NTNU – Trondheim
Norwegian University of
Science and Technology

The potential energy savings by application of a wave foil on the autonomous container vessel ReVolt

Eivind Finne Riley

Marine Technology	
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Supervisor:	Sverre Steen, IMT
Co-supervisor:	Eirik Bøckmann, IMT

Norwegian University of Science and Technology
Department of Marine Technology

MASTER THESIS IN MARINE TECHNOLOGY
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FOR
EIVIND FINNE RILEY

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An ongoing research project in DNV GL Research is the autonomous, electrically propelled container ship concept ReVolt; a container vessel designed to operate in the Norwegian coastal seas between Oslo and Trondheim. The ship is designed to sail at slow forward speeds, minimizing the energy needed for propulsion. The preliminary calculations show that the needed power output for sailing at 6knots in calm seas is merely 50kW. However, in sea states with waves, the power needed to sail in the desired speed of 6 knots increases significantly, and added resistance in waves becomes the largest resistance component of the vessel.

In order to always being able to return safely to harbor, ReVolt has to be equipped with a battery pack with sufficient energy stored to safely return the ship to harbor at a worst case weather scenario. This master project will look into the use of a wave foil to reduce the ReVolt ships resistance when operating in waves, in order to reduce the size of the required battery pack, and also to reduce the power consumption in general.

The objective of the master project is therefore to design an optimized wave foil system aiming to minimize the required battery capacity on the ReVolt ship.

To reach the objective, the following steps are recommended:

Design a wave foil system for ReVolt. The foils must be retractable to avoid resistance increase in calm water. A detailed study of the mechanisms for retraction is out of scope, but indications of how it can be achieved should be given. It is likely that an iterative approach must be taken to reach a foil system design which is as close to optimal as possible.

Establish methods for evaluation of the net thrust produced by the foil system(s) in different wave conditions. It is foreseen that this part can be based on existing methods, but a selection of method has to be performed, and the choices made should be argued for. It is recommended to somehow include the effect of stall on the foil lift and drag. It is also recommended to check the benefit of pitch control, either active (by use of an active control system) or passive (feathering).

It can be assumed that the ship will stay in harbor when the operating conditions are such that important operational criteria might be exceeded. Such criteria might be of different types. Examples are: sufficient battery capacity, safety and stability of vessel, cargo safety criteria related to accelerations and/or maximum inclination angles. It is recommended to establish a set of operational criteria, and use them to assess under which conditions the ship should leave port. It might be of interest to see how the operability of the ship changes when it is equipped with foils.

Evaluate the foil thrust and resulting required propeller power in the critical routes under all expected weather conditions. Compare the required total energy for the case of no foils, with fixed foils, and with controlled foils (could be spring loaded). It should be kept in mind that for the alternatives with foils the conditions with the largest waves might not require the most energy, due to the effect of the wave foils. It is recommended to relax the requirement for keeping a speed of six knots.

Give recommendations for further work, and for what is considered the best option for ReVolt with respect to use of foils.

In the thesis the candidate shall present his personal contribution to the resolution of problem within the scope of the thesis work. Theories and conclusions shall be based on mathematical derivations and/or logic reasoning identifying the various steps in the deduction.

The thesis work shall be based on the current state of knowledge in the field of study. The current state of knowledge shall be established through a thorough literature study, the results of this study shall be written into the thesis. The candidate should utilize the existing possibilities for obtaining relevant literature.

The thesis should be organized in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of symbols and acronyms, reference and (optional) appendices. All figures, tables and equations shall be numerated.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work. The plan should include a budget for the use of computer and laboratory resources that will be charged to the department. Overruns shall be reported to the supervisor.

The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

The thesis shall be submitted electronically (pdf) in DAIM:

- Signed by the candidate
- The text defining the scope (signed by the supervisor) included
- Computer code, input files, videos and other electronic appendages can be uploaded in a zip-file in DAIM. Any electronic appendages shall be listed in the main thesis.

The candidate will receive a printed copy of the thesis.

Supervisor : Professor Sverre Steen
Advisor : Eirik Bøckmann
Start : 15.01.2015
Deadline : 10.06.2015

Trondheim, 15.01.2015

Sverre Steen
Supervisor

Preface

This report is my MSc. Thesis in marine hydrodynamics written at the Dpt. Of Marine Technology at the Norwegian Institute of Technology and Science (NTNU) in Trondheim, Norway. The project was written in the spring of 2015.

The motivation behind the thesis is to determine whether an application of propulsion foils could reduce the dimensioning battery size of the autonomous, electrically driven concept container ship ReVolt. The idea arose after seeing a presentation of ReVolt at a summer internship at DNV GL at Høvik. I had vaguely heard about propulsion foils before attending the presentation, and after hearing that ReVolts major contributor to the battery pack size was the added resistance imposed in waves. I suggested doing an analysis of this in my master thesis in hydrodynamics, and caught DNV GLs interest in the subject.

Many people deserve thanks for the completion of this project. I would like to thank my supervisor Sverre Steen for accepting the thesis, and for his guidance during the work. PhD candidate Eirik Bøckmann at NTNU also deserves many thanks for his help. Lars Øien and Dariusz Fathi at MARINTEK has also helped with use of computer programs used in this thesis.

I would also like to thank Hans-Anton Tvete, Christos Chryssakis and Bjørn-Johan Vartdal at DNV GL Høvik for taking interest in the subject and for their help, in addition to Bingjie Guo and Stian Bakke Tornes.

My friends and fellow office-dwellers at NTNU Tyholt deserve great thanks for their continuing help and friendship. Especially Rasmus Borenius has been an important friend and working companion throughout my years in Trondheim.

Finally, I would like to thank my parents, Elisabeth and Hugh. Their support and love seems never-ending, and I would not be where I am today without you.

Trondheim, June 10th 2015

Eivind Finne Riley

Summary

ReVolt is an electrically propelled, autonomous concept container ship designed by DNV GL to minimize the energy consumption and cost; however, the added resistance in waves is a large resistance contributor. Effectively, this means that the battery packs of ReVolt have to be dimensioned sufficiently large to be able to complete its route legs in the *worst* sea states ReVolt might encounter. Batteries of today associated with a high cost.

The main focus in this thesis is assessing the benefits in terms of capital expenses (CAPEX) for ReVolt achievable by fitting so-called *wave foils* at the bow of the vessel. Continuous operational expenses (OPEX) is also assessed to a lesser extent.

A considerable amount of previous work has been done on the topic of wave foils in the past by other authors, and an overview of previous theoretical work and model- and full scale trials is presented. As far as known by the author, this is the first time wave foils have been tried as a CAPEX savings device in relation to electrical, sea going vessels – earlier work on fuel savings have been performed more in relation to general OPEX savings.

To examine the foil performance in irregular sea, a large amount of irregular sea states are simulated, and the time averaged foil performance is found through a frequency-domain analysis. Linear foil theory is applied; however, a stalling model is implemented to model the potentially important stalling effects on the foil, which is not included in regular foil theory. The model also includes the effect of unsteady lift on an oscillating foil, and additional resistance components imposed by the foil system.

The thrust production and motion dampening effect reduces the total ship resistance in sea states applicable for wave foils. Further, the needed brake power in the examined sea states is calculated. The brake power is then converted to total energy consumption by defining a dimensioning sailing distance. This is then used to find the largest total energy consumption for ReVolt, which is what we define as the *worst case scenario* (WCS) for a ReVolt with and without wave foils equipped.

An overview of foil various foil mechanisms is given, with focus on the retractability of the foils. Foil size and submergence level is also looked at. Both passive foils, mounted in a fixed position, and pitching foils, able to rotate around their spanwise axis, are modelled.

The sailing conditions for ReVolt are examined by looking at scatter diagrams for the route of ReVolt. A scope of applicable sea states (made up by the parameters H_S and T_P) is defined.

Within this scope applicable ranges of ship speed and wave heading angles are also defined. Wind resistance is also assessed. We seek to give an overview of the working range of the wave foils for ReVolt, and compare passive foils to pitching foils to assess what sea states are optimal for each foil configuration.

The foils are observed to yield benefits in terms of energy consumption reduction for a large amount of scenarios defined by the outlined scope. The largest thrust production is found at sea states with longer peak wave periods than the peak period giving the largest added resistance, but the foils still seem effective at reducing the energy consumption in the worst case scenarios.

At Revolt's design speed of six knots, our results imply a reduction of dimensioning battery size by 16.6%, or 1.27MWh, associated with a CAPEX reduction of 1.27MUSD, or 10.1MNOK.

At lower vessel speeds, the foil performance decreases, and within our range of speeds examined, the foil performance increases with increasing vessel speed. A result of this is that at the worst case scenario, the dimensioning battery size has been shown to be only slightly higher for a ReVolt completing a worst case scenario route leg at eight knots, when compared to the energy needed to complete a WCS route leg at four knots. Thus, reducing the speed to overcome the WCS might not be the best option for ReVolt equipped with wave foils. Rather, with the benefits of a much shorter sailing time for a route leg also taken into consideration, *increasing* the ship speed to overcome a WCS is thought to be a good option.

OPEX savings are discussed, and potential OPEX benefits are found in a large amount of the sea states considered. As ReVolt does not consume a large amount of energy, the OPEX savings are not very large – but accumulated into a whole fleet of ships, in service over a long time, the OPEX benefits might too be of a considerable size.

Wave foils thus seem to be an efficient way of reducing the CAPEX associated with batteries. The vessel ReVolt is in focus in this thesis, but the concept should be applicable to all electrically propelled vessels where added resistance in waves leads to a large dimensioned battery size.

Sammendrag

ReVolt er et elektrisk drevet, autonomt kontainerskip designet av DNV GL for å minimere energiforbruket og -kostnadene. Likevel får skipet en høy tilleggsmotstand i bølger, som betyr at batteripakken i ReVolt må dimensjoneres slik at den inneholder tilstrekkelig energi til å komme seg fra havn til havn i de verste sjøforholdene ReVolt er designet for å seile i. Batterier forbindes i dag med en høy kapitalkostnad (CAPEX).

Hovedfokuset i denne masteroppgaven er å se på hvilke besparelser i kapitalkostnader for ReVolts batteripakke man kan oppnå ved å montere såkalte fremdriftsproduserende *bølgefoiler* i baugen på fartøyet. Foilenes påvirkning på kontinuerlige operasjonskostnader (OPEX) vurderes også, men i mindre grad.

Det er tidligere blitt gjennomført betydelig forskningsarbeid på temaet bølgefoiler, og en oversikt over tidligere teoretisk arbeid, og forsøk i modell- og fullskala presenteres i denne oppgaven. Så vidt forfatteren av denne oppgaven kjenner til er dette første gangen bølgefoiler prøves som en CAPEX-besparende innretning på et elektrisk, sjøgående fartøy – tidligere arbeid vedrørende drivstoffbesparelser med bølgefoiler har dreid seg mer i retning generell OPEX-besparelse.

For å undersøke foilenes ytelse i irregulær sjø simuleres irregulære sjøtilstander, og foilenes tidsgjennomsnittlige ytelse har blitt funnet gjennom en analyse i frekvensplanet. Lineær foilteori benyttes, men en en modell for *stalling* har blitt implementert for å modellere de potensielt viktige effektene som inntreffer om foilen staller, noe som ikke er mulig med den grunnleggende lineære foilteorien. Modellen inneholder også effekten av ustødig løft på en oscillerende foil og tilleggsmotstanden påtvunget på foilsystemet.

Foilenes fremdriftsproduksjon og bevegelsesdempende effekt reduserer skipets totalmotstand i sjøtilstander egnet for bølgefoiler. Fra totalmotstanden regnes skipets bremsekraft ut. Bremsekraften gjøres så om til totalt energiforbruk ved å definere en dimensjonerende seileavstand. Dette benyttes til å finne sjøtilstanden som gir det største totale energiforbruket gjennom den dimensjonerende strekningen, noe vi har definert som *worst case scenario* (WCS) for ReVolt. Vi finner WCS for ReVolt både med og uten bølgefoiler. Et overblikk over forskjellige foilmekanismer gis, med fokus på foilenes evne til å trekke seg tilbake. Vi ser også på foilstørrelse og neddykning. Vi har modellert passive foiler, montert i fast stilling, og foiler med evne til å rotere rundt sin egen spennvise akse.

Vi undersøker ReVolts seileforhold ved å se på bølgepunktdiagram for ReVolts rute. Fra dette defineres et område av sjøtilstander egnet for ReVolt, gjort opp av signifikant bølgehøyde og topperiode. Innenfor dette området defineres også aktuelle skipshastigheter og bølgemøteretninger. Vindmotstand er også tatt med i motstandsberegningen.

Vi forsøker å gi et overblikk over i hvilket område passive bølgefoiler fungerer som tiltenkt, og sammenligner roterende bølgefoiler med passive bølgefoiler for å se hvilke sjøtilstander som er mest egnet for de forskjellige foilkonfigurasjonene. Vi vil se at foilene er fordelaktige med tanke på reduksjon av energiforbruk for et stort antall scenarier definert av vårt sjøtilstandsområde. Den største fremdriftsproduksjonen finnes ved topperioder som er lengre enn perioden som gir størst tilleggsmotstand i bølger, men foilene later til også å være effektive til å redusere energiforbruket i worst case-scenariet.

Ved ReVolts designhastighet på seks knop indikerer resultatene våre en reduksjon av dimensjonert batteristørrelse på 16.6%, eller 1.27MWh, som assosieres med en CAPEX-reduksjon på 1.27MUSD, eller 10.1 MNOK. Ved lavere hastigheter synker ytelsen fra foilene, og innenfor vårt definerte hastighetsområde stiger foilytelsen med økende skipshastighet. Et resultat av dette er at ved sjøtilstanden som gir worst case-scenariet, vil den dimensjonerende batteristørrelsen kun være noe høyere for å gjennomføre en dimensjonerende seileavstand ved åtte knop sammenlignet med ved fire knop. Fra dette ser det ikke ut til at å redusere skipshastigheten er en god strategi for å overkomme worst case-scenariet hvis ReVolt utstyres med bølgefoiler. Snarere ser det ut – spesielt om man tar med fordelene av den kortere seiletiden på en rutestrekning – til at å *øke* skipshastigheten for å overkomme worst case scenariet er en god strategi.

Vi diskuterer besparelser i OPEX, og finner potensielle besparelser i en stor andel av sjøtilstandene vurdert. Siden ReVolt ikke bruker mye energi er ikke OPEX-besparelsene veldig store – men akkummulert til en hel flåte av ReVolt, i service over lang tid, kan også besparelsene i OPEX bli betydelige. Bølgefoiler later til å være en effektiv måte å redusere kapitalkostandene assosiert med batterier. I denne oppgaven er ReVolt i fokus, men konseptet og resultatene bør være overførbare til alle elektrisk drevne skip hvor tilleggsmotstand i bølger fører til en stor dimensjonerende batteristørrelse.

Nomenclature

Various terms for foils creating propulsion from waves have been coined in the past. They have been referred to as wave foils, propulsion foils, whale tail foils and wave devouring foils in earlier work. We will refer to a “wave foil” or “wave foils” in this thesis.

The ship ReVolt will be interchangeably be referred to as “ReVolt”, “the vessel” and “the ship”.

A ReVolt without foils equipped will be referred to as an “unfoiled ReVolt”. Passive foils are denoted as “passive foils”, and ReVolt with such foils is referred to as “passively foiled”. Pitching foils are denoted “pitching foils”, and ReVolt equipped with such foils is denoted “pitch foiled”.

List of symbols

α	Angle of attack
α_0	Flow angle of attack relative to horizontal
α_E	Effective angle of attack
$a_{rel,vertical}$	Relative vert. acc. between foil and surrounding fluid
β	Wave heading angle
β_{wind}	Wind heading angle
ϵ_i	Wave phase angle
$\eta_{5,foil}$	Pitch displacement of foil
η_i	Displacement response of degree of freedom *i*
$\dot{\eta_\imath}$	Velocity response of degree of freedom *i*
$\ddot{\eta_\imath}$	Accelleration response of degree of freedom *i*
η_0	Open water efficiency
η_H	Hull efficiency
η_M	Mechanical efficiency
η_R	Rotative efficiency

ζ_a	Wave amplitude	
ρ	Density of fluid surrounding foil	
ρ_{air}	Density of air	
φ_I	Velocity potential of incident wave train	
ω_0	Wave frequency	$\sqrt{gk}$ for deep water
ω_e	Encounter frequency	
θ_i	Phase angle of ship displacements, velocities and accelerations	
Λ	Aspect ratio	
c	Chord length	
i	$\sqrt{-1}$	
k	Wave number	
k_f	Spring stiffness (total)	
k_r	Reduced frequency	
g	Gravity constant	
$p_{Rayleigh}$	Rayleigh probability distribution	
s	Transverse foil span	
$\bar{s}$	General displacement	
t	Time	
t	Thrust reduction factor	
t_{leg}	Time it takes to sail a route leg at applicable speed	
$\bar{u}$	Mean wind speed of working area	
w_w	Vertical wave particle velocity	
$\dot{w}_w$	Vertical wave particle acceleration	
u_w	Horizontal wave particle velocity	

v	Kinematic viscosity of water
A	Projected area of ship above waterline, bow projection
B	Breadth molded of ReVolt
C(k_r)	Theodorsen Function
C_{added}	Added resistance in waves coefficient
$C_{A,waves}$	Dimensionless added resistance coefficient
C_F	Friction coefficient
C_D	Drag coefficient
$C_{D,wind}$	Drag coefficient of ship above waterline at head wind
$C_{D,viscous}$	Viscous drag coefficient
$C_{D,struts}$	Viscous drag coefficient of foil struts
C_L	Lift coefficient
C_P	Power coefficient
D	Drag produced by foil
D	Diameter of wind turbine
$D_{struts,visc}$	Viscous drag of struts
$D_{struts,spray}$	Spray resistance of struts
F	Total force on the foil
F_{added}	Added mass force for foil
F_N	Froude number
${H_n}^{(2)}$	Hankel function
H(ω)	Transfer function
H_s	Significant wave height
J	Propulsion point

J_n	Bessel function, first kind
K	Reduced frequency
K_T	Thrust coefficient
K_Q	Torque coefficient
L_{pp}	Length between perpendiculars
$M_{hydrodynamic}$	Moment on foil imposed by lift and added mass
$M_{springs}$	Moment imposed on foil springs
$\bar{P}$	Average power delivered by wind turbine
P_B	Engine power (brake power)
P_E	Effective power
$R_{A,Waves}$	Added resistance in waves
$R_{A,Wind}$	Added wind resistance
R_N	Reynolds number
Re[]	Denotes real part of value in bracket
RPM	Revolutions per minute
R_{TS}	Total resistance on ship
R_{calm}	Calm water resistance on ReVolt
S	Planform area of foil
T_{active}	Thrust produced by active foil
$T_{passive}$	Thrust produced by passive foil
U	Ship velocity
$U_{rel,wind}$	Relative vel. comp. between ship and wind, perpendicular to front
U_{wind}	Absolute velocity of wind
V_{in}	Incoming fluid velocity on foil

$Y_{C,F,strip}$	Transverse position of foil strip relative to centerline
Y_n	Bessel functions, second kind
Z_0	Static vertical foil position relative to calm water surface
$Z_{C,F}$	Dynamic vertical foil position

List of acronyms

CAPEX	Capital expense
DPI	Direct pressure integration
MNOK	Million Norwegian Kroners
MUSD	Million US Dollars
RAO	Response Amplitude Operator
RPM	Revolutions per minute
WCS	Worst Case Scenario

Summary

Tables

Figures

1 Introduction

1.1 The concept of ReVolt

Figure 1: The concept ship ReVolt (DNV GL)

ReVolt is a concept ship designed by DNV GL Research & Innovation. The motivation behind the project is based in the National Transport Plan of 2013-2014 (NTP, 2012), stating that "..the transport of goods should be moved from road to sea due to the benefits associated with decreased road congestion and wear, as well as reduction in emissions associated with the transport of goods". As the actual advantage of such a shift is dependent on the ship used, DNV GL set out to find out how much of an improvement it was possible to achieve by suggesting an optimized design concept for short distance transport of goods.

The margins in the short sea shipping segment are low, primarily due to the cost of fuel and crew. DNV GL therefore focused on the cost of fuel and crew, setting out to find a concept that could minimize these costs.

The project has culminated into an autonomously driven, battery powered container vessel purposed to operate between Oslo and Trondheim. To minimize the costs associated with propulsive energy, the planned service speed is set to 6knots. To be able to sufficiently cover this stretch, a conveyer belt approach has been assigned to the logistics chain, implying a large number of ships in operation.

Table 1: Key figures for ReVolt

LOA	**Depth**	**Draught**	**Beam**
60.2m	13m	5.02m	14.5m
Freeboard	**Container capacity**	**Dead Weight**	**Calm water prop. Effect at 6 knots**
7.98m	100TEU	1300DWT	50kW

1.2 Motivation for thesis in relation to ReVolt

ReVolt is designed to minimize the energy needed for propulsion between ports, thus the service speed is set to a low 6 knots. However, in sea states with waves, the added resistance due to waves becomes significant. In fact, it becomes the largest resistance component of the vessel in adverse weather condition. The size of the battery pack fitted in ReVolt has to be dimensioned to contain enough energy to bring ReVolt to port in the worst sea states it can encounter in its route. As of today, the cost of batteries is high, so minimizing the size of the fitted battery pack is important with respect to making ReVolt a financially attractive option for the short sea shipping segment.

As the added resistance in waves is large for ReVolt, this resistance is significant when dimensioning the battery pack size. One potential measure for reducing the added resistance in waves for ReVolt is implementing wave propulsion foils close to the bow. The purpose of wave foils is to dampen wave induced ship motions and generate thrust. If theoretically proven as a viable concept for ReVolt, wave foils could contribute significantly in minimizing the initial CAPEX of ReVolt. This would make the concept especially interesting for electrically propelled vessels, as the CAPEX increase associated with larger batteries is much larger than for an equivalent fuel tank. With present rising awareness of energy reducing measurements in the maritime industry(DNVGL, 2015), (TekniskUkeblad, 2015), the concept is increasingly relevant also in terms of OPEX savings.

1.3 Background and previous work on wavefoils

It is a known and intuitive phenomenon that a ship sailing in waves experiences increased resistance relative to the resistance experienced by a an equal ship sailing at the same speed in calm seas. This increase of resistance in waves can be associated with the energy transported in sea waves effectively working to counteract the forward motion of a ship. The prospect of utilizing the abundant energy in sea waves to contribute to, rather than counteract, the forward motion of a ship has been subject to significant research in the past centuries. The idea of utilizing a foil system to produce thrust might have risen from observing whalers cutting off the flukes of dead whales to prevent them from gaining speed against the waves when lying dead in the water (E. Bøckmann, 2015).

Both theoretical work, model and full-scale trials of foil systems purposed to generate propulsive force from waves have been performed in the past, and the results have generally looked promising. In the following, a summary of previous theoretical work and model simulations will be presented.

1.3.1 Previous model and full scale trials

The earliest recorded document describing a wave-powered vessel is an US patent by Daniel Vrooman (Vrooman, 1858). In his patent, Vrooman explains how wave powered propulsion can be produced by attaching flexible fins or wings to his ship. It is not known whether Vroomans ideas were ever put to life. Later, a British patent was filed by Hermann Linden REF, obtaining thrust from underwater steel plates fitted to the hull of a vessel. Linden built a 13ft boat, which he named *Autonaut* that was able to travel at a speed of 3-4mph solely powered by waves.

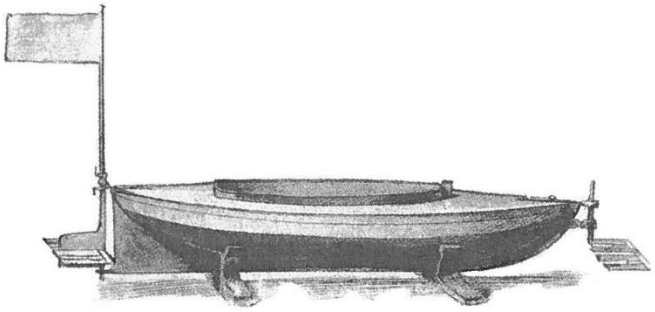
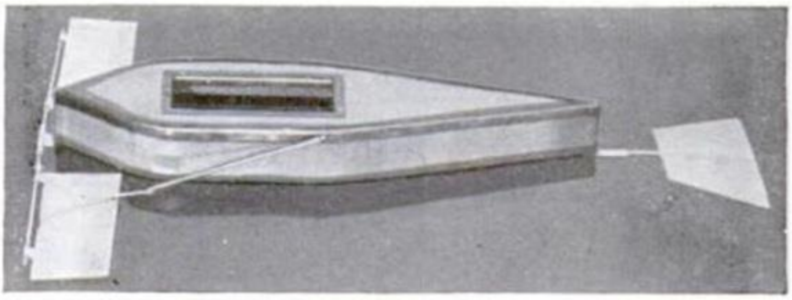


Figure 1-2: A drawing of the Autonaut *from Pearson's Magazine, December 1898 (Burnett, 1979)*

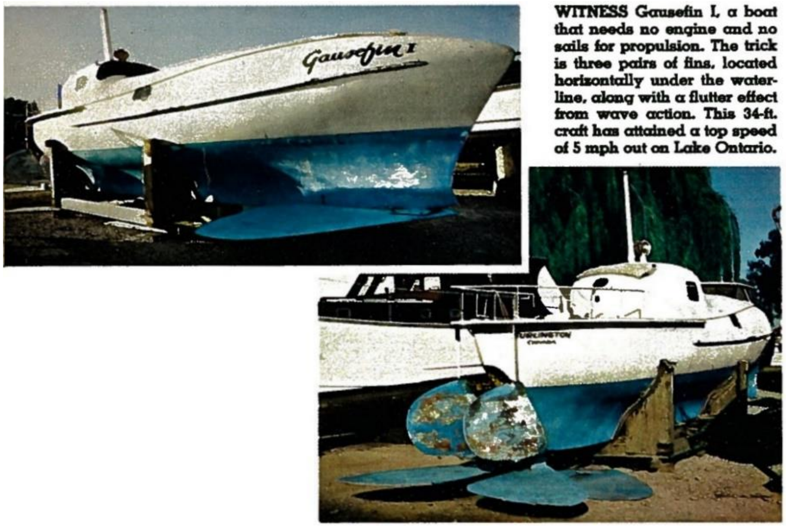
Lindens boat received praise in contemporary newspapers, but it seems his contribution to the subject was forgotten by the scientific community, as the magazine Popular Science in 1935 claimed that "it remained for a Long Beach, Calif. inventor to design a wave-operated mechanism to propel a boat" (PopularScience, 1935). The authors name is not mentioned. Reportedly, his 18 inch model could achieve, by utilizing two fins in the bow and one in the stern, a speed of five miles per hour. The speed of this model seems unrealistically large when compared with model vessels of similar size mentioned in this section.



Close-up of model, showing fins that gather energy from waves

Figure 1-3: View of the wave-powered model boat of 1935. Inventor unknown. (PopularScience, 1935)

The first half of the 20th century was the time when wind-powered sailing vessels were receiving the final blows towards the end their era of dominating the seas, as the diesel-powered marine engine were becoming increasingly popular and sophisticated. Not much work is known regarding wave propulsion devices from this time, which might be understandable considered the seemingly endless possibilities the diesel engine could introduce. In the latter half of the 20th century, however, more stories appeared about people building full scale, wave-powered boats. An article describing a wave-powered vessel built by Australian John S. McCubbin was published in (PopularScience, 1935), and Canadian Joseph A. Gause filed a patent for a wave-powered boat in 1966 (Gause, 1966). Gause built a 34ft vessel, attaining a top speed of 5mph recorded on the Lake Ontario, utilizing foils three pairs of fixed fins attached to the hull. The fins were thickest at the root and gradually tapered outward to toward a thin trailing edge, allowing the fins to flex when hit by a wave.



