WB = zeros(size(vAnalysis));

HFSO_euro_saved_H2WB = zeros(size(vAnalysis));
VLSFO_euro_saved_H2WB = zeros(size(vAnalysis));
LNG_euro_saved_H2WB = zeros(size(vAnalysis));
LH2_euro_saved_H2WB = zeros(size(vAnalysis));
LH2_euro_saved_FC_H2WB = zeros(size(vAnalysis));
LNH3_euro_saved_H2WB = zeros(size(vAnalysis));
LNH3_euro_saved_FC_H2WB = zeros(size(vAnalysis));

% Walvis Bay -> Hamburg
E_req_total_WB2H = zeros(size(vAnalysis));
E_sails_sum_WB2H = zeros(size(vAnalysis));
P_avg_WB2H = zeros(size(vAnalysis));
E_saved_WB2H = zeros(size(vAnalysis));

```

```
HFSO_mass_WB2H = zeros(size(vAnalysis));
VLSFO_mass_WB2H = zeros(size(vAnalysis));
LNG_mass_WB2H = zeros(size(vAnalysis));
LH2_mass_WB2H = zeros(size(vAnalysis));
LH2_mass_FC_WB2H = zeros(size(vAnalysis));
LNH3_mass_WB2H = zeros(size(vAnalysis));
LNH3_mass_FC_WB2H = zeros(size(vAnalysis));

HFSO_vol_WB2H = zeros(size(vAnalysis));
VLSFO_vol_WB2H = zeros(size(vAnalysis));
LNG_vol_WB2H = zeros(size(vAnalysis));
LH2_vol_WB2H = zeros(size(vAnalysis));
LH2_vol_FC_WB2H = zeros(size(vAnalysis));
LNH3_vol_WB2H = zeros(size(vAnalysis));
LNH3_vol_FC_WB2H = zeros(size(vAnalysis));

HFSO_mass_saved_WB2H = zeros(size(vAnalysis));
VLSFO_mass_saved_WB2H = zeros(size(vAnalysis));
LNG_mass_saved_WB2H = zeros(size(vAnalysis));
LH2_mass_saved_WB2H = zeros(size(vAnalysis));
LH2_mass_saved_FC_WB2H = zeros(size(vAnalysis));
LNH3_mass_saved_WB2H = zeros(size(vAnalysis));
LNH3_mass_saved_FC_WB2H = zeros(size(vAnalysis));

HFSO_CO2_saved_WB2H = zeros(size(vAnalysis));
VLSFO_CO2_saved_WB2H = zeros(size(vAnalysis));
LNG_CO2_saved_WB2H = zeros(size(vAnalysis));

HFSO_euro_saved_WB2H = zeros(size(vAnalysis));
VLSFO_euro_saved_WB2H = zeros(size(vAnalysis));
LNG_euro_saved_WB2H = zeros(size(vAnalysis));
LH2_euro_saved_WB2H = zeros(size(vAnalysis));
LH2_euro_saved_FC_WB2H = zeros(size(vAnalysis));
LNH3_euro_saved_WB2H = zeros(size(vAnalysis));
LNH3_euro_saved_FC_WB2H = zeros(size(vAnalysis));

% Hamburg -> Walvis Bay Round Trip
trips_annual_H2WB = zeros(size(vAnalysis));
trips_annual_H2V = zeros(size(vAnalysis));
service_life = zeros(size(vAnalysis));

P_avg_H2WBRT = zeros(size(vAnalysis));
E_saved_H2WBRT = zeros(size(vAnalysis));

HFSO_mass_H2WBRT = zeros(size(vAnalysis));
VLSFO_mass_H2WBRT = zeros(size(vAnalysis));
LNG_mass_H2WBRT = zeros(size(vAnalysis));
LH2_mass_H2WBRT = zeros(size(vAnalysis));
LH2_mass_FC_H2WBRT = zeros(size(vAnalysis));
LNH3_mass_H2WBRT = zeros(size(vAnalysis));
LNH3_mass_FC_H2WBRT = zeros(size(vAnalysis));

HFSO_vol_H2WBRT = zeros(size(vAnalysis));
VLSFO_vol_H2WBRT = zeros(size(vAnalysis));
LNG_vol_H2WBRT = zeros(size(vAnalysis));
LH2_vol_H2WBRT = zeros(size(vAnalysis));
LH2_vol_FC_H2WBRT = zeros(size(vAnalysis));
```

```
LNH3_vol_H2WBRT = zeros(size(vAnalysis));
LNH3_vol_FC_H2WBRT = zeros(size(vAnalysis));

HFSO_mass_saved_H2WBRT = zeros(size(vAnalysis));
VLSFO_mass_saved_H2WBRT = zeros(size(vAnalysis));
LNG_mass_saved_H2WBRT = zeros(size(vAnalysis));
LH2_mass_saved_H2WBRT = zeros(size(vAnalysis));
LH2_mass_saved_FC_H2WBRT = zeros(size(vAnalysis));
LNH3_mass_saved_H2WBRT = zeros(size(vAnalysis));
LNH3_mass_saved_FC_H2WBRT = zeros(size(vAnalysis));

HFSO_CO2_saved_H2WBRT = zeros(size(vAnalysis));
VLSFO_CO2_saved_H2WBRT = zeros(size(vAnalysis));
LNG_CO2_saved_H2WBRT = zeros(size(vAnalysis));

HFSO_euro_saved_H2WBRT = zeros(size(vAnalysis));
VLSFO_euro_saved_H2WBRT = zeros(size(vAnalysis));
LNG_euro_saved_H2WBRT = zeros(size(vAnalysis));
LH2_euro_saved_H2WBRT = zeros(size(vAnalysis));
LH2_euro_saved_FC_H2WBRT = zeros(size(vAnalysis));
LNH3_euro_saved_H2WBRT = zeros(size(vAnalysis));
LNH3_euro_saved_FC_H2WBRT = zeros(size(vAnalysis));

HFSO_mass_saved_H2WBRT_yr = zeros(size(vAnalysis));
VLSFO_mass_saved_H2WBRT_yr = zeros(size(vAnalysis));
LNG_mass_saved_H2WBRT_yr = zeros(size(vAnalysis));
LH2_mass_saved_H2WBRT_yr = zeros(size(vAnalysis));
LH2_mass_saved_FC_H2WBRT_yr = zeros(size(vAnalysis));
LNH3_mass_saved_H2WBRT_yr = zeros(size(vAnalysis));
LNH3_mass_saved_FC_H2WBRT_yr = zeros(size(vAnalysis));

HFSO_CO2_saved_H2WBRT_yr = zeros(size(vAnalysis));
VLSFO_CO2_saved_H2WBRT_yr = zeros(size(vAnalysis));
LNG_CO2_saved_H2WBRT_yr = zeros(size(vAnalysis));

HFSO_euro_saved_H2WBRT_yr = zeros(size(vAnalysis));
VLSFO_euro_saved_H2WBRT_yr = zeros(size(vAnalysis));
LNG_euro_saved_H2WBRT_yr = zeros(size(vAnalysis));
LH2_euro_saved_H2WBRT_yr = zeros(size(vAnalysis));
LH2_euro_saved_FC_H2WBRT_yr = zeros(size(vAnalysis));
LNH3_euro_saved_H2WBRT_yr = zeros(size(vAnalysis));
LNH3_euro_saved_FC_H2WBRT_yr = zeros(size(vAnalysis));

HFSO_mass_saved_H2WBRT_SL = zeros(size(vAnalysis));
VLSFO_mass_saved_H2WBRT_SL = zeros(size(vAnalysis));
LNG_mass_saved_H2WBRT_SL = zeros(size(vAnalysis));
LH2_mass_saved_H2WBRT_SL = zeros(size(vAnalysis));
LH2_mass_saved_FC_H2WBRT_SL = zeros(size(vAnalysis));
LNH3_mass_saved_H2WBRT_SL = zeros(size(vAnalysis));
LNH3_mass_saved_FC_H2WBRT_SL = zeros(size(vAnalysis));

HFSO_CO2_saved_H2WBRT_SL = zeros(size(vAnalysis));
VLSFO_CO2_saved_H2WBRT_SL = zeros(size(vAnalysis));
LNG_CO2_saved_H2WBRT_SL = zeros(size(vAnalysis));

HFSO_euro_saved_H2WBRT_SL = zeros(size(vAnalysis));
VLSFO_euro_saved_H2WBRT_SL = zeros(size(vAnalysis));
```

```
LNG_euro_saved_H2WBRT_SL = zeros(size(vAnalysis));
LH2_euro_saved_H2WBRT_SL = zeros(size(vAnalysis));
LH2_euro_saved_FC_H2WBRT_SL = zeros(size(vAnalysis));
LNH3_euro_saved_H2WBRT_SL = zeros(size(vAnalysis));
LNH3_euro_saved_FC_H2WBRT_SL = zeros(size(vAnalysis));

% Hamburg -> Walvis Bay Round Trip NPV
HFSO_NPV_H2WBRT = zeros(size(vAnalysis));
VLSFO_NPV_H2WBRT = zeros(size(vAnalysis));
LNG_NPV_H2WBRT = zeros(size(vAnalysis));
LH2_NPV_H2WBRT = zeros(size(vAnalysis));
LH2_NPV_FC_H2WBRT = zeros(size(vAnalysis));
LNH3_NPV_H2WBRT = zeros(size(vAnalysis));
LNH3_NPV_FC_H2WBRT = zeros(size(vAnalysis));

% Hamburg -> Walvis Bay Round Trip SPP
HFSO_SPP_H2WBRT = zeros(size(vAnalysis));
VLSFO_SPP_H2WBRT = zeros(size(vAnalysis));
LNG_SPP_H2WBRT = zeros(size(vAnalysis));
LH2_SPP_H2WBRT = zeros(size(vAnalysis));
LH2_SPP_FC_H2WBRT = zeros(size(vAnalysis));
LNH3_SPP_H2WBRT = zeros(size(vAnalysis));
LNH3_SPP_FC_H2WBRT = zeros(size(vAnalysis));

for v = 1:size(vAnalysis,2)
%% Ship and Sail Specific Parameters
vShip = 0.51444444444*vAnalysis(v); % [m/s] - ship speed
d = 14;                             % [m] - chord length
h = 56;                             % [m] - height of sail
aSail = 2*806.1;                    % [m^2] - area of 1 wing sail
nSails = 3;                         % [-] - number of sails
rho = 1.292;                        % [kg/m^3] - water density at STP
                                    % (0 degree C and 1 ATM)
mu = 1.328*10^(-5);                 % [m^2/s] - dynamic viscosity at STP
                                    % (0 degree C and 1 ATM)

%% Maximum wind speed and apparent wind angle when thrust coefficent is 0
vSailLimit = 35*.5144;              % [m/s] - upper apparent wind speed
                                    % limit for sail operation
AWA_Upper_Limit = 330;              % [degree] - upper apparent wind angle
                                    %limit for sail operation
AWA_Lower_Limit = 30;               % [degree] - lower apparent wind angle limit for sail operation

%% Journey Parmeters
dist_Hamburg_Walvis_Bay = 5809*1852;% [m] - distance between Hamburg and Walvis Bay
dist_Hamburg_Valparaiso = 7715*1852;% [m] - distance between Hamburg and Valparaiso
time_Hamburg_Walvis_Bay = ...       % [s] - time for journey
    dist_Hamburg_Walvis_Bay/vShip;
time_Hamburg_Valparaiso = ...       % [s] - time for journey
    dist_Hamburg_Valparaiso/vShip;


%% Fuel and Energy Parameters
% HFO is assumed to be stored at 25 degree C and 1ATM
```

```
HSFO_Density = 970;                 % [kg/m^3] - Density of high sulfur heavy fuel oil
HSFO_Spec_Energy = 44.2*10^6;       % [J/t] - Energy density of high sulfur heavy fuel oil
HSFO_tCO2 = 2.90;                   % [t-CO2/t-fuel]
HSFO_eta_combustion = 0.50;         % [-] - Efficency of combustion engine
HSFO_cost = (390+535)/2*.95;        % [€/tonne] - Cost of high sulfur heavy fuel oil
% DFO is aassumed to be stored at 25 degree C and 1ATM
VLSFO_Density = 890;                % [kg/m^3] - Density of low sulfur heavy fuel oil
VLSFO_Spec_Energy = 43.2*10^6;      % [J/t] - Energy density of low sulfur heavy fuel oil
VLSFO_tCO2 = 2.80;                  % [t-CO2/t-fuel]
VLSFO_eta_combustion = 0.50;        % [-] - Efficency of combustion engine
VLSFO_cost = (475+650)/2*.95;       % [€/tonne] - cost of diesel fuel oil
% LNG is assumed to be stored at -162 degree C and 1ATM
LNG_Density = 510;                  % [kg/m^3] - Density of liquefied natural gas
LNG_Spec_Energy = 55.0*10^6;        % [J/t] - Energy density of liquefied natural gas
LNG_tCO2 = 2.750;                   % [t-CO2/t-fuel]
LNG_eta_combustion = 0.60;          % [-] - Efficency of combustion engine
LNG_cost = 2434*.95;                % [€/tonne] - cost of liquefied natural gas
% LH2 is assumed to be stored at -253 degree C and 1ATM
LH2_Density = 71;                   % [kg/m^3] - Density of liquefied natural gas
LH2_Spec_Energy = 142*10^6;         % [J/t] - Energy density of liquefied natural gas
LH2_eta_combustion = 0.25;          % [-] - Efficency of combustion engine
LH2_eta_fuel_cell = 0.60;           % [-] - Efficency of fuel cell
LH2_cost = 2788*.95;                % [€/tonne] - cost of liquefied natural gas
% LNH3 is assumed to be stored at -33 degree C and 1ATM
LNH3_Density = 700;                 % [kg/m^3] - Density of liquefied natural gas
LNH3_Spec_Energy = 22.8*10^6;       % [J/t] - Energy density of liquefied natural gas
LNH3_eta_combustion = 0.25;         % [-] - Efficency of combustion engine
LNH3_eta_fuel_cell = 0.60;          % [-] - Efficency of fuel cell
LNH3_cost = 2720*.95;               % [€/tonne] - cost of liquefied natural gas

%% Economic Parameters
construction_cost = h*d*3500;       % [€] - construction cost per sail
developement_cost = 0.3*...         % [€] - total deisgn costs of sail array
    construction_cost;
install_cost = 0.20*...             % [€] - installation cost per sail
    construction_cost;
training_cost = 0.2*...             % [€] - cost to train personnel
    developement_cost;
trips_annual_H2WB(v) = round(250/...% [#] - trips annually
(time_Hamburg_Walvis_Bay/60/60/24));%       (assume 250 days in transit)
trips_annual_H2V(v) = round(250/... % [#] - trips annually
(time_Hamburg_Valparaiso/60/60/24));%       (assume 250 days in transit)
service_life(v) = 30;               % [years] - vessel service life
```