WITNESS Gausefin I, a boat that needs no engine and no sails for propulsion. The trick is three pairs of fins, located horizontally under the waterline, along with a flutter effect from wave action. This 34-ft. craft has attained a top speed of 5 mph out on Lake Ontario.

Figure 1-4: The Gausefin I: Bow shown to the left, stern to the right. ("Mechanix Illustrated ", 1972)

In 1978, Norwegian engineer Einar Jakobsen started experimenting with wave-powered vessels, and named his wave propulsion device the “foil propeller”. He did experiments on several ship models, and claimed that his foil propeller had potential for wide range of vessel sizes, from small manually powered crafts to large vessels. From model experiments performed at MARINTEK in Trondheim, he presented his results in (Jakobsen, 1981). His 1.025m model was fitted with a spring-loaded foil mounted to an extension from the bow, and another spring-loaded foil mounted to an extension from aft of the stern. The purpose of the spring loading was to adjust, and thus optimize, the angle of attack of the incoming relative fluid flow. In regular head sea waves of height 0.05m and a period of 1.2s, his vessel reportedly reached a speed of 0.84m/s. Jakobsen was at the time senior engineer in a company named Wave Control Company, performing a full size trial on a 7.5m sailing boat. Using a combination of two and four foils, each measuring 0.5m^2, a maximum speed of six knots were recorded at sea (Anon., 1983).

Succeeding these experiments, the Norwegian government sponsored NOK 450.000 to equip the 20m and 180t fishing vessel *Kystfangst* with a bulbous bow and two foils with a total area of 3m^2. Trials were performed at a speed of 4-8knots. In a sea state measuring a significant wave height of roughly 3m, the foils produced a thrust corresponding to 16-22% of the vessels estimated resistance. The foils were mounted on struts, enabling the foils to be lifted out of the sea. When the resistance on the struts were taken into consideration, the thrust corresponded to 8-16% of the estimated total vessel resistance (Berg, 1985). In addition, reduced pitching motions of the vessel in head seas, and reduced rolling motion in following seas were observed. It is worth noting that the wavelengths *Kystfangst* was tested in were roughly 80m, corresponding to roughly four times the ship length. With reference to model tests performed by (Kjærland, 1979) and (Nagata, 2010), we can comment that the largest speeds of wave powered vessels occurs at a beam sea wave length of 1.1-1.2 times the ship length, and at 1.5-2.2 times the ship length in head seas. From this we may conclude that the beneficial effects of the foils fitted to *Kystfangst* would have been larger if the vessel had been tested in longer wavelengths.

Figure 1-5: View of the foils fixed to struts in the bow of fishing vessel Kystfangst (Dybdahl, 1988)

In the 1990s, a 174t Russian research fishing vessel was fitted with two foils in the bow to extract energy from waves for propulsion. Measurements reportedly showed that engine power could be decreased by up to 45-87% and reduce ship motions by a factor of 2-2.5 (Nikolaev, 1995).

Figure 1-6: Russian trawler with bow-mounted wave foils (Nikolaev, 1995)

In Japan, a theoretical and experimental study of wave powered boats commenced at the same as Jakobsen started his work, performed by Hiroshi Isshiki of the Technical Research Institute, Hitachi Shipbulding & Engineering Co., Ltd. in Osaka, in addition to Yutaka Terao of Tokai University in Japan, who was working on what he called “wave devouring propulsion”. In 1991, Isshiki and Terao presented results from a full scale trial on a 15.7m fishing vessel (Terao, 1991). A foil with projected hydrofoil area of 7.4% of the waterline area was fitted to the bow of the ship, using struts to fasten the foil to the vessel. Using the foil resulted in reduced pitching motion, reduced bow slamming and increased speed in waves.

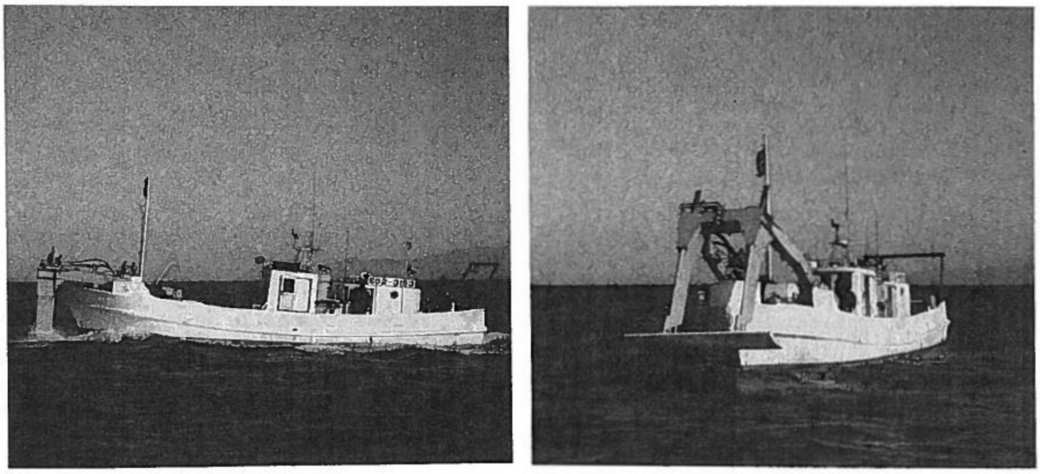


Figure 1-7: Japanese fishing with wave foils fixed to struts (Terao, 1991)

In more recent times, a Japanese sailor named Kenichi Horie set out to be the first person crossing the Pacific Ocean in a vessel solely powered by waves, setting out from Hawaii towards Japan. The vessel, 31-foot Suntory Mermaid II, was fitted with a wave propulsion system in the bow, designed by Yutaka Terao. The journey took 111 days, as opposed to the scheduled 60 days, due to unusually good weather along the route. Despite this, the journey was considered a success, as they were able to prove that a wave powered propulsion system was able to deliver a 7000km voyage (Geoghegan, 2008a).

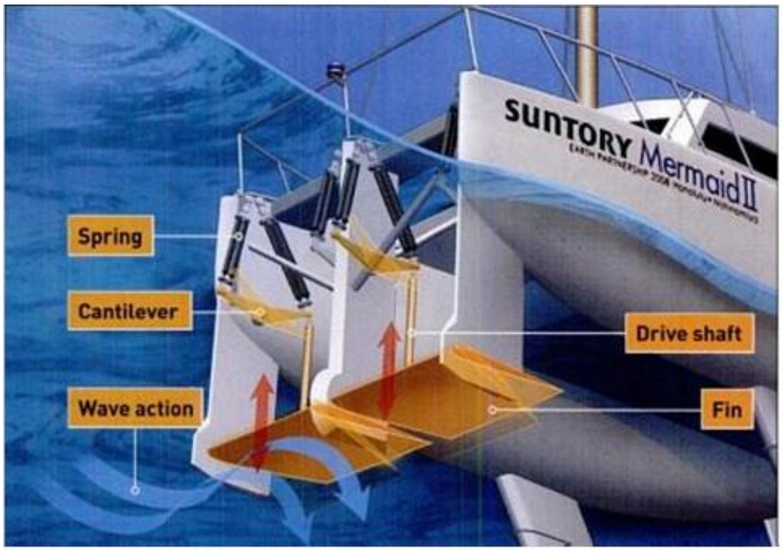


Figure 1-8: Foil propulsion system on Suntory Mermaid II (Geoghegan, 2008b)

Also in Japan, model tests of a 2m model of an 80m container vessel was performed by (Nagata, 2010). The ship was fitted with a wave foil in the bow, and due to space limitations in their towing tank, only free running tests were deemed reliable. The span of the foil was 2.34 times the ship beam, and in head sea waves of wavelength 3.12 times the ship length between perpendiculars and wave height of 0.1m, the ship cruised at a speed of roughly 0.7m/s against the waves. Roughly the same speed was achieved in following seas, but then at a wave length of 0.96 times the ship length between perpendiculars. When Froude-scaled to full scale, this corresponds to an 80m ship sailing at 8.6 knots in 4m wave height.

At the Norwegian Institute of Science and Technology in Trondheim, Norway, Eirik Bøckmann has done his PhD on wave powered propulsion for ships, finishing in 2014, with a goal of developing solutions for using actively pitch-controlled foils to reduce fuel consumption of ships travelling in waves (E. Bøckmann, 2015). In March 2012 model tests were performed at the MARINTEK towing tank at Tyholt, Trondheim. A second model test was done in September 2013 due to problems with the pitching mechanism in the 2012 testing. The model was made based on the 90m supply ship *Far Searcher,* and the model size was 5.6m. The foil was fastened to the hull by a swing arm to allow for the foil to be retracted out of the water, see FIGURE. To minimize the chance of foil slamming, the foil was placed as deep as 8.7m below the water line of the full size vessel.

Theoretical simulations were done using an actively controlled pitching system, a spring-loaded pitching system and fixed foils. Due to time restrictions, model tests were done for only the actively controlled and the fixed system. The model trials were done for full scale speeds of 8, 10 and 12 knots. Results from a model tests at a full scale speed of 8 knots is presented in Table 2, showing significant reduction in ship resistance and heave/pitch motion at regular head sea waves of roughly 3m. An interesting video, clearly showing the reduced pitching movements of the vessel, can be seen in (Aftenposten, 2013).

Table 2: Experimental results from Bøckmann (2015). F and P indicates fixed and pitch controlled foils respectively. NaN indicates that no experimental data is available.

	Reduction in ship resistance [%]		**Reduction in heave motion [%]**		**Reduction in pitch motion [%]**	
T [s]	**F**	**P**	**F**	**P**	**F**	**P**
11.5	23	NaN	-2	NaN	15	NaN
10.5	36	NaN	-6	NaN	28	NaN
9.5	49	67	-1	-8	34	27
8.5	45	50	13	7	34	27
7.5	62	60	56	55	48	46
6.5	43	NaN	49	NaN	55	NaN

Figure 1-9: Model of supply ship Far Searcher used in model trials by Bøckmann (Aftenposten, 2013)

1.3.2 Previous theoretical studies on wave propulsion

1.3.2.1 Theoretical work: Theory on oscillating foils

Although there has been an interest in utilizing wave energy to produce forward thrust by means of foils since the 19th century, not much theoretical work on the subject is known to the author of this thesis until the 1970s, when (Wu, 1972) and (Chwang, 1975) studied the generation of thrust of an oscillating hydrofoil advancing in waves. These studies neglected the effect of the free surface and solid bottom, a simplification Wu deemed satisfactory if the foil was held at least two chord lengths away from these boundaries.

The next decade, Isshiki theoretically and experimentally investigated the propulsive efficiencies of a foil system to convert wave energy into propulsion through four reports. In the first report, (Isshiki, 1982b) improved Wu’s theory by including an approximation of the free-surface effect and studied a non-oscillating hydrofoil advancing in waves. The second report included heaving and pitching motion of the hydrofoil given that the power required for creating this heaving and pitching motion was zero (Isshiki, 1982a). The third and fourth reports included verification and comparison with theory by experimental results (Isshiki & Murakami, 1983), (Isshiki & Murakami, 1984).

(Grue, 1988) also included the effects of the free surface in the PhD thesis, examining the propulsion of a foil moving through the water close to the free surface in 2D. They applied a vortex distribution along the centreline of the foil and wake and solved for vortex strength, and linearized the equations. They assumed that the foil was moving downwards when the velocity field was moving upwards, and that the heave motion amplitude of the ship was of the same order of magnitude as the incoming waves. From their results, the ability of the foil to propel a ship in waves was studied, finding that a 40m long ship in 1m high regular waves would travel at a speed of 8 knots.

The rear fins of whales and dolphins are analogous to wave foil fitted to ship hulls, as they too utilize a pitching motion of the foils to generate thrust. Cetacean mammals (Bose & Lien, 1990) studied the performance of this animalic propulsion, finding that a fin whale of 14.5m length would save about 25% propulsive power in head seas and 33% in following seas, assuming a wave generating wind speed of 20m/s, swimming depth of 2.0m and swimming speed of 2.5m/s. As can be expected from decaying fluid particle motion with depth, the energy savings for the aquatic animals dropped with depth.

(Naito & Isshiki, 2005) performed experiments with an actively controlled pitching bow-mounted foils added to a model ship. The wings rotated harmonically in pitch, and the phase of the pitching motion was varied relative to the incoming head sea waves. Based on measuring of the bottom pressure on the foil together with the amplitude of the angle of attack of the wings, they proposed and simulated a control system which could receive bottom pressures on the foil as input, and give optimal bow wing angle as output. They assumed that the vertical foil force oscillated with the wave encounter frequency, making it possible to use a frequency-domain approach to the problem. The frequency domain solution could then be Fourier-transformed to a time-domain solution to be able to study the response in irregular waves.

(Politis, 2014), (Belibassakis & Politis, 2012) and (Belibassakis & Politis, 2013) studied an actively controlled pitching foil, using a boundary element method to accurately model the forces on an oscillating foil. They set the foil pitch to have a linear relation with the inflow angle. The 2014 report also showed that the energy consumption for actively pitching the flow was low relative to the propulsive power produced from the actively controlled foil.

More advanced numerical (CFD) methods have also been utilized to study the extraction of wave energy by means of wave foil propulsion. The commercially available FLUENT code was used by (De Silva, 2012) to study a 2D hydrofoil oscillating harmonically in heave and pitch under the influence of free-surface waves. Results were compared with (Isshiki & Murakami, 1984) and found to be in good agreement. The results also shown that foil thrust and efficiency was highest when the foil oscillation frequency was the same as the wave encounter frequency.

1.3.2.2 Theoretical work: Focus on fuel savings

The main goal of this thesis is to reduce the energy need of ReVolt utilising wave foils, and thus the earlier work where actual fuel savings have been in focus are of the highest relevance.

In Norway, a former subsidiary of Det Norske Veritas (today DNV GL Group), Veritec, analysed the propulsive effect of wavefoils near the bow of vessels of length 20m, 40m and 70m (Veritec, 1985), (Veritec, 1986). The study utilized strip theory in its calculations, but left out the (positively contributing) effect of heave and pitch damping of the foil, in addition to leaving out the effect of foil drag and dynamic foil effects. Most relevant for this thesis, the 70m ship was found to gain fuel savings of 43% at a speed of 10.6 knots and 10% at 15.9 knots.

Two master theses from Norwegian University of Science and Technology did case studies on vessels to examine the potential for fuel savings utilizing bow-mounted foils to extract energy from waves (Angvik, 2009), (Borgen, 2010). Angvik studied only an offshore supply vessel, while Borgen studied an offshore supply vessel, a purse seiner and a coastal tanker. The MARINTEK software ShipX extension VERES (Vessel Responses) was used to produce RAOs of heave, pitch and roll for the ships in a given wave condition. A frequency-domain simulation was then done in MATLAB to estimate the mean thrust of the foils in a given sea state based on the JONSWAP sea spectrum. Still water resistance was found using the ShipX extension ShipX Speed and Powering, added resistance reduction due to reduced ship motions were found from VERES, and wind resistance was also included in the calculations. Angvik did not include the effects of unsteady lift, which was implemented by Borgen by a correction factor. Full size ship speeds of 9-17 knots were examined, from following seas to head seas. Passive and spring-loaded foils were examined, along with an array of different foil sizes. Practical solutions for installing retractable foils to a ship hull was also examined. The reported fuel savings in their work was promising, and for some conditions and foil configurations the fuel savings reached 100% - even in head sea.

(E. Bøckmann, 2015) of the Norwegian University of Science and Technology wrote his PhD thesis on wave propulsion foils, focusing on practical solutions for wave foils and fuel savings. His theoretical work included taking unsteady lift effects and a dynamic stall model into account, looking into actively controlled, spring-controlled and passive (fixed) foils. Using the time-domain ship simulator VeSim from MARINTEK, wave foil forces were calculated. This was done to develop an efficient and reliable tool for predicting the performance of ships with wave foils where dynamic stall could occur. The theoretical results were compared with a model trial done at MARINTEK, and the method was found to produce reasonably accurate results, although room for improvement was still present. Simulations showed that fixed foils for the modelled 90m offshore supply vessels could give fuel savings of 2-15% depending on wave direction. For a similar sized RORO vessel with slightly larger waves and foil span relative to the ship beam, fuel savings were found to be 29-50% in head seas and 9-17% for following seas. The results for spring-controlled and actively controlled foils yielded more beneficial results.

1.3.3 Work of particular relevance to current work on ReVolt

Although all of the previously mentioned work points towards wave foil propulsion being a feasible way of utilizing wave energy to propel a ship, some work is of more relevance for this thesis.

It is of interest to note the results from the full size trials of *Kystfangst* pointing towards good results even for a ship sailing in seas where the wave length is not optimal relative to the length of the ship. Although the wavelengths used in the full size trials of (Nikolaev, 1995) is not known to the author of this thesis, the performance of this vessel showed significantly better results than those of *Kystfangst*, though the vessels were of similar size. This can be expected, although not certainly, to be a result of the Russian trawler being tested in sea states of wave lengths more optimal for foil thrust production. Results from (Kjærland, 1979) and (Nagata, 2010) implies wave lengths of 1.5-2.2 times the ship length being optimal for foil thrust production in head seas. Related to ReVolt, this corresponds to a wave length of 90-132m, or in terms of wave periods, 7.6-9.2s. It is worth noting that the optimal wave length is of course sensitive of the ship’s forward speed, as this changes the encounter frequency of the waves.

From examining the scatter diagrams for the route of ReVolt, we see that sea states with these wave lengths are abundant in ReVolts sailing route. (Riley, 2014) is the predecessor to this thesis, and the added resistance in waves for ReVolt were found to be largest in head sea for a wave period of 6-7s, or wave lengths of 56-76m. We see that the optimal wave lengths for thrust production versus the conditions producing most added resistance for ReVolt do not overlap completely, but they are close enough to expect a significant thrust production by the foils for the wave periods most important for ReVolt. In the simulations done in (Riley, 2014), it was found that the foils indeed produce significant thrust in this region. One should use caution when looking at this thrust, though, as the simulations were done with passive foils, using linear foil theory with no stall model. For the low speeds of ReVolt we expect stall to play an important role, especially with passive foils.

The Veritec reports (1985-1986) analyse a ship of similar length as ReVolt. Their results are promising, showing a fuel saving of 43% at a speed of 10.6knots for the 70m vessel simulation. The speed of the simulated vessel is higher than that of ReVolt, and are not directly relatable to ReVolt. From knowing that the foils seem effective at higher speeds than 6 knots, though, one can imagine that the average cruising speed of ReVolt can be increased if wave foils are deemed effective for ReVolt, as added resistance in waves is the main limiting factor for the sailing speed. Increased sailing speed could further the concept’s attractiveness.

This thesis will model ReVolt equipped with both passive (fixed) and rotating (pitching) foils. How the foils are to be pitched in the active configuration has to be decided, and both spring-loaded systems and actively controlled systems (by means of hydraulics or pneumatics) are possibilities. The latter system measures pressures at the foil to obtain the optimal pitching angles as output. The PhD thesis of (E. Bøckmann, 2015) provides interesting results and considerations to this aspect. Although an actively controlled pitching system based on input from pressure sensors at the foil seems more sophisticated than the spring-loaded system, Bøckmanns simulations and model trials showed better results for spring-loaded systems. Bøckmann suggests this result is due to the phase shift between the heave and pitch motion. Thus, the spring-loaded foil is recommended by Bøckmann as the better solution, at least until a better system for predicting optimal pitching angles of the foil has been developed. As it is important to keep the costs of the foil system down for ReVolt, it also seems sensible to use a spring-loaded system due to the relative simplicity of this (mechanical) system as opposed to a more sophisticated, and thus expectedly more expensive system of actively pitching foils.

The master theses of (Angvik, 2009) and (Borgen, 2010) are also highly relevant for this thesis, as their calculation methods are also within the frequency domain. The mechanism intended to control the foil pitch and the effect of foil stalling is thus not accounted for in their work. Borgen modelled the effect of unsteady lift by means of a correction factor found in (Minsaas, 2006), but the basis upon which this correction factor is formed is somewhat unclear. Their work is relevant for comparison of calculation methods, but the calculation model has to go some steps further in complexity to be able to reproduce all the hydrodynamic effects we wish to include in this thesis.

2 Wave foil basics

2.1 Purpose of foils and mechanisms reducing the added resistance in waves

A ship moving in waves will experience a higher resistance than a ship moving in still water at the same speed, influencing ship speed, stability and energy consumption. The comparative resistance increase is an effect of the wave induced motions of the ship and the radiated waves produced by these wave induced ship movements. The main purpose utilizing wave foils in this thesis is reducing the added resistance imposed when the vessel is sailing in waves.

When a typical ship in forward motion encounters head wave(s), the loads excited on the ship hull by the waves will induce heave and pitch motions on the vessel. It has been shown theoretically, and in model and full-scale trials that if a ship is equipped with a functioning wave foil device, the vessel will more easily surge through the waves. Indeed, vessels with such devices seem able to travel against the waves on their own, even when starting with zero forward velocity.

The phenomenon is explained by a hydrodynamic lift produced on the foil. This lift can be partially decomposed into a thrust force working in the ship surge direction, and in addition the lift will act as damping on the wave induced ship motions. Both of these effects contribute to reducing the resistance a ship sailing in waves has to overcome. We will go into more detail as to how the lift is produced in Section 3.

2.2 Passive and pitch-controlled foils: Stalling avoidance

The foils could be fastened to the hull directly, or by the use of struts. To maximize motions at the foil position, they are typically placed near the bow or stern of a ship, far from the ship’s rotation center, to maximize the motions of the foil due to ship rotation. They can be fixed, hindering rotation or translation of the foil relative to the hull. We call this a *passive* wave foil. Alternatively, the foils could be installed with passive or active pitch control. In the latter case, the foil can rotate along an axis parallel to the span of the foil to optimize the angle of attack imposed by the incoming flow on the foil. Note that a more precise definition of terms will follow in Section 4. As we will see in this section, the production of lift and thrust is directly related to the angle of attack of the incoming flow.

The intention of a pitching foil is to ensure that the foils are not operating at angles of attack too large. As the angle α increases, the lift will increase until the flow separates from the flow at the suction side of the foil – a phenomenon called stalling. The lift will rapidly decrease when this occurs, as exemplified in Figure 2-1. Stalling typically occurs if the inflow angle exceeds 15° (Faltinsen, 2005), but this is dependent on the foil type chosen.

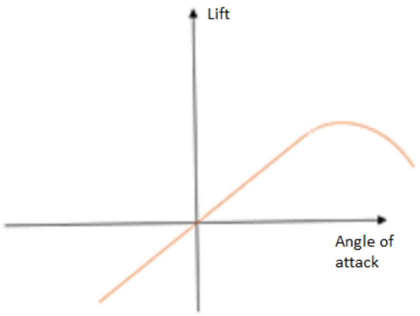


Figure 2-1: Lift coefficient on foil without camber

The stalling phenomenon will be addressed in detail in this thesis, as we expect that the angles of attack at times will exceed the stalling limit. The stalling phenomenon is less important for pitch-controlled foils, as the pitching of the foils is done to avoid this phenomenon.

Passive foils is the simplest option, and can be expected to be the cheapest option due to the lack of pitching mechanism/control. However, one can also expect that the range of sea states where the foils produce a positive thrusting effect to be smaller than for pitching foils, as the angle of attack will exceed the stalling value more easily than it would for a pitching foil, causing stalling and a drop in lift and thus thrust on the foil.

Pitching control can be done passively or actively; passively controlled foils controls the pitching angle by rotational springs in the fastening point(s) of the foil(s). At all times hydrodynamic forces are imposed on the foil, giving a hydrodynamic moment around the foil pitching axis. This moment will cause the foil to rotate towards a smaller angle of attack, and how much the foils rotates is then determined by the spring stiffness and the location of the rotational axis. This spring configuration does not require a control system for the foils, as the foil pitch is controlled mechanically by the hydrodynamic pitching moment and spring stiffness. As a result this configuration is anticipated to be cheaper than active foil control. Another benefit is that no energy needs to be supplied the system to perform the foil pitching motion.

Active foil control is performed by rotating the foils actively around its pitching axis, based on pressure sensors installed on the foil. Based on measurements from the pressure sensors, the optimal angle of attack is obtained. Due to the need for a device rotating the foils, and the pressure sensors and control system, we expect this system to be significantly more expensive than a passive control system. Due to the desirable simplicity of the systems, and expectedly lower cost, only passive (fixed) foils and passively controlled, spring-loaded foils will be examined in this thesis.

3 Modelling: Wave foil principle explained within linear theory

3.1 Assumptions within linear foil theory

To calculate the production of lift on the wave foil, we will utilize linear foil theory in this thesis. Linear foil theory is a simplified model, with the great benefit that we can superimpose the effects a camber and an angle of attack has on the lift produced. The requirements for using linear foil theory states (Steen, 2014)

- The maximum thickness of the foil needs to be much smaller than the chord length, or stated mathematically, t<<c.
- The chamber to chord ratio is small. As we will see, our foil will need no camber.
- The angle of attack is small.

The result of the above assumptions for reasonably shaped foils are (Steen, 2014)

- No flow separation from the foil
- Thin boundary layers
- A linear relation between lift an angle of attack

The latter statements in these two lists are related, and small angles f attack is a very dubious assumption in our thesis, as angles of attack are expected to go beyond what can be considered as “small”. More on this topic will follow.

We know from basic foil theory that for a hydrofoil to produce lift, we have two necessary conditions:

- There must be a relative velocity between the fluid and the foil
- Circulation has to occur around the foil.

From this we understand that if a foil with no camber is placed in a uniform current, with its nose-tail line parallel with the flow direction, no lift will occur, because the angle of attack will be zero. Thus, the total circulation around the foil would be zero. However, if a transverse velocity component is imposed in the flow, a circulation will occur and a lift will be induced on the foil. Both ship motions and oscillatory wave movements contribute to transverse velocity components in the incoming flow, and thus an angle of attack, creating a lift.

3.2 Wave foil concept: in linear foil theory

To visualize the situation, we look at a two-dimensional foil strip assumed to be in uniform flow. We incline a foil without camber to a uniform flow direction in Figure 3-1, creating an angle between the nose-tail line of the foil and the inflow direction. This happens when the vessel is in a heaving, pitching or rolling motion, when the ship is in a pitched position, or due to the oscillatory orbital fluid particle motions induced by the waves. Due to the induced angle, the necessary transverse velocity component occurs, and a hydrodynamic force is thus imposed on the foil. In the following figures, all vectors (except the spanwise axis) are working in the plane defined by the chordwise and transverse axis, in order to make a two-dimensional problem.

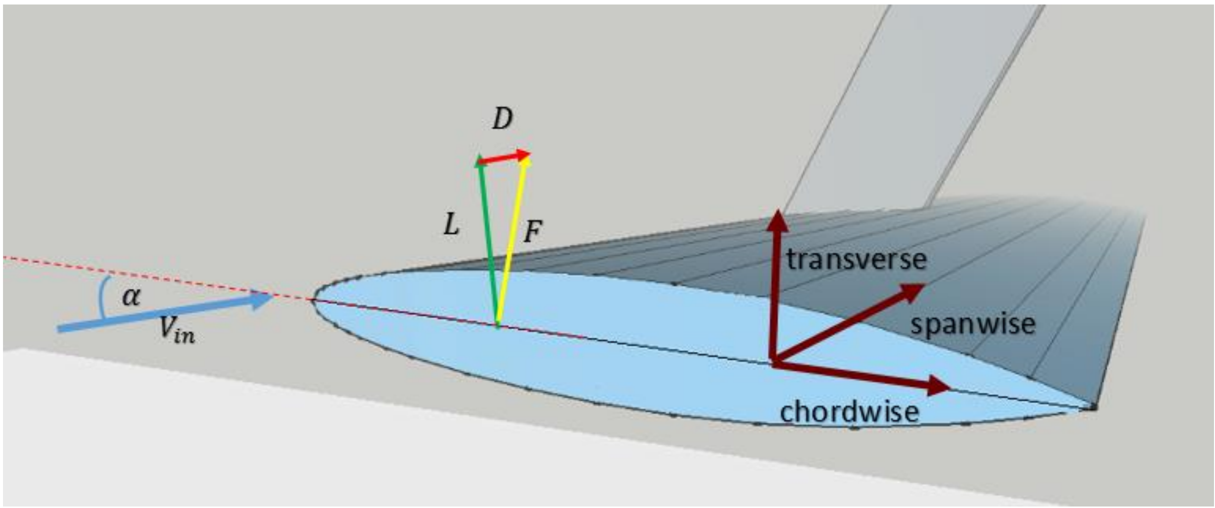


Figure 3-1: Flow with inflow angle past camberless 2D hydrofoil section (Google Sketchup)

F is the induced force on the foil, and decomposing this provides the lift force L and the drag force D. The lift is defined as normal-, and the drag as parallel to the incoming flow direction. V_{in} is the incoming fluid velocity and α is the angle between the foils nose-tail line. The chord length is the distance between the nose-tail line seen in the 2D foil section, and the foil span is the total length of the foil in the direction denoted as spanwise.

The vertical orientation of the lift L depends on the vertical orientation of the incoming flow, as shown in Figure 3-2. The direction of the incoming flow will oscillate between meeting the foil from above or below.

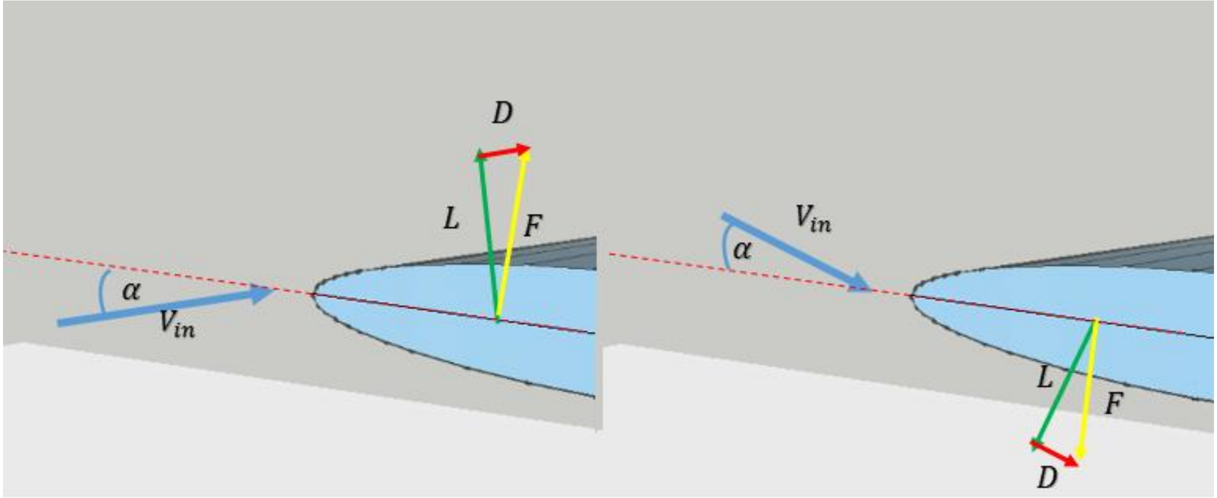


Figure 3-2: Lift direction dependence on inflow direction (Google Sketchup)

The lift is further decomposed into a thrust force working in the chordwise direction, as seen in Figure 3-3. We see by that irrespective of the vertical flow component meeting the foil from below or above, the lift can be decomposed into a thrust force working in the positive propagating direction of the foil. This is the reason the foil has no camber, as it is to work equally well whether the vertical relative fluid component is coming from above or below. In addition to the lift L, a drag force D is also produced parallel to the incoming flow. This force can also be decomposed to find the drag force in the negative propagating direction of the foil by similar decomposition (not shown in figure).

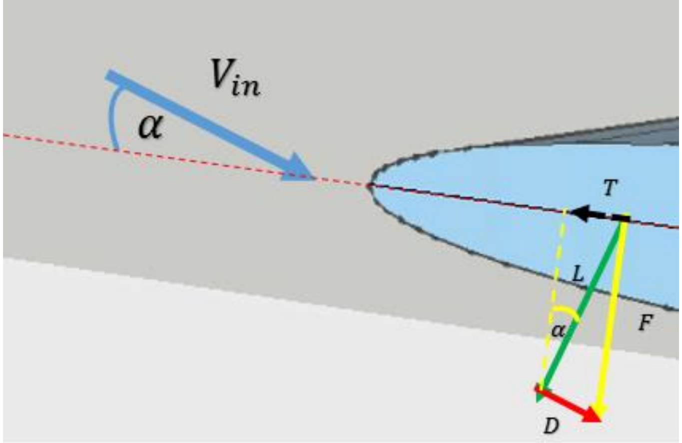


Figure 3-3: Decomposing lift L into thrust T (Google Sketchup)

Through this decomposition, the thrust can be expressed as

$$T = L * sin(\alpha) - D * \cos(\alpha) \qquad \text{Eq. 1}$$

The *planform area* S can be defined as the projected area of the foil in the direction of the lift force for zero angle of attack α (Faltinsen, 2005), or simply $S = c * s$. Then, the lift and drag can be expressed on dimensionless form by the coefficients C_L and C_D:

$$C_L = \frac{L}{\frac{\rho}{2} {V_{in}}^2 S} \qquad \text{Eq. 2}$$

$$C_D = \frac{D}{\frac{\rho}{2} {V_{in}}^2 S} \qquad \text{Eq. 3}$$

The aspect ratio of a foil is defined by

$$\Lambda = \frac{s^2}{S} = \frac{s}{c} \qquad \text{Eq. 4}$$

In linear foil theory, the lift slope $\frac{dL}{d\alpha}$ is constant, meaning that the lift increases linearly with increasing angle of attack. For a spanwise infinitely long foil, the lift slope for a flat plate is defined as $\frac{dL}{d\alpha}$ = 2$\boldsymbol{\pi}$. However, our foil will have a final span, which will influence the lift and drag produced. In lifting line theory, the lift- and drag coefficients are dependent of the aspect ratio, as they are able to take the effects of a finite span into account.

The *lifting line theory* assumes a high aspect ratio foil. Knowing the aspect ratio, the lift and drag coefficients are defined, respectively, lifting line theory in (Faltinsen, 2005) as

$$C_L = \frac{2\pi\alpha}{1 + \frac{2}{\Lambda}} \qquad \text{Eq. 5}$$

and

$$C_D = \frac{2\pi\alpha^2\Lambda}{(\Lambda + 2)^2} \qquad \text{Eq. 6}$$

The lift still depends linearly on the angle of attack, but a magnitude reduction of the coefficient is done to reproduce the effects of a finite foil span. We see that the drag depends of α squared, so at small values for α, small values for the drag can be expected.

3.3 Challenge within linear foil theory: stalling

Until now, we are assuming linear foil theory. Linear foil theory can only be assumed valid in conditions where the foil is not in a *stalling* condition, that is when α is sufficiently small, so flow separation does not occur. If the angle of attack α exceeds the value where flow separation occurs, the lift will decrease and the drag will typically increase. We expect the angle of attack to exceed the stalling limit in our calculations, so we have to develop a way of assessing stall even when doing our calculations based on linear foil theory, in order to produce realistic results.

We will try to implement the effect of stalling by looking to tabulated data for the angle of attack-dependent lift and drag coefficients of a foil section for a large number of α-values, including values where stalling is expected. The tabulated data used is only valid for 2D foil sections (where the foil span is assumed infinitely long), so we will have to modify the tabulated data to include the effects of a final span. We do this by modifying the tabulated lift coefficients with a certain factor, in order to fit with the lift coefficient produced by Eq. 5 in the α-region where linear foil theory applies. The tabulated lift coefficients for α-values larger than the stalling limit is corrected by the same factor. This makes the tabulated lift coefficients in compliance with lifting line theory in the α-region below stalling, meaning that the tabulated lift coefficients are decreased by a constant factor over the entire range of α-values. The method is described more in-depth in Section 4.3.4.

As the foil oscillates vertically relative to the flow, a decrease of angle of attack occurs, effecting the lift negatively. This is modelled by the use of the Theodorsen function, further elaborated upon in Section 4.3.5.

We have now shown the basics of how the thrust is calculated in our thesis. The input parameters, such as inflow velocity, angle of attack, lift and drag coefficient and thus lift, drag and thrust, are still unknown. Section 4 focuses how these parameters are found in our thesis.

4 Modelling: Foil thrust, passive and pitching foils

Our calculations are solved in the frequency domain, using a quasi-steady approach to make a time series of the relevant parameters. The quasi-steady approach means that no transient effects are transferred from one time step to the next. We will simulate irregular seas, and find the orbital fluid particle motions as well as the foil displacement, velocity and acceleration to ultimately find the resulting foil thrust. We start by explaining how these parameters are found in principle in the frequency domain approach.

4.1 Calculating vessel response in the frequency domain

Using linear theory, we can calculate the response of a vessel in an irregular sea state by linear superposition of the response from a large number of regular waves. Linear theory simply states that there is a linear relation between the response and the incoming wave amplitude (Faltinsen, 1990). Linear theory assumes that the wave steepness is small; the waves are far from breaking.

The wave elevation for a single, regular wave at point x can be expressed by

$$\zeta(t) = \zeta_a \cos(\omega t - kx + \epsilon) \qquad \text{Eq. 7}$$

Here ζ_a is the amplitude of the regular wave, ω the wave frequency, k the wave number and ϵ the phase of the wave. Combining a large number of regular waves with different amplitudes $\zeta_{a.i}$, wave phases ϵ_i and frequencies ω_i, we can simulate an irregular sea state.

To determine this irregular sea state, we use a sea spectrum S(ω), containing information as to how much energy is found in each frequency component of the frequency spectrum of an irregular sea. The JONSWAP spectrum is used with the same values for α and the peakedness parameter γ as used in (Borgen, 2010):

$$\alpha = 0.036 - 0.0056 \frac{T_p}{\sqrt{H_s}} \qquad \text{Eq. 8}$$

$$\gamma = 5 \quad \text{if} \quad \frac{T_p}{\sqrt{H_s}} \leq 3.6$$

$$\gamma = e^{\left(5.75-1.15\frac{T_p}{\sqrt{H_s}}\right)} \quad \text{if} \quad 3.6 \leq \frac{T_p}{\sqrt{H_s}} \leq 5 \qquad \text{Eq. 9}$$

$$\gamma = 1 \quad \text{if} \quad \frac{T_p}{\sqrt{H_s}} \geq 5$$

The sea spectrum changes for every value of T_p and H_s, and an example of the JONSWAP sea spectrum is shown in Figure 4-1.

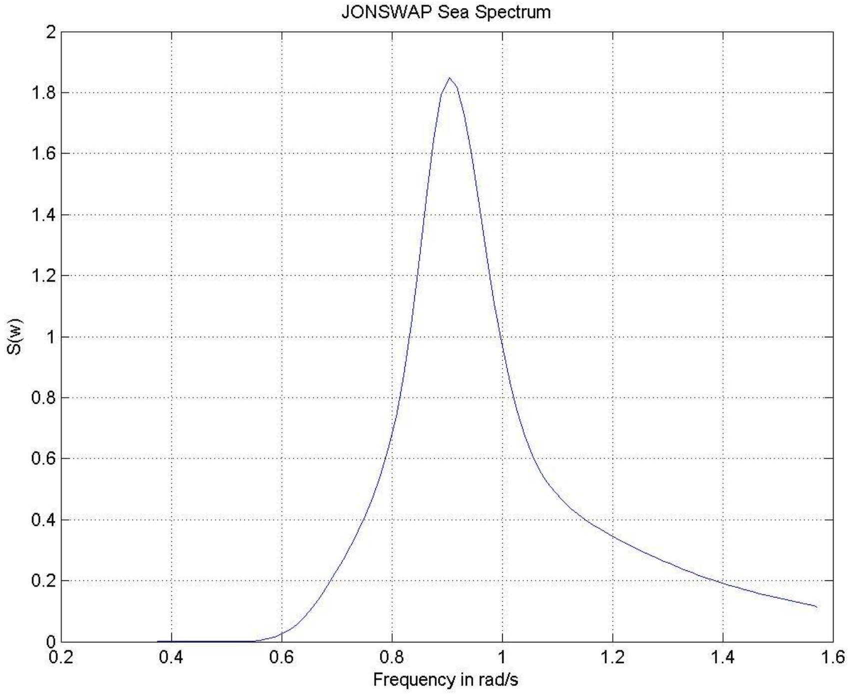


Figure 4-1: JONSWAP sea spectrum for H_S *= 3.0m,* T_P *=7.0s*

The spectrum is divided into bands of width $\Delta\omega$ (Faltinsen, 1990), and the wave amplitude of each frequency component is calculated by

$$\zeta_{a,i} = \sqrt{2S(\omega_i)\Delta\omega_i} \qquad \text{Eq. 10}$$

The response, for now denoted as η, can then be found by using a transfer function H(ω), also called a Response Amplitude Operator, or RAO. H(ω) contains the vessel response amplitude per unit wave amplitude for each frequency band in the wave spectrum. The vessel response from a regular wave (of index i) can thus be expressed, as seen in (Faltinsen, 1990), by

$$\eta_i = \zeta_{a,i}|H(\omega_i)|\cos(\omega_i t + \theta_i + \epsilon_i) \qquad \text{Eq. 11}$$

The wave phases ϵ_i are for each wave frequency given arbitrary values between 0 and $2\boldsymbol{\pi}$. θ_i is here the phase angle associated with the response, found by looking at the real and imaginary parts of the transfer functions:

$$\theta_i = \tan^{-1}\frac{Im|H_i(\omega)|}{Re|H_i(\omega)|} \qquad \text{Eq. 12}$$

The ship motions will oscillate with the same frequency as the ship meets the waves, so the encounter frequency for each frequency regular wave frequency, $\omega_{e,i}$ is used in Eq. 11. The RAO's are of course also based upon the relevant ω_e. ω_e can be found by Eq. 13 (Faltinsen, 2005), where ω_0 is the wave frequency, U the ship speed and β the wave heading.

$$\omega_e = \omega_0 + \frac{{\omega_0}^2 U}{g} cos\beta \qquad \text{Eq. 13}$$

Thus, superposing the response linearly for each regular incident wave (N in total) (Faltinsen, 1990), the steady-state response can be written as

$$\eta(t) = \sum_{i=1}^{N} \zeta_{a,i}|H(\omega_i)|\cos(\omega_i t + \theta_i + \epsilon_i) \qquad \text{Eq. 14}$$

The problem is divided into time steps, and each frequency component of the irregular sea is treated individually to calculate the response. The response of each frequency component is summed up to a total response. Thus, we can find the quasi-steady thrust, before moving on to the next time step. The thrust is finally averaged over the time series to find the mean thrust. We have used a time series of 2hrs with 0.5second time steps.

4.2 Ship motions and displacements

We need to find the ship motions and displacements in heave, pitch and roll, as they will be important parameters to determine the foil thrust. The ship displacements and motions are defined as in Figure 4-2 and

Table 3.

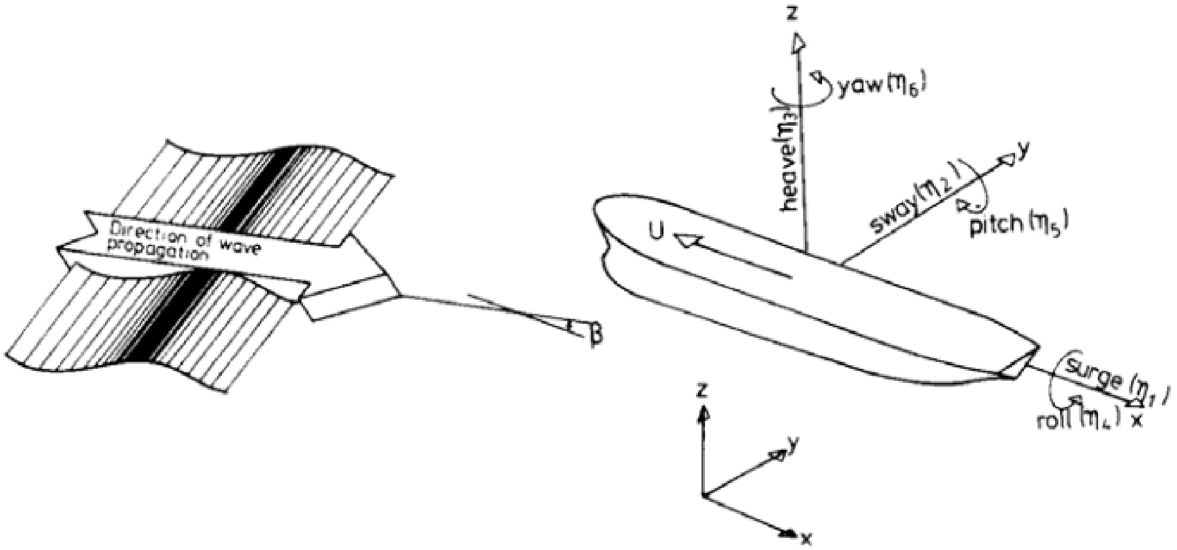


Figure 4-2: Definition of coordinate axes and ship motions and displacements (Fathi, 2005)

Table 3: Definitions of ship displacements

Translatory motion	Along x-axis	Along y-axis	Along z-axis
	Surge: η_1	Sway: η_2	Heave: η_3
Rotational motion	**Around x-axis**	**Around y-axis**	**Around z-axis**
	Roll: η_4	Pitch: η_5	Yaw: η_6

To find the inflow angle on the foils, we need to find the ship pitch displacement η_5, as well as the velocities in heave, roll and pitch: $\dot{\eta}_3$, $\dot{\eta}_4$ and $\dot{\eta}_5$, respectively, where the dot represents a time derivative. A double dot will later denote a double time derivative, in order to find accelerations. The displacement $\bar{s}$ of any point on the ship is in (Faltinsen, 1990) defined as

$$\bar{s} = (\eta_1 + z\eta_5 - y\eta_6)\bar{\imath} + (\eta_2 - z\eta_4 + x\eta_6)\bar{\jmath} + (\eta_3 + y\eta_4 - x\eta_5)\bar{k} \qquad \text{Eq. 15}$$

When the ship is in any sea state other than head or following seas, roll motions will be induced. We will later see that finding the vertical relative fluid velocity on the foils will be a main contributor in the production of forward thrust from the foil. When the ship is in a rolling motion, the vertical relative fluid flow will vary with the transverse position on the foil. Therefore the foil needs to be divided into strips and evaluated separately to find the correct velocities in any sea state other than head or following seas. Along the span, the foil is divided into 20 strips of equal span and analysed separately.

4.3 Calculating thrust: Passive foils

4.3.1 Ship motions in irregular sea

From ShipX, we have acquired Response Amplitude Operators (denoted by $H_{\eta_i}(\omega)$, also called RAOs) for ReVolt in heave, roll and pitch, relating wave frequency to ship response. Using these transfer functions, we can find the relevant ship velocities and displacements for each frequency component by

$$\dot{\eta}_{3,i}(t) = -\zeta_{a,i}\left|H_{\eta_{3,i}}(\omega)\right| \sin(\omega_{e,i}t + \theta_{3,i} + \epsilon_i) \qquad \text{Eq. 16}$$

$$\dot{\eta}_{4,i}(t) = -\zeta_{a.i}\left|H_{\eta_{4,i}}(\omega)\right| \sin(\omega_{e,i}t + \theta_{4,i} + \epsilon_i) \qquad \text{Eq. 17}$$

$$\dot{\eta}_{5,i}(t) = -\zeta_{a,i}\left|H_{\eta_{5,i}}(\omega)\right| \sin(\omega_{e,i}t + \theta_{4,i} + \epsilon_i) \qquad \text{Eq. 18}$$

$$\eta_{3,i}(t) = \frac{\zeta_{a,i}}{\omega_{e,i}}\left|H_{\eta_{3,i}}(\omega)\right| \cos(\omega_{e,i}t + \theta_{3,i} + \epsilon_i) \qquad \text{Eq. 19}$$

$$\eta_{4,i}(t) = \frac{\zeta_{a,i}}{\omega_{e,i}}\left|H_{\eta_{4,i}}(\omega)\right| \cos(\omega_{e,i}t + \theta_{4,i} + \epsilon_i) \qquad \text{Eq. 20}$$

$$\eta_{5,i}(t) = \frac{\zeta_{a,i}}{\omega_{e,i}} \left|H_{\eta_{5,i}}(\omega)\right| \cos(\,\omega_{e,i}t + \theta_{5,i} + \,\epsilon_i) \qquad \text{Eq. 21}$$

The response from each frequency is summed up to a total response according to linear theory. Thus, the responses for the ship is found for every time step in our calculation. This is then used to determine the foil thrust, as elaborated upon in Section 4.3.2 through Section 4.3.5.

4.3.2 Incoming fluid velocity

The thrust will be a function of the inflow angle the foil "sees" and the incoming flow velocity, which will be a function of both ship and the orbital wave particle motion. To find the inflow velocity the foil "sees", we need the wave induced fluid particle motion at the foil position. The horizontal water velocity meeting the foil will then be a sum of the ship speed and water velocity, so that

$$u_{REL} = \, U + u_w \qquad \text{Eq. 22}$$

u_w is the horizontal velocity of the fluid particle as the foil. In reality the ship speed will not be entirely constant, as hydrodynamic forces will cause surge accelerations, but we assume that the ship has a constant forward speed U.

For the relative vertical component of the incoming flow, we have

$$w_{REL} = \, w_w - w_F = \, w_w - (\dot{\eta}_3 + Y_{C,F,strip}\dot{\eta}_4 - X_{C,F}\dot{\eta}_5 - U\eta_5) \qquad \text{Eq. 23}$$

w_F is the vertical velocity of the foil, derived from Eq. 15. Here $X_{C,F}$ and $Y_{C,F,strip}$ represents the longitudinal and transverse position of each foil strip. Here we have assumed that the presence of the ship hull in the flow does not cause any significant changes in the flow entering the foil. As the foils are mounted fore of the bow of the ship, this assumption should not lead to any significant errors.

To find the vertical and horizontal wave particle velocity w_w at the foil position, we take the potential for an incident wave, assuming deep water:

$$\varphi_I = \frac{g\zeta_a}{\omega_0} e^{kZ_{C,F}} e^{i(\omega_e t - k(X_{C,F}\cos\beta + Y_{C,F}\sin\beta)} \qquad \text{Eq. 24}$$

$Z_{C,F}$ is here instananeous vertical position of the foils relative to the still water surface, found by

$$Z_{C,F}(\mathrm{t}) = Z_0 + \eta_3(t) + \eta_4(t) Y_{C,F,strip} - \eta_5(t) X_{C,F} \qquad \text{Eq. 25}$$

Z_0 is the submergence depth of the foils in calm seas when no displacements have occurred. The submergence depth used in elaborated upon in Section 0. Differentiating the potential in vertical and horizontal direction yields the expression for vertical fluid particle motion at the foil position, respectively:

$$w_w = \omega_0 \zeta_a e^{kZ_{C,F}} e^{i(\omega_e t - k(X_{C,F}\cos\beta + Y_{C,F}\sin\beta)} \qquad \text{Eq. 26}$$

$$u_w = -\frac{k\omega_e \cos\beta}{\omega_0} \zeta_a e^{kZ_{C,F}} e^{i(\omega_e t - k(X_{C,F}\cos\beta + Y_{C,F}\sin\beta)} \qquad \text{Eq. 27}$$

Knowing the relative fluid motion horizontally and vertically, the resultant inflow velocity can then be expressed as

$$V_{in} = \frac{U + u_w}{cos\alpha_0} \qquad \text{Eq. 28}$$

The angle α_0 is expressed as

$$\alpha_0 = \tan^{-1}\left(\frac{w_{REL}}{U + u_w}\right) \qquad \text{Eq. 29}$$

4.3.3 Angle of attack

We can now find the inflow angle of attack. If the nose-tail line of the foil is horizontal, the inflow angle α_0 is simply dependent on the vertical and horizontal components of the incoming relative flow, as shown in Eq. 29.

However, as the foils are fixed to the ship hull (for passive foils), the nose-tail line of the foils will always have a pitching angle equal to the pitching angle of the ship, η_5. The effect of this is that the angle of attack α is a function of not only the horizontal and vertical inflow velocity components, but also of the ship pitching angle η_5, so that we can express the inflow angle by

$$\alpha = \alpha^0 - \eta_5 \cong \frac{w_{REL}}{U} - \eta_5 \qquad \text{Eq. 30}$$

The situation is depicted in Figure 4-3, where the red dotted arrow represents the inflow velocity V_{in}.

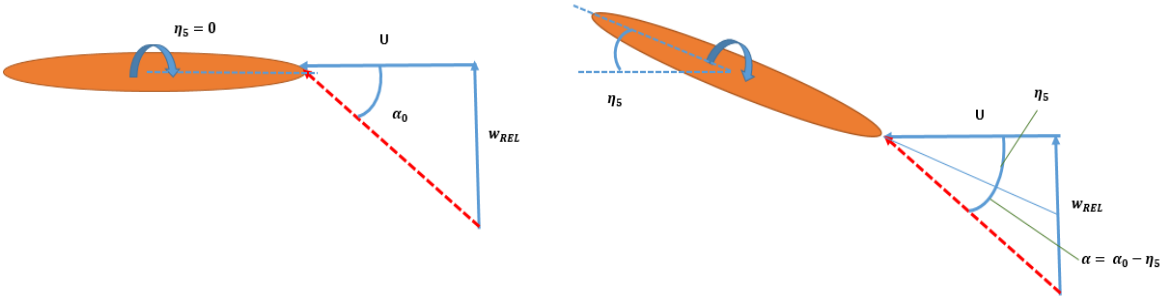


Figure 4-3: Inflow angle on foil with $\eta_5 = 0$ *(left) and* $\eta_5 \neq 0$ *(right)*

4.3.4 Lift and drag: Effect of finite span and stall

In Eq. 2 and Eq. 3 we have defined the lift and drag in terms of coefficients, and these must be established. In (Riley, 2014), we used the lifting line theory to find the foil thrust. This theory models the lift and drag of the foils, respectively, as linear and quadratic functions of the angle of attack α, and is able to take into account the effect of a finite foil span. Using this theory without modifying would render us unable to take into account any effects of stalling. As we anticipate that taking stalling into account will have a large significance on the results, we try to alter our approach to be able to take into account the effect of stalling.