```



%% Resistance and Power Data from Holtrop Analysis
Vessel_RandP= struct('v_kt',[2 4 6 8 10 12 14 16 18 20], ...
    'Rbare_N',[16419.3,61015.7,132138.2,228745.8,350708.1,503299.5, ...
    707032.4,1006872.3,1473607.8,2198212.5], ...
    'PE_W',[16.9*10^3,125.6*10^3,407.9*10^3,941.4*10^3,1804.2*10^3,3107.0*10^3, ...
    5092.2*10^3,8287.7*10^3,13645.6*10^3,22617.2*10^3], ...
    'PP_W',[33.8*10^3,251.1*10^3,815.7*10^3,1882.8*10^3,3608.4*10^3,6214.1*10^3, ...
    10184.4*10^3,16575.4*10^3,27291.2*10^3,45234.3*10^3]);

%% Load XFOIL Data
XFOIL_Results = readtable("Wind_Data_and_Lift_Drag_Simulations.xlsx" ...
    ,"Sheet","LiftDragData","FileType","spreadsheet");

% Create structure which stores ideal A0A, CL and CD for a given speed
XFOIL_Ideal = struct('vWind',[XFOIL_Results.Speed_m_per_s(33), ...
    XFOIL_Results.Speed_m_per_s(92), XFOIL_Results.Speed_m_per_s(149), ...
    XFOIL_Results.Speed_m_per_s(209),XFOIL_Results.Speed_m_per_s(270), ...
    XFOIL_Results.Speed_m_per_s(332),XFOIL_Results.Speed_m_per_s(394), ...
    XFOIL_Results.Speed_m_per_s(456),XFOIL_Results.Speed_m_per_s(518), ...
    XFOIL_Results.Speed_m_per_s(578),XFOIL_Results.Speed_m_per_s(637), ...
    XFOIL_Results.Speed_m_per_s(698),XFOIL_Results.Speed_m_per_s(758), ...
    XFOIL_Results.Speed_m_per_s(818),XFOIL_Results.Speed_m_per_s(879), ...
    XFOIL_Results.Speed_m_per_s(941),XFOIL_Results.Speed_m_per_s(1002), ...
    XFOIL_Results.Speed_m_per_s(1064),XFOIL_Results.Speed_m_per_s(1125), ...
    XFOIL_Results.Speed_m_per_s(1249),XFOIL_Results.Speed_m_per_s(1310), ...
    XFOIL_Results.Speed_m_per_s(1370),XFOIL_Results.Speed_m_per_s(1431), ...
    XFOIL_Results.Speed_m_per_s(1492),XFOIL_Results.Speed_m_per_s(1552), ...
    XFOIL_Results.Speed_m_per_s(1614),XFOIL_Results.Speed_m_per_s(1677), ...
    XFOIL_Results.Speed_m_per_s(1739),XFOIL_Results.Speed_m_per_s(1799), ...
    XFOIL_Results.Speed_m_per_s(1858),XFOIL_Results.Speed_m_per_s(1920), ...
    XFOIL_Results.Speed_m_per_s(1979),XFOIL_Results.Speed_m_per_s(2039), ...
    XFOIL_Results.Speed_m_per_s(2099),XFOIL_Results.Speed_m_per_s(2161), ...
    XFOIL_Results.Speed_m_per_s(2222),XFOIL_Results.Speed_m_per_s(2282), ...
    XFOIL_Results.Speed_m_per_s(2341),XFOIL_Results.Speed_m_per_s(2402), ...
    XFOIL_Results.Speed_m_per_s(2463),XFOIL_Results.Speed_m_per_s(2524), ...
    XFOIL_Results.Speed_m_per_s(2582),XFOIL_Results.Speed_m_per_s(2641), ...
    XFOIL_Results.Speed_m_per_s(2698),XFOIL_Results.Speed_m_per_s(2759), ...
    XFOIL_Results.Speed_m_per_s(2819),XFOIL_Results.Speed_m_per_s(2875), ...
    XFOIL_Results.Speed_m_per_s(2934),XFOIL_Results.Speed_m_per_s(2991), ...
    XFOIL_Results.Speed_m_per_s(3052)], ...
    ...
    'AoA',[XFOIL_Results.alpha(33),XFOIL_Results.alpha(92), ...
    XFOIL_Results.alpha(149),XFOIL_Results.alpha(209),XFOIL_Results.alpha(270), ...
    XFOIL_Results.alpha(332),XFOIL_Results.alpha(394),XFOIL_Results.alpha(456), ...
```

```
    XFOIL_Results.alpha(518),XFOIL_Results.alpha(578),XFOIL_Results.alpha(637), ...
    XFOIL_Results.alpha(698),XFOIL_Results.alpha(758),XFOIL_Results.alpha(818), ...
    XFOIL_Results.alpha(879),XFOIL_Results.alpha(941),XFOIL_Results.alpha(1002), ...
    XFOIL_Results.alpha(1064),XFOIL_Results.alpha(1125),XFOIL_Results.alpha(1249), ...
    XFOIL_Results.alpha(1310),XFOIL_Results.alpha(1370),XFOIL_Results.alpha(1431), ...
    XFOIL_Results.alpha(1492),XFOIL_Results.alpha(1552),XFOIL_Results.alpha(1614), ...
    XFOIL_Results.alpha(1677),XFOIL_Results.alpha(1739),XFOIL_Results.alpha(1799), ...
    XFOIL_Results.alpha(1858),XFOIL_Results.alpha(1920),XFOIL_Results.alpha(1979), ...
    XFOIL_Results.alpha(2039),XFOIL_Results.alpha(2099),XFOIL_Results.alpha(2161), ...
    XFOIL_Results.alpha(2222),XFOIL_Results.alpha(2282),XFOIL_Results.alpha(2341), ...
    XFOIL_Results.alpha(2402),XFOIL_Results.alpha(2463),XFOIL_Results.alpha(2524), ...
    XFOIL_Results.alpha(2582),XFOIL_Results.alpha(2641),XFOIL_Results.alpha(2698), ...
    XFOIL_Results.alpha(2759),XFOIL_Results.alpha(2819),XFOIL_Results.alpha(2875), ...
    XFOIL_Results.alpha(2934),XFOIL_Results.alpha(2991),XFOIL_Results.alpha(3052)], ...
    ...
    'CLoCD',[XFOIL_Results.Cl_over_cD(33),XFOIL_Results.Cl_over_cD(92), ...
    XFOIL_Results.Cl_over_cD(149),XFOIL_Results.Cl_over_cD(209), ...
    XFOIL_Results.Cl_over_cD(270),XFOIL_Results.Cl_over_cD(332), ...
    XFOIL_Results.Cl_over_cD(394),XFOIL_Results.Cl_over_cD(456), ...
    XFOIL_Results.Cl_over_cD(518),XFOIL_Results.Cl_over_cD(578), ...
    XFOIL_Results.Cl_over_cD(637),XFOIL_Results.Cl_over_cD(698), ...
    XFOIL_Results.Cl_over_cD(758),XFOIL_Results.Cl_over_cD(818), ...
    XFOIL_Results.Cl_over_cD(879),XFOIL_Results.Cl_over_cD(941), ...
    XFOIL_Results.Cl_over_cD(1002),XFOIL_Results.Cl_over_cD(1064), ...
    XFOIL_Results.Cl_over_cD(1125),XFOIL_Results.Cl_over_cD(1249), ...
    XFOIL_Results.Cl_over_cD(1310),XFOIL_Results.Cl_over_cD(1370), ...
    XFOIL_Results.Cl_over_cD(1431),XFOIL_Results.Cl_over_cD(1492), ...
    XFOIL_Results.Cl_over_cD(1552),XFOIL_Results.Cl_over_cD(1614), ...
    XFOIL_Results.Cl_over_cD(1677),XFOIL_Results.Cl_over_cD(1739), ...
```

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XFOIL_Results.Cl_over_cD(1920),XFOIL_Results.Cl_over_cD(1979), ...
XFOIL_Results.Cl_over_cD(2039),XFOIL_Results.Cl_over_cD(2099), ...
XFOIL_Results.Cl_over_cD(2161),XFOIL_Results.Cl_over_cD(2222), ...
XFOIL_Results.Cl_over_cD(2282),XFOIL_Results.Cl_over_cD(2341), ...
XFOIL_Results.Cl_over_cD(2402),XFOIL_Results.Cl_over_cD(2463), ...
XFOIL_Results.Cl_over_cD(2524),XFOIL_Results.Cl_over_cD(2582), ...
XFOIL_Results.Cl_over_cD(2641),XFOIL_Results.Cl_over_cD(2698), ...
XFOIL_Results.Cl_over_cD(2759),XFOIL_Results.Cl_over_cD(2819), ...
XFOIL_Results.Cl_over_cD(2875),XFOIL_Results.Cl_over_cD(2934), ...
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...
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XFOIL_Results.CL(2222),XFOIL_Results.CL(2282),XFOIL_Results.CL(2341), ...
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XFOIL_Results.CL(2582),XFOIL_Results.CL(2641),XFOIL_Results.CL(2698), ...
XFOIL_Results.CL(2759),XFOIL_Results.CL(2819),XFOIL_Results.CL(2875), ...
XFOIL_Results.CL(2934),XFOIL_Results.CL(2991),XFOIL_Results.CL(3052)], ...
...
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XFOIL_Results.CD(332),XFOIL_Results.CD(394),XFOIL_Results.CD(456), ...
XFOIL_Results.CD(518),XFOIL_Results.CD(578),XFOIL_Results.CD(637), ...
XFOIL_Results.CD(698),XFOIL_Results.CD(758),XFOIL_Results.CD(818), ...
XFOIL_Results.CD(879),XFOIL_Results.CD(941),XFOIL_Results.CD(1002), ...
XFOIL_Results.CD(1064),XFOIL_Results.CD(1125),XFOIL_Results.CD(1249), ...
XFOIL_Results.CD(1310),XFOIL_Results.CD(1370),XFOIL_Results.CD(1431), ...
XFOIL_Results.CD(1492),XFOIL_Results.CD(1552),XFOIL_Results.CD(1614), ...
XFOIL_Results.CD(1677),XFOIL_Results.CD(1739),XFOIL_Results.CD(1799), ...
XFOIL_Results.CD(1858),XFOIL_Results.CD(1920),XFOIL_Results.CD(1979), ...
```

```
    XFOIL_Results.CD(2039),XFOIL_Results.CD(2099),XFOIL_Results.CD(2161), ...
    XFOIL_Results.CD(2222),XFOIL_Results.CD(2282),XFOIL_Results.CD(2341), ...
    XFOIL_Results.CD(2402),XFOIL_Results.CD(2463),XFOIL_Results.CD(2524), ...
    XFOIL_Results.CD(2582),XFOIL_Results.CD(2641),XFOIL_Results.CD(2698), ...
    XFOIL_Results.CD(2759),XFOIL_Results.CD(2819),XFOIL_Results.CD(2875), ...
    XFOIL_Results.CD(2934),XFOIL_Results.CD(2991),XFOIL_Results.CD(3052)]);

%% ------------------------ HAMBURG-TO-WALVIS-BAY-------------------------%%
TWA_VS_TWS_matrix_H2WB = readtable("Wind_Data_and_Lift_Drag_Simulations.xlsx", ...
    "Sheet","Hamburg->WalvisBay","FileType","spreadsheet");

%% Calculate the energy required for the ship at each wind heading and wind speed
%PropulsivePower = interp1(Vessel_RandP.v_kt*0.51444444444444,Vessel_RandP.PP_W,vShip,"spline");
E_req_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % from the first column to the end column
        if i == 1 && j ==1
            E_req_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            E_req_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            E_req_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            E_req_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j} ...
                *interp1(Vessel_RandP.v_kt*0.51444444444444,Vessel_RandP.PP_W,vShip,"spline") ...
                *time_Hamburg_Walvis_Bay;
            E_req_total_H2WB(v) = E_req_total_H2WB(v) ...
                +E_req_matrix_H2WB(i,j);
        end
    end
end

%% Calculate the Apperant Wind Speed (AWS)
AWS_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % from the first column to the end column
        if i == 1 && j ==1
            AWS_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            AWS_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            AWS_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            AWS_matrix_H2WB(i,j) = abs(sqrt(power(TWA_VS_TWS_matrix_H2WB{1,j},2) ...
```

```
                +vShip^2-(2*TWA_VS_TWS_matrix_H2WB{1,j} ...
                *vShip*cosd(TWA_VS_TWS_matrix_H2WB{i,1}))));
        end
    end
end

%% Calculate the Apperant Wind Angle (AWA)
AWA_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % from the first column to the end column
        if i == 1 && j ==1
            AWA_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            AWA_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            AWA_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            AWA_matrix_H2WB(i,j) = norm(atand((TWA_VS_TWS_matrix_H2WB{1,j} ...
                *sind(TWA_VS_TWS_matrix_H2WB{i,1}))/(vShip+ ...
                TWA_VS_TWS_matrix_H2WB{1,j}*cosd(TWA_VS_TWS_matrix_H2WB{i,1}))));
        end
    end
end

%% Calculate thrust coefficent(Cx) and side force coefficent(Cy)
Cx_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
Cy_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % from the first column to the end column
        if i == 1 && j ==1
            Cx_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            Cx_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            Cx_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif AWS_matrix_H2WB(i,j) > vSailLimit || AWA_matrix_H2WB(i,j) > AWA_Upper_Limit ...
                || AWA_matrix_H2WB(i,j) < AWA_Lower_Limit || i == 38
            Cx_matrix_H2WB(i,j) = 0;
        else
            ClTemp = interp1(XFOIL_Ideal.vWind,XFOIL_Ideal.CL,AWS_matrix_H2WB(i,j));
            CdTemp = interp1(XFOIL_Ideal.vWind,XFOIL_Ideal.CD,AWS_matrix_H2WB(i,j));
            Cx_matrix_H2WB(i,j) = ClTemp*sind(AWA_matrix_H2WB(i,j)) - ...
                CdTemp*cosd(AWA_matrix_H2WB(i,j));
            Cy_matrix_H2WB(i,j) = ClTemp*cosd(AWA_matrix_H2WB(i,j)) + ...
                CdTemp*sind(AWA_matrix_H2WB(i,j));
        end
    end
end

%% Calculate Force Generated by ONE sail
```

```
F_sail_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % starting from the first column to the end column
        if i == 1 && j ==1
            F_sail_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            F_sail_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            F_sail_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif AWS_matrix_H2WB(i,j) > 25.72
            F_sail_matrix_H2WB(i,j) = 0;
        else
            F_sail_matrix_H2WB(i,j) = 1/2*Cx_matrix_H2WB(i,j)...
                *rho*power(AWS_matrix_H2WB(i,j),2)*aSail;
        end
    end
end

%% Calculate power generated by ONE sail
P_sail_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_sail_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_sail_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_sail_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif AWS_matrix_H2WB(i,j) > 25.72
            P_sail_matrix_H2WB(i,j) = 0;
        else
            P_sail_matrix_H2WB(i,j) = F_sail_matrix_H2WB(i,j)...
                *vShip;
        end
    end
end

%% Calculate power generated by ALL sails
P_ALL_sails_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_ALL_sails_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_ALL_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_ALL_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            P_ALL_sails_matrix_H2WB(i,j) = nSails*P_sail_matrix_H2WB(i,j);
        end
    end
```

```
end

%% Calculate the percentage of power generated from the sail array
P_Percent_sails_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_Percent_sails_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_Percent_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_Percent_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            P_Percent_sails_matrix_H2WB(i,j) = P_ALL_sails_matrix_H2WB(i,j) ...
                /interp1(Vessel_RandP.v_kt*0.514444444444444,Vessel_RandP.PP_W,vShip,"spline");
        end
    end
end

%% Calculate the energy generated from the sails
E_sails_matrix_H2WB = zeros(size(TWA_VS_TWS_matrix_H2WB));
for i = 1:size(TWA_VS_TWS_matrix_H2WB,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_H2WB,2) % starting from the first column to the end column
        if i == 1 && j ==1
            E_sails_matrix_H2WB(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            E_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        elseif j == 1 % When in the first column assign the same label
            E_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j};
        else
            E_sails_matrix_H2WB(i,j) = TWA_VS_TWS_matrix_H2WB{i,j} ...
                *P_ALL_sails_matrix_H2WB(i,j) ...
                *time_Hamburg_Walvis_Bay;
            E_sails_sum_H2WB(v) = E_sails_sum_H2WB(v) ...
                +E_sails_matrix_H2WB(i,j);
        end
    end
end

%% Calculate energy savings using sails
% 1 - Used for plot of Average Power from Sails Vs Speed
% 2 - Used for plot of AVG Power from Sails and Required Propulsive Power Vs Speed
P_avg_H2WB(v) = E_sails_sum_H2WB(v)/time_Hamburg_Walvis_Bay; % [W] - power

% 3 - Used for plot of Percent Energy/Power from Sails Vs Speed
E_saved_H2WB(v) = E_sails_sum_H2WB(v)/E_req_total_H2WB(v)*100; % [%] - percent energy/power