In the lifting line theory, the lift- and drag coefficients are dependent on the aspect ratio, as they are able to take the effects of a finite span into account.

Knowing the aspect ratio, the lift and drag coefficients in lifting line theory are defined in (Faltinsen, 2005) as

$$C_L = \frac{2\pi\alpha}{1 + \frac{2}{\Lambda}} \qquad \text{Eq. 31}$$

and

$$C_D = \frac{2\pi\alpha^2\Lambda}{(\Lambda + 2)^2} \qquad \text{Eq. 32}$$

Here α is the inflow angle seen by the foil. We see that the lift coefficient is a function of α, while the drag coefficient is a function of α^2. These equations will form a basis for forming functions for the lift and drag coefficients that are able to take into account both the effects of finite foil span and stall. To do this, we look to foil data for NACA0015 foils in (Robert E.

Sheldahl, 1981), providing data for lift- and drag coefficients for different Reynolds numbers and angles of attack. This tabulated data takes the effect of stall into account, but not the effect of finite span. For our foils, the Reynolds number can be found by

$$R_N = \frac{Uc}{v} = \frac{6 * 0.5144 * 2}{1.18 * 10^{-6}} = 5.23 * 10^{6} \qquad \text{Eq. 33}$$

The Reynolds number will of course vary with time due to the fluid flow and ship movements and speed, but this is difficult to take into consideration. We will use the tabulated data for a Reynolds number of $5*10^6$. As this data is only valid for 2D foils, the coefficients have to be modified to take into account a finite foil span of aspect ratio 6. We do this by looking to the coefficients produced by the lifting line theory, and scale the tabulated 2D coefficients to fit with the lifting line coefficients at low values of α. The C_L from lifting line theory, and unmodified tabulated two-dimensional C_L is shown in Figure 4-4.

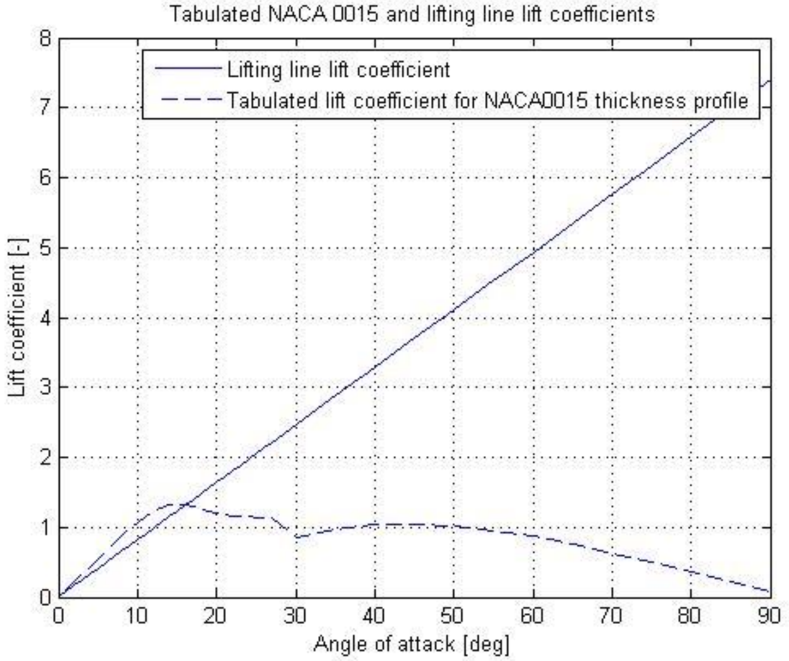


Figure 4-4: Lift coefficients from lifting line theory and tabulated 2D data

We see that lifting line theory underpredicts the lift for inflow angles up to 15-16°. After this point, lifting line theory severely overpredicts the lift. To make the tabulated 2D data valid for a finite foil span, the data is then fitted to the lifting line data by multiplying with a factor of 0.77, to produce a function for the lift coefficient that takes into account both stall and finite span. The curve fitting is done for angles of attack in the range of 0-90 degrees.

The resulting relationship between angle of attack and lift coefficient used in this thesis can thus be seen as the dotted line in Figure 4-5. The factor of 0.77 is chosen to make the 2D coefficients fit with the lifting line coefficients for angles below stalling. The validity of the lift coefficient values at alpha values higher than stalling limit is unknown, but we assume in this thesis that the relative thrust drop is of equal magnitude in a stalling condition as in a non-stalling condition.

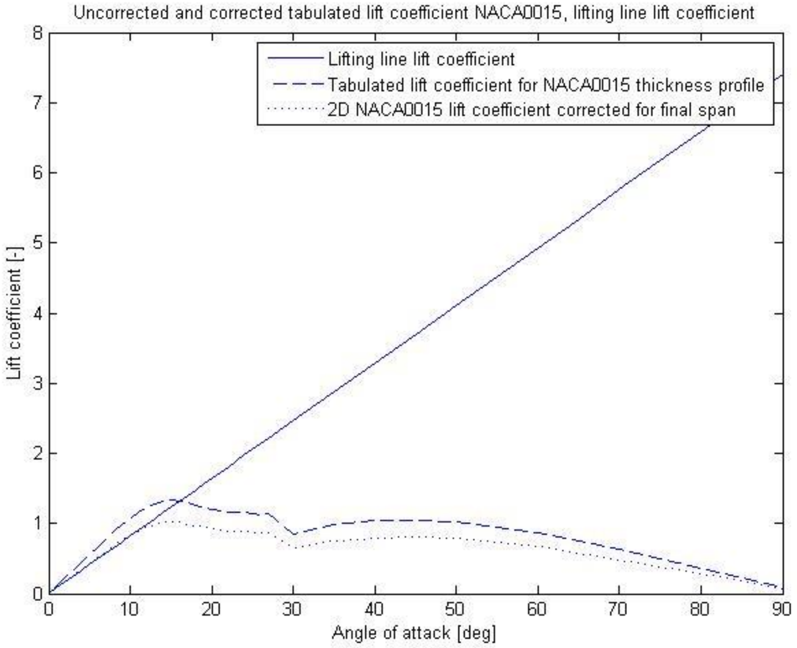


Figure 4-5: Lift coefficients including correction for finite span

For the drag coefficient, the coefficients are very low for α-values below stalling. The drag coefficient as a function of inflow angle can be seen in Figure 4-6. The lifting line theory continues to predict low drag coefficients above the stall point, while the tabulated drag coefficient shoots upwards when stalling occurs. The drag coefficient is very similar for the two curves in the region below stalling, and thus we will use the tabulated drag coefficients directly without any scaling for finite span. We observe a sharp increase in C_D after α = 19°, and this is expectedly due to flow separation.

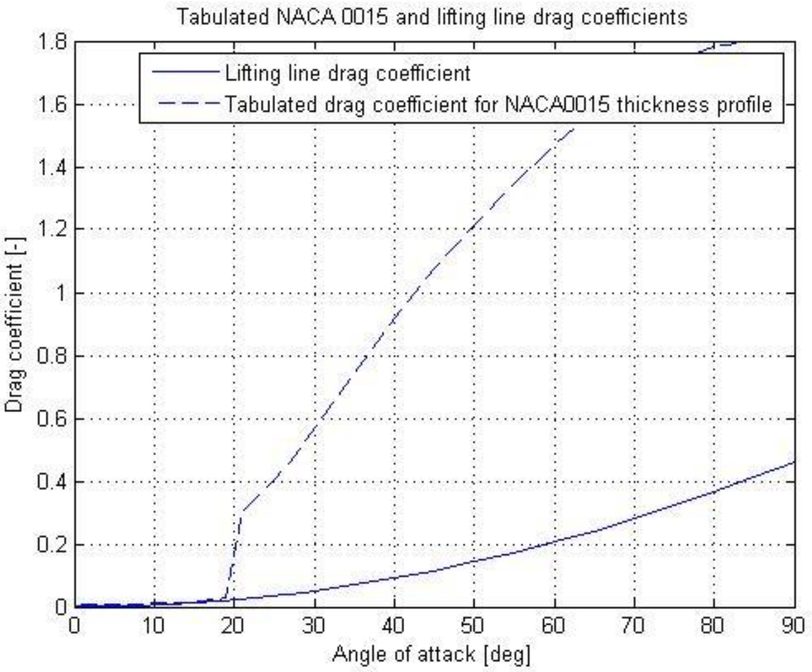


Figure 4-6: Tabulated and lifting line drag coefficients as function of alpha

Having obtained the lift- and drag coefficients, we can obtain the quasi-steady lift and drag on the foil. Inserting EQUATION 18 into EQUATION 1 and 2, we obtain the following expressions for the lift and drag:

$$L = C_L(\alpha) * 0.5\rho\left(\frac{U + u_w}{cos\alpha_0}\right)^2 S \qquad \text{Eq. 34}$$

$$D = \ C_D(\alpha) * 0.5\rho\left(\frac{U + u_w}{cos\alpha_0}\right)^2 S \qquad \text{Eq. 35}$$

Note that the drag produced by Eq. 35 now is a function of α, not α^2 as in the lifting line theory. Inserting into Eq. 1, we obtain the quasi-steady thrust by

$$T = C_L(\alpha) * 0.5\rho\left(\frac{U + u_w}{cos\alpha_0}\right)^2 S\sin\alpha - C_L(\alpha) * 0.5\rho\left(\frac{U + u_w}{cos\alpha_0}\right)^2 S\cos\alpha \qquad \text{Eq. 36}$$

To account for the effects of unsteady lift, elaborated upon in Section 4.3.5, the angle of attack α is finally replaced by the effective angle of attack α_E given by Eq. 42 in our calculations.

The thrust will be counter effected by viscous drag on the foil and struts, and spray drag on the struts, as explained in Section 0. These drag components are subtracted from the quasi-steady thrust in our calculation, so

$$\begin{aligned} T = {} & C_L(\alpha_E\,) * 0.5\rho\left(\frac{U+u_w}{cos\alpha_0}\right)^2 S\sin\alpha \\ & - C_L(\alpha_E\,) * 0.5\rho\left(\frac{U+u_w}{cos\alpha_0}\right)^2 S\cos\alpha \\ & - D_{struts} - D_{spray} - D_{viscous} \end{aligned} \qquad \text{Eq. 37}$$

4.3.5 Unsteady lift effect

As the foil oscillates between giving a lift upwards and downwards, there is a period of time between these two states in which the lift is about to change direction. This period of time affects the lift, and a vortex will be shed and pass along the chord length of the foil towards the trailing edge. This causes instability in the pressure gradient, effectively reducing the lift further. As the thrust depends on the lift, this reduces the thrust. There have been various attempts at how to model this effect, and a good summary is given in Chapter 3 in (E. Bøckmann, 2015).

(Theodorsen, 1935) provided an analytical expression for the unsteady lift on a harmonically oscillating two-dimensional flat plate. The flow is assumed to be inviscid and incompressible, and the transverse motion of the plate is assumed to be small, so it can be assumed that the vortices shed in the wake of the flat plate would remain on a straight line behind the foil. We know from the Kutta theorem that in inviscid, barotropic flow with conservative body forces, the circulation around a closed curve remains constant. When the angle of attack on the plate increases due to the oscillatory motion of the flat plate, the lift and thus also the circulation around the plate will change. To keep the circulation around a closed curve including the wake constant, there must be an associated drop in circulation in the wake; a vortex with opposite sign of the change in circulation is formed. The result is a change in *effective angle of attack* α_E, which can be found by multiplying the time-varying, quasi-steady angle of attack (induced by pitch angle, pitch velocity and heave velocity) by the *Theodorsen Function* $C(k_r)$, which uses the *reduced frequency* k_r as input, defined by Eq. 38.

$$k_r = \frac{\omega_e c}{2U} \qquad \text{Eq. 38}$$

Where ω_e is the encounter frequency, c the chord length of the plate, and U the velocity the plate is moving (in our case the ship speed). We will use the relevant value of T_p, ship speed and heading to find the value for ω_e, noting that this is only strictly correct for regular waves. The Theodorsen Function is defined by

$$C(k_r) = F(k_r) + iG(k_r) = \frac{{H_1}^{(2)}(k_r)}{{H_1}^{(2)}(k_r) + i{H_0}^{(2)}(k_r)} \qquad \text{Eq. 39}$$

Here, F and G is the real and imaginary parts of C(k_r). ${H_n}^{(2)}$ are Hankel Functions (Abramovitz, 1972) given as

$${H_n}^{(2)} = J_n - iY_n \qquad \text{Eq. 40}$$

where J_n and Y_n are Bessel functions of the first and second kind, respectivey. Using this, the amplitude of the unsteady lift will reach half the amplitude of the quasi-steady lift as k_r reaches infinity (E. Bøckmann, 2015). Bøckmanns thesis provides a numerical approximation of the Theodorsen Function, given as

$$C(k_r) = 1 - \frac{ik_r A_1}{b_1 + ik_r} - \frac{ik_r A_2}{b_2 + ik_r} \qquad \text{Eq. 41}$$

Where A_1, A_2, b_1 and b_2 are constants of value 0.165, 0.335, 0.0455 and 0.3, respectively. This approximation is computationally simple, and will be used in our calculations. The effective angle of attack can at each time instant, for each frequency component then be found by

$$\alpha_E = \alpha * |C(k_r)| \qquad \text{Eq. 42}$$

This is then the AOA inserted into Eq. 36 in our calculations.

4.4 Calculating trust: pitching foils

4.4.1 Principle

Due to hydrodynamic lift and added mass forces from the fluid surrounding the foil, a pitching moment will at each time instant be imposed on the foil. Passive inflow angle control is applied by utilizing this pitching moment to rotate the foil to a more optimal angle of attack. The pitch displacement of the foil due to the pitching moment is controlled by springs in the fastening points between the struts and foil. The optimal spring stiffness, yielding desired inflow angles for a given condition, must be obtained.

The pitching axis along the foil span has to be chosen, and is set to one 8th of the chord length from the leading edge. As the lift acts in the quarterchord, and the added mass forces works in the midchord, this ensures that both lift and added mass forces generally are contributing to the pitching moment in the same direction.

In this situation, the inflow angle α can be written, by including the pitching angle of the foil $\eta_{5,foil}$, as

$$\alpha = \alpha^0 - \eta_5 - \eta_{5,foil} \cong \frac{w_{REL}}{U} - \eta_5 - \eta_{5,foil} \qquad \text{Eq. 43}$$

4.4.2 Forces contributing to pitching moment on the foils

To find the added mass force imposed on the foil, the foil is modelled as a flat plate with relative heave accelerations in the vertical direction. The pitching displacement of the foil and ship is neglected in this calculation; thus, the projected area in the xy-plane will be kept constant for each time instant, which in turn keeps the added mass force constant inside each time instant.

The added mass force can then be found by

$$F_{added}(t) = C_{added} a_{rel,vertical}(t) \qquad \text{Eq. 44}$$

Here, C_{added} is the added mass force coefficient for a flat plate, found in (Pettersen, 2007) as

$$C_{added} = \rho\pi \left(\frac{c}{2}\right)^2 s \qquad \text{Eq. 45}$$

The relative vertical fluid acceleration $a_{rel,vertical}(t)$ can be found by taking the time derivative of the relative vertical fluid velocity:

$$a_{rel,vertical}(t) = \dot{w}_{rel} = \dot{w}_w - \dot{w}_F = \dot{w}_w - (\ddot{\eta}_3 - X_{C,F}\ddot{\eta}_5 - U\dot{\eta}_5) \qquad \text{Eq. 46}$$

Where $\dot{w}_w$, $\ddot{\eta}_3$ and $\ddot{\eta}_5$ is found by looking at each frequency component and summing up the total response, as explained in Section 4.3.1, using the equations below:

$$\dot{w}_w = \omega_0 \omega_e e^{kZ_{C,F}} e^{i(\omega_e t - kX_{C,F})} \qquad \text{Eq. 47}$$

$$\ddot{\eta}_3 = -\zeta_{a.i}\omega_{e,i}\left|H_{\eta_{3,i}}(\omega)\right| \cos((\omega_{e,i}t + \theta_{3,i} + \epsilon_i) \qquad \text{Eq. 48}$$

$$\ddot{\eta}_5 = -\zeta_{a.i}\omega_{e,i}\left|H_{\eta_{5,i}}(\omega)\right| \cos((\omega_{e,i}t + \theta_{3,i} + \epsilon_i) \qquad \text{Eq. 49}$$

4.4.3 Pitching moment on foil

The pitching moment imposed on the foil is comprised of added mass forces and lifting forces. The resultant added mass force acts in the half-chord of the foil, while the lift force resultant is working in the quarter-chord from the nose for non-stalling conditions. The foil pitching moment at each time instant can then be calculated by

$$M_{hydrodynamic}(t) = F_{added} * \frac{3c}{8} + L * \frac{c}{8} \qquad \text{Eq. 50}$$

4.4.4 Iteration process: Determining actual foil pitch

Knowing the pitching moment M, one could calculate the foil pitch directly using the spring stiffness k_f. However, as the foil pitches and decreases the angle of attack, the angle-dependent hydrodynamic lift will also decrease. Using the static angle change calculated by the initial pitching moment would therefore overestimate the actual foil pitch. An iteration process where the foil pitch ($\eta_{5,f}$) is steadily decreased is therefore performed by MATLAB to find the value of foil pitch where the pitching moment reaches equilibrium with the moment imposed by the springs, as seen in Eq. 51.

$$M_{springs} = M_{hydrodynamic} \tag{Eq. 51}$$

where $M_{springs}$ is calculated by

$$M_{springs} = k_f \eta_{5,foil} \tag{Eq. 52}$$

This iteration is done for every time instant of every sea state and ship speed considered. Thus, the value for foil pitch $\eta_{5,f}$ where the moment from added mass forces reaches equilibrium with the moment from the lift will be the pitching angle used in Eq. 43. For each case investigated this produces a time series for the pitch corrected angle of attack. The lift, drag and resulting foil thrust can then be calculated as in the case for passive foils.

4.4.4.1 Verification of spring stiffness iteration process

The script calculating the thrust for a foil equipped with spring controlled rotating foils (*active.m)* is rather complicated, and its validity should be examined. We do this by noting that when $k_f \rightarrow \infty$, the foil system is essentially a passive foil system, as no foil rotation is possible. This means that when $k_f \rightarrow \infty$, $T_{active} \rightarrow T_{passive}$ for the method to work. This test have been performed by looking at incrementally larger values for k_f. The results of this analysis will not be performed here, other than noting that the script seems to work as intended; for sea states where stalling is happening so often that it reduces the mean thrust, increasing k_f yields larger values for T_{active} up until a certain value, before T_{active} starts do decrease again, finally converging with $T_{passive}$ when k_f reaches a very high value.

4.4.5 Spring stiffness optimization

The stiffness of the springs k_f controlling the pitching motion of the foil has to be decided. One could choose a fixed spring stiffness, or springs with variable stiffness optimized for the different sea states encountered by ReVolt. If the stiffness chosen is too large, the foil will not pitch sufficiently, while a too small stiffness will make the foil pitch too much, making the angles of attack smaller than optimal.

The foil will be fitted to the struts with rotational springs with a spring stiffness k_f. Note that in our calculations, the foil is only controlled by *one* spring. In real life, at least one spring will be fitted to each strut fastening point, meaning there are at least two springs. As the springs can be assumed to be working in parallel, with *n* springs fitted to the system, the spring stiffness of each spring k_{f_i} becomes

$$k_{f_i} = \frac{k_f}{n} \tag{Eq. 53}$$

We will only refer to the total spring stiffness, k_f, for the remainder of this thesis.

The optimal spring stiffness is unknown. It is likely that different spring stiffnesses will be optimal for different sea states. To examine this, we will perform two types of simulations:

- *Worst case scenario simulation*: For the worst case scenario (for each ship speed), an array of k_f values is tested using our established mean thrust calculation method. Thus, at a constant sea state and ship speed, the mean thrust is plotted against the different k_f values investigated. As this analysis will show what spring stiffness gives the best performance at the worst case scenario, it is very relevant for calculating the potential CAPEX savings when utilizing pitching foils. This simulation is therefore from now on referenced to as the *CAPEX Stiffness Simulation*. The results of this simulation is shown graphically in Section 10.2.1.
- *Peak wave period simulation:* From the previous simulation, we have obtained information about what k_f values that seem most promising in a thrust production point of view. We have however only looked at the peak period (T_p) giving the worst case scenario, and it is also of interest to find how the foils perform in the range of peak periods relevant for ReVolt. Using a smaller range of k_f values, we look to how the foils perform in the relevant range of T_p values. The simulation is done for different ship speeds and H_s values. As this approach covers a larger range of sea states than the previous section, it is more relevant in an OPEX point of view, and is from now on referenced to as the *OPEX Stiffness Simulation*. The results of this simulation is shown graphically in Section 10.2.2.

From these simulations we have a quite good overview of the pitching foil performance in head seas, and data from these simulations will be used further to investigate the actual benefits in terms of OPEX for the pitching foils in Section 11.2.

5 Modelling: Resistance components and open water efficiency

5.1 Added resistance in waves

The added resistance in irregular waves is calculated by ShipX Veres as elaborated upon in Section 8.1. The resistance calculated by ShipX is given on dimensionless form as $C_{A,waves}$. The dimensionless added resistance is picked out from the ShipX output files by a MATLAB routine, and the mean added resistance $R_{A,waves}$ [N] for the relevant sea state is calculated in Excel by

$$R_{A,waves} = C_{A,waves}\rho g \left(\frac{H_s}{2}\right)^2 \frac{B^2}{L_{pp}} \qquad \text{Eq. 54}$$

5.2 Additional resistance components

When mounting the wave foils to ReVolt, several resistance components occurs that would not occur for an unfoiled ReVolt. We term them *additional* resistance components, as they would not occur for an unfoiled ReVolt. These resistance components should be subtracted from the produced thrust T, as they will counter effect the thrust produced from the foils. The magnitudes of these resistance components can be seen in Section 9.1.

5.2.1 Strut resistance

The struts holding the foils in place will impose two additional resistance components: viscous strut resistance and strut spray resistance. The mean viscous strut resistance can be expressed by

$$D_{struts,visc} = \frac{1}{2}\rho U^2 C_{D,struts} z * 2 \qquad \text{Eq. 55}$$

The struts will have a mean submergence depth of z=4.0m. The drag coefficient of the struts can be found by

$$C_{D,struts} = 2\left(1 + 2\frac{t}{c}\right) C_F \qquad \text{Eq. 56}$$

Here t is the maximum transverse thickness of a strut, c is the strut length in longitudinal direction, and C_F is the friction drag coefficient, here defined by the ITTC'57 friction line in Eq. 57:

$$C_F = \frac{0.075}{(\log(R_N - 2)^2} \qquad \text{Eq. 57}$$

Where the Reynolds number is found by

$$R_N = \frac{Uc}{v} \qquad \text{Eq. 58}$$

In addition, the two struts holding the foil in place will penetrate the water surface, and there will be a spray of water from the struts at the surface, imposing additional resistance. To model this drag we look to (Hoerner, 1965) and use the expression, for each strut,

$$D_{struts,spray} = 0.24\frac{1}{2}\rho U^2 t^2 \qquad \text{Eq. 59}$$

5.2.2 Viscous foil resistance

Inviscid potential theory is used in the calculations, meaning that viscous effects are not taken into account. We correct this by subtracting a viscous drag force from the thrust by means of an empirical formula:

$$D_{foil,viscous} = \frac{1}{2}\rho U^2 C_{D,viscous} S \qquad \text{Eq. 60}$$

Where $C_{D,viscous}$ is the viscous drag coefficient, and the incoming velocity on the foil U is used for simplicity. The order of magnitude for the viscous drag is small compared with the thrust, and the exact value of the drag coefficient is not of great importance. The drag coefficient will vary with the angle of attack, but is given a constant value 0.015 after conferring with (Miller, 2008).

5.3 Wind resistance

The ship will also be subject to a drag force due to incoming wind. The drag force D_{wind} is calculated by

$$D_{wind} = \frac{1}{2}\rho_{air} C_{D,wind} A {U_{rel,wind}}^2 \qquad \text{Eq. 61}$$

Here A is the projected area of ReVolt above the waterline when looking from a position in front of the ship (approximated to $116m^2$) and ρ_{air} is the air density. $C_{D,wind}$ is the drag coefficient for the geometry of the hull. We do not have an exact value for $C_{D,wind}$, and use a value of 0.8 according to (ITTC, 2011). $U_{rel,wind}$ is the wind velocity that meets the front of the ship parallel with the longitudinal axis of the ship. As we are interested in finding the worst case scenario, only head wind will be examined, as the added resistance in wind is expected to be largest here. This velocity is simply calculated by

$$U_{rel,wind} = U_{ship} + U_{wind} \qquad \text{Eq. 62}$$

It can be argued that the wind resistance of ReVolt generally will increase (relative to an unfoiled ReVolt) when the wavefoils are lifted out of the water, depending on the position in which the foils are stored when lifted out of the water. We assume in this thesis that that the increased wind resistance from the retracted wave foils are negligible, meaning that wind the resistance of an unfoiled and foiled ReVolt is assumed equal.

5.4 Calm water resistance

The ShipX extension Ship Speed and Powering is used to produce the calm water resistance for ReVolt for speeds of 4-8 knots, using the Hollenbach'98 method with good lines. DNV GL has done calm water resistance predictions for ReVolt already, using the CFD software Numeca, but only at a speed of 6 knots. However, the results predicted from ShipX does not match the DNV GL results exactly: at a speed of 6 knots, DNV GL CFD data yields 12.65kN in calm water resistance, while ShipX gives 14.32 kN. The author has not been able to detect the reason for this discrepancy between the calculated calm water resistance. We will therefore use our calm water resistance curve from ShipX, and scale the data to fit DNV GL's CFD data at 6 knots, to be able to produce results comparable with DNV GL's total resistance results. The results can be seen in Section 9.2.

5.5 Resistance reduction

Due to the reduced ship motions when fitting ReVolt with wave foils, the ship will experience less added resistance in waves than a ship without wave foils. This difference in added resistance will be a factor in decreasing the total ship resistance in addition to the produced thrust. The added resistance in foiled and unfoiled conditions is determined by the software ShipX, and we can express the total resistance of an unfoiled and foiled ReVolt respectively by Eq. 62 and E1. 64. Here we remember that the additional drag components imposed on the foil is incorporated into the thrust.

$$R_{unfoiled} = R_{calm} + R_{added,waves} + R_{wind} \qquad \text{Eq. 63}$$

$$R_{foiled} = R_{calm} + R_{added,waves,w/foils} + R_{wind} + R_{struts} - T_{foil} \qquad \text{Eq. 64}$$

5.6 Open water efficiency

5.6.1 Calculation method

To find the engine power P_B at a given sea state and heading, the open water efficiency at the resulting ship resistance has to be determined. An open water diagram for ReVolt has been provided by DNV GL, giving a relation between the propulsion point J and K_T, K_Q and η_0. The diagram is used to find the engine power P_B by using the following relations and equations (Steen, 2007):

$$\frac{K_T}{J^2} = \frac{R_{TS}}{\rho(1-t)D^2U^2(1-w)^2} \qquad \text{Eq. 65}$$

$\frac{K_T}{J^2}$ from the open water diagram is calculated for an array of J-values in MATLAB. Inserting for R_{TS} , we use the calculated $\frac{K_T}{J^2}$ to find the corresponding propulsion point J* at the given ship resistance.

$$RPM = \frac{60(1-w)}{D} * \frac{U}{J^*} \qquad \text{Eq. 66}$$

Eq. 66 is then used to find the needed rotational speed of the propeller, using the propulsion point J*. Further, J* is used to find the ${K_Q}^*$ value for the given ship resistance. This can then be used to find the needed engine brake power by using the equation below.

$$P_B = 2\pi\rho D^5 \left(\frac{RPM}{60}\right)^3 \frac{{K_Q}^*}{\eta_R} \qquad \text{Eq. 67}$$

J, K_T and K_Q are defined as follows:

$$J = \frac{U}{nD} \qquad \text{Eq. 68}$$

$$K_T = \frac{T}{\rho n^2 D^4} \qquad \text{Eq. 69}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \qquad \text{Eq. 70}$$

Here, the parameters are defined as follows:

- K_T: Dimensionless thrust
- K_Q: Dimensionless torque
- J: Propulsion point
- R_{TS}: Total resistance
- t: thrust reduction. t = 0.175 provided by DNV GL
- D: Propeller diameter
- U: Ship speed
- w: Wake coefficient. w=0.031 provided by DNV GL
- n: Propeller rate of revolution
- T: Thrust
- Q: Torque
- RPM: propeller rate of revolution [revolutions/min]
- η_R: Rotational efficiency, given as 0.97 by DNV GL
- P_B: Brake power of engine
- * indicates the values at the relevant ship resistance

5.6.2 Open water diagram

It is possible to produce an open water diagram using the MARINTEK software ShipX, but in this thesis we will use an open water diagram for ReVolt provided by DNV GL, as this diagram is expected to be more accurate than the one ShipX would produce. The reasoning behind this is that due to the low speed of ReVolt, the propellers used is rather unconventional, and would probably be difficult to model correctly in ShipX.

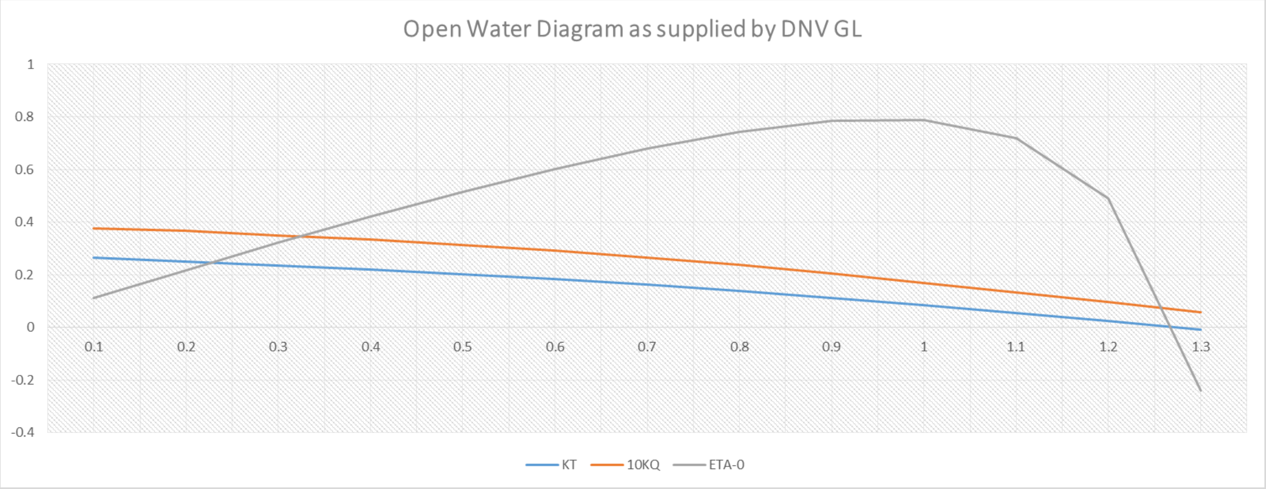


Figure 5-1: Open water diagram of Revolt

It is important to note that ReVolt is a twin-screw ship, therefore half the total ship resistance must be used as input into the open water diagram, and the resulting brake power must be multiplied by 2.

Also worth mentioning is that placing a wavefoil at the bow might alter the way the water flows into the propeller, and thus the open water diagram would change. However, at a ship speed of 6 knots, the time that passes between the water hitting the foil and the water hitting the propeller would be roughly 20 seconds, and a large portion of the foil induced disturbances are assumed to be dissipated by then. We therefore use the same open water diagram for a foiled and unfoiled ReVolt.

6 Foil characteristics and retractability

Several parameters and characteristics of the foil and foil system has to be determined before the actual thrust and energy calculations can take place. In this chapter we will look into these parameters and characteristics, and try to find the solutions most optimal for ReVolt. For the cases where quantifiable reasoning is needed, decisions will be made based on calculations. The sea state expected to be our worst case scenario within our sea state scope (see Section 7.3) will be used: H_S = 3.0m, head sea, T_P = 6.5s. Some preliminary results are therefore produced and presented in this section.

6.1 Foil retractability analysis

The propulsion foils have to be stowed away when coming alongside quays. They also increase resistance when sailing in calm seas, as thrust-inducing lift is only produced when a vertical flow component is present, which happens when the ship is excited by waves. Having the foils fixed to the hull is therefore not an option; it must be possible to stow them away. In this section we will look at concepts for folding in the foils. We do not want to interfere with the cargo space, so geometric limitations are apparent after looking at Figure 6-1 and Figure 6-2. Green boxes indicate containers, and black lines are hull contours. Breadths in Figure 6-2 are given in the vertical level as indicated by the orange line in Figure 6-1, and the three blue points indicate the horizontal positions of the breadths shown in Figure 6-2.

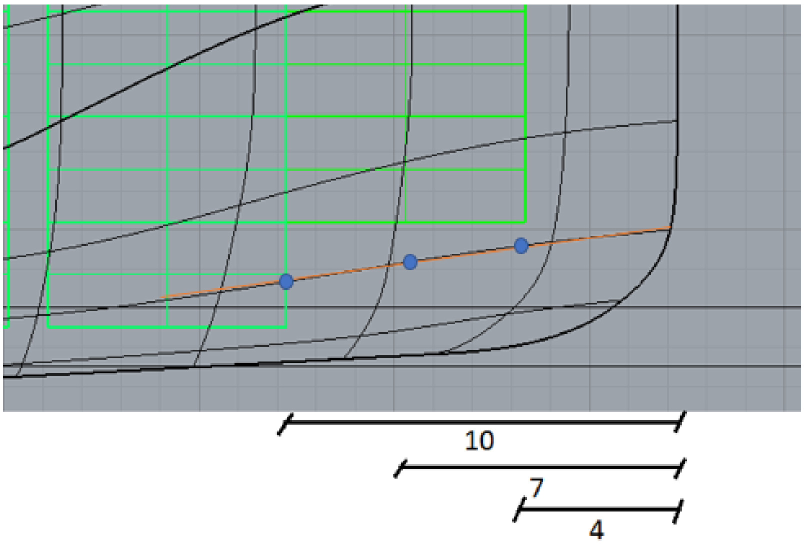


Figure 6-1: Side view of bow, measurements in metres

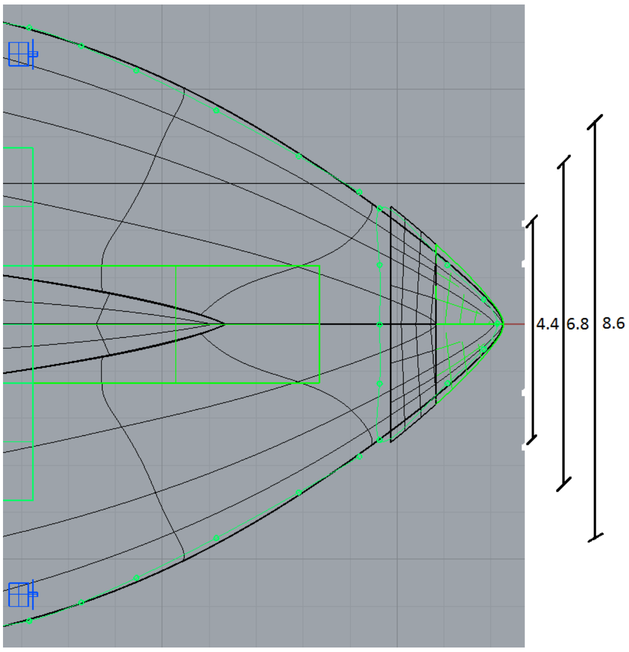


Figure 6-2: Top view of bow, measurements in metres

The foils should be stowed away in a manner that does not produce unnecessary hydrodynamic drag; ideally the hull at the bow should look as if it did not have a foil pair stowed away to minimize the drag. The mechanisms involved has to endure the tough and repeating forces they are exposed to when the foils are in use. (Borgen, 2010) presents three viable options for stowing away the foils, here reproduced for ReVolt.

6.1.1 Backwards retractable foils

The foils could be folded backwards and into the hull in a horizontal motion rotating around the vertical axis. This concept is simple, and already in use in roll damping fins. The concept has already proven possible, and should not pose too large a challenge to design. The concept is exemplified in Figure 6-3.

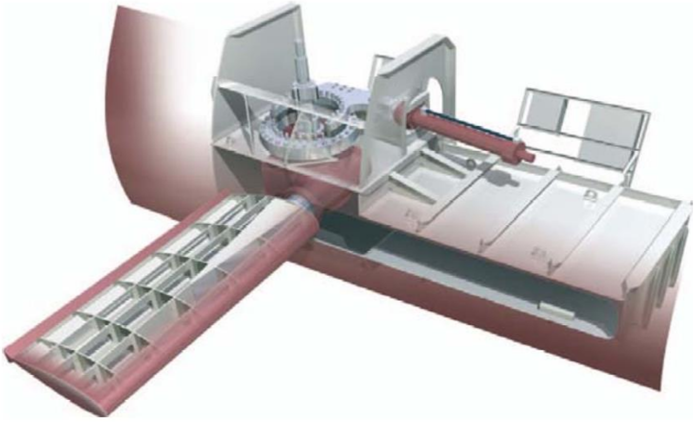


Figure 6-3: Backwards retractable foils (Rolls-Royce, 2007)

The concept has its drawbacks; as reasoned in Section 6.2, the foils should be placed as close to the bow as possible. The breadth at the bow is small, and in order to have sufficient space for the foils when folded in, the breadth where the foils are fastened and aft wards has to be at a minimum two times the chord length of the foil. The situation is seen in Figure 6-4.

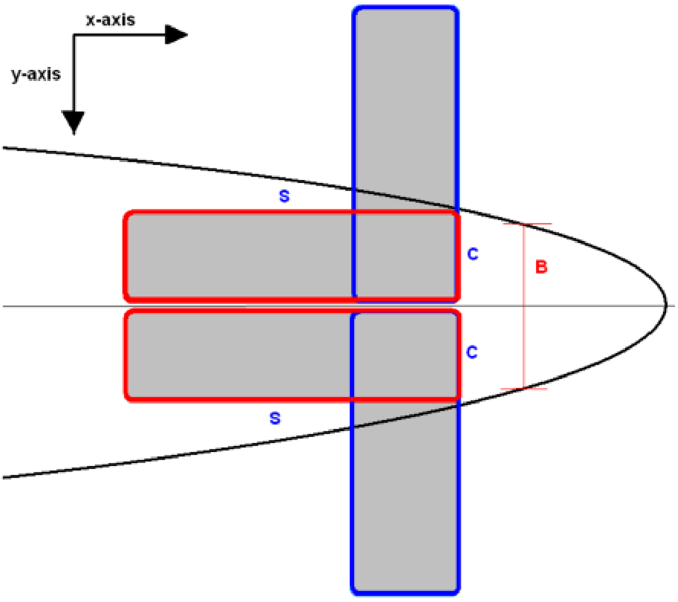


Figure 6-4: Spatial limitations for backwards retractable foils (Borgen, 2010)

There are also structural concerns to consider. The space needed to fold the foils in creates a structural weakness addressed in Figure 6-5.

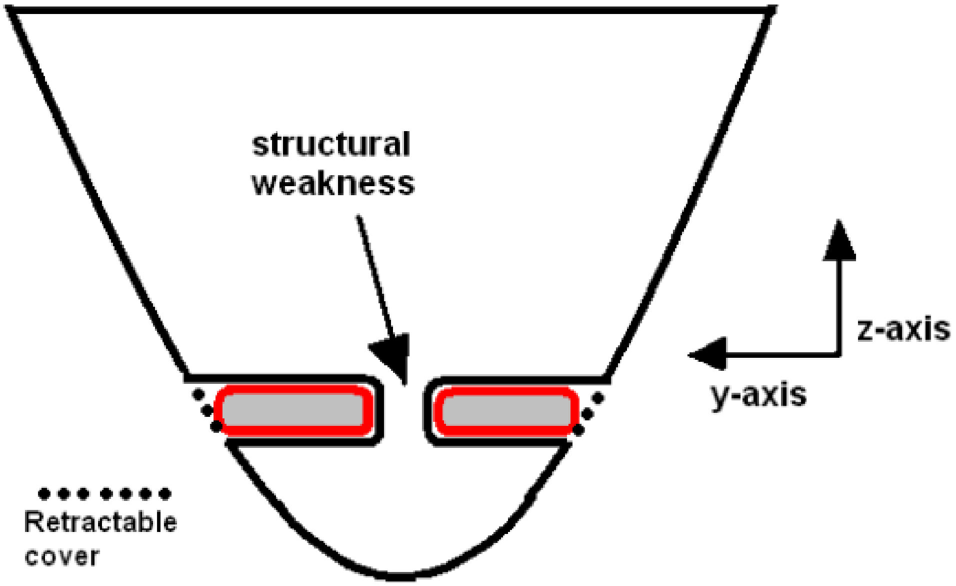


Figure 6-5: Structural concern with backwards retractable foils (Borgen, 2010)

6.1.2 Vertical telescopic retraction

The foils could also be telescopically retracted in the span-wise direction into the hull. They cannot be retracted horizontally where they are positioned, as the port and starboard foils would be in the way of each other. Instead they could be tilted downwards into a vertical position, and then retracted upwards into the hull, as seen in Figure 6-6. This would beneficially allow them to be placed closer to the bow, as a typical foil has a thickness-to-chord ratio $\frac{t}{c} \ll 1$. The collision bulkhead compartment in ships is often reserved for ballast tanks, but ReVolt is a ballast free design. If the chord length of the foils are smaller than the length of the collision bulkhead, this could prove a good use of the unused space here. The mechanisms involved would, however, be more complex than the case for backwards retractable foils.

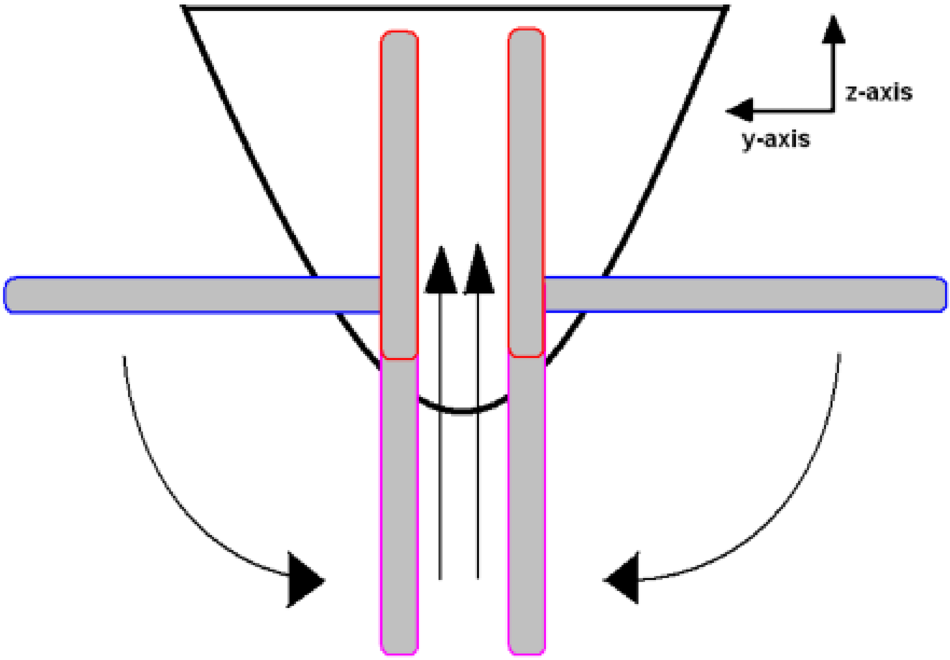


Figure 6-6: Vertical telescopic retraction (Borgen, 2010)

6.1.3 Diagonal telescopic retraction

While horizontal backwards retraction is out of the question if the foils have a span of more than half the ship breadth at the fastening point, other options for telescopically retracting the foils are virtually endless. (Borgen, 2010) imagines a rather complicated concept where the foils are folded not purely vertically, but rather diagonally forward into the bulkhead compartment of the hull. The foils would first have to rotate around the y-axis to the position indicated in Figure 6-7. The foil is then tilted downwards, before being retracted telescopically into the hull. This is similar to the vertical telescopic retraction, but in this case the foil will have an inclination to the vertical axis. For some cases this could give better space efficiency, but when examining Figure 6-1 it is hard to imagine any benefits from this when compared to the purely vertical retraction in the case of ReVolt.

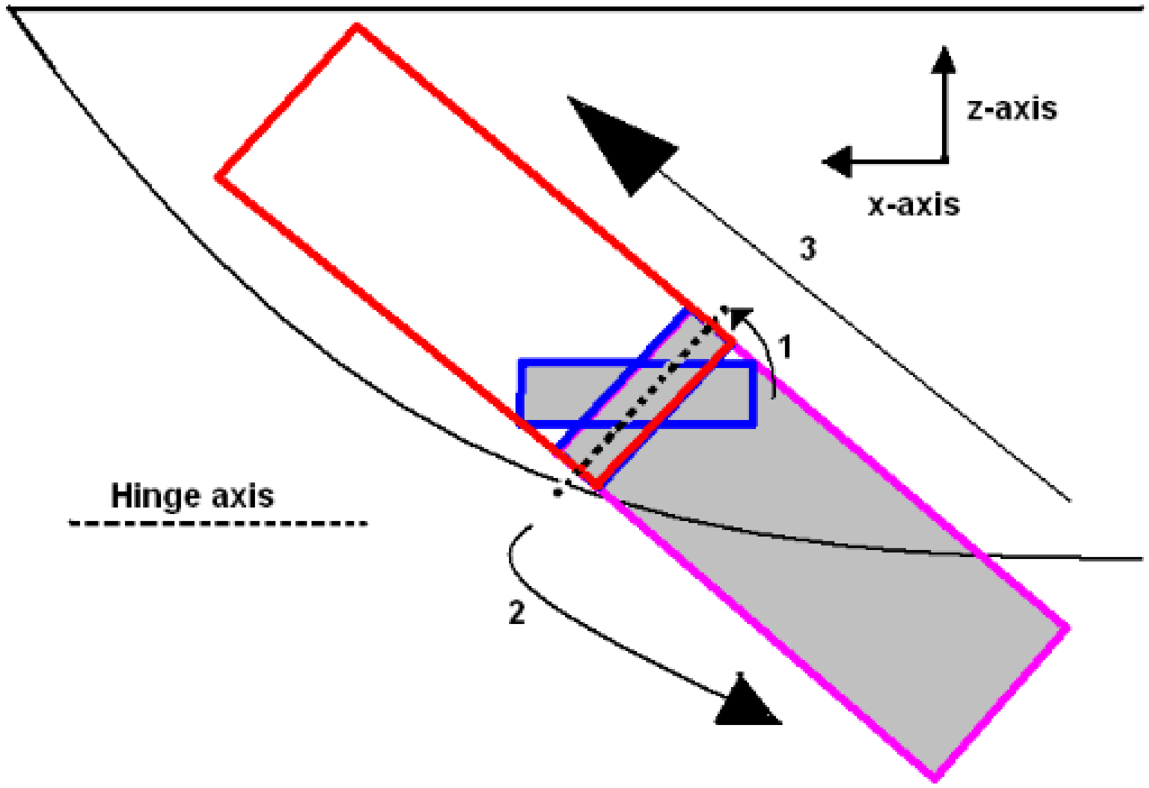


Figure 6-7: Diagonal telescopic retraction (Borgen, 2010)

6.1.4 Forward pivoting foil

Another mechanism was used during the propulsion foil trials of M/S Kystfangst (Berg, 1985). Instead of two foils fixed to the hull, one foil is fixed to two struts leading to the hull. The struts are fastened to a point on the hull, and are able to rotate around the fastening points. With a pivoting motion of the struts around the transverse ship direction, the foil can then be lifted out of the water. This solution has several upsides: because the foil can be placed below, or even in front of the hull, the hull does not come in the way for the foil. This increases the potential size of the foil. The foil does not need to “fit into” the hull, which also takes away this size limiting factor. Neither do you have to significantly modify the interior of the hull to do this installment. One downside is that the struts holding the foil will cause added resistance in themselves. In the elevated position, the foil and struts could also come in the way when harboring. The struts could also come in the way for other equipment, such as the anchor. For ReVolts case, the mechanism could potentially interfere with the guidance system cameras at the bow. A sketch of a forward pivoting foil equipped on ReVolt is shown in Figure 6-8.

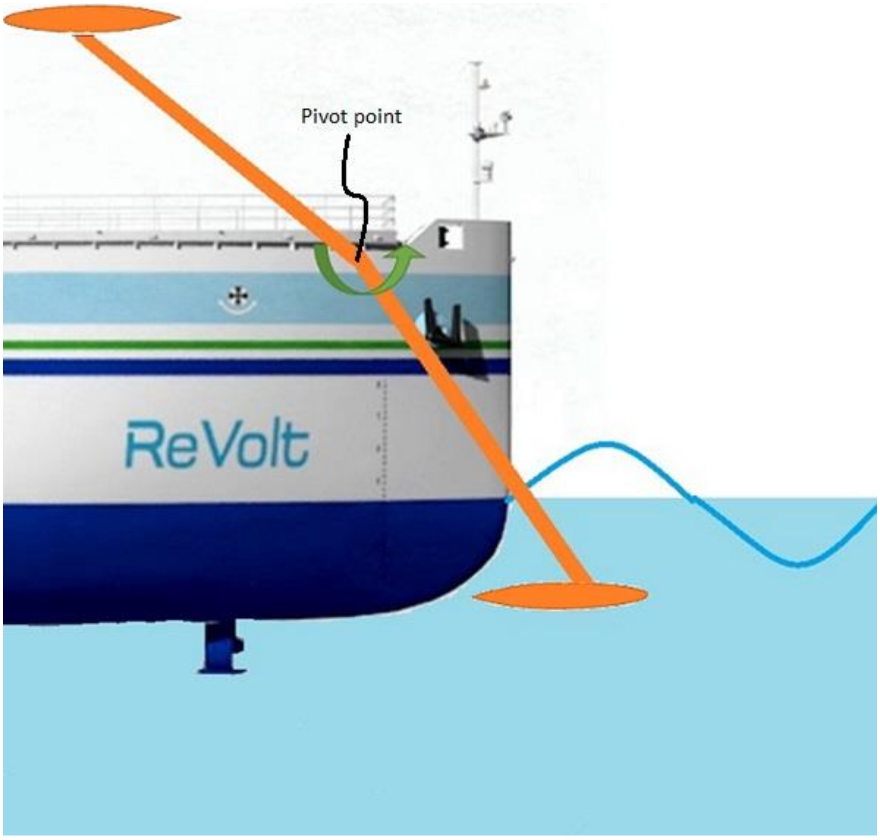


Figure 6-8: Forward pivoting foil exemplified. Figure not to scale

6.2 Positioning of foils and choosing folding mechanism

The purpose of the foils is to generate as much lift, and thereby thrust, as possible. The thrust generated in the region where linear foil theory applies is proportional to w_{REL} squared. We therefore want to maximize w_{REL} .

The oscillating foil component of w_{REL} is largest with increasing distance from the center of gravity. We therefore want to place the foils as close to the bow as possible, or even fore of the bow. This also makes sense in a flow disturbance point of view, as the flow disturbances from the hull close to the bow is assumed negligible.

As the wave motions decrease with increasing depth, the wave component of w_{REL} is largest close to the surface, due to the orbital wave velocities, making us want to vertically place our foils as close to the surface as possible. The vertical position has a limiting factor; in a flow velocity point of view, a position close to the surface is beneficial, but this increases the risk of the foil exiting the water, which could lead to slamming of the foils in certain wave conditions. This could lead to severe structural damage of the foils and/or hull, and the risk of slamming occurring has to be minimized. Neither can the foils be placed too close to the keel for some of the storing mechanisms, as problems with foil storing space could arise. This also depends of the nature of the storing space and mechanisms, as discussed in Section 6.1.

Another problem with positioning the foil close to the free surface is that the foil will interfere with the free surface, creating waves, resulting in additional drag force on the foil. The wave making drag coefficient is dependent on the submergence Froude number $F_N = \frac{U}{\sqrt{gd}}$, and is explored in the project thesis of (Kramer, 2013), p. 43. As a misplaced foil may cause additional unwanted drag, this topic could be of interest to consider. The topic will not be explored further in this thesis, as we expect slamming avoidance to play a significantly more important role than foil wave making in the vertical positioning of the foils.

6.2.1 Folding mechanism

In (Riley, 2014), added resistance tests in regular waves were done for the different storing mechanisms applied to ReVolt. Results implying a reduction in pitching motion were observed for all mechanisms and geometries tested. In this thesis, it was concluded that the vertical telescopic retraction mechanism was most promising for ReVolt, and further thrust calculation was only performed for this mechanism.

However, following later discussions with DNV GL, we have decided to look to the forward pivoting foil in our analysis; no modifications are required to the hull below the waterline to implement this mechanism, and in addition there will be no geometrical restrictions to the foil size. Another positive side is that the foils can be placed further ahead than the hull-fastened foils, which will be positive for the thrust generation for non-stalling conditions. Also, in a worst case scenario with the structure failing, damage would only be done to the foils/struts, while with the other mechanisms one could imagine serious damage happening to the hull, which could potentially be catastrophic. Looking at the pivoting mechanism does, however, require us to model the viscous and spray drag on the struts.

The foils are chosen to be positioned at a distance of 64m in front of the aft perpendicular, leaving ample space for the foils in front of the bow.

6.2.2 Foil submergence

The submergence of the foils need to be examined further. Using the frequency domain method developed, we have looked at the mean thrust produced from the foils at different submergence depths at head seas, H_S=3m, T_P=7s and at a ship speed of 6 knots. The geometry of the foil is otherwise as specified in Section 6.3.

Table 4: Thrust dependence on foil submergence

Vertical foil position [m]	**-2.0**	**-2.5**	**-3.0**	**-3.5**	**-4.0**
Mean thrust [kN]	10.36	10.24	10.15	10.06	9.98

We see in Table 4 that the thrust decrement with increasing foil submergence is very small. As it is vital that foil slamming is avoided, we will continue working with the foil submergence depth of 4.0m.

We have also produced a time series for the vertical position of the foil relative to the mean water line, to assess the risk of slamming. A 10 minute exert of the 2hr time series is shown in Figure 6-9, where we have looked at head seas, ship speed 6kn H_S = 3.0m and T_P = 7s.