```

```
%% Calculate amount of fuel needed[t], volume needed[m^3], fuel saved[t], CO2 saved[t], and euro saved[] per trip
% 4 - Used for plot of Fuel Mass Required Vs Speed per trip
HFSO_mass_H2WB(v) = (E_req_total_H2WB(v)/HSFO_Spec_Energy)...
    /HSFO_eta_combustion/1000; % [t] - combustion
VLSFO_mass_H2WB(v) = (E_req_total_H2WB(v)/VLSFO_Spec_Energy)...
    /VLSFO_eta_combustion/1000; % [t] - combustion
LNG_mass_H2WB(v) = (E_req_total_H2WB(v)/LNG_Spec_Energy)...
    /LNG_eta_combustion/1000; % [t] - combustion
LH2_mass_H2WB(v) = (E_req_total_H2WB(v)/LH2_Spec_Energy)...
    /LH2_eta_combustion/1000; % [t] - combustion
LH2_mass_FC_H2WB(v) = (E_req_total_H2WB(v)/LH2_Spec_Energy)...
    /LH2_eta_fuel_cell/1000; % [t] - fuel cells
LNH3_mass_H2WB(v) = (E_req_total_H2WB(v)/LNH3_Spec_Energy)...
    /LNH3_eta_combustion/1000; % [t] - combustion
LNH3_mass_FC_H2WB(v) = (E_req_total_H2WB(v)/LNH3_Spec_Energy)...
    /LNH3_eta_fuel_cell/1000; % [t] - fuel cells

% 5 - Used for plot of Fuel Volume Required Vs Speed per trip
HFSO_vol_H2WB(v) = HFSO_mass_H2WB(v)/(HSFO_Density/1000); % [m^3] - combustion
VLSFO_vol_H2WB(v) = VLSFO_mass_H2WB(v)/(VLSFO_Density/1000); % [m^3] - combustion
LNG_vol_H2WB(v) = LNG_mass_H2WB(v)/(LNG_Density/1000); % [m^3] - combustion
LH2_vol_H2WB(v) = LH2_mass_H2WB(v)/(LH2_Density/1000); % [m^3] - combustion
LH2_vol_FC_H2WB(v) = LH2_mass_FC_H2WB(v)/(LH2_Density/1000); % [m^3] - fuel cells
LNH3_vol_H2WB(v) = LNH3_mass_H2WB(v)/(LNH3_Density/1000); % [m^3] - combustion
LNH3_vol_FC_H2WB(v) = LNH3_mass_FC_H2WB(v)/(LNH3_Density/1000); % [m^3] - fuel cells

% 6 - Used for plot of Fuel Mass Saved from Sails Vs Speed per trip
HFSO_mass_saved_H2WB(v) = HFSO_mass_H2WB(v)*E_saved_H2WB(v)/100; % [t] - combustion
VLSFO_mass_saved_H2WB(v) = VLSFO_mass_H2WB(v)*E_saved_H2WB(v)/100; % [t] - combustion
LNG_mass_saved_H2WB(v) = LNG_mass_H2WB(v)*E_saved_H2WB(v)/100; % [t] - combustion
LH2_mass_saved_H2WB(v) = LH2_mass_H2WB(v)*E_saved_H2WB(v)/100; % [t] - combustion
LH2_mass_saved_FC_H2WB(v) = LH2_mass_FC_H2WB(v)*E_saved_H2WB(v)/100; % [t] - fuel cells
LNH3_mass_saved_H2WB(v) = LNH3_mass_H2WB(v)*E_saved_H2WB(v)/100; % [t] - combustion
LNH3_mass_saved_FC_H2WB(v) = LNH3_mass_FC_H2WB(v)*E_saved_H2WB(v)/100; % [t] - fuel cells

% 7 - Used for plot of CO2 Saved from Sails Vs Speed per trip
HFSO_CO2_saved_H2WB(v) = HFSO_mass_saved_H2WB(v)*HSFO_tCO2; % [t] - combustion
VLSFO_CO2_saved_H2WB(v) = VLSFO_mass_saved_H2WB(v)*VLSFO_tCO2; % [t] - combustion
LNG_CO2_saved_H2WB(v) = LNG_mass_saved_H2WB(v)*LNG_tCO2; % [t] - combustion

% 8 - Used for plot of Euros Saved from Sails Vs Speed per trip
```

```
HFSO_euro_saved_H2WB(v) = HFSO_mass_saved_H2WB(v)*HSFO_cost; % [€] - savings per trip
VLSFO_euro_saved_H2WB(v) = VLSFO_mass_saved_H2WB(v)*VLSFO_cost; % [€] - savings per trip
LNG_euro_saved_H2WB(v) = LNG_mass_saved_H2WB(v)*LNG_cost; % [€] - savings per trip
LH2_euro_saved_H2WB(v) = LH2_mass_saved_H2WB(v)*LH2_cost; % [€] - savings per trip
LH2_euro_saved_FC_H2WB(v) = LH2_mass_saved_FC_H2WB(v)*LH2_cost; % [€] - savings per trip
LNH3_euro_saved_H2WB(v) = LNH3_mass_saved_H2WB(v)*LNH3_cost; % [€] - savings per trip
LNH3_euro_saved_FC_H2WB(v) = LNH3_mass_saved_FC_H2WB(v)*LNH3_cost; % [€] - savings per trip

%% ------------------------ WALVIS-BAY-TO-HAMBURG-------------------------- %%
TWA_VS_TWS_matrix_WB2H = readtable("Wind_Data_and_Lift_Drag_Simulations.xlsx", ...
    "Sheet","WalvisBay->Hamburg","FileType","spreadsheet");

%% Calculate the energy required for the ship at each wind heading and wind speed
PropulsivePower = interp1(Vessel_RandP.v_kt*0.51444444444444,Vessel_RandP.PP_W,vShip,"spline");
E_req_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % from the first column to the end column
        if i == 1 && j ==1
            E_req_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            E_req_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            E_req_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        else
            E_req_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j} ...
                *interp1(Vessel_RandP.v_kt*0.51444444444444,Vessel_RandP.PP_W,vShip,"spline") ...
                *time_Hamburg_Walvis_Bay;
            E_req_total_WB2H(v) = E_req_total_WB2H(v) ...
                +E_req_matrix_WB2H(i,j);
        end
    end
end

%% Calculate the Apperant Wind Speed (AWS)
AWS_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % from the first column to the end column
        if i == 1 && j ==1
            AWS_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            AWS_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
```

```
                AWS_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
            else
                AWS_matrix_WB2H(i,j) = abs(sqrt(power(TWA_VS_TWS_matrix_WB2H{1,j},2) ...
                    +vShip^2-(2*TWA_VS_TWS_matrix_WB2H{1,j} ...
                    *vShip*cosd(TWA_VS_TWS_matrix_WB2H{i,1}))));
            end
        end
    end

    %% Calculate the Apperant Wind Angle (AWA)
    AWA_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
    for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % from the first row to the end row
        for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % from the first column to the end column
            if i == 1 && j ==1
                AWA_matrix_WB2H(i,j) = 0;
            elseif i == 1 % When in the first row assign the same label
                AWA_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
            elseif j == 1 % When in the first column assign the same label
                AWA_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
            else
                AWA_matrix_WB2H(i,j) = norm(atand((TWA_VS_TWS_matrix_WB2H{1,j} ...
                    *sind(TWA_VS_TWS_matrix_WB2H{i,1}))/(vShip+ ...
TWA_VS_TWS_matrix_WB2H{1,j}*cosd(TWA_VS_TWS_matrix_WB2H{i,1}))));
            end
        end
    end

    %% Calculate thrust coefficent(Cx) and side force coefficent(Cy)
    Cx_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
    Cy_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
    for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % from the first row to the end row
        for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % from the first column to the end column
            if i == 1 && j ==1
                Cx_matrix_WB2H(i,j) = 0;
            elseif i == 1 % When in the first row assign the same label
                Cx_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
            elseif j == 1 % When in the first column assign the same label
                Cx_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
            elseif AWS_matrix_WB2H(i,j) > vSailLimit || AWA_matrix_WB2H(i,j) > AWA_Upper_Limit ...
                    || AWA_matrix_WB2H(i,j) < AWA_Lower_Limit || i == 38
                Cx_matrix_WB2H(i,j) = 0;
            else
                ClTemp = interp1(XFOIL_Ideal.vWind,XFOIL_Ideal.CL,AWS_matrix_WB2H(i,j));
                CdTemp = interp1(XFOIL_Ideal.vWind,XFOIL_Ideal.CD,AWS_matrix_WB2H(i,j));
                Cx_matrix_WB2H(i,j) = ClTemp*sind(AWA_matrix_WB2H(i,j)) - ...
                    CdTemp*cosd(AWA_matrix_WB2H(i,j));
                Cy_matrix_WB2H(i,j) = ClTemp*cosd(AWA_matrix_WB2H(i,j)) + ...
                    CdTemp*sind(AWA_matrix_WB2H(i,j));
            end
```

```
    end
end

%% Calculate Force Generated by ONE sail
F_sail_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % starting from the first column to the end column
        if i == 1 && j ==1
            F_sail_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            F_sail_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            F_sail_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif AWS_matrix_WB2H(i,j) > 25.72
            F_sail_matrix_WB2H(i,j) = 0;
        else
            F_sail_matrix_WB2H(i,j) = 1/2*Cx_matrix_WB2H(i,j)...
                *rho*power(AWS_matrix_WB2H(i,j),2)*aSail;
        end
    end
end

%% Calculate power generated by ONE sail
P_sail_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_sail_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_sail_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_sail_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif AWS_matrix_WB2H(i,j) > 25.72
            P_sail_matrix_WB2H(i,j) = 0;
        else
            P_sail_matrix_WB2H(i,j) = F_sail_matrix_WB2H(i,j)...
                *vShip;
        end
    end
end

%% Calculate power generated by ALL sails
P_ALL_sails_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_ALL_sails_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_ALL_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_ALL_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
```

```
        else
            P_ALL_sails_matrix_WB2H(i,j) = nSails*P_sail_matrix_WB2H(i,j);
        end
    end
end

%% Calculate the percentage of power generated from the sail array
P_Percent_sails_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % starting from the first column to the end column
        if i == 1 && j ==1
            P_Percent_sails_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            P_Percent_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            P_Percent_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        else
            P_Percent_sails_matrix_WB2H(i,j) = P_ALL_sails_matrix_WB2H(i,j) ...
/interp1(Vessel_RandP.v_kt*0.514444444444444,Vessel_RandP.PP_W,vShip,"spline");
        end
    end
end

%% Calculate the energy generated from the sails
E_sails_matrix_WB2H = zeros(size(TWA_VS_TWS_matrix_WB2H));
for i = 1:size(TWA_VS_TWS_matrix_WB2H,1) % starting from the first row to the end row
    for j = 1:size(TWA_VS_TWS_matrix_WB2H,2) % starting from the first column to the end column
        if i == 1 && j ==1
            E_sails_matrix_WB2H(i,j) = 0;
        elseif i == 1 % When in the first row assign the same label
            E_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        elseif j == 1 % When in the first column assign the same label
            E_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j};
        else
            E_sails_matrix_WB2H(i,j) = TWA_VS_TWS_matrix_WB2H{i,j} ...
                *P_ALL_sails_matrix_WB2H(i,j) ...
                *time_Hamburg_Walvis_Bay;
            E_sails_sum_WB2H(v) = E_sails_sum_WB2H(v) ...
                +E_sails_matrix_WB2H(i,j);
        end
    end
end

%% Calculate energy savings using sails
% 1 - Used for plot of Average Power from Sails Vs Speed
% 2 - Used for plot of AVG Power from Sails and Required Propulsive Power Vs Speed
P_avg_WB2H(v) = E_sails_sum_WB2H(v)/time_Hamburg_Walvis_Bay; % [W] - power

% 3 - Used for plot of Percent Energy/Power from Sails Vs Speed
```

```
E_saved_WB2H(v) = E_sails_sum_WB2H(v)/E_req_total_WB2H(v)*100; % [%] - percent energy/power

%% Calculate amount of fuel needed[t], volume needed[m^3], fuel saved[t], CO2 saved[t], and euro saved[€] per trip
% 4 - Used for plot of Fuel Mass Required Vs Speed per trip
HFSO_mass_WB2H(v) = (E_req_total_WB2H(v)/HSFO_Spec_Energy)...
    /HSFO_eta_combustion/1000; % [t] - combustion
VLSFO_mass_WB2H(v) = (E_req_total_WB2H(v)/VLSFO_Spec_Energy)...
    /VLSFO_eta_combustion/1000; % [t] - combustion
LNG_mass_WB2H(v) = (E_req_total_WB2H(v)/LNG_Spec_Energy)...
    /LNG_eta_combustion/1000; % [t] - combustion
LH2_mass_WB2H(v) = (E_req_total_WB2H(v)/LH2_Spec_Energy)...
    /LH2_eta_combustion/1000; % [t] - combustion
LH2_mass_FC_WB2H(v) = (E_req_total_WB2H(v)/LH2_Spec_Energy)...
    /LH2_eta_fuel_cell/1000; % [t] - fuel cells
LNH3_mass_WB2H(v) = (E_req_total_WB2H(v)/LNH3_Spec_Energy)...
    /LNH3_eta_combustion/1000; % [t] - combustion
LNH3_mass_FC_WB2H(v) = (E_req_total_WB2H(v)/LNH3_Spec_Energy)...
    /LNH3_eta_fuel_cell/1000; % [t] - fuel cells

% 5 - Used for plot of Fuel Volume Required Vs Speed per trip
HFSO_vol_WB2H(v) = HFSO_mass_WB2H(v)/(HSFO_Density/1000); % [m^3] - combustion
VLSFO_vol_WB2H(v) = VLSFO_mass_WB2H(v)/(VLSFO_Density/1000); % [m^3] - combustion
LNG_vol_WB2H(v) = LNG_mass_WB2H(v)/(LNG_Density/1000); % [m^3] - combustion
LH2_vol_WB2H(v) = LH2_mass_WB2H(v)/(LH2_Density/1000); % [m^3] - combustion
LH2_vol_FC_WB2H(v) = LH2_mass_FC_WB2H(v)/(LH2_Density/1000); % [m^3] - fuel cells
LNH3_vol_WB2H(v) = LNH3_mass_WB2H(v)/(LNH3_Density/1000); % [m^3] - combustion
LNH3_vol_FC_WB2H(v) = LNH3_mass_FC_WB2H(v)/(LNH3_Density/1000); % [m^3] - fuel cells

% 6 - Used for plot of Fuel Mass Saved from Sails Vs Speed per trip
HFSO_mass_saved_WB2H(v) = HFSO_mass_WB2H(v)*E_saved_WB2H(v)/100; % [t] - combustion
VLSFO_mass_saved_WB2H(v) = VLSFO_mass_WB2H(v)*E_saved_WB2H(v)/100; % [t] - combustion
LNG_mass_saved_WB2H(v) = LNG_mass_WB2H(v)*E_saved_WB2H(v)/100; % [t] - combustion
LH2_mass_saved_WB2H(v) = LH2_mass_WB2H(v)*E_saved_WB2H(v)/100; % [t] - combustion
LH2_mass_saved_FC_WB2H(v) = LH2_mass_FC_WB2H(v)*E_saved_WB2H(v)/100; % [t] - fuel cells
LNH3_mass_saved_WB2H(v) = LNH3_mass_WB2H(v)*E_saved_WB2H(v)/100; % [t] - combustion
LNH3_mass_saved_FC_WB2H(v) = LNH3_mass_FC_WB2H(v)*E_saved_WB2H(v)/100; % [t] - fuel cells

% 7 - Used for plot of CO2 Saved from Sails Vs Speed per trip
HFSO_CO2_saved_WB2H(v) = HFSO_mass_saved_WB2H(v)*HSFO_tCO2; % [t] - combustion
VLSFO_CO2_saved_WB2H(v) = VLSFO_mass_saved_WB2H(v)*VLSFO_tCO2; % [t] - combustion
LNG_CO2_saved_WB2H(v) = LNG_mass_saved_WB2H(v)*LNG_tCO2; % [t] - combustion
```