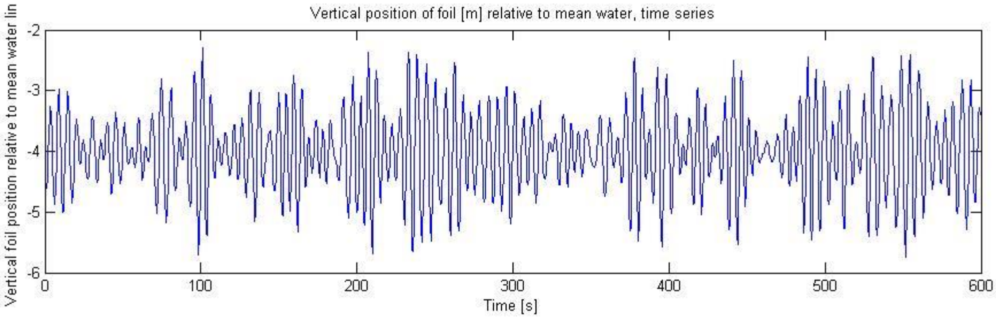


Figure 6-9: Time series of vertical foil position relative to mean water line

We see that in this 10 min exert, the minimum values of z are roughly -2.5m – that is a 2.5m distance from the mean water line. The same goes for the complete time series. Doing the same analysis for a significant wave height of 5.0m, the minimum values for z are roughly -1.75m – still far below the mean waterline. Thus, the foil submergence of -4.0m seems sufficient to avoid slamming. It should be noted, though, that there is a possibility that in the time instant the foil is at -2.5m (in the H_S=3.0 scenario), a large wave through *could* also be present at the foil. The possibility of foil slamming would then be present, should the foil exit the water in the through. To be completely sure of slamming avoidance, this analysis could be taken further by looking at the difference between wave elevation and foil submergence, which should never be larger than zero. However, as the foil thrust has been shown not to decrease much with increasing foil submergence, we have chosen not to take this analysis any further in this thesis.

We can also mention some further drawbacks with a large foil submergence: following a larger foil submergence depth are increased length of the struts, giving a larger strut drag, and larger strut dimensions needed to withstand the bending moment imposed by the foils, yet again giving a larger strut drag in addition to material costs.

6.2.3 Strut size

It will be demonstrated in Section 9.1 that the additional resistance components of the struts are small compared to the thrust gained by the foil, and the choosing of strut size is therefore of minimal importance in respect to foil thrust, although it of course is very important in terms of structural integrity. We have therefore guesstimated a strut size of longitudinal length 0.8m and maximum thickness 0.3m, for each strut.

6.3 Foil geometry:

6.3.1 Foil profile

The foil geometry has to be chosen before any thrust calculations can be performed. As previously mentioned, the foil will have no camber, as it needs to work equally well when the foil is pitching upwards and downwards. In linear foil theory, the foil thickness does not influence the lift produced, and thus the thickness will not play a vital role. We should, however, keep in mind that decreasing the thickness of the foil increases the risk of stalling. On the other hand, increasing the thickness will increase the foil drag, and increase the structural strength of the foil. Increasing thickness also means increased CAPEX costs due to material cost.

In the case of passive foils, stall avoidance is of great importance. We will therefore choose a relatively thick foil profile to minimize the risk of stalling. A camberless NACA 0015 profile is chosen, implying a maximum thickness to chord-ratio of 15%. The profile is shown in Figure 6-10. The viscous drag coefficient C_D depends on the angle of attack, but looking to Table 1 in (Miller, 2008), assuming an averaged C_D of 0.015 seems reasonable. We also note that this profile has a relatively large curvature radius at the nose, which is beneficial in terms of nose cavitation avoidance when the foil is lifting with an angle of attack, which is always the case for wavefoils. Due to the low speed of ReVolt, however, we do not expect cavitation to occur.

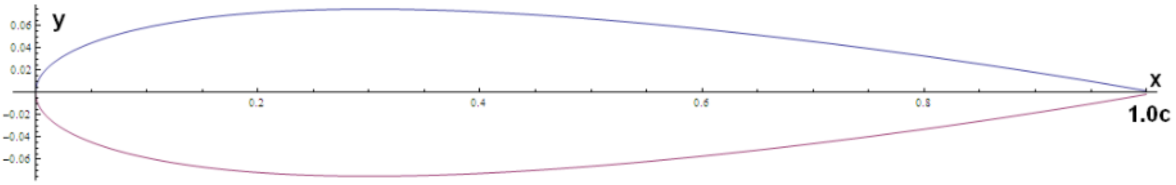


Figure 6-10: Chordwise thickness distribution of NACA 0015 foil profile (Aerospaceweb.org, 2015)

6.3.2 Foil size: span and chord length

Deciding the span (s) and chord length (c) of the foil is of the utmost importance, as it will greatly affect the performance of the foils. If the foil size chosen is too small, the foil will not fulfill its true potential. If the foil chosen is too large, the motion dampening effect of the foils could get too large; as the relative vertical fluid motion induced thrust production partly is a consequence of the ship motions, we do not want to reduce these motions *too* much. A large foil size could also lead to imposing a large bending moment on the struts, affecting the material use in the struts and hence also the CAPEX costs associated. Strut drag would also increase. With a large span, the foils are more prone to fatigue, as the bending moment at the strut fastening points will increase with increasing span.

To determine our foil size for ReVolt, we perform a simulation of the thrust produced with increasing foil size. As we do not want our foil to be able to interfere with land-based equipment when coming alongside a quay, our maximum foil span will be 12m, whereas the maximum breadth of ReVolt is 14.5m. Strut drag and viscous foil drag is taken deducted from the mean foil thrust in this analysis. The results from the analysis is seen in Table 5.

Table 5: Net added resistance dependency on foil size. H_s*=3.0m,* $T_p = 6.5s$*, head seas*

Foil span [m]	**3**	**4**	**5**	**6**
Chord length [m]	1	1.33	1.66	2
Foiled added resistance [kN]	45.6	44.4	44.2	44.0
Mean foil thrust [kN]	2.3	4.1	6.2	8.4
Unfoiled added resistance [kN]	50.6	50.6	50.6	50.6
Foiled net added resistance [kN]	43.3	40.3	38.1	35.6

We see that the net added resistance is steadily decreasing with increasing foil size up to our largest foil. There is no reason to believe that the net added resistance has reached a minimum when we arrive at our largest foils, but since we do not want our foils to be any larger due to practical reasons, we will use the largest foil configuration used in this analysis throughout the rest of this thesis. Larger foil sizes could be used, but would be problematic space-wise unless a better folding mechanism is proposed.

7 Route of ReVolt, scope of sea states considered and determining the WCS's

The battery pack of ReVolt has to be dimensioned in accordance with the "worst case scenario" (WCS) it might encounter. By this we mean that, for a given route leg, ReVolt has to be able to make port in the least favorable weather conditions it may encounter in this leg. This WCS will then determine how much energy is needed to safely make port in this condition, this being dimensioning for the battery pack.

7.1 Planned sailing route of ReVolt

ReVolt is planned to enter 11 ports along its route between Oslo and Trondheim, and the route can then be divided into 10 different route legs. The ports are displayed in red and route leg numbers in green in Figure 7-1. The black numbering is related to the wave scatter diagrams provided by DNV GL.

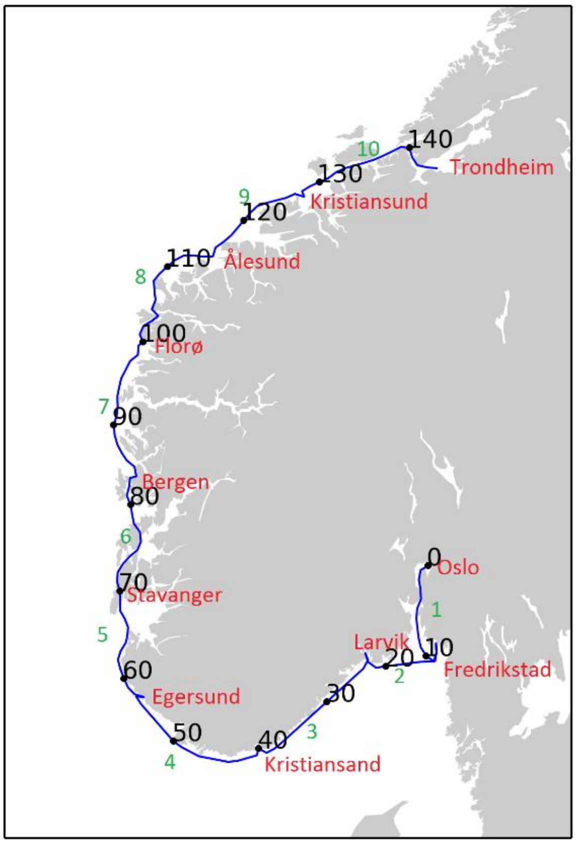


Figure 7-1: Route of ReVolt

The route features vastly different sea conditions, from sheltered fjords to open sea, and the characteristics of each leg are different. The distances of each leg are approximated in Table 6 along with a crude assessment of each leg’s openness.

Table 6: Leg distances and sheltering conditions

Leg no.	**Starting point**	**End point**	**Total distance [km]**	**Sea conditions**
1	Oslo	Fredrikstad	102	Sheltered
2	Fredrikstad	Larvik	58	Sheltered
3	Larvik	Kristiansand	176	Somewhat sheltered
4	Kristiansand	Egersund	173	Open
5	Egersund	Stavanger	76	Open
6	Stavanger	Bergen	185	Open and sheltered
7	Bergen	Florø	153	Mostly open
8	Florø	Ålesund	157	Mostly open
9	Ålesund	Kristiansund	127	Mostly open
10	Kristiansund	Trondheim	174	Mostly sheltered

7.2 Wave conditions in sailing route

Looking to Figure 7-1, the black numbering represents locations of wave scatter diagrams used by DNV GL to assess the wave conditions in ReVolts route. Inn all a number of 112 scatter diagrams have been provided by DNV GL. We have looked into each, finding the percentage of sea states with H_s > 2m and H_s > 3m. The result from every scatter diagram can be found in APPENDIX A.

Late autumn 2014, DNV GL concluded that they were not satisfied with the battery dimensioning done, and that they would increase the share of sea states too severe for ReVolt to sail in to 2.8%. Omitting the worst 2.8% of the sea states should therefore be the goal in our thesis as well. Through discussion with DNV GL, we have suggested to omit sea states with H_s > 3m. We look into our wave scatter diagrams to assess the validity of this suggestion.

We observe that the severity of the wave conditions vary a lot along the route, with the worst sea states occurring along the route between Stavanger and Trondheim. In the "worst" sample points, H_s > 2m 27.96% of the time, and H_s > 3m 12.71% of the time. Closer examination of these sample points reveals that H_s > 4m 5.06% of the time. This occurs only in a small portion of ReVolts route. For most of the scatter diagrams provided for ReVolts route, the occurance of higher significant wave height than 3m is rare. The purpose of this thesis is to reduce the added resistance in waves in the *worst* sea states ReVolt might encounter, not including the sea states deemed too severe for ReVolt to sail in. We will therefore use a H_s = 3m to be the dimensioning wave height, as previously stated, but we should also look into sea states of H_s = 4m and 5m to see how well the foils perform in these conditions. If the benefit is great, perhaps the sea states of H_s =4m and 5m also may be included in the range of sea states deemed suitable for ReVolt to sail in.

The added resistance in waves will increase with increasing H_s. For the peak wave period T_p, however, it is a matter of finding the wave period where the added resistance is largest – this should be where the induced ship motions from the waves are largest.

7.3 Range of scenarios examined: Passive foils

We except our worst case scenario to be in head seas, but it is also of interest to examine the foil performance when the waves are meeting ReVolt with an angle. We therefore examine wave heading angles of 0° > β > 90° with an increment of 22.5°. We omit larger values of β for two reasons: firstly, the worst case scenario will certainly not occur when the waves are meeting ReVolt from aft. Secondly, the RAO production from ShipX is not very accurate for values of β over 90°, as the encounter frequency will tend to be low in this circumstances. As ShipX relies on high frequency theory (Angvik, 2009), the quality of the calculations will be poorer at $\beta > 90°$.

It is of interest to examine the foil performance at different speeds. The foil performance is examined at ship speeds 4kn > U > 8kn with an increment of 1kn.

For the wave height, we observe values of H_S up to 8m in the scatter diagrams provided by DNV GL. However, such high sea states are rare, and in any case not part of the sea states deemed suitable for ReVolt to sail in. We therefore look at sea states with 1m > H_S > 5m with an increment of 1m. As 1m > H_S > 3m is the wave height values deemed "allowable" for ReVolt, the main focus with regards to CAPEX will be in this range.

The added resistance in waves is highest for 4.0s > T_P > 10.0s, so the focus will mainly be in this region. We use an increment of 0.5s. We use such small increments because the added resistance and foil thrust will vary greatly in the peak period region containing the WCS, and a good resolution is desirable.

For the wind resistance, we look at a constant head wind of 16m/s in all scenarios.

We see then, imagining all the possible combinations of wave heading, significant wave height, peak wave periods and ship speeds this could give, that the amount of calculation loops becomes very large.

7.4 Range of scenarios examined: Pitching foils

The calculation of thrust in irregular seas for the scenarios in the above scope demands roughly 120 hours of computational time in MATLAB, not counting the manual labor. One reason for the long calculation time for passive foils is the division into foil strips. The calculation for pitching foils includes a fairly time-consuming iteration as well, and though it is possible, and due to time constraints, we decide not to include the foil strip formulation in our calculation for pitching foils. This means that only head seas can be examined, as this is the only instance where the incident wave phases will be constant over the foil span for all time steps.

In any case, as we later will see, the worst case scenario occurs at β = 0°, so our limitation of wave heading angles will not interfere with our goal of finding potential CAPEX savings with pitching foils. The domain of all other parameters used for assessing the performance of pitching foils are as defined in Section 7.3, with an addition of H_S= 4.0m and 5.0m.

7.5 Strategy for calculating worst case scenario energy consumption

In the predecessor to this report, we set out to find the worst case scenario using the actual route legs and looking at different wave propagating directions to find the worst case scenario (Riley, 2014). Perhaps not surprisingly, the situation soon became very complex – a very large amount of scenarios had to be examined.

We will therefore use a simpler, more effective way of determining the worst case scenario energy consumption: we will look to our brake power results, and find the scenarios where the largest brake power demand occurs. We assume that ReVolt will sail 100nm (185.2km) in this condition, and calculate the worst case energy consumption by

$$E_{WCS} = P_B * t_{leg} \qquad \text{Eq. 71}$$

Here t_{leg} is the sailing time for 100nm at the applicable, constant sailing speed. This approach is rather crude, as the probability of ReVolt meeting the WCS over an entire route leg is small. It is however not impossible, and it is also the method used by DNV GL for their battery dimensioning process.

7.5.1 Empirical assessment of WCS energy consumption strategy validity

During the process of making this thesis, the author has studied wave- and wind conditions in the route of ReVolt empirically throughout the writing process using interactive weather data from the US National Weather Service (Nullschool, 2015). An example from February 28th 2015 is shown below:

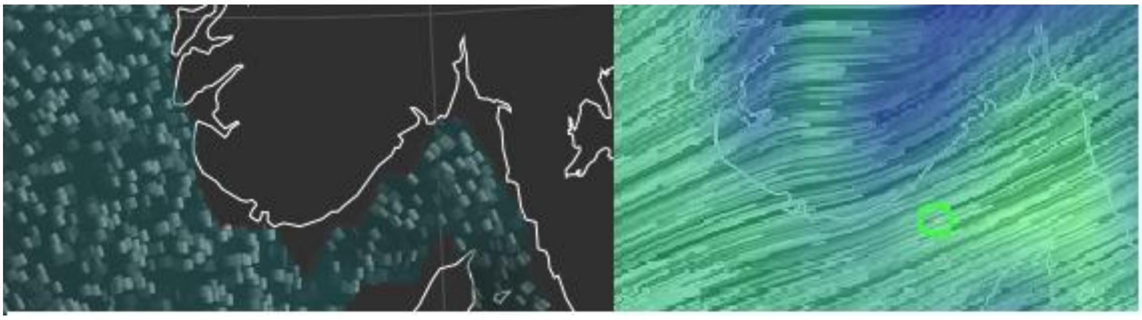


Figure 7-2: Empirical assessment of waves and wind in the route of ReVolt

In Figure 7-2, the propagating direction of the wave crests is shown to the left, and streamlines of wind shown to the right. We see that in the route leg Larvik-Kristiansand, a route with a length of 174 km, ReVolt would this particular day be sailing in close to head seas and head wind for a large portion of the route. This has led the author to believe that the above outlined WCS energy consumption determination method is not as excessively conservative as one might initially believe.

8 Software

8.1 ShipX

ShipX is a computer software developed by MARINTEK, featuring a range of pre-programmed applications made for finding many important characteristics in ship hydrodynamics and vessel responses.

For our case, we are interested in finding the vessel responses in waves, in the form of Response Amplitude Operators, and the added resistance caused by waves, both for a foil-equipped and foilless ship. To be able to calculate the total power reduction in a route leg, the calm water resistance is also found in ShipX, before the resistance is scaled to fit with DNV GL data. See also Section 5.4.

8.1.1 ShipX Veres

The vessel response program VERES is used to estimate the motions of the ship, including the estimations of the reduced pitch motions. The hull geometry was imported from a .dxf file produced by Rhinoceros 3D. Loading conditions have to be entered manually, and the draught for a fully loaded revolt is set to 5.02m. The radii of gyration is set to 3.26m after conferring with (Fathi, 2005).

By using VERES, we find the displacement RAOs and added resistance coefficients. The range of input wave periods has been set to [4.0s, 30.0s]. To find the displacement RAOs and added resistance coefficients for a ship equipped with propulsion foils, foils are added through the “Roll damping etc..” option, where the foil geometries and positions are defined.

The calculation is done by ordinary strip theory. When calculating added resistance, a choice between using direct pressure integration (DPI) method and Gerritsma & Beukelman method occurs. DPI is more time-consuming, but Gerritsma & Beukelman produces less accurate results for following seas. As the most important headings for our results are expected to be within the head-beam sea range, we choose to use the Gerritsma & Beukelman method for our calculations.

For calculating the added resistance in irregular waves, the added resistance coefficients are found by selecting the “irregular seas” option in the added resistance postprocessor. The JONSWAP sea spectrum is used.

8.1.2 Assumptions and simplifications within VERES

The calculations done in VERES is based on several assumptions and simplifications:

- The response calculations are based on linear theory; the translations are small, and only small waves with small wave steepness occur. The motion amplitudes induced by waves have a linearly proportional relationship with the wave amplitude. As a results, the superposition principle can be used to derive the loads, motions and accelerations in a sea state.
- The conditions are assumed steady-state. The vessel will oscillate harmonically with the frequency of encounter. Transient and hydro-elastic effects are not accounted for; this implies that potentially important effects such as slamming and water on deck are not covered by VERES. The linear hydrodynamic coefficients are solved in the frequency-domain.
- VERES utilizes potential theory, meaning that the fluid around the hull is incompressible, homogenous, irrotational and inviscid. A velocity potential is used to describe the fluid properties (velocities and pressure). The effect of viscous roll damping is included in VERES by empirical formulas.
- The ship length is assumed to be much larger than the beam and draught of the ship; a slender ship body is assumed. The assumption for this is that the length/beam ratio is > 2.5. Slender body theory can thereby be used, and the hydrodynamic coefficients are calculated using strip theory. The interactions between strips are not used for small speeds, and therefore 3D effects are neglected.
- The ship is assumed symmetric around the center-line.
- Motions and loads can be solved in both time- and frequency domain.

8.1.3 Ship speed and powering

The calm water resistance is found by using the “Ship Speed and Powering” application in VERES. The calculation is done with the Hollenbach’98 method. Propeller data have been supplied from DNV GL, and is used in the calculation. The input propeller data is the following:

- Propeller diameter D=3.0m
- Two propellers
- The propeller positions
- Number of blades: 2

- Pitch/Diameter ratio P/D: 0.7
- Blade area ratio Ae/Ao = 0.15
- The Wageningen B series is used in the calculations, though the propeller designed for ReVolt is not a part of the Wageningen B series.

Regarding the further use of the ShipX calculated calm water resistance, see Section 5.4.

8.2 MATLAB

Calculations of thrust generation and the needed brake power are done by scripts written for use in MATLAB. The scripts used in this thesis are described briefly below:

- *passive.m* imports RAOs from ShipX and calculates the mean thrust generated by the foil in irregular seas by superposition of each frequency component in the JONSWAP spectrum. Wave headings from 0°-180° with an increment of 22.5° can be used. The script is able to reproduce the effect of ship roll motion on the thrust, due to the division into foil strips. The script takes into account stall and unsteady lift effect, and also takes viscous strut and foil resistance and strut spray resistance into account.
- *active.m* is similar to *passive.m*, but is in addition able to calculate the effect of a spring-controlled pitching mechanism of the foil by an iterative procedure. This script will only produce correct results in head seas, as the effects of roll motion is not included in this script. As no foil strip formulation is necessary for head seas, this script is faster than *active.m*.
- *pbuX.m*, where X denotes ship speed, imports total ship resistance and calculates the mean brake power needed from the electrical engine to meet the resistance in the applicable sea state and ship speed.
- *seastatecounter.m* analyses scatter diagram data along the route of ReVolt to find and quantify the amount of sea states exceeding the operational limit of ReVolt.
- Numerous other MATLAB scripts are made and used for data handling purposes; however, they will not be summarized further in this thesis.

8.3 Excel

The worksheet software Microsoft Excel is primarily used for data handling purposes and simple calculations in this thesis.

8.4 Rhinoceros 3D

The hull geometry of ReVolt is supplied by DNV GL in the form of .stp and .igs-files, before being imported into Rhinoceros 3D, a commercial CAD software. Contour lines of one side the hull, plus the keel line, is exported to a .dxf file suitable for importing into ShipX.

8.5 Google Sketchup

The simple, free 3D modelling software Google Sketchup has been used to produce some of the figures in this thesis.

8.6 Work flow

The main parts of the calculation procedure used in our analysis of foil performance is shown schematically in Figure 8-1.

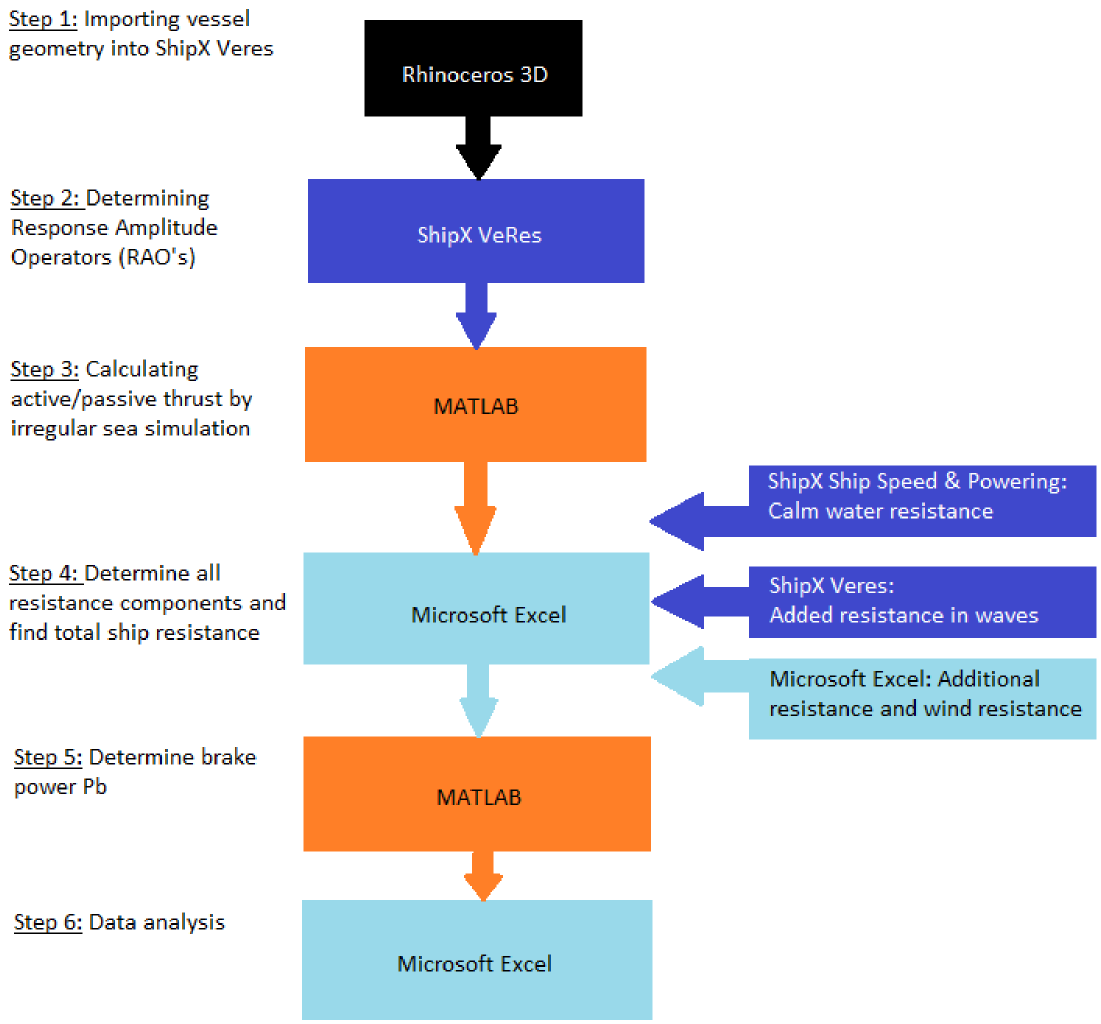


Figure 8-1: Schematic view of main parts of work flow in foil performance prediction

9 Results: Resistance components

9.1 Additional resistance components

The additional resistance components imposed from fitting ReVolt with propulsion foils mounted on struts can be seen in Figure 9-1 and Table 7 below. We see that the viscous foil resistance dominates the additional resistance; this is an additional resistance component that would occur even if a strutless folding mechanism is chosen. The negative impact, in a thrust production point of view, of choosing a mechanism utilizing struts should therefore be small.