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% 8 - Used for plot of Euros Saved from Sails Vs Speed per trip
HFSO_euro_saved_WB2H(v) = HFSO_mass_saved_WB2H(v)*HSFO_cost; % [€] - savings per trip
VLSFO_euro_saved_WB2H(v) = VLSFO_mass_saved_WB2H(v)*VLSFO_cost; % [€] - savings per trip
LNG_euro_saved_WB2H(v) = LNG_mass_saved_WB2H(v)*LNG_cost; % [€] - savings per trip
LH2_euro_saved_WB2H(v) = LH2_mass_saved_WB2H(v)*LH2_cost; % [€] - savings per trip
LH2_euro_saved_FC_WB2H(v) = LH2_mass_saved_FC_WB2H(v)*LH2_cost; % [€] - savings per trip
LNH3_euro_saved_WB2H(v) = LNH3_mass_saved_WB2H(v)*LNH3_cost; % [€] - savings per trip
LNH3_euro_saved_FC_WB2H(v) = LNH3_mass_saved_FC_WB2H(v)*LNH3_cost; % [€] - savings per trip

% %% -------------------- HAMBURG-TO-WALVIS-BAY-ROUND-TRIP----------------- %%
%% Calculate energy savings using sails
% 1 - Used for plot of Average Power from Sails Vs Speed
% 2 - Used for plot of AVG Power from Sails and Required Propulsive Power Vs Speed
P_avg_H2WBRT(v) = (P_avg_H2WB(v)+P_avg_WB2H(v))/2; % [W] - power

% 3 - Used for plot of Percent Energy/Power from Sails Vs Speed
E_saved_H2WBRT(v) = (E_saved_H2WB(v)+E_saved_WB2H(v))/2; % [%] - percent energy/power

%% Calculate amount of fuel needed[t], volume needed[m^3], fuel saved[t], CO2 saved[t], and euro saved[] per ROUND trip
% 4 - Used for plot of Fuel Mass Required Vs Speed per trip
HFSO_mass_H2WBRT(v) = HFSO_mass_H2WB(v)+HFSO_mass_WB2H(v); % [t] - combustion
VLSFO_mass_H2WBRT(v) = VLSFO_mass_H2WB(v)+VLSFO_mass_WB2H(v); % [t] - combustion
LNG_mass_H2WBRT(v) = LNG_mass_H2WB(v)+LNG_mass_WB2H(v); % [t] - combustion
LH2_mass_H2WBRT(v) = LH2_mass_H2WB(v)+LH2_mass_WB2H(v); % [t] - combustion
LH2_mass_FC_H2WBRT(v) = LH2_mass_FC_H2WB(v)+LH2_mass_FC_WB2H(v); % [t] - fuel cells
LNH3_mass_H2WBRT(v) = LNH3_mass_H2WB(v)+LNH3_mass_WB2H(v); % [t] - combustion
LNH3_mass_FC_H2WBRT(v) = LNH3_mass_FC_H2WB(v)+LNH3_mass_FC_WB2H(v); % [t] - fuel cells

% 5 - Used for plot of Fuel Volume Required Vs Speed per trip
HFSO_vol_H2WBRT(v) = HFSO_vol_H2WB(v)+HFSO_vol_WB2H(v); % [m^3] - combustion
VLSFO_vol_H2WBRT(v) = VLSFO_vol_H2WB(v)+VLSFO_vol_WB2H(v); % [m^3] - combustion
LNG_vol_H2WBRT(v) = LNG_vol_H2WB(v)+LNG_vol_WB2H(v); % [m^3] - combustion
LH2_vol_H2WBRT(v) = LH2_vol_H2WB(v)+LH2_vol_WB2H(v); % [m^3] - combustion
LH2_vol_FC_H2WBRT(v) = LH2_vol_FC_H2WB(v)+LH2_vol_FC_WB2H(v); % [m^3] - fuel cells
LNH3_vol_H2WBRT(v) = LNH3_vol_H2WB(v)+LNH3_vol_WB2H(v); % [m^3] - combustion
LNH3_vol_FC_H2WBRT(v) = LNH3_vol_FC_H2WB(v)+LNH3_vol_FC_WB2H(v); % [m^3] - fuel cells

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```
% 6 - Used for plot of Fuel Mass Saved from Sails Vs Speed per trip
HFSO_mass_saved_H2WBRT(v) = HFSO_mass_saved_H2WB(v)+HFSO_mass_saved_WB2H(v); % [t] - combustion
VLSFO_mass_saved_H2WBRT(v) = VLSFO_mass_saved_H2WB(v)+VLSFO_mass_saved_WB2H(v); % [t] - combustion
LNG_mass_saved_H2WBRT(v) = LNG_mass_saved_H2WB(v)+LNG_mass_saved_WB2H(v); % [t] - combustion
LH2_mass_saved_H2WBRT(v) = LH2_mass_saved_H2WB(v)+LH2_mass_saved_WB2H(v); % [t] - combustion
LH2_mass_saved_FC_H2WBRT(v) = LH2_mass_saved_FC_H2WB(v)+LH2_mass_saved_FC_WB2H(v); % [t] - fuel cells
LNH3_mass_saved_H2WBRT(v) = LNH3_mass_saved_H2WB(v)+LNH3_mass_saved_WB2H(v); % [t] - combustion
LNH3_mass_saved_FC_H2WBRT(v) = LNH3_mass_saved_FC_H2WB(v)+LNH3_mass_saved_FC_WB2H(v); % [t] - fuel cells

% 7 - Used for plot of CO2 Saved from Sails Vs Speed per trip
HFSO_CO2_saved_H2WBRT(v) = HFSO_CO2_saved_H2WB(v)+HFSO_CO2_saved_WB2H(v); % [t] - combustion
VLSFO_CO2_saved_H2WBRT(v) = VLSFO_CO2_saved_H2WB(v)+VLSFO_CO2_saved_WB2H(v); % [t] - combustion
LNG_CO2_saved_H2WBRT(v) = LNG_CO2_saved_H2WB(v)+LNG_CO2_saved_WB2H(v); % [t] - combustion

% 8 - Used for plot of Euros Saved from Sails Vs Speed per trip
HFSO_euro_saved_H2WBRT(v) = HFSO_euro_saved_H2WB(v)+HFSO_euro_saved_WB2H(v); % [€] - savings per trip
VLSFO_euro_saved_H2WBRT(v) = VLSFO_euro_saved_H2WB(v)+VLSFO_euro_saved_WB2H(v); % [€] - savings per trip
LNG_euro_saved_H2WBRT(v) = LNG_euro_saved_H2WB(v)+LNG_euro_saved_WB2H(v); % [€] - savings per trip
LH2_euro_saved_H2WBRT(v) = LH2_euro_saved_H2WB(v)+LH2_euro_saved_WB2H(v); % [€] - savings per trip
LH2_euro_saved_FC_H2WBRT(v) = LH2_euro_saved_FC_H2WB(v)+LH2_euro_saved_FC_WB2H(v); % [€] - savings per trip
LNH3_euro_saved_H2WBRT(v) = LNH3_euro_saved_H2WB(v)+LNH3_euro_saved_WB2H(v); % [€] - savings per trip
LNH3_euro_saved_FC_H2WBRT(v) = LNH3_euro_saved_FC_H2WB(v)+LNH3_euro_saved_FC_WB2H(v); % [€] - savings per trip

%% Calculate yearly and service life savings for fuel [t], CO2 [t], Euro[€]
% 9 - Used for plot of Fuel Mass Saved from Sails Vs Speed per YEAR
HFSO_mass_saved_H2WBRT_yr(v) = HFSO_mass_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
VLSFO_mass_saved_H2WBRT_yr(v) = VLSFO_mass_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
LNG_mass_saved_H2WBRT_yr(v) = LNG_mass_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
LH2_mass_saved_H2WBRT_yr(v) = LH2_mass_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
LH2_mass_saved_FC_H2WBRT_yr(v) = LH2_mass_saved_FC_H2WBRT(v)*trips_annual_H2WB(v); % [t] - fuel cells
LNH3_mass_saved_H2WBRT_yr(v) = LNH3_mass_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
LNH3_mass_saved_FC_H2WBRT_yr(v) = LNH3_mass_saved_FC_H2WBRT(v)*trips_annual_H2WB(v); % [t] - fuel cells
```

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% 10 - Used for plot of CO2 Saved from Sails Vs Speed per YEAR
HFSO_CO2_saved_H2WBRT_yr(v) = HFSO_CO2_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
VLSFO_CO2_saved_H2WBRT_yr(v) = VLSFO_CO2_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion
LNG_CO2_saved_H2WBRT_yr(v) = LNG_CO2_saved_H2WBRT(v)*trips_annual_H2WB(v); % [t] - combustion

% 11 - Used for plot of Euros Saved from Sails Vs Speed per YEAR
HFSO_euro_saved_H2WBRT_yr(v) = HFSO_euro_saved_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
VLSFO_euro_saved_H2WBRT_yr(v) = VLSFO_euro_saved_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
LNG_euro_saved_H2WBRT_yr(v) = LNG_euro_saved_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
LH2_euro_saved_H2WBRT_yr(v) = LH2_euro_saved_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
LH2_euro_saved_FC_H2WBRT_yr(v) = LH2_euro_saved_FC_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
LNH3_euro_saved_H2WBRT_yr(v) = LNH3_euro_saved_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip
LNH3_euro_saved_FC_H2WBRT_yr(v) = LNH3_euro_saved_FC_H2WBRT(v)*trips_annual_H2WB(v); % [€] - savings per trip

% 12 - Used for plot of Fuel Mass Saved from Sails Vs Speed (SERVICE LIFE)
HFSO_mass_saved_H2WBRT_SL(v) = HFSO_mass_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
VLSFO_mass_saved_H2WBRT_SL(v) = VLSFO_mass_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
LNG_mass_saved_H2WBRT_SL(v) = LNG_mass_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
LH2_mass_saved_H2WBRT_SL(v) = LH2_mass_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
LH2_mass_saved_FC_H2WBRT_SL(v) = LH2_mass_saved_FC_H2WBRT_yr(v)*service_life(v); % [t] - fuel cells
LNH3_mass_saved_H2WBRT_SL(v) = LNH3_mass_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
LNH3_mass_saved_FC_H2WBRT_SL(v) = LNH3_mass_saved_FC_H2WBRT_yr(v)*service_life(v); % [t] - fuel cells

% 13 - Used for plot of CO2 Saved from Sails Vs Speed (SERVICE LIFE)
HFSO_CO2_saved_H2WBRT_SL(v) = HFSO_CO2_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
VLSFO_CO2_saved_H2WBRT_SL(v) = VLSFO_CO2_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion
LNG_CO2_saved_H2WBRT_SL(v) = LNG_CO2_saved_H2WBRT_yr(v)*service_life(v); % [t] - combustion

% 14 - Used for plot of Euros Saved from Sails Vs Speed (SERVICE LIFE)
HFSO_euro_saved_H2WBRT_SL(v) = HFSO_euro_saved_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
VLSFO_euro_saved_H2WBRT_SL(v) = VLSFO_euro_saved_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
LNG_euro_saved_H2WBRT_SL(v) = LNG_euro_saved_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
```

```
LH2_euro_saved_H2WBRT_SL(v) = LH2_euro_saved_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
LH2_euro_saved_FC_H2WBRT_SL(v) = LH2_euro_saved_FC_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
LNH3_euro_saved_H2WBRT_SL(v) = LNH3_euro_saved_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip
LNH3_euro_saved_FC_H2WBRT_SL(v) = LNH3_euro_saved_FC_H2WBRT_yr(v)*service_life(v); % [€] - savings per trip

% Calculate Net Present Value (NPV)
HFSO_NPV_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((HFSO_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
VLSFO_NPV_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((VLSFO_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
LNG_NPV_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((LNG_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
LH2_NPV_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((LH2_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
LH2_NPV_FC_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((LH2_euro_saved_FC_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
LNH3_NPV_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((LNH3_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV
LNH3_NPV_FC_H2WBRT(v) = (-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    +service_life(v)*((LNH3_euro_saved_FC_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost))+(0.3*nSails*construction_cost);% [€] - NPV

% Calculate Simple Payback Period (SPP)
HFSO_SPP_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((HFSO_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
VLSFO_SPP_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
```

```
    /((VLSFO_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
LNG_SPP_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((LNG_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
LH2_SPP_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((LH2_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
LH2_SPP_FC_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((LH2_euro_saved_FC_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
LNH3_SPP_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((LNH3_euro_saved_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
LNH3_SPP_FC_H2WBRT(v) = abs((-nSails*developement_cost-nSails*construction_cost...
    -nSails*install_cost-nSails*training_cost)...
    /((LNH3_euro_saved_FC_H2WBRT_yr(v))-0.10*(nSails*construction_cost...
    +nSails*install_cost)));
end



%% -------------------- HAMBURG-TO-VALPARAISO-ROUND-TRIP----------------%%
% Calculate per trip, yearly and lifetime savings for fuel [t], CO2 [t], Euro[€]

% Calculate Net Present Value (NPV)

% Calculate Simple Payback Period (SPP)

%% ------------------------------ XFOIL-Plots---------------------------%%
% Ideal Angle of Attack Change VS Wind Speed
figure(1) % 1-XFOIL_Ideal_A0A_Vs_Wind_Speed
plot(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.AoA,'b.',MarkerSize=9)
hold on
AoA_Pfit = polyfit(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.AoA,2);
AoA_Pval = polyval(AoA_Pfit,round(XFOIL_Ideal.vWind/.514,0));
plot(round(XFOIL_Ideal.vWind/.514,0),AoA_Pval,'k-')
xlabel('Wind Speed [Knots]')
xlim([0,50])
ylim([0,15])
ylabel('Ideal Angle of Attack [\circ]')
title('XFOIL: Ideal Angle of Attack VS Wind Speed')
legend('AoA data','',Location='southoutside')

% Ideal CL/CD VS Wind Speed
figure(2) % 2-XFOIL_Ideal_CL_Vs_Wind_Speed
plot(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.CLoCD,'b.',MarkerSize=9)
```

```
hold on
CLoCD_Pfit = polyfit(round(XFOIL_Ideal.vWind(2:end)/.514,0),XFOIL_Ideal.CLoCD(2:end),4);
CLoCD_Pval = polyval(CLoCD_Pfit,round(XFOIL_Ideal.vWind(2:end)/.514,0));
plot(round(XFOIL_Ideal.vWind(2:end)/.514,0),CLoCD_Pval,'k-')
xlabel('Wind Speed [Knots]')
ylabel('CL/CD [-]')
title('XFOIL: Lift Divided by Drag VS Wind Speed')
legend('CL/CD data','',Location='southoutside')

% Ideal CL VS Wind Speed
figure(3) % 3-XFOIL_Ideal_CD_Vs_Wind_Speed
plot(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.CL,'b.',MarkerSize=9)
hold on
CL_Pfit = polyfit(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.CL,2);
CL_Pval = polyval(CL_Pfit,round(XFOIL_Ideal.vWind/.514,0));
plot(round(XFOIL_Ideal.vWind/.514,0),CL_Pval,'k-')
xlabel('Wind Speed [Knots]')
ylabel('CL [-]')
title('XFOIL: Coefficient of Lift VS Wind Speed')
legend('CL data','',Location='southoutside')

% Ideal CD VS Wind Speed
figure(4) % 4-XFOIL_Ideal_CLoCD_Vs_Wind_Speed
plot(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.CD*10^2,'b.',MarkerSize=9)
hold on
CD_Pfit = polyfit(round(XFOIL_Ideal.vWind/.514,0),XFOIL_Ideal.CD*10^2,2);
CD_Pval = polyval(CD_Pfit,round(XFOIL_Ideal.vWind/.514,0));
plot(round(XFOIL_Ideal.vWind/.514,0),CD_Pval,'k-')
xlabel('Wind Speed [Knots]')
ylabel('CD x 10^2 [-]')
title('XFOIL: Coefficient of Drag VS Wind Speed')
legend('CD data','',Location='southoutside')

% --------------------- HAMBURG-TO-WALVIS-BAY-PLOTS---------------------%%
%plot of Average Power from Sails Vs Speed
figure(5) % 5-H2WB_Avg_Pwr_Sails_VS_Speed
plot(vAnalysis,P_avg_H2WB/1000,'b.',MarkerSize=9)
hold on
P_avg_H2WBfit = polyfit(vAnalysis,P_avg_H2WB/1000,5);
P_avg_H2WBval = polyval(P_avg_H2WBfit,vAnalysis);
plot(vAnalysis,P_avg_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Sail Power [kW]')
title({'Hamburg to Walvis Bay','Average Power from Sails VS Speed'})

%plot of Required and Average Sail Power VS Speed
figure(6) % 6-H2WB_Req_and_Sail_Pwr_VS_Speed
plot(vAnalysis,P_avg_H2WB/1000,'b.',MarkerSize=9)
hold on
P_avg_H2WBfit = polyfit(vAnalysis,P_avg_H2WB/1000,3);
P_avg_H2WBval = polyval(P_avg_H2WBfit,vAnalysis);
plot(vAnalysis,P_avg_H2WBval,'k-')

plot(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),'g.',MarkerSize=9)
Vessel_RandPfit = polyfit(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),3);
Vessel_RandPval = polyval(Vessel_RandPfit,vAnalysis);
```

```
plot(vAnalysis,Vessel_RandPval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Power [kW]')
title({'Hamburg to Walvis Bay','Required and Average Sail Power VS Speed'})
legend('Average Power (Sails)','','Power (Required)','','Location','southoutside')

%plot of Percent Power/Energy from Sails Vs Speed
figure(7) % 7-H2WB_Percent_Energy_Sails_VS_Speed
plot(vAnalysis,E_saved_H2WB,'b.',MarkerSize=9)
hold on
E_saved_H2WBfit = polyfit(vAnalysis,E_saved_H2WB,3);
E_saved_H2WBval = polyval(E_saved_H2WBfit,vAnalysis);
plot(vAnalysis,E_saved_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Energy/Power from Sails [%]')
title({'Hamburg to Walvis Bay','Energy/Power from Sails VS Speed'})

%plot Fuel Mass Required Vs Speed per trip
%HFSO
figure(8) % 8-H2WB_Fuel_Mass_VS_Speed
plot(vAnalysis,HFSO_mass_H2WB,'b.',MarkerSize=9)
hold on
HFSO_mass_H2WBfit = polyfit(vAnalysis,HFSO_mass_H2WB,3);
HFSO_mass_H2WBval = polyval(HFSO_mass_H2WBfit,vAnalysis);
plot(vAnalysis,HFSO_mass_H2WBval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_H2WB,'g.',MarkerSize=9)
VLSFO_mass_H2WBfit = polyfit(vAnalysis,VLSFO_mass_H2WB,3);
VLSFO_mass_H2WBval = polyval(VLSFO_mass_H2WBfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_H2WBval,'k-')
%LNG
plot(vAnalysis,LNG_mass_H2WB,'c.',MarkerSize=9)
hold on
LNG_mass_H2WBfit = polyfit(vAnalysis,LNG_mass_H2WB,3);
LNG_mass_H2WBval = polyval(LNG_mass_H2WBfit,vAnalysis);
plot(vAnalysis,LNG_mass_H2WBval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_H2WB,'m.',MarkerSize=9)
hold on
LH2_mass_H2WBfit = polyfit(vAnalysis,LH2_mass_H2WB,3);
LH2_mass_H2WBval = polyval(LH2_mass_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_mass_H2WBval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_FC_H2WB,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_FC_H2WBfit = polyfit(vAnalysis,LH2_mass_FC_H2WB,3);
LH2_mass_FC_H2WBval = polyval(LH2_mass_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_mass_FC_H2WBval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_H2WB,'r.',MarkerSize=9)
hold on
LNH3_mass_H2WBfit = polyfit(vAnalysis,LNH3_mass_H2WB,3);
LNH3_mass_H2WBval = polyval(LNH3_mass_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_mass_H2WBval,'k-')
%LNH3 - Fuel Cell
```

```
plot(vAnalysis,LNH3_mass_FC_H2WB,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_FC_H2WBfit = polyfit(vAnalysis,LNH3_mass_FC_H2WB,3);
LNH3_mass_FC_H2WBval = polyval(LNH3_mass_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_mass_FC_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay','Fuel Mass Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Volume Required Vs Speed per trip
%HFSO
figure(9) % 9-H2WB_Fuel_Volume_VS_Speed
plot(vAnalysis,HFSO_vol_H2WB,'b.',MarkerSize=9)
hold on
HFSO_vol_H2WBfit = polyfit(vAnalysis,HFSO_vol_H2WB,3);
HFSO_vol_H2WBval = polyval(HFSO_vol_H2WBfit,vAnalysis);
plot(vAnalysis,HFSO_vol_H2WBval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_vol_H2WB,'g.',MarkerSize=9)
VLSFO_vol_H2WBfit = polyfit(vAnalysis,VLSFO_vol_H2WB,3);
VLSFO_vol_H2WBval = polyval(VLSFO_vol_H2WBfit,vAnalysis);
plot(vAnalysis,VLSFO_vol_H2WBval,'k-')
%LNG
plot(vAnalysis,LNG_vol_H2WB,'c.',MarkerSize=9)
hold on
LNG_vol_H2WBfit = polyfit(vAnalysis,LNG_vol_H2WB,3);
LNG_vol_H2WBval = polyval(LNG_vol_H2WBfit,vAnalysis);
plot(vAnalysis,LNG_vol_H2WBval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_vol_H2WB,'m.',MarkerSize=9)
hold on
LH2_vol_H2WBfit = polyfit(vAnalysis,LH2_vol_H2WB,3);
LH2_vol_H2WBval = polyval(LH2_vol_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_vol_H2WBval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_vol_FC_H2WB,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_vol_FC_H2WBfit = polyfit(vAnalysis,LH2_vol_FC_H2WB,3);
LH2_vol_FC_H2WBval = polyval(LH2_vol_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_vol_FC_H2WBval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_vol_H2WB,'r.',MarkerSize=9)
hold on
LNH3_vol_H2WBfit = polyfit(vAnalysis,LNH3_vol_H2WB,3);
LNH3_vol_H2WBval = polyval(LNH3_vol_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_vol_H2WBval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_vol_FC_H2WB,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_vol_FC_H2WBfit = polyfit(vAnalysis,LNH3_vol_FC_H2WB,3);
LNH3_vol_FC_H2WBval = polyval(LNH3_vol_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_vol_FC_H2WBval,'k-')
```

```
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Volume [m^3]')
title({'Hamburg to Walvis Bay','Fuel Volume Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Mass Saved from Sails Vs Speed per trip
%HFSO
figure(10) % 10-H2WB_Fuel_Mass_Saved_VS_Speed
plot(vAnalysis,HFSO_mass_saved_H2WB,'b.',MarkerSize=9)
hold on
HFSO_mass_saved_H2WBfit = polyfit(vAnalysis,HFSO_mass_saved_H2WB,3);
HFSO_mass_saved_H2WBval = polyval(HFSO_mass_saved_H2WBfit,vAnalysis);
plot(vAnalysis,HFSO_mass_saved_H2WBval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_saved_H2WB,'g.',MarkerSize=9)