Table 7: Additional resistance components

U [kn]	4	5	6	7	8
$D_{strut,visc}$ $[N]$	121	183	257	342	439
$D_{strut,spray}[N]$	94	146	211	287	375
$D_{foil,visc}[N]$	781	1221	1758	2393	3125
$D_{additional}[N]$	**996**	**1550**	**2225**	**3022**	**3939**

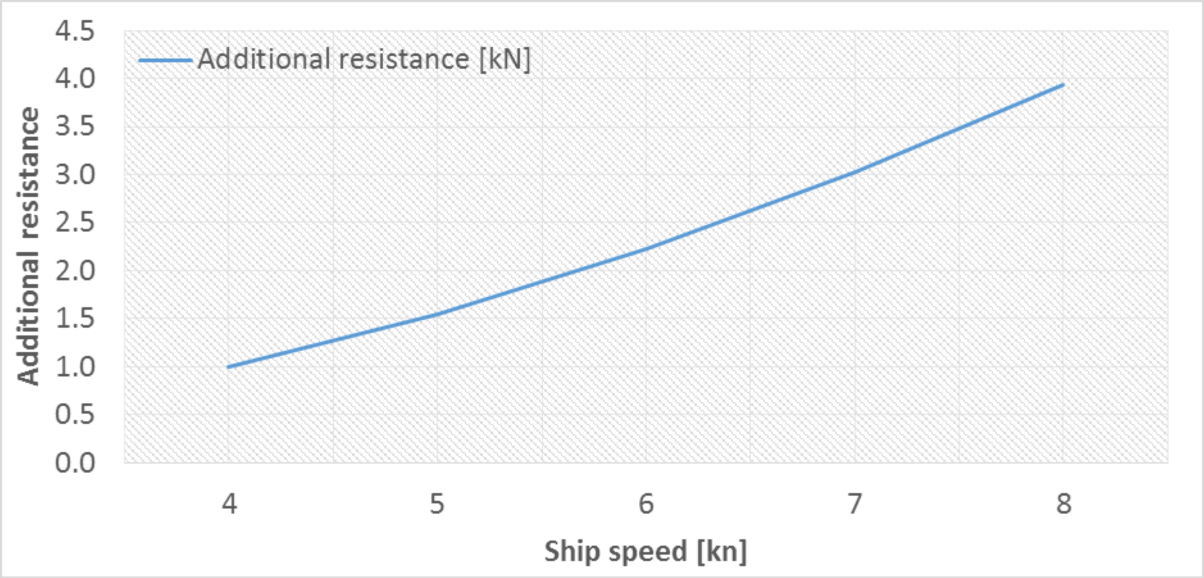


Figure 9-1: Speed dependent additional resistance in kN

9.2 Calm water resistance

The calm water resistance produced by ShipX Speed and Powering is corrected to fit with DNV GL CFD data by the method outlined in Section 5.4.

Table 8: Corrected calm water resistance

Ship speed [kn]	**4**	**5**	**6**	**7**	**8**
ShipX Ship Speed and Powering [kN]	7.2	10.5	14.3	19.3	25.8
Scaled calm water resistance [kN]	6.1	8.9	12.1	16.4	21.9

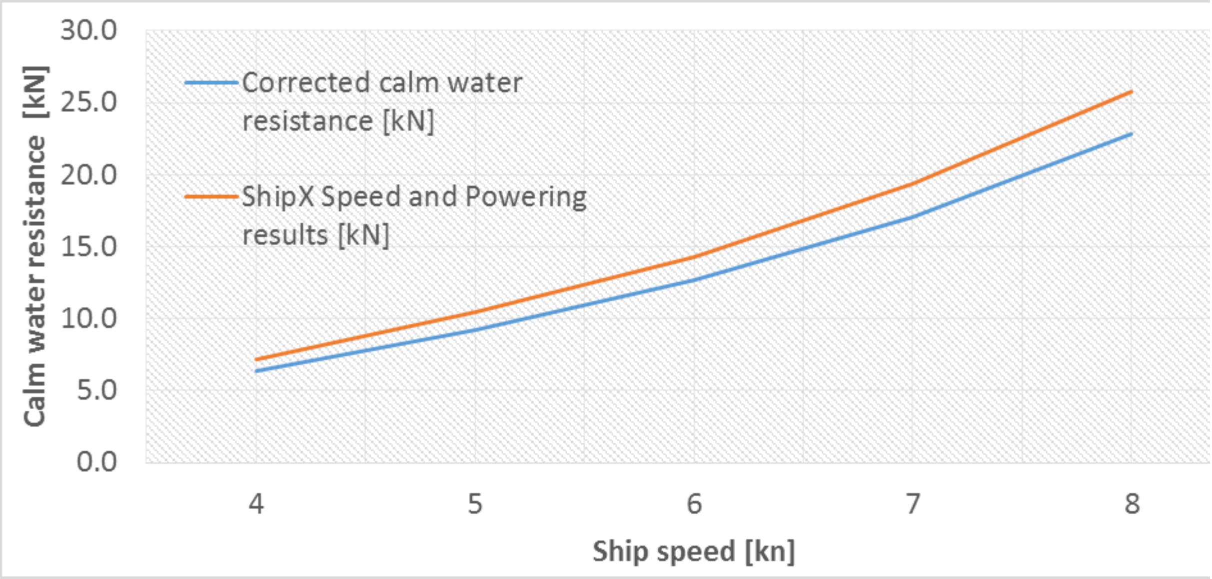


Figure 9-2: Corrected calm water resistance

9.3 Wind resistance

We choose a wind speed of 16m/s to be the dimensioning wind, corresponding to near gale winds in the Beaufort scale. Logically, head sea wind resistance increases slightly with increasing ship speed. The head wind resistance for our ship speeds is shown in Table 9.

Table 9: Wind resistance in head sea

Ship Speed U [kn]	**4**	**5**	**6**	**7**	**8**
$R_{wind}\ [kN]$	19.67	20.81	21.97	23.18	24.41

9.4 Added resistance in waves

The added resistance R_{added} is calculated for all our examined sea states, and will not be reproduced in its entirety here. We show an example of the calculated dimensionless added resistance $C_{A,waves}$ for a sailing speed of 6 knots, all wave heading angles and peak periods, for an unfoiled and foiled ReVolt in Figure 9-3 and Figure 9-4. The added resistance for all our conditions are shown in tabulated form in Appendix B.

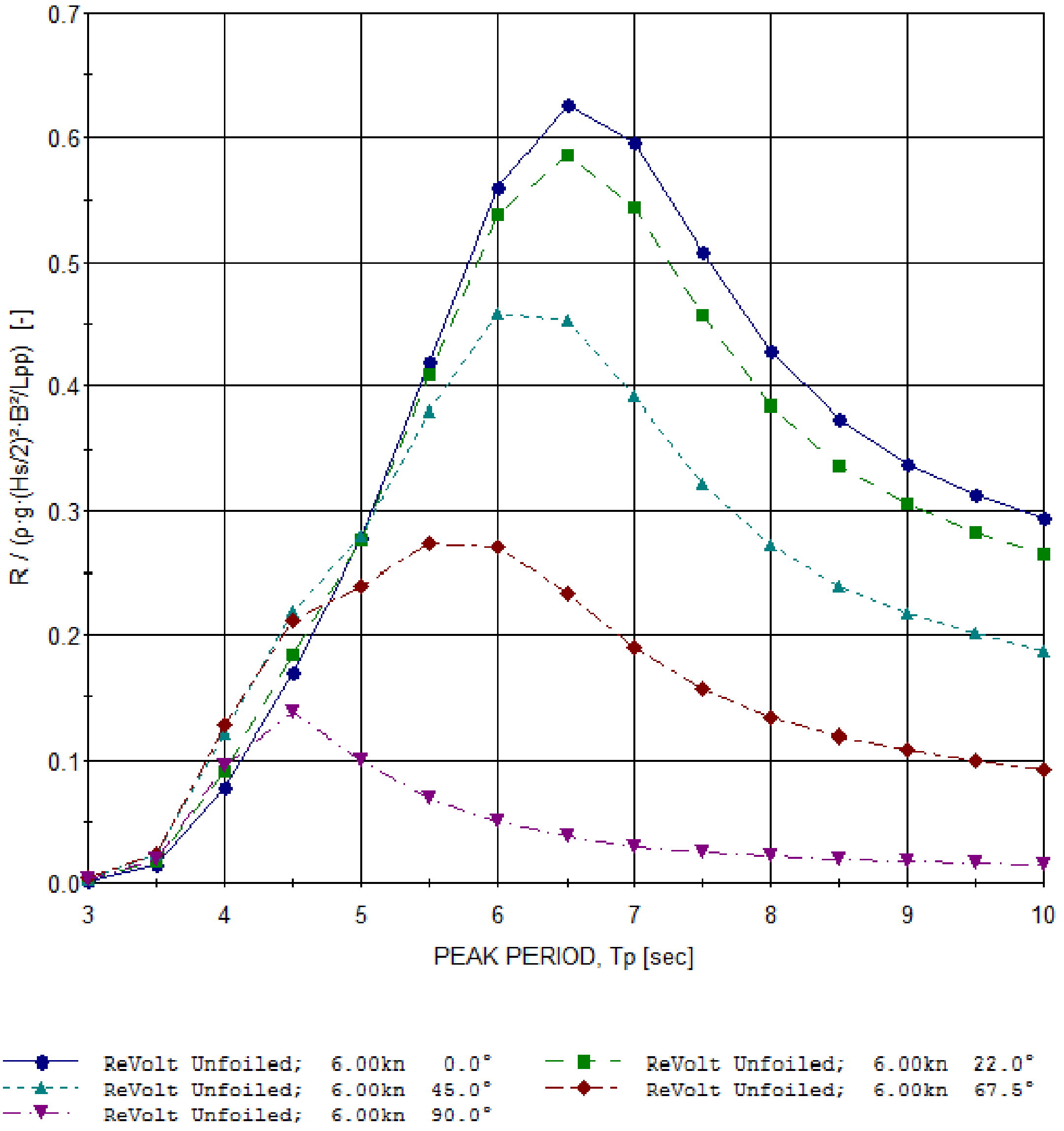


Figure 9-3: Dimensionless added resistance for an unfoiled ReVolt, U = 6kn

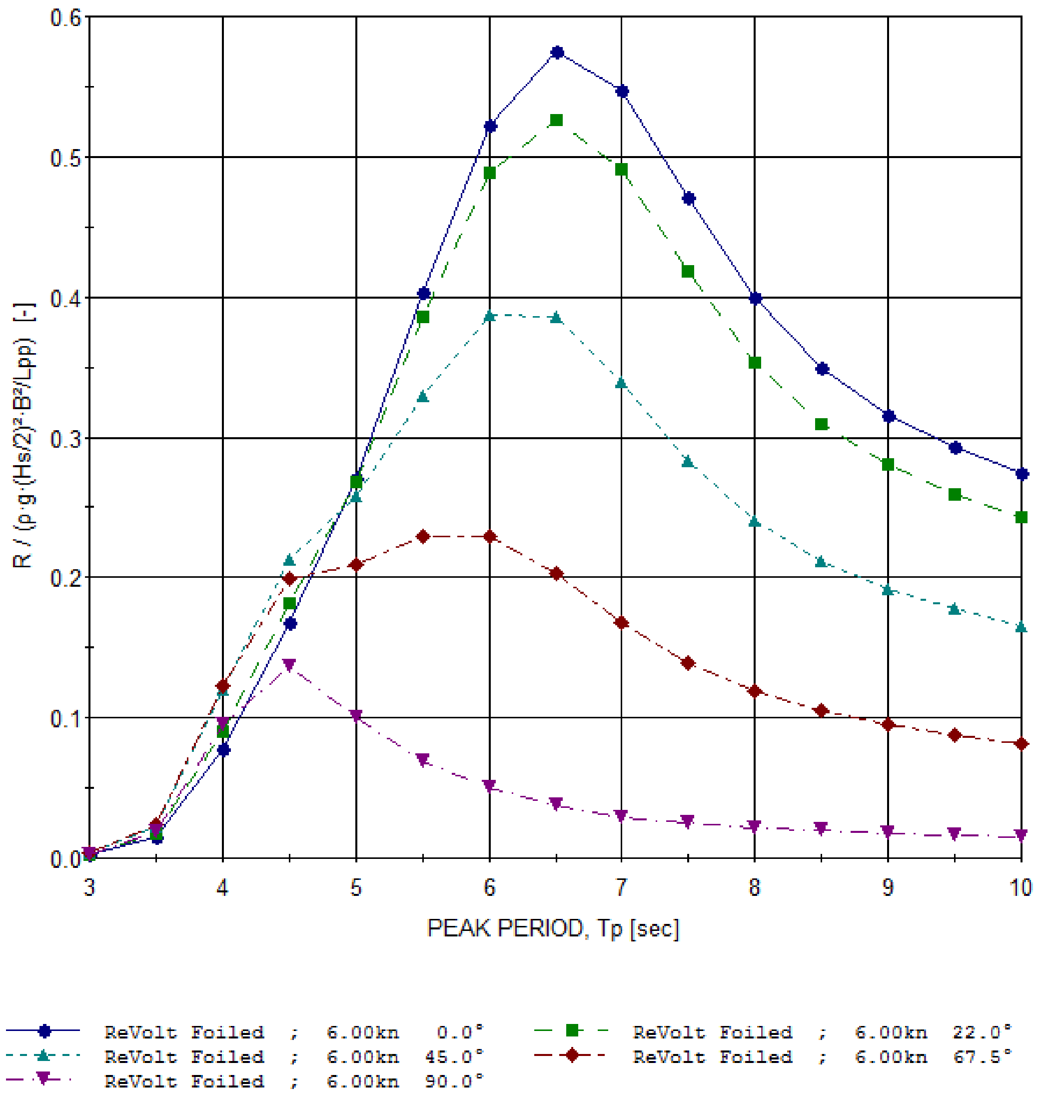


Figure 9-4: Dimensionless added resistance for a foiled ReVolt, U = 6kn

9.4.1 Comments: Added resistance in waves

We observe a decrease in added resistance for all wave heading angles except 90° when wave foils are equipped. The resistance peak is at T_P = 6.5s for head sea waves and a ship speed of 6 knots. When β increases, the resistance peak occurs at a lower peak period because ω_e decreases, meaning that the resonant wave period will occur at a lower wave period than at head sea. Not shown here, but observed in the added resistance in the appendix, is that the resistance peak shifts towards longer waves when the ship speed increases, and towards shorter waves when the ship speed decreases. Again, this is due to the changing ω_e, and this effect is expected. The resistance peaks range between 6.5s and 7.0s for ships speeds of 4-8kn.

It is somewhat surprising that no resistance reduction is observed in beam seas β = 90°, as roll stabilization produced by the foils should reduce the added resistance to some degree. Examining the displacement RAO's for roll motion produced by ShipX, we observe a decrease in the magnitude of the transfer function for a foiled ReVolt compared to an unfoiled. Thus, one should expect the added resistance to decrease somewhat. It seems that ShipX is not able to take this effect into consideration. In any case, the added resistance in beam seas is small compared to head seas, and this error will not be important in the process of finding the worst case scenario.

One additional note should be made regarding the foiled added resistance: ShipX is only able to simulate the effect of passive (fixed) foils, while the motion reduction for pitching foils will differ from the motion reduction for passive foils; this means that the added resistance also will differ in these two conditions. As ShipX is not able to include this effect, the added resistance in waves will therefore be equal for passively and pitch foiled simulations. We do not expect this error to be of any importance.

9.5 Total ship resistance

The total ship resistance for all scenarios examined have been calculated, and is shown in tabulated form in Appendix C. The total resistance is merely a sum of all other resistance and thrust components, and is only a step on the way to finding the brake power. Therefore we will not reproduce any results for R_{TS} here. R_{TS} is given in the appendix both with and without the wind resistance included; this for the reader to more easily see the benefits of the wave foil without wind interference.

10 Results: Thrust

10.1 Passive foils: Thrust production in irregular waves

The mean thrust for irregular seas has been calculated for a vast amount of different sea states, wave headings and ship speeds. Reproducing all thrust results in this thesis would be far too extensive; therefore we will look into the different parameters' (ship speed, wave height, wave heading and wave period) effect on the mean thrust in this section. Mean thrust results for all values of the different parameters explored can be found in Appendix D.

10.1.1 Mean thrust: ship speed and wave period dependence

In Figure 10-1 we look at the ship speed dependence of the mean thrust, plotting the mean thrust for T_P between 4s and 16s for each examined ship speed. As H_S = 3.0m is the largest wave height dimensioning for ReVolt, we use this value for H_S.

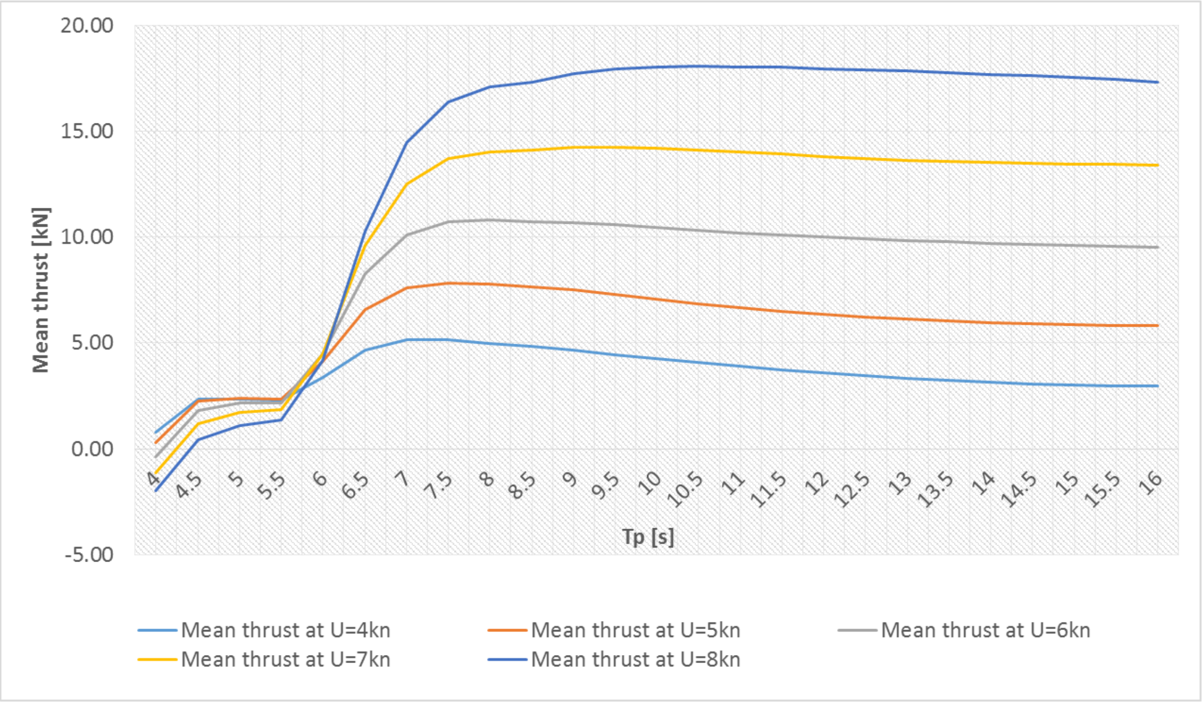


Figure 10-1: Mean thrust speed dependence, head sea, H_S = 3.0m

We see that for wave periods lower than ~6.5s, where ship motions are expected to be highest at 6kn in head sea, the thrust production is minimal. Over T_P ~6s, the thrust increases rapidly. The thrust production reaches a maximum at T_P values between 7-10s, depending on the ship speed, before slowly decreasing at higher values of T_P. Thus, when foils are fitted, we can expect to find our worst case scenario at T_P values lower than the T_P value giving the maximum added resistance – due to the low production of thrust at lower peak wave periods.

Also, we find that the foil thrust generally increases with increasing ship speed. This is expected, as the lift on the foil is dependent on the inflow velocity squared. However, the total ship resistance also increases significantly with increasing ship speed, and we can not at this point draw any conclusions as to what ship speed is most beneficial for ReVolt with foils equipped.

10.1.2 Mean thrust: wave height dependence

In Figure 10-2, we assess how the foil thrust changes in sea states with different values of significant wave height H_s, for different ship speeds. For each ship speed, the wave period inducing the largest added resistance for ReVolt has been chosen.

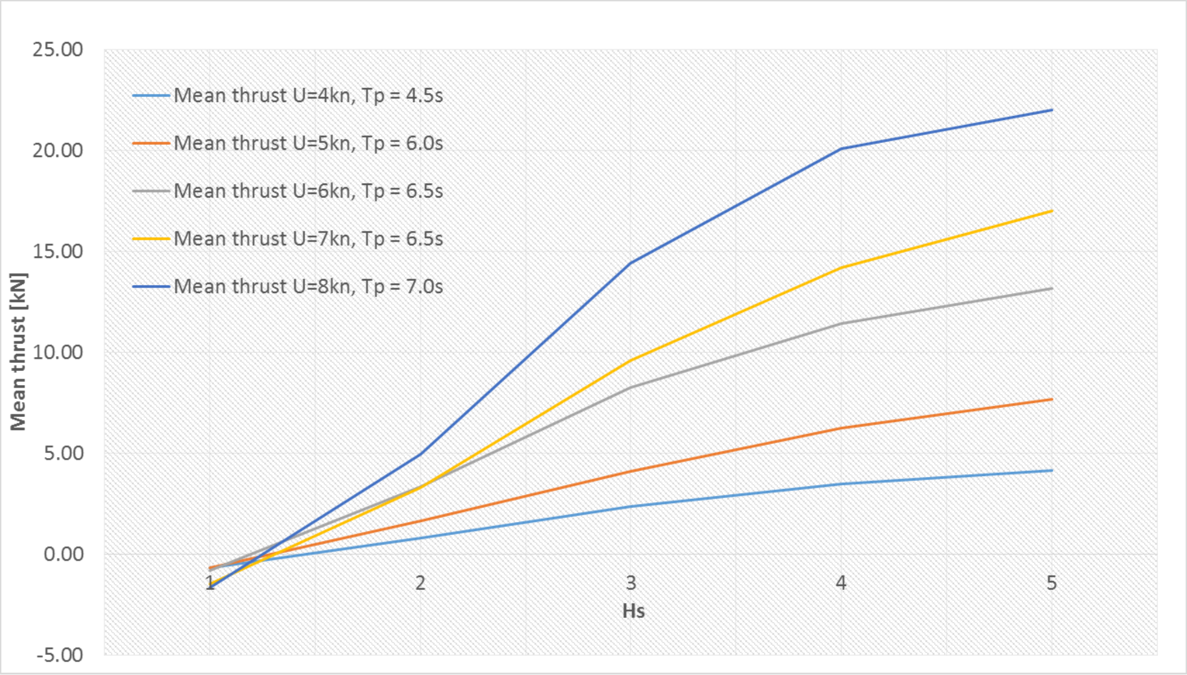


Figure 10-2: Mean foil thrust: Wave height dependence

As expected, we see that the foil thrust generally increases with the wave height, which can be explained by the increased orbital velocities and induced ship motions for larger H_s, causing larger inflow angles and thus a larger thrust production.

We note that wave heights of H_s = 1m in most cases yields a negative thrust, implying that the additional resistance imposed by the foils and struts overcomes the thrust produced by the foil. The foils are therefore not considered beneficial in this scenario, unless the motion dampening effect of the foil should be of importance.

We also see that the thrust gradient is largest between H_S of 2m and 3m. As we can expect w_{REL} to increase with the wave height, and the thrust is a function of w_{REL} squared in linear foil theory, the thrust gradient should be strictly increasing with increasing H_S for non-stalling conditions. When H_S exceeds 3m, we see that the thrust gradient is decreasing. This is an indication that foil stalling starts to occur at H_S values larger than 3m. Stalling on passive foils will be commented further in Section 10.1.2.

10.1.3 Mean thrust: wave heading dependence

At head seas, only the heaving and pitching motion of the vessel and the orbital velocities of the fluid particles produce thrust inducing relative vertical fluid motion. However, as the waves meets the vessel with an angle, rolling motion will be induced, also contributing to relative vertical fluid motion. Looking to the master thesis of (Borgen, 2010), his results imply that virtually no thrust is produced at beam seas, which is in direct conflict with, for instance, model trials performed by Einar Jakobsen.

In Figure 10-3, we assess the mean thrust produced at all ship speeds and all wave heading angles that have been analyzed. The resonant T_P will change depending on the ship angle; we look at a constant T_P of 6.5s here.

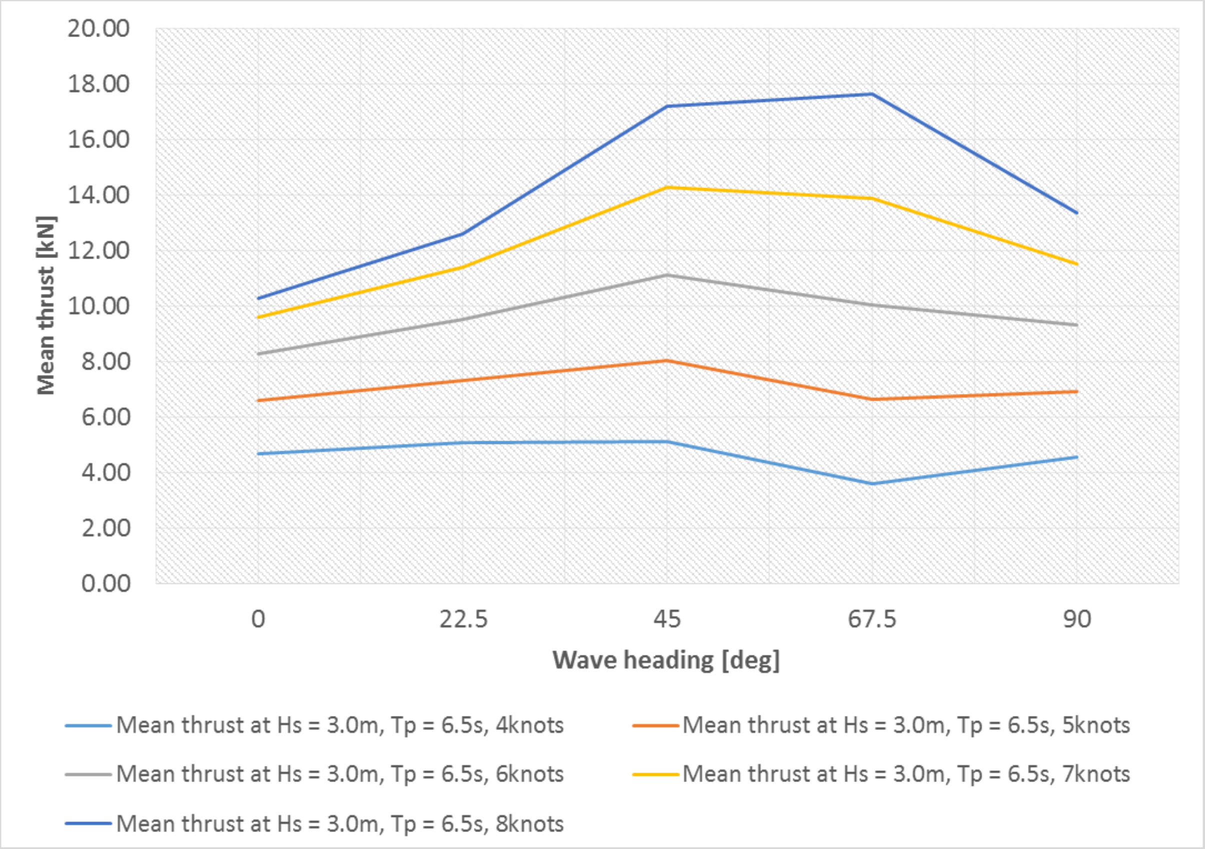


Figure 10-3: Thrust dependence on wave heading

Quite in contrary to the results of Borgen, the foil thrust seems to rise when the vessel is no longer sailing in head seas. We expect this to be due to the overall increased potential for higher relative vertical fluid motion when the ship is sailing outside of head or beam seas – because all the relevant ship motions contributes.

The picture of when foils are beneficial in other than head seas is rather complicated. We give an example: As can be seen from the results in the Appendix F, at beam seas (6kn) the thrust is higher for H_S = 3m than for H_S = 5m, for high T_P values. We disregard the results in sea states where H_S is large and T_P is low (see Section 13.1, first paragraph). We expect this to be due to occurrences of foil stalling when the wave heights reaches a certain value. Stalling can typically be avoided/controlled by pitching the foils, but as the wave phases will be different along the transverse position of the foil in beam seas, finding a foil pitching angle that will reduce the angles of attack over the whole foil might prove difficult.