VLSFO_mass_saved_H2WBfit = polyfit(vAnalysis,VLSFO_mass_saved_H2WB,3);
VLSFO_mass_saved_H2WBval = polyval(VLSFO_mass_saved_H2WBfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_saved_H2WBval,'k-')
%LNG
plot(vAnalysis,LNG_mass_saved_H2WB,'c.',MarkerSize=9)
hold on
LNG_mass_saved_H2WBfit = polyfit(vAnalysis,LNG_mass_saved_H2WB,3);
LNG_mass_saved_H2WBval = polyval(LNG_mass_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LNG_mass_saved_H2WBval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_saved_H2WB,'m.',MarkerSize=9)
hold on
LH2_mass_saved_H2WBfit = polyfit(vAnalysis,LH2_mass_saved_H2WB,3);
LH2_mass_saved_H2WBval = polyval(LH2_mass_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_H2WBval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_saved_FC_H2WB,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_saved_FC_H2WBfit = polyfit(vAnalysis,LH2_mass_saved_FC_H2WB,3);
LH2_mass_saved_FC_H2WBval = polyval(LH2_mass_saved_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_FC_H2WBval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_saved_H2WB,'r.',MarkerSize=9)
hold on
LNH3_mass_saved_H2WBfit = polyfit(vAnalysis,LNH3_mass_saved_H2WB,3);
LNH3_mass_saved_H2WBval = polyval(LNH3_mass_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_H2WBval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_saved_FC_H2WB,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_saved_FC_H2WBfit = polyfit(vAnalysis,LNH3_mass_saved_FC_H2WB,3);
LNH3_mass_saved_FC_H2WBval = polyval(LNH3_mass_saved_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_FC_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay','Fuel Mass Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')
```

```

%plot of CO2 Saved from Sails Vs Speed per trip
%HFSO
figure(11) % 11-H2WB_CO2_Emissions_Saved_VS_Speed
plot(vAnalysis,HFSO_CO2_saved_H2WB,'b.',MarkerSize=9)
hold on
HFSO_CO2_saved_H2WBfit = polyfit(vAnalysis,HFSO_CO2_saved_H2WB,5);
HFSO_CO2_saved_H2WBval = polyval(HFSO_CO2_saved_H2WBfit,vAnalysis);
plot(vAnalysis,HFSO_CO2_saved_H2WBval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_CO2_saved_H2WB,'g.',MarkerSize=9)
VLSFO_CO2_saved_H2WBfit = polyfit(vAnalysis,VLSFO_CO2_saved_H2WB,5);
VLSFO_CO2_saved_H2WBval = polyval(VLSFO_CO2_saved_H2WBfit,vAnalysis);
plot(vAnalysis,VLSFO_CO2_saved_H2WBval,'k-')
%LNG
plot(vAnalysis,LNG_CO2_saved_H2WB,'c.',MarkerSize=9)
hold on
LNG_CO2_saved_H2WBfit = polyfit(vAnalysis,LNG_CO2_saved_H2WB,5);
LNG_CO2_saved_H2WBval = polyval(LNG_CO2_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LNG_CO2_saved_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('CO_2 Emissions Saved [tonnes]')
title({'Hamburg to Walvis Bay','CO_2 Emissions Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','',Location='eastoutside')

%plot of Euros Saved from Sails Vs Speed per trip
%HFSO
figure(12) % 12-H2WB_Euro_Saved_VS_Speed
plot(vAnalysis,HFSO_euro_saved_H2WB,'b.',MarkerSize=9)
hold on
HFSO_euro_saved_H2WBfit = polyfit(vAnalysis,HFSO_euro_saved_H2WB,3);
HFSO_euro_saved_H2WBval = polyval(HFSO_euro_saved_H2WBfit,vAnalysis);
plot(vAnalysis,HFSO_euro_saved_H2WBval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_euro_saved_H2WB,'g.',MarkerSize=9)
VLSFO_euro_saved_H2WBfit = polyfit(vAnalysis,VLSFO_euro_saved_H2WB,3);
VLSFO_euro_saved_H2WBval = polyval(VLSFO_euro_saved_H2WBfit,vAnalysis);
plot(vAnalysis,VLSFO_euro_saved_H2WBval,'k-')
%LNG
plot(vAnalysis,LNG_euro_saved_H2WB,'c.',MarkerSize=9)
hold on
LNG_euro_saved_H2WBfit = polyfit(vAnalysis,LNG_euro_saved_H2WB,3);
LNG_euro_saved_H2WBval = polyval(LNG_euro_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LNG_euro_saved_H2WBval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_euro_saved_H2WB,'m.',MarkerSize=9)
hold on
LH2_euro_saved_H2WBfit = polyfit(vAnalysis,LH2_euro_saved_H2WB,3);
LH2_euro_saved_H2WBval = polyval(LH2_euro_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_H2WBval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_euro_saved_FC_H2WB,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_euro_saved_FC_H2WBfit = polyfit(vAnalysis,LH2_euro_saved_FC_H2WB,3);
LH2_euro_saved_FC_H2WBval = polyval(LH2_euro_saved_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_FC_H2WBval,'k-')
%LNH3 - Combustion
```

```
plot(vAnalysis,LNH3_euro_saved_H2WB,'r.',MarkerSize=9)
hold on
LNH3_euro_saved_H2WBfit = polyfit(vAnalysis,LNH3_euro_saved_H2WB,3);
LNH3_euro_saved_H2WBval = polyval(LNH3_euro_saved_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_H2WBval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_euro_saved_FC_H2WB,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_euro_saved_FC_H2WBfit = polyfit(vAnalysis,LNH3_euro_saved_FC_H2WB,3);
LNH3_euro_saved_FC_H2WBval = polyval(LNH3_euro_saved_FC_H2WBfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_FC_H2WBval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' Financial Incentive [€]')
title({'Hamburg to Walvis Bay','€ Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%% --------------------- WALVIS-BAY-TO-HAMBURG-PLOTS---------------------%%
%plot of Average Power from Sails Vs Speed
figure(13) % 13-WB2H_Avg_Pwr_Sails_VS_Speed
plot(vAnalysis,P_avg_WB2H/1000,'b.',MarkerSize=9)
hold on
P_avg_WB2Hfit = polyfit(vAnalysis,P_avg_WB2H/1000,5);
P_avg_WB2Hval = polyval(P_avg_WB2Hfit,vAnalysis);
plot(vAnalysis,P_avg_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Sail Power [kW]')
title({'Walvis Bay to Hamburg','Average Power from Sails VS Speed'})

%plot of Required and Average Sail Power VS Speed
figure(14) % 14-WB2H_Req_and_Sail_Pwr_VS_Speed
plot(vAnalysis,P_avg_WB2H/1000,'b.',MarkerSize=9)
hold on
P_avg_WB2Hfit = polyfit(vAnalysis,P_avg_WB2H/1000,3);
P_avg_WB2Hval = polyval(P_avg_WB2Hfit,vAnalysis);
plot(vAnalysis,P_avg_WB2Hval,'k-')

plot(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),'g.',MarkerSize=9)
Vessel_RandPfit = polyfit(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),3);
Vessel_RandPval = polyval(Vessel_RandPfit,vAnalysis);
plot(vAnalysis,Vessel_RandPval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Power [kW]')
title({'Walvis Bay to Hamburg','Required and Average Sail Power VS Speed'})
legend('Average Power (Sails)','','Power (Required)','','Location','southoutside')

%plot of Percent Power/Energy from Sails Vs Speed
figure(15) % 15-WB2H_Percent_Energy_Sails_VS_Speed
plot(vAnalysis,E_saved_WB2H,'b.',MarkerSize=9)
hold on
E_saved_WB2Hfit = polyfit(vAnalysis,E_saved_WB2H,3);
E_saved_WB2Hval = polyval(E_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,E_saved_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
```

```
ylabel('Energy/Power from Sails [%]')
title({'Walvis Bay to Hamburg','Energy/Power from Sails VS Speed'})

%plot Fuel Mass Required Vs Speed per trip
%HFSO
figure(16) % 16-WB2H_Fuel_Mass_VS_Speed
plot(vAnalysis,HFSO_mass_WB2H,'b.',MarkerSize=9)
hold on
HFSO_mass_WB2Hfit = polyfit(vAnalysis,HFSO_mass_WB2H,3);
HFSO_mass_WB2Hval = polyval(HFSO_mass_WB2Hfit,vAnalysis);
plot(vAnalysis,HFSO_mass_WB2Hval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_WB2H,'g.',MarkerSize=9)
VLSFO_mass_WB2Hfit = polyfit(vAnalysis,VLSFO_mass_WB2H,3);
VLSFO_mass_WB2Hval = polyval(VLSFO_mass_WB2Hfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_WB2Hval,'k-')
%LNG
plot(vAnalysis,LNG_mass_WB2H,'c.',MarkerSize=9)
hold on
LNG_mass_WB2Hfit = polyfit(vAnalysis,LNG_mass_WB2H,3);
LNG_mass_WB2Hval = polyval(LNG_mass_WB2Hfit,vAnalysis);
plot(vAnalysis,LNG_mass_WB2Hval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_WB2H,'m.',MarkerSize=9)
hold on
LH2_mass_WB2Hfit = polyfit(vAnalysis,LH2_mass_WB2H,3);
LH2_mass_WB2Hval = polyval(LH2_mass_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_mass_WB2Hval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_FC_WB2H,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_FC_WB2Hfit = polyfit(vAnalysis,LH2_mass_FC_WB2H,3);
LH2_mass_FC_WB2Hval = polyval(LH2_mass_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_mass_FC_WB2Hval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_WB2H,'r.',MarkerSize=9)
hold on
LNH3_mass_WB2Hfit = polyfit(vAnalysis,LNH3_mass_WB2H,3);
LNH3_mass_WB2Hval = polyval(LNH3_mass_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_mass_WB2Hval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_FC_WB2H,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_FC_WB2Hfit = polyfit(vAnalysis,LNH3_mass_FC_WB2H,3);
LNH3_mass_FC_WB2Hval = polyval(LNH3_mass_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_mass_FC_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Walvis Bay to Hamburg','Fuel Mass Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Volume Required Vs Speed per trip
%HFSO
figure(17) % 17-WB2H_Fuel_Volume_VS_Speed
```

```
plot(vAnalysis,HFSO_vol_WB2H,'b.',MarkerSize=9)
hold on
HFSO_vol_WB2Hfit = polyfit(vAnalysis,HFSO_vol_WB2H,3);
HFSO_vol_WB2Hval = polyval(HFSO_vol_WB2Hfit,vAnalysis);
plot(vAnalysis,HFSO_vol_WB2Hval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_vol_WB2H,'g.',MarkerSize=9)
VLSFO_vol_WB2Hfit = polyfit(vAnalysis,VLSFO_vol_WB2H,3);
VLSFO_vol_WB2Hval = polyval(VLSFO_vol_WB2Hfit,vAnalysis);
plot(vAnalysis,VLSFO_vol_WB2Hval,'k-')
%LNG
plot(vAnalysis,LNG_vol_WB2H,'c.',MarkerSize=9)
hold on
LNG_vol_WB2Hfit = polyfit(vAnalysis,LNG_vol_WB2H,3);
LNG_vol_WB2Hval = polyval(LNG_vol_WB2Hfit,vAnalysis);
plot(vAnalysis,LNG_vol_WB2Hval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_vol_WB2H,'m.',MarkerSize=9)
hold on
LH2_vol_WB2Hfit = polyfit(vAnalysis,LH2_vol_WB2H,3);
LH2_vol_WB2Hval = polyval(LH2_vol_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_vol_WB2Hval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_vol_FC_WB2H,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_vol_FC_WB2Hfit = polyfit(vAnalysis,LH2_vol_FC_WB2H,3);
LH2_vol_FC_WB2Hval = polyval(LH2_vol_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_vol_FC_WB2Hval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_vol_WB2H,'r.',MarkerSize=9)
hold on
LNH3_vol_WB2Hfit = polyfit(vAnalysis,LNH3_vol_WB2H,3);
LNH3_vol_WB2Hval = polyval(LNH3_vol_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_vol_WB2Hval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_vol_FC_WB2H,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_vol_FC_WB2Hfit = polyfit(vAnalysis,LNH3_vol_FC_WB2H,3);
LNH3_vol_FC_WB2Hval = polyval(LNH3_vol_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_vol_FC_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Volume [m^3]')
title({'Walvis Bay to Hamburg','Fuel Volume Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Mass Saved from Sails Vs Speed per trip
%HFSO
figure(18) % 18-WB2H_Fuel_Mass_Saved_VS_Speed
plot(vAnalysis,HFSO_mass_saved_WB2H,'b.',MarkerSize=9)
hold on
HFSO_mass_saved_WB2Hfit = polyfit(vAnalysis,HFSO_mass_saved_WB2H,3);
HFSO_mass_saved_WB2Hval = polyval(HFSO_mass_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,HFSO_mass_saved_WB2Hval,'k-')
%VLSFO
```

```
plot(vAnalysis,VLSFO_mass_saved_WB2H,'g.',MarkerSize=9)
VLSFO_mass_saved_WB2Hfit = polyfit(vAnalysis,VLSFO_mass_saved_WB2H,3);
VLSFO_mass_saved_WB2Hval = polyval(VLSFO_mass_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_saved_WB2Hval,'k-')
%LNG
plot(vAnalysis,LNG_mass_saved_WB2H,'c.',MarkerSize=9)
hold on
LNG_mass_saved_WB2Hfit = polyfit(vAnalysis,LNG_mass_saved_WB2H,3);
LNG_mass_saved_WB2Hval = polyval(LNG_mass_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LNG_mass_saved_WB2Hval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_saved_WB2H,'m.',MarkerSize=9)
hold on
LH2_mass_saved_WB2Hfit = polyfit(vAnalysis,LH2_mass_saved_WB2H,3);
LH2_mass_saved_WB2Hval = polyval(LH2_mass_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_WB2Hval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_saved_FC_WB2H,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_saved_FC_WB2Hfit = polyfit(vAnalysis,LH2_mass_saved_FC_WB2H,3);
LH2_mass_saved_FC_WB2Hval = polyval(LH2_mass_saved_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_FC_WB2Hval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_saved_WB2H,'r.',MarkerSize=9)
hold on
LNH3_mass_saved_WB2Hfit = polyfit(vAnalysis,LNH3_mass_saved_WB2H,3);
LNH3_mass_saved_WB2Hval = polyval(LNH3_mass_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_WB2Hval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_saved_FC_WB2H,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_saved_FC_WB2Hfit = polyfit(vAnalysis,LNH3_mass_saved_FC_WB2H,3);
LNH3_mass_saved_FC_WB2Hval = polyval(LNH3_mass_saved_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_FC_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Walvis Bay to Hamburg','Fuel Mass Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot of CO2 Saved from Sails Vs Speed per trip
%HFSO
figure(19) % 19-WB2H_CO2_Emissions_Saved_VS_Speed
plot(vAnalysis,HFSO_CO2_saved_WB2H,'b.',MarkerSize=9)
hold on
HFSO_CO2_saved_WB2Hfit = polyfit(vAnalysis,HFSO_CO2_saved_WB2H,5);
HFSO_CO2_saved_WB2Hval = polyval(HFSO_CO2_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,HFSO_CO2_saved_WB2Hval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_CO2_saved_WB2H,'g.',MarkerSize=9)
VLSFO_CO2_saved_WB2Hfit = polyfit(vAnalysis,VLSFO_CO2_saved_WB2H,5);
VLSFO_CO2_saved_WB2Hval = polyval(VLSFO_CO2_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,VLSFO_CO2_saved_WB2Hval,'k-')
%LNG
plot(vAnalysis,LNG_CO2_saved_WB2H,'c.',MarkerSize=9)
```

```
hold on
LNG_CO2_saved_WB2Hfit = polyfit(vAnalysis,LNG_CO2_saved_WB2H,5);
LNG_CO2_saved_WB2Hval = polyval(LNG_CO2_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LNG_CO2_saved_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('CO_2 Emissions Saved [tonnes]')
title({'Walvis Bay to Hamburg','CO_2 Emissions Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','',Location='eastoutside')

%plot of Euros Saved from Sails Vs Speed per trip
%HFSO
figure(20) % 20-WB2H_Euro_Saved_VS_Speed
plot(vAnalysis,HFSO_euro_saved_WB2H,'b.',MarkerSize=9)
hold on
HFSO_euro_saved_WB2Hfit = polyfit(vAnalysis,HFSO_euro_saved_WB2H,3);
HFSO_euro_saved_WB2Hval = polyval(HFSO_euro_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,HFSO_euro_saved_WB2Hval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_euro_saved_WB2H,'g.',MarkerSize=9)
VLSFO_euro_saved_WB2Hfit = polyfit(vAnalysis,VLSFO_euro_saved_WB2H,3);
VLSFO_euro_saved_WB2Hval = polyval(VLSFO_euro_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,VLSFO_euro_saved_WB2Hval,'k-')
%LNG
plot(vAnalysis,LNG_euro_saved_WB2H,'c.',MarkerSize=9)
hold on
LNG_euro_saved_WB2Hfit = polyfit(vAnalysis,LNG_euro_saved_WB2H,3);
LNG_euro_saved_WB2Hval = polyval(LNG_euro_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LNG_euro_saved_WB2Hval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_euro_saved_WB2H,'m.',MarkerSize=9)
hold on
LH2_euro_saved_WB2Hfit = polyfit(vAnalysis,LH2_euro_saved_WB2H,3);
LH2_euro_saved_WB2Hval = polyval(LH2_euro_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_WB2Hval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_euro_saved_FC_WB2H,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_euro_saved_FC_WB2Hfit = polyfit(vAnalysis,LH2_euro_saved_FC_WB2H,3);
LH2_euro_saved_FC_WB2Hval = polyval(LH2_euro_saved_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_FC_WB2Hval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_euro_saved_WB2H,'r.',MarkerSize=9)
hold on
LNH3_euro_saved_WB2Hfit = polyfit(vAnalysis,LNH3_euro_saved_WB2H,3);
LNH3_euro_saved_WB2Hval = polyval(LNH3_euro_saved_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_WB2Hval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_euro_saved_FC_WB2H,'.','Color',[0.635 0.078
    0.184],MarkerSize=9)
hold on
LNH3_euro_saved_FC_WB2Hfit = polyfit(vAnalysis,LNH3_euro_saved_FC_WB2H,3);
LNH3_euro_saved_FC_WB2Hval = polyval(LNH3_euro_saved_FC_WB2Hfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_FC_WB2Hval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' Financial Incentive [€]')
title({'Walvis Bay to Hamburg','€ Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
```

```
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')


% ---------------- HAMBURG-TO-WALVIS-BAY-ROUND-TRIP-PLOTS---------------%%
%plot of Average Power from Sails Vs Speed
figure(21) % 21-H2WBRT_Avg_Pwr_Sails_VS_Speed
plot(vAnalysis,P_avg_H2WBRT/1000,'b.',MarkerSize=9)
hold on
P_avg_H2WBRTfit = polyfit(vAnalysis,P_avg_H2WBRT/1000,5);
P_avg_H2WBRTval = polyval(P_avg_H2WBRTfit,vAnalysis);
plot(vAnalysis,P_avg_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Sail Power [kW]')
title({'Hamburg to Walvis Bay Round Trip','Average Power from Sails VS Speed'})

%plot of Required and Average Sail Power VS Speed
figure(22) % 22-H2WBRT_Req_and_Sail_Pwr_VS_Speed
plot(vAnalysis,P_avg_H2WBRT/1000,'b.',MarkerSize=9)
hold on
P_avg_H2WBRTfit = polyfit(vAnalysis,P_avg_H2WBRT/1000,3);
P_avg_H2WBRTval = polyval(P_avg_H2WBRTfit,vAnalysis);
plot(vAnalysis,P_avg_H2WBRTval,'k-')

plot(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),'g.',MarkerSize=9)
Vessel_RandPfit = polyfit(vAnalysis,(Vessel_RandP.PP_W(5:end)/1000),3);
Vessel_RandPval = polyval(Vessel_RandPfit,vAnalysis);
plot(vAnalysis,Vessel_RandPval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Power [kW]')
title({'Hamburg to Walvis Bay Round Trip','Required and Average Sail Power VS Speed'})
legend('Average Power (Sails)','','Power (Required)','','Location','southoutside')

%plot of Percent Power/Energy from Sails Vs Speed
figure(23) % 23-H2WBRT_Percent_Energy_Sails_VS_Speed
plot(vAnalysis,E_saved_H2WBRT,'b.',MarkerSize=9)
hold on
E_saved_H2WBRTfit = polyfit(vAnalysis,E_saved_H2WBRT,3);
E_saved_H2WBRTval = polyval(E_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,E_saved_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Energy/Power from Sails [%]')
title({'Hamburg to Walvis Bay Round Trip','Energy/Power from Sails VS Speed'})

%plot Fuel Mass Required Vs Speed per trip
%HFSO
figure(24) % 24-H2WBRT_Fuel_Mass_VS_Speed
plot(vAnalysis,HFSO_mass_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_mass_H2WBRTfit = polyfit(vAnalysis,HFSO_mass_H2WBRT,3);
HFSO_mass_H2WBRTval = polyval(HFSO_mass_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_mass_H2WBRTval,'k-')
%VLSFO
```

```
plot(vAnalysis,VLSFO_mass_H2WBRT,'g.',MarkerSize=9)
VLSFO_mass_H2WBRTfit = polyfit(vAnalysis,VLSFO_mass_H2WBRT,3);
VLSFO_mass_H2WBRTval = polyval(VLSFO_mass_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_mass_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_mass_H2WBRTfit = polyfit(vAnalysis,LNG_mass_H2WBRT,3);
LNG_mass_H2WBRTval = polyval(LNG_mass_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_mass_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_H2WBRT,'m.',MarkerSize=9)
hold on
LH2_mass_H2WBRTfit = polyfit(vAnalysis,LH2_mass_H2WBRT,3);
LH2_mass_H2WBRTval = polyval(LH2_mass_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_mass_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_FC_H2WBRTfit = polyfit(vAnalysis,LH2_mass_FC_H2WBRT,3);
LH2_mass_FC_H2WBRTval = polyval(LH2_mass_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_mass_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_H2WBRT,'r.',MarkerSize=9)
hold on
LNH3_mass_H2WBRTfit = polyfit(vAnalysis,LNH3_mass_H2WBRT,3);
LNH3_mass_H2WBRTval = polyval(LNH3_mass_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_mass_H2WBRTval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_mass_FC_H2WBRT,3);
LNH3_mass_FC_H2WBRTval = polyval(LNH3_mass_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_mass_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','Fuel Mass Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Volume Required Vs Speed per trip
%HFSO
figure(25) % 25-H2WBRT_Fuel_Volume_VS_Speed
plot(vAnalysis,HFSO_vol_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_vol_H2WBRTfit = polyfit(vAnalysis,HFSO_vol_H2WBRT,3);
HFSO_vol_H2WBRTval = polyval(HFSO_vol_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_vol_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_vol_H2WBRT,'g.',MarkerSize=9)
VLSFO_vol_H2WBRTfit = polyfit(vAnalysis,VLSFO_vol_H2WBRT,3);
VLSFO_vol_H2WBRTval = polyval(VLSFO_vol_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_vol_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_vol_H2WBRT,'c.',MarkerSize=9)
```

```
hold on
LNG_vol_H2WBRTfit = polyfit(vAnalysis,LNG_vol_H2WBRT,3);
LNG_vol_H2WBRTval = polyval(LNG_vol_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_vol_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_vol_H2WBRT,'m.',MarkerSize=9)
hold on
LH2_vol_H2WBRTfit = polyfit(vAnalysis,LH2_vol_H2WBRT,3);
LH2_vol_H2WBRTval = polyval(LH2_vol_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_vol_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_vol_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_vol_FC_H2WBRTfit = polyfit(vAnalysis,LH2_vol_FC_H2WBRT,3);
LH2_vol_FC_H2WBRTval = polyval(LH2_vol_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_vol_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_vol_H2WBRT,'r.',MarkerSize=9)
hold on
LNH3_vol_H2WBRTfit = polyfit(vAnalysis,LNH3_vol_H2WBRT,3);
LNH3_vol_H2WBRTval = polyval(LNH3_vol_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_vol_H2WBRTval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_vol_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_vol_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_vol_FC_H2WBRT,3);
LNH3_vol_FC_H2WBRTval = polyval(LNH3_vol_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_vol_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Volume [m^3]')
title({'Hamburg to Walvis Bay Round Trip','Fuel Volume Required VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Mass Saved from Sails Vs Speed per trip
%HFSO
figure(26) % 26-H2WBRT_Fuel_Mass_Saved_VS_Speed
plot(vAnalysis,HFSO_mass_saved_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_mass_saved_H2WBRTfit = polyfit(vAnalysis,HFSO_mass_saved_H2WBRT,3);
HFSO_mass_saved_H2WBRTval = polyval(HFSO_mass_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_mass_saved_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_saved_H2WBRT,'g.',MarkerSize=9)
VLSFO_mass_saved_H2WBRTfit = polyfit(vAnalysis,VLSFO_mass_saved_H2WBRT,3);
VLSFO_mass_saved_H2WBRTval = polyval(VLSFO_mass_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_saved_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_mass_saved_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_mass_saved_H2WBRTfit = polyfit(vAnalysis,LNG_mass_saved_H2WBRT,3);
LNG_mass_saved_H2WBRTval = polyval(LNG_mass_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_mass_saved_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_saved_H2WBRT,'m.',MarkerSize=9)
```

```
hold on
LH2_mass_saved_H2WBRTfit = polyfit(vAnalysis,LH2_mass_saved_H2WBRT,3);
LH2_mass_saved_H2WBRTval = polyval(LH2_mass_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_saved_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_saved_FC_H2WBRTfit = polyfit(vAnalysis,LH2_mass_saved_FC_H2WBRT,3);
LH2_mass_saved_FC_H2WBRTval = polyval(LH2_mass_saved_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_saved_H2WBRT,'r.',MarkerSize=9)
hold on
LNH3_mass_saved_H2WBRTfit = polyfit(vAnalysis,LNH3_mass_saved_H2WBRT,3);
LNH3_mass_saved_H2WBRTval = polyval(LNH3_mass_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_H2WBRTval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_saved_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_mass_saved_FC_H2WBRT,3);
LNH3_mass_saved_FC_H2WBRTval = polyval(LNH3_mass_saved_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','Fuel Mass Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Mass Saved from Sails Vs Speed per YEAR
%HFSO
figure(27) % 27-H2WBRT_Annual_Fuel_Mass_Saved_VS_Speed
plot(vAnalysis,HFSO_mass_saved_H2WBRT_yr,'b.',MarkerSize=9)
hold on
HFSO_mass_saved_H2WBRT_yrfit = polyfit(vAnalysis,HFSO_mass_saved_H2WBRT_yr,3);
HFSO_mass_saved_H2WBRT_yrval = polyval(HFSO_mass_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,HFSO_mass_saved_H2WBRT_yrval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_saved_H2WBRT_yr,'g.',MarkerSize=9)
VLSFO_mass_saved_H2WBRT_yrfit = polyfit(vAnalysis,VLSFO_mass_saved_H2WBRT_yr,3);
VLSFO_mass_saved_H2WBRT_yrval = polyval(VLSFO_mass_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_saved_H2WBRT_yrval,'k-')
%LNG
plot(vAnalysis,LNG_mass_saved_H2WBRT_yr,'c.',MarkerSize=9)
hold on
LNG_mass_saved_H2WBRT_yrfit = polyfit(vAnalysis,LNG_mass_saved_H2WBRT_yr,3);
LNG_mass_saved_H2WBRT_yrval = polyval(LNG_mass_saved_H2WBRT_yrfit,vAnalysis);
```

```
plot(vAnalysis,LNG_mass_saved_H2WBRT_yrval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_saved_H2WBRT_yr,'m.',MarkerSize=9)
hold on
LH2_mass_saved_H2WBRT_yrfit = polyfit(vAnalysis,LH2_mass_saved_H2WBRT_yr,3);
LH2_mass_saved_H2WBRT_yrval = polyval(LH2_mass_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_H2WBRT_yrval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_saved_FC_H2WBRT_yr,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_saved_FC_H2WBRT_yrfit = polyfit(vAnalysis,LH2_mass_saved_FC_H2WBRT_yr,3);
LH2_mass_saved_FC_H2WBRT_yrval = polyval(LH2_mass_saved_FC_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_FC_H2WBRT_yrval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_saved_H2WBRT_yr,'r.',MarkerSize=9)
hold on
LNH3_mass_saved_H2WBRT_yrfit = polyfit(vAnalysis,LNH3_mass_saved_H2WBRT_yr,3);
LNH3_mass_saved_H2WBRT_yrval = polyval(LNH3_mass_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_H2WBRT_yrval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRT_yr,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_saved_FC_H2WBRT_yrfit = polyfit(vAnalysis,LNH3_mass_saved_FC_H2WBRT_yr,3);
LNH3_mass_saved_FC_H2WBRT_yrval = polyval(LNH3_mass_saved_FC_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRT_yrval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','Annual Fuel Mass Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

% plot of Fuel Mass Saved from Sails Vs Speed (SERVICE LIFE)
%HFSO
figure(28) % 28-H2WBRT_Service_Life_Fuel_Mass_Saved_VS_Speed
plot(vAnalysis,HFSO_mass_saved_H2WBRT_SL,'b.',MarkerSize=9)
hold on
HFSO_mass_saved_H2WBRT_SLfit = polyfit(vAnalysis,HFSO_mass_saved_H2WBRT_SL,3);
HFSO_mass_saved_H2WBRT_SLval = polyval(HFSO_mass_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,HFSO_mass_saved_H2WBRT_SLval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_mass_saved_H2WBRT_SL,'g.',MarkerSize=9)
VLSFO_mass_saved_H2WBRT_SLfit = polyfit(vAnalysis,VLSFO_mass_saved_H2WBRT_SL,3);
```

```
VLSFO_mass_saved_H2WBRT_SLval = polyval(VLSFO_mass_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,VLSFO_mass_saved_H2WBRT_SLval,'k-')
%LNG
plot(vAnalysis,LNG_mass_saved_H2WBRT_SL,'c.',MarkerSize=9)
hold on
LNG_mass_saved_H2WBRT_SLfit = polyfit(vAnalysis,LNG_mass_saved_H2WBRT_SL,3);
LNG_mass_saved_H2WBRT_SLval = polyval(LNG_mass_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNG_mass_saved_H2WBRT_SLval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_mass_saved_H2WBRT_SL,'m.',MarkerSize=9)
hold on
LH2_mass_saved_H2WBRT_SLfit = polyfit(vAnalysis,LH2_mass_saved_H2WBRT_SL,3);
LH2_mass_saved_H2WBRT_SLval = polyval(LH2_mass_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_H2WBRT_SLval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_mass_saved_FC_H2WBRT_SL,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_mass_saved_FC_H2WBRT_SLfit = polyfit(vAnalysis,LH2_mass_saved_FC_H2WBRT_SL,3);
LH2_mass_saved_FC_H2WBRT_SLval = polyval(LH2_mass_saved_FC_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LH2_mass_saved_FC_H2WBRT_SLval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_mass_saved_H2WBRT_SL,'r.',MarkerSize=9)
hold on
LNH3_mass_saved_H2WBRT_SLfit = polyfit(vAnalysis,LNH3_mass_saved_H2WBRT_SL,3);
LNH3_mass_saved_H2WBRT_SLval = polyval(LNH3_mass_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_H2WBRT_SLval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRT_SL,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_mass_saved_FC_H2WBRT_SLfit = polyfit(vAnalysis,LNH3_mass_saved_FC_H2WBRT_SL,3);
LNH3_mass_saved_FC_H2WBRT_SLval = polyval(LNH3_mass_saved_FC_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNH3_mass_saved_FC_H2WBRT_SLval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('Fuel Mass [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','Service Life Fuel Mass Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot of CO2 Saved from Sails Vs Speed per trip
%HFSO
figure(29) % 29-H2WBRT_CO2_Saved_VS_Speed
plot(vAnalysis,HFSO_CO2_saved_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_CO2_saved_H2WBRTfit = polyfit(vAnalysis,HFSO_CO2_saved_H2WBRT,5);
```

```