All in all, the foils seem effective at all wave heading angles examined in this thesis. What heading angle gives the largest thrust will depend on ship speed, wave height, wave periods and whether stalling occurs or not.

10.1.4 Stalling of passive foils

As previously mentioned, at a certain value of H_S (of course, depending on the ship speed, peak period and wave heading) the produced foil thrust seems to start decreasing, and we expect the explanation for this to be the occurrence of stalling. To examine this further, we produce 10 minute time series of angles of attack on the foil for four different scenarios at six knots: Head seas at H_S = 3.0 and 5.0m at a T_P of 6.5s, and beam seas for the same values of H_S and T_P. For beam seas the angles of attack are displayed at a position close to the foil tips, where the roll induced relative fluid motion generally will be largest. For head seas the choice of foil position will not matter, as the phase of the wave- and ship motions are equal over the entire foil span.

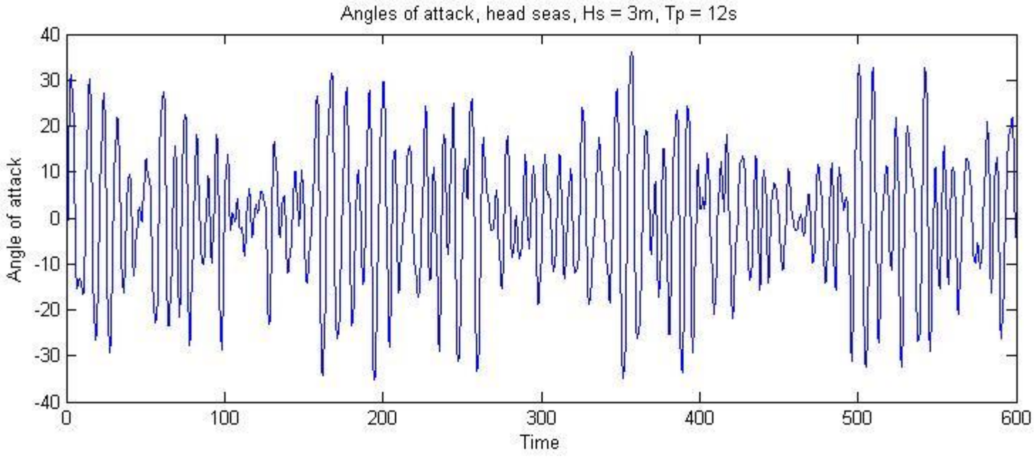


Figure 10-4: Time series of angle of attack, head sea, H_S = 3.0m

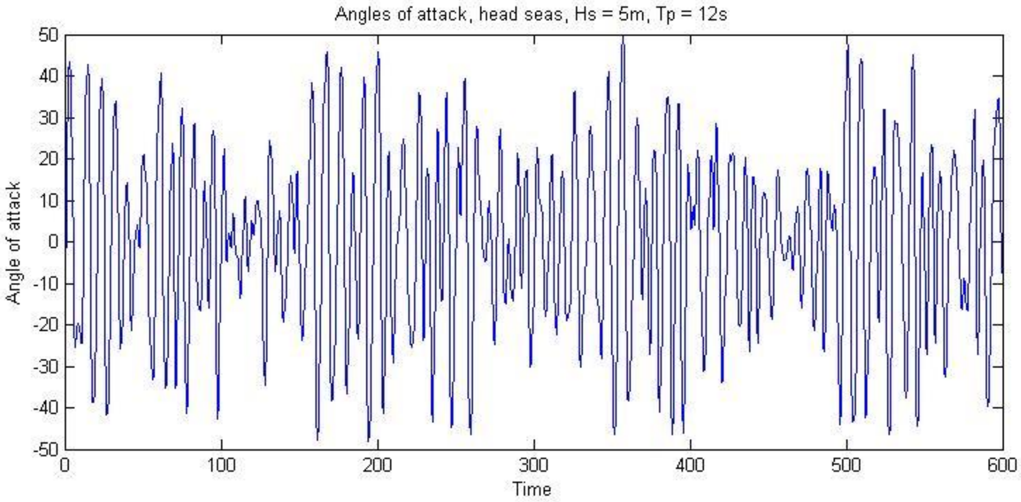


Figure 10-5: Time series of angle of attack, head sea, H_S = 5.0m

We see from the two previous figures for head sea that the angles of attack for H_S = 3.0m seldom exceeds the stalling limit of ~15 degrees, although it happens. For H_S = 5.0m, however, the stalling limit is exceeded far more often – and by more. Stalling thus happens more often in the latter condition, which is of course detrimental for the thrust production. For higher angles of attack, the drag of the foil is also significantly higher.

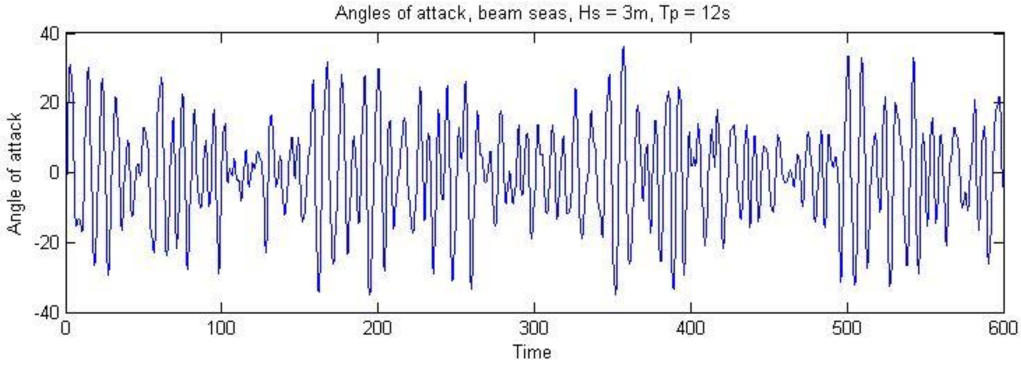


Figure 10-6: Time series of angle of attack, beam seas, H_S *= 3.0m*

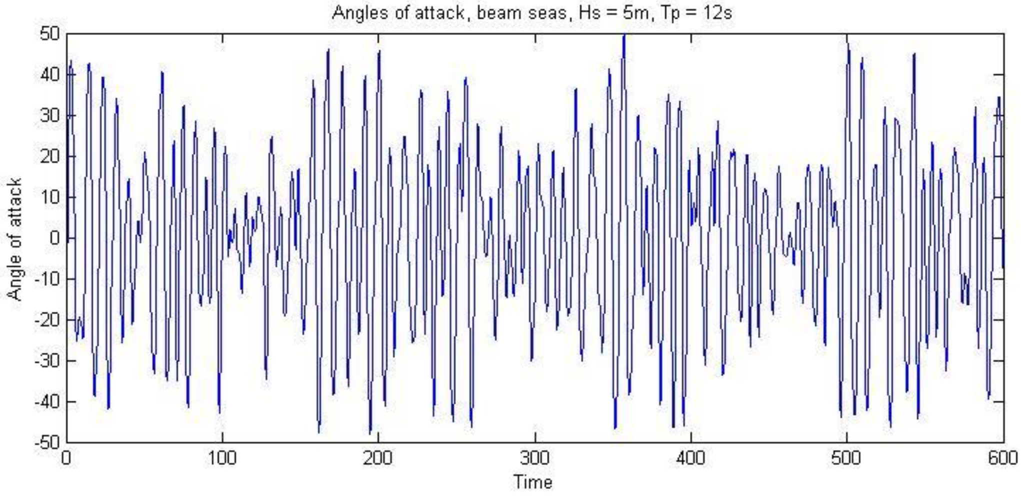


Figure 10-7: Time series of angle of attack, beam seas, H_S *= 5.0m*

The same remark can be made for beam seas: the stalling limit is far more often exceeded (and the exceedance is larger) in the larger sea state. The difference is that stalling can be more easily avoided in head seas, as the waves meets the foil with the same phase over the whole span of the foil, while for beam seas the waves will travel along the span of the foil, and thus the foil will experience different phases of the waves at different spanwise positions.

Based on this analysis, pitching foils seems to be beneficial at H_S values larger than 3m, and the focus in the later analysis of pitching foils will be focused on sea states with larger waves. It is also worth mentioning that for sea states up to H_S = 3.0m, passive foils might actually be more beneficial than pitching foils, as the angle of attack on a pitching foil will be decreased also for low angles of attack; this will cause an unwelcome reduction of thrust.

Also, as expected logically (due to the larger horizontal fluid velocity component with increasing speeds), but not shown in this analysis, the angles of attack are generally higher for low ship speeds than for high ship speeds. This means that passive foils can "handle" a larger amount of sea states for higher ship speeds than for lower ones.

10.2 Thrust results: Pitching (feathered) foils

10.2.1 Spring stiffness optimization: Worst case scenario simulation

We first examine the foil performance for increasing spring stiffness at the worst case scenario, which is of course the most relevant scenario to look at in a CAPEX point of view. The analysis is done for all ship speeds, for high sea states where active foils are expected to have a potential benefit. H_S values of 3.0-5.0m are examined. k_f values in the range of 10-60kNm/deg are examined along with all ship speeds. The comparison is done for a constant T_P = 6.5s, which is at or close to the WCS for all ship speeds.

10.2.1.1 U=4kn

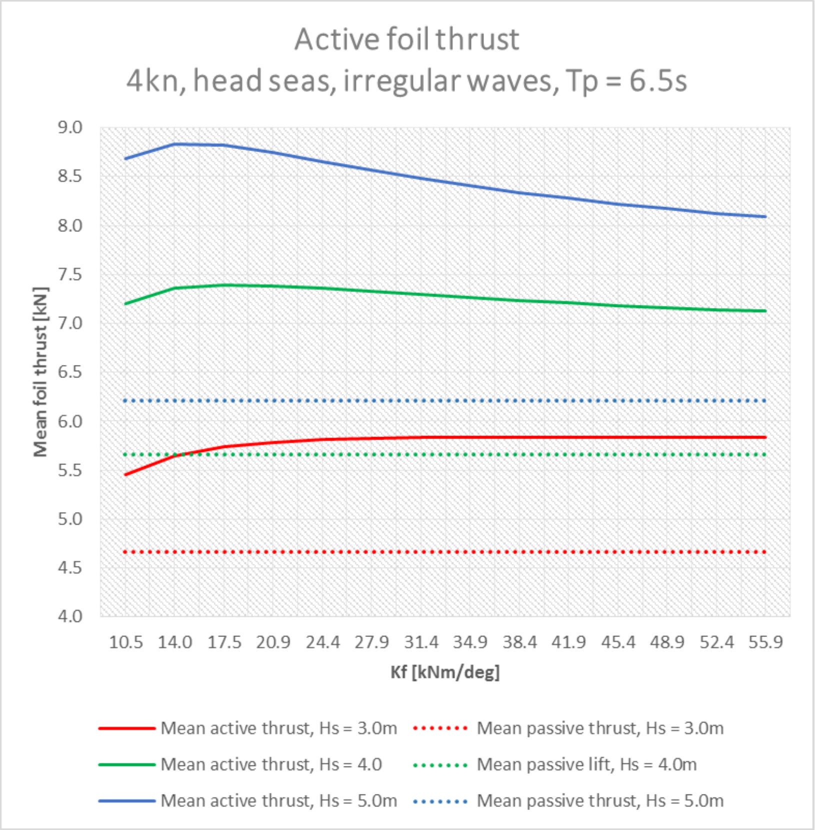


Figure 10-8: Mean thrust dependence on spring stiffness at U = 4kn

10.2.1.2 U=5kn

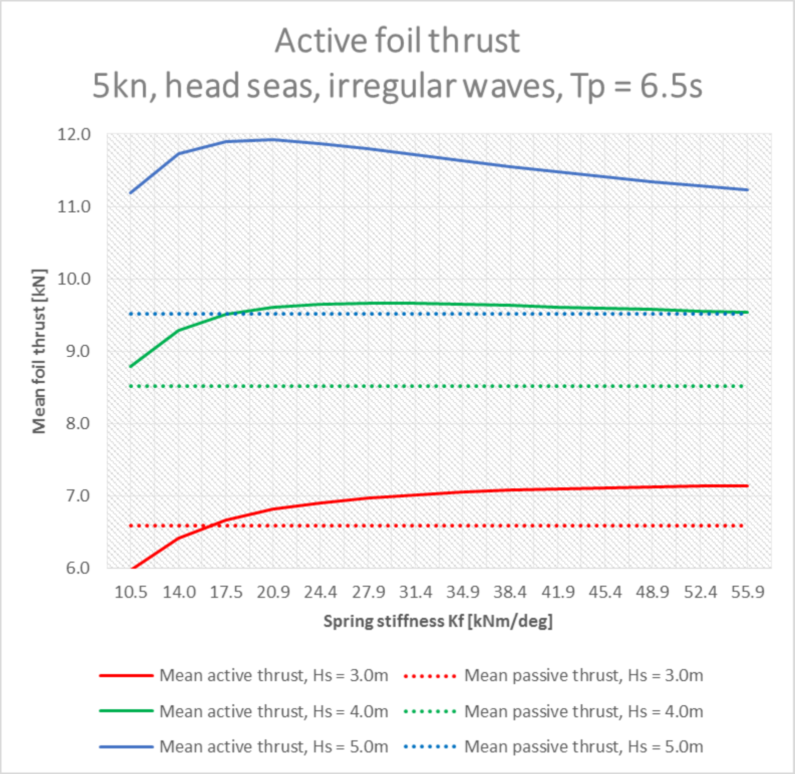


Figure 10-9: Mean thrust dependence on spring stiffness at U = 5kn

10.2.1.3 U=6kn

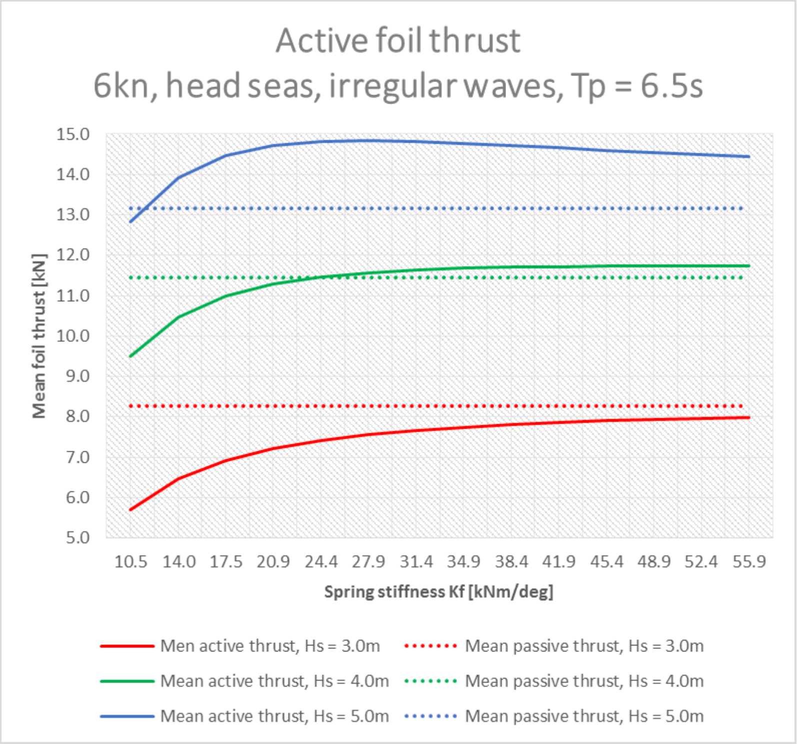


Figure 10-10: Mean thrust dependence on spring stiffness at U = 6kn

10.2.1.4 U=7kn

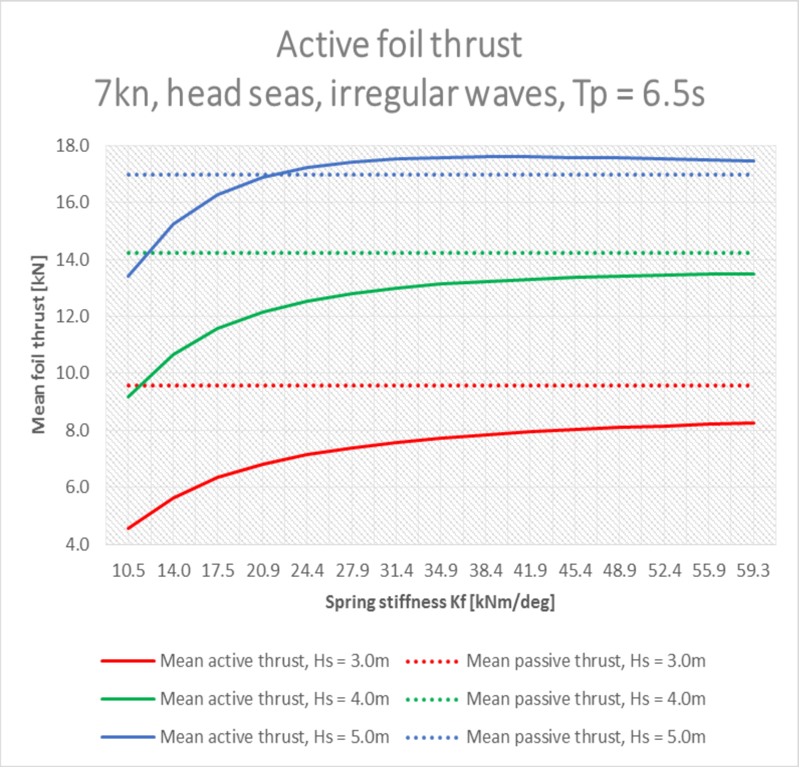


Figure 10-11: Mean thrust dependence on spring stiffness at U = 7kn

10.2.1.5 U=8kn

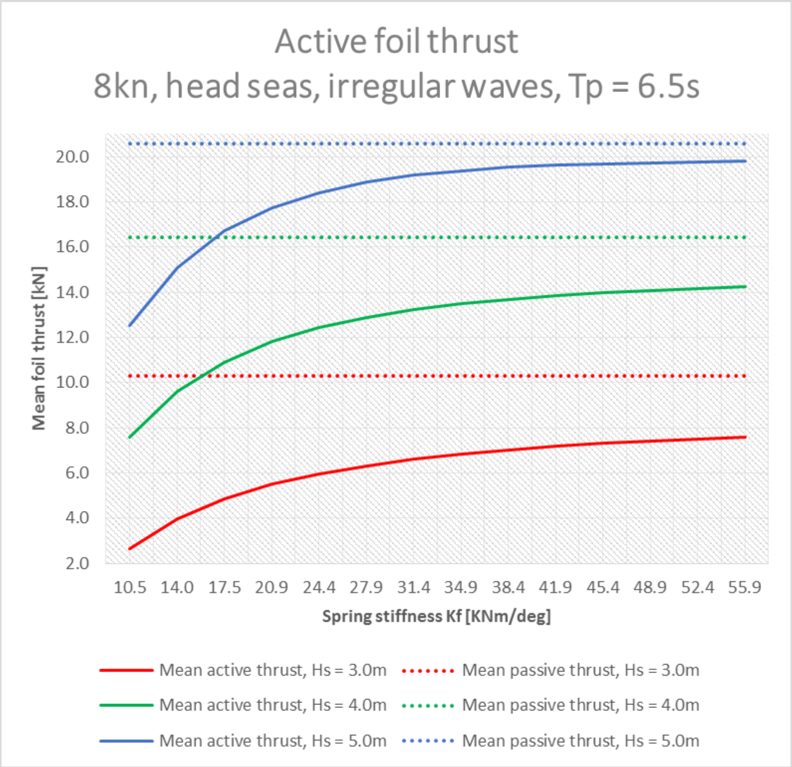


Figure 10-12: Mean thrust dependence on spring stiffness at U = 8kn

10.2.2 Discussion: Worst case scenario simulation

We define the *performance peak* of a thrust curve T(k_f) as the thrust peak occurring at the k_f value where the largest thrust is produced. We see that the performance peak changes position for different ship speeds; generally the performance peak k_f value seems to increase with increasing ship speeds. This is as expected, as the hydrodynamic lift created by the foil generally increases with increasing ship speed, meaning that a stiffer spring is required to obtain the same angle of attack.

The performance peak shifts towards greater stiffnesses with increasing H_s. For the same reasoning as above, this is as expected due to the greater hydrodynamic lift produced.

A performance peak is not found in all scenarios examined, as we see that the thrust is strictly increasing in some of the scenarios for all spring stiffnesses examined. Remembering that we in Section 4.4.4.1 validated that as k_f goes towards infinity, the thrust production will equal passive thrust production. This implies in cases such as these, a passive foil is more beneficial, as the thrust performance is strictly increasing with increasing k_f, up to the point where passive foil thrust is met.

No performance peak seems to occur in the green active thrust line (H_s = 4.0m, 6knots) in Figure 10-10, and the active thrust seems to converge at a greater performance than the passive foil, which is an unreasonable result. This is could be explained by the peak performance occurring at a stiffer spring stiffness than those modelled, but looking to the other peak performance values of k_f, this seems improbable. This discrepancy is left unexplained.

Pitching foils seems more beneficial at the worst case scenario than passive when the ship speed is low, that is up to 6knots. At 6 knots, pitching foils are beneficial at H_s = 4.0m and 5.0m, but not at lower wave heights. At 7 knots, pitching foils are only beneficial at H_s = 5.0m, and at 8 knots no benefits are observed by pitching foils.

The optimal values for k_f range in the domain 12kNm/deg < k_f < 24 kNm/deg.

10.2.3 Spring stiffness optimization: Peak wave period simulation

In this section, we choose an array of values for k_f from the k_f range that seems most promising from the analysis in Section 10.2.1.

The actively pitching foils only seem effective at speeds ≤ 6kn when $H_s \leq 3.0$m. At these speeds, the thrust performance peaks range from 12kNm/deg < k_f < 24 kNm/deg. Based on this we choose to look at values for the spring stiffness of k_f = 12, 16, 20 and 24 kNm/deg. The analysis is done for all ship speeds, H_s =3.0m - 5.0m and T_p = 4.0s - 10.0s.

10.2.3.1 U = 4kn

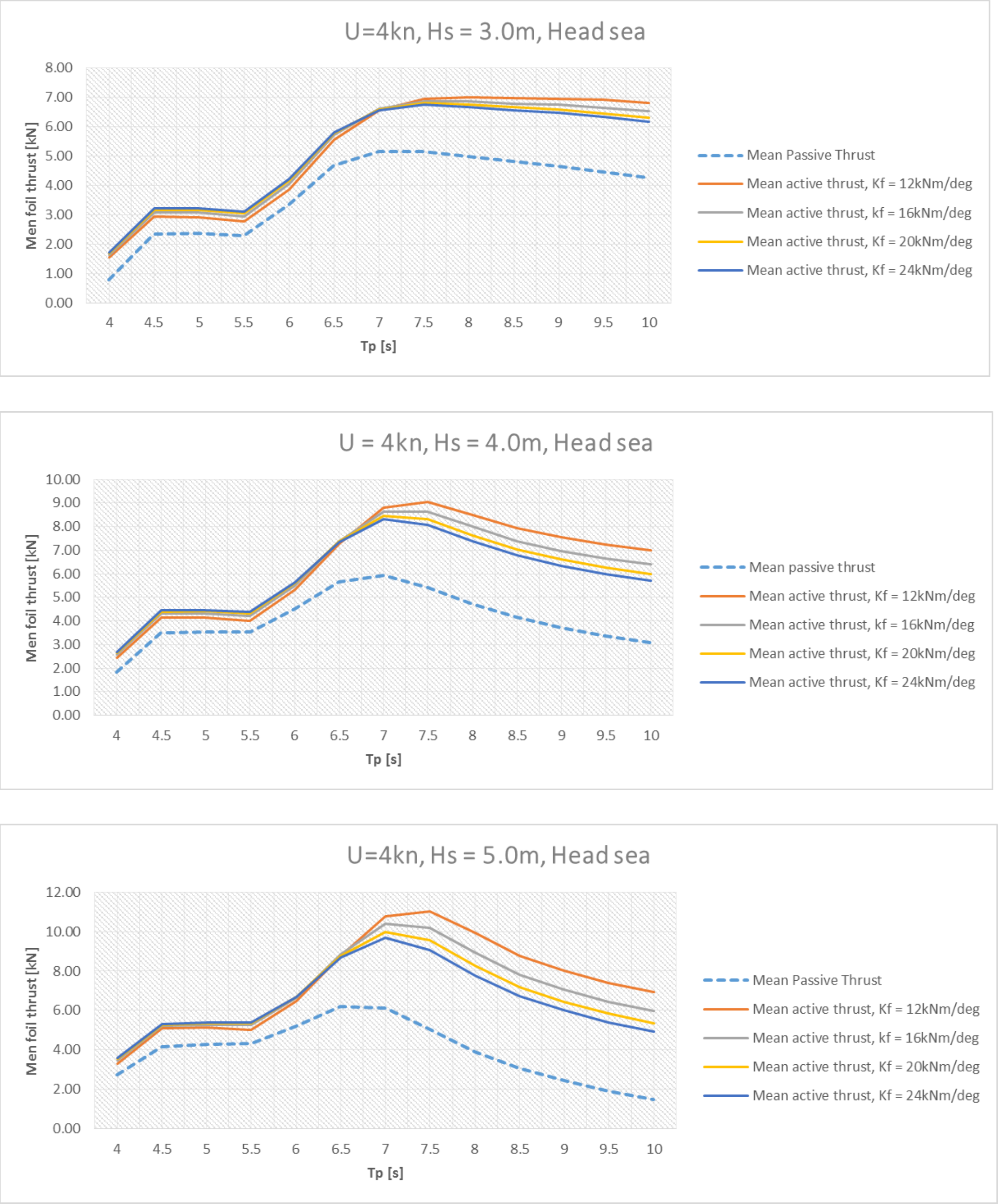
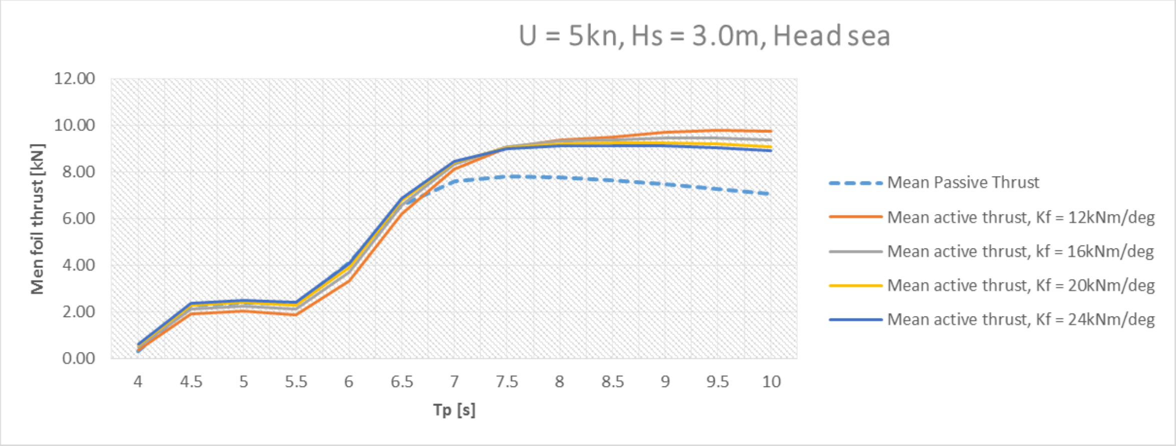