HFSO_CO2_saved_H2WBRTval = polyval(HFSO_CO2_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_CO2_saved_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_CO2_saved_H2WBRT,'g.',MarkerSize=9)
VLSFO_CO2_saved_H2WBRTfit = polyfit(vAnalysis,VLSFO_CO2_saved_H2WBRT,5);
VLSFO_CO2_saved_H2WBRTval = polyval(VLSFO_CO2_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_CO2_saved_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_CO2_saved_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_CO2_saved_H2WBRTfit = polyfit(vAnalysis,LNG_CO2_saved_H2WBRT,5);
LNG_CO2_saved_H2WBRTval = polyval(LNG_CO2_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_CO2_saved_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('CO_2 Emissions Saved [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','CO_2 Emissions Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','',Location='eastoutside')

%plot of CO2 Saved from Sails Vs Speed per YEAR
%HFSO
figure(30) % 30-H2WBRT_Annual_CO2_Saved_VS_Speed
plot(vAnalysis,HFSO_CO2_saved_H2WBRT_yr,'b.',MarkerSize=9)
hold on
HFSO_CO2_saved_H2WBRT_yrfit = polyfit(vAnalysis,HFSO_CO2_saved_H2WBRT_yr,5);
HFSO_CO2_saved_H2WBRT_yrval = polyval(HFSO_CO2_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,HFSO_CO2_saved_H2WBRT_yrval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_CO2_saved_H2WBRT_yr,'g.',MarkerSize=9)
VLSFO_CO2_saved_H2WBRT_yrfit = polyfit(vAnalysis,VLSFO_CO2_saved_H2WBRT_yr,5);
VLSFO_CO2_saved_H2WBRT_yrval = polyval(VLSFO_CO2_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,VLSFO_CO2_saved_H2WBRT_yrval,'k-')
%LNG
plot(vAnalysis,LNG_CO2_saved_H2WBRT_yr,'c.',MarkerSize=9)
hold on
LNG_CO2_saved_H2WBRT_yrfit = polyfit(vAnalysis,LNG_CO2_saved_H2WBRT_yr,5);
LNG_CO2_saved_H2WBRT_yrval = polyval(LNG_CO2_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNG_CO2_saved_H2WBRT_yrval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('CO_2 Emissions Saved [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','CO_2 Emissions Saved Annually VS Speed'})
legend('HFSO','','VLSFO','','LNG','',Location='eastoutside')

%plot of CO2 Saved from Sails Vs Speed (SERVICE LIFE)
%HFSO
figure(31) % 31-H2WBRT_Service_Life_CO2_Saved_VS_Speed
plot(vAnalysis,HFSO_CO2_saved_H2WBRT_SL,'b.',MarkerSize=9)
hold on
HFSO_CO2_saved_H2WBRT_SLfit = polyfit(vAnalysis,HFSO_CO2_saved_H2WBRT_SL,5);
HFSO_CO2_saved_H2WBRT_SLval = polyval(HFSO_CO2_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,HFSO_CO2_saved_H2WBRT_SLval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_CO2_saved_H2WBRT_SL,'g.',MarkerSize=9)
```

```
VLSFO_CO2_saved_H2WBRT_SLfit = polyfit(vAnalysis,VLSFO_CO2_saved_H2WBRT_SL,5);
VLSFO_CO2_saved_H2WBRT_SLval = polyval(VLSFO_CO2_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,VLSFO_CO2_saved_H2WBRT_SLval,'k-')
%LNG
plot(vAnalysis,LNG_CO2_saved_H2WBRT_SL,'c.',MarkerSize=9)
hold on
LNG_CO2_saved_H2WBRT_SLfit = polyfit(vAnalysis,LNG_CO2_saved_H2WBRT_SL,5);
LNG_CO2_saved_H2WBRT_SLval = polyval(LNG_CO2_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNG_CO2_saved_H2WBRT_SLval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel('CO_2 Emissions Saved [tonnes]')
title({'Hamburg to Walvis Bay Round Trip','Service Life CO_2 Emissions Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','',Location='eastoutside')

%plot of Euros Saved from Sails Vs Speed per trip
%HFSO
figure(32) % 32-H2WBRT_Euro_Saved_VS_Speed
plot(vAnalysis,HFSO_euro_saved_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_euro_saved_H2WBRTfit = polyfit(vAnalysis,HFSO_euro_saved_H2WBRT,3);
HFSO_euro_saved_H2WBRTval = polyval(HFSO_euro_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_euro_saved_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_euro_saved_H2WBRT,'g.',MarkerSize=9)
VLSFO_euro_saved_H2WBRTfit = polyfit(vAnalysis,VLSFO_euro_saved_H2WBRT,3);
VLSFO_euro_saved_H2WBRTval = polyval(VLSFO_euro_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_euro_saved_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_euro_saved_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_euro_saved_H2WBRTfit = polyfit(vAnalysis,LNG_euro_saved_H2WBRT,3);
LNG_euro_saved_H2WBRTval = polyval(LNG_euro_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_euro_saved_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_euro_saved_H2WBRT,'m.',MarkerSize=9)
hold on
LH2_euro_saved_H2WBRTfit = polyfit(vAnalysis,LH2_euro_saved_H2WBRT,3);
LH2_euro_saved_H2WBRTval = polyval(LH2_euro_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_euro_saved_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_euro_saved_FC_H2WBRTfit = polyfit(vAnalysis,LH2_euro_saved_FC_H2WBRT,3);
LH2_euro_saved_FC_H2WBRTval = polyval(LH2_euro_saved_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_euro_saved_H2WBRT,'r.',MarkerSize=9)
hold on
LNH3_euro_saved_H2WBRTfit = polyfit(vAnalysis,LNH3_euro_saved_H2WBRT,3);
LNH3_euro_saved_H2WBRTval = polyval(LNH3_euro_saved_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_H2WBRTval,'k-')
%LNH3 - Fuel Cell
```

```
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_euro_saved_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_euro_saved_FC_H2WBRT,3);
LNH3_euro_saved_FC_H2WBRTval = polyval(LNH3_euro_saved_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' Financial Incentive [€]')
title({'Hamburg to Walvis Bay Round Trip','€ Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot of Euros Saved from Sails Vs Speed per YEAR
%HFSO
figure(33) % 33-H2WBRT_Annual_Euro_Saved_VS_Speed
plot(vAnalysis,HFSO_euro_saved_H2WBRT_yr,'b.',MarkerSize=9)
hold on
HFSO_euro_saved_H2WBRT_yrfit = polyfit(vAnalysis,HFSO_euro_saved_H2WBRT_yr,3);
HFSO_euro_saved_H2WBRT_yrval = polyval(HFSO_euro_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,HFSO_euro_saved_H2WBRT_yrval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_euro_saved_H2WBRT_yr,'g.',MarkerSize=9)
VLSFO_euro_saved_H2WBRT_yrfit = polyfit(vAnalysis,VLSFO_euro_saved_H2WBRT_yr,3);
VLSFO_euro_saved_H2WBRT_yrval = polyval(VLSFO_euro_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,VLSFO_euro_saved_H2WBRT_yrval,'k-')
%LNG
plot(vAnalysis,LNG_euro_saved_H2WBRT_yr,'c.',MarkerSize=9)
hold on
LNG_euro_saved_H2WBRT_yrfit = polyfit(vAnalysis,LNG_euro_saved_H2WBRT_yr,3);
LNG_euro_saved_H2WBRT_yrval = polyval(LNG_euro_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNG_euro_saved_H2WBRT_yrval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_euro_saved_H2WBRT_yr,'m.',MarkerSize=9)
hold on
LH2_euro_saved_H2WBRT_yrfit = polyfit(vAnalysis,LH2_euro_saved_H2WBRT_yr,3);
LH2_euro_saved_H2WBRT_yrval = polyval(LH2_euro_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_H2WBRT_yrval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_euro_saved_FC_H2WBRT_yr,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_euro_saved_FC_H2WBRT_yrfit = polyfit(vAnalysis,LH2_euro_saved_FC_H2WBRT_yr,3);
LH2_euro_saved_FC_H2WBRT_yrval = polyval(LH2_euro_saved_FC_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_FC_H2WBRT_yrval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_euro_saved_H2WBRT_yr,'r.',MarkerSize=9)
```

```
hold on
LNH3_euro_saved_H2WBRT_yrfit = polyfit(vAnalysis,LNH3_euro_saved_H2WBRT_yr,3);
LNH3_euro_saved_H2WBRT_yrval = polyval(LNH3_euro_saved_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_H2WBRT_yrval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRT_yr,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_euro_saved_FC_H2WBRT_yrfit = polyfit(vAnalysis,LNH3_euro_saved_FC_H2WBRT_yr,3);
LNH3_euro_saved_FC_H2WBRT_yrval = polyval(LNH3_euro_saved_FC_H2WBRT_yrfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRT_yrval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' Financial Incentive [€]')
title({'Hamburg to Walvis Bay Round Trip','Annual € Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot of Euros Saved from Sails Vs Speed SERVICE LIFE
%HFSO
figure(34) % 34-H2WBRT_Service_Life_Euro_Saved_VS_Speed
plot(vAnalysis,HFSO_euro_saved_H2WBRT_SL,'b.',MarkerSize=9)
hold on
HFSO_euro_saved_H2WBRT_SLfit = polyfit(vAnalysis,HFSO_euro_saved_H2WBRT_SL,3);
HFSO_euro_saved_H2WBRT_SLval = polyval(HFSO_euro_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,HFSO_euro_saved_H2WBRT_SLval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_euro_saved_H2WBRT_SL,'g.',MarkerSize=9)
VLSFO_euro_saved_H2WBRT_SLfit = polyfit(vAnalysis,VLSFO_euro_saved_H2WBRT_SL,3);
VLSFO_euro_saved_H2WBRT_SLval = polyval(VLSFO_euro_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,VLSFO_euro_saved_H2WBRT_SLval,'k-')
%LNG
plot(vAnalysis,LNG_euro_saved_H2WBRT_SL,'c.',MarkerSize=9)
hold on
LNG_euro_saved_H2WBRT_SLfit = polyfit(vAnalysis,LNG_euro_saved_H2WBRT_SL,3);
LNG_euro_saved_H2WBRT_SLval = polyval(LNG_euro_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNG_euro_saved_H2WBRT_SLval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_euro_saved_H2WBRT_SL,'m.',MarkerSize=9)
hold on
LH2_euro_saved_H2WBRT_SLfit = polyfit(vAnalysis,LH2_euro_saved_H2WBRT_SL,3);
LH2_euro_saved_H2WBRT_SLval = polyval(LH2_euro_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_H2WBRT_SLval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_euro_saved_FC_H2WBRT_SL,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
```

```
LH2_euro_saved_FC_H2WBRT_SLfit = polyfit(vAnalysis,LH2_euro_saved_FC_H2WBRT_SL,3);
LH2_euro_saved_FC_H2WBRT_SLval = polyval(LH2_euro_saved_FC_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LH2_euro_saved_FC_H2WBRT_SLval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_euro_saved_H2WBRT_SL,'r.',MarkerSize=9)
hold on
LNH3_euro_saved_H2WBRT_SLfit = polyfit(vAnalysis,LNH3_euro_saved_H2WBRT_SL,3);
LNH3_euro_saved_H2WBRT_SLval = polyval(LNH3_euro_saved_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_H2WBRT_SLval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRT_SL,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_euro_saved_FC_H2WBRT_SLfit = polyfit(vAnalysis,LNH3_euro_saved_FC_H2WBRT_SL,3);
LNH3_euro_saved_FC_H2WBRT_SLval = polyval(LNH3_euro_saved_FC_H2WBRT_SLfit,vAnalysis);
plot(vAnalysis,LNH3_euro_saved_FC_H2WBRT_SLval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' Financial Incentive [€]')
title({'Hamburg to Walvis Bay Round Trip','Service Life € Saved VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot of NPV VS Speed
%HFSO
figure(35) % 35-H2WBRT_NPV_VS_Speed
plot(vAnalysis,HFSO_NPV_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_NPV_H2WBRTfit = polyfit(vAnalysis,HFSO_NPV_H2WBRT,3);
HFSO_NPV_H2WBRTval = polyval(HFSO_NPV_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_NPV_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_NPV_H2WBRT,'g.',MarkerSize=9)
VLSFO_NPV_H2WBRTfit = polyfit(vAnalysis,VLSFO_NPV_H2WBRT,3);
VLSFO_NPV_H2WBRTval = polyval(VLSFO_NPV_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_NPV_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_NPV_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_NPV_H2WBRTfit = polyfit(vAnalysis,LNG_NPV_H2WBRT,3);
LNG_NPV_H2WBRTval = polyval(LNG_NPV_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_NPV_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_NPV_H2WBRT,'m.',MarkerSize=9)
hold on
LH2_NPV_H2WBRTfit = polyfit(vAnalysis,LH2_NPV_H2WBRT,3);
LH2_NPV_H2WBRTval = polyval(LH2_NPV_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_NPV_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_NPV_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
```

```
LH2_NPV_FC_H2WBRTfit = polyfit(vAnalysis,LH2_NPV_FC_H2WBRT,3);
LH2_NPV_FC_H2WBRTval = polyval(LH2_NPV_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_NPV_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_NPV_H2WBRT,'r.',MarkerSize=9)
hold on
LNH3_NPV_H2WBRTfit = polyfit(vAnalysis,LNH3_NPV_H2WBRT,3);
LNH3_NPV_H2WBRTval = polyval(LNH3_NPV_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_NPV_H2WBRTval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_NPV_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_NPV_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_NPV_FC_H2WBRT,3);
LNH3_NPV_FC_H2WBRTval = polyval(LNH3_NPV_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_NPV_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' NPV [€]')
title({'Hamburg to Walvis Bay Round Trip','Net Present Value VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')

%plot Simple Payback Period(SPP) Vs Speed
%plot of SPP VS Speed
%HFSO
figure(36) % 36-H2WBRT_SPP_VS_Speed
plot(vAnalysis,HFSO_SPP_H2WBRT,'b.',MarkerSize=9)
hold on
HFSO_SPP_H2WBRTfit = polyfit(vAnalysis,HFSO_SPP_H2WBRT,5);
HFSO_SPP_H2WBRTval = polyval(HFSO_SPP_H2WBRTfit,vAnalysis);
plot(vAnalysis,HFSO_SPP_H2WBRTval,'k-')
%VLSFO
plot(vAnalysis,VLSFO_SPP_H2WBRT,'g.',MarkerSize=9)
VLSFO_SPP_H2WBRTfit = polyfit(vAnalysis,VLSFO_SPP_H2WBRT,5);
VLSFO_SPP_H2WBRTval = polyval(VLSFO_SPP_H2WBRTfit,vAnalysis);
plot(vAnalysis,VLSFO_SPP_H2WBRTval,'k-')
%LNG
plot(vAnalysis,LNG_SPP_H2WBRT,'c.',MarkerSize=9)
hold on
LNG_SPP_H2WBRTfit = polyfit(vAnalysis,LNG_SPP_H2WBRT,5);
LNG_SPP_H2WBRTval = polyval(LNG_SPP_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNG_SPP_H2WBRTval,'k-')
%LH2 - Combustion
plot(vAnalysis,LH2_SPP_H2WBRT,'m.',MarkerSize=9)
hold on
LH2_SPP_H2WBRTfit = polyfit(vAnalysis,LH2_SPP_H2WBRT,5);
LH2_SPP_H2WBRTval = polyval(LH2_SPP_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_SPP_H2WBRTval,'k-')
%LH2 - Fuel Cell
plot(vAnalysis,LH2_SPP_FC_H2WBRT,'.','Color',[0.5 0 0.8],MarkerSize=9)
hold on
LH2_SPP_FC_H2WBRTfit = polyfit(vAnalysis,LH2_SPP_FC_H2WBRT,5);
LH2_SPP_FC_H2WBRTval = polyval(LH2_SPP_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LH2_SPP_FC_H2WBRTval,'k-')
%LNH3 - Combustion
plot(vAnalysis,LNH3_SPP_H2WBRT,'r.',MarkerSize=9)
```

```
hold on
LNH3_SPP_H2WBRTfit = polyfit(vAnalysis,LNH3_SPP_H2WBRT,5);
LNH3_SPP_H2WBRTval = polyval(LNH3_SPP_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_SPP_H2WBRTval,'k-')
%LNH3 - Fuel Cell
plot(vAnalysis,LNH3_SPP_FC_H2WBRT,'.','Color',[0.635 0.078 0.184],MarkerSize=9)
hold on
LNH3_SPP_FC_H2WBRTfit = polyfit(vAnalysis,LNH3_SPP_FC_H2WBRT,5);
LNH3_SPP_FC_H2WBRTval = polyval(LNH3_SPP_FC_H2WBRTfit,vAnalysis);
plot(vAnalysis,LNH3_SPP_FC_H2WBRTval,'k-')
xlabel('Vessel Speed [Knots]')
ylabel(' SPP [years]')
title({'Hamburg to Walvis Bay Round Trip','Simple Payback Period VS Speed'})
legend('HFSO','','VLSFO','','LNG','','LH2 Combustion','', ...
    'LH2 Fuel Cell','','LNH3 Combustion','','LNH3 Fuel Cell', ...
    '',Location='eastoutside')
```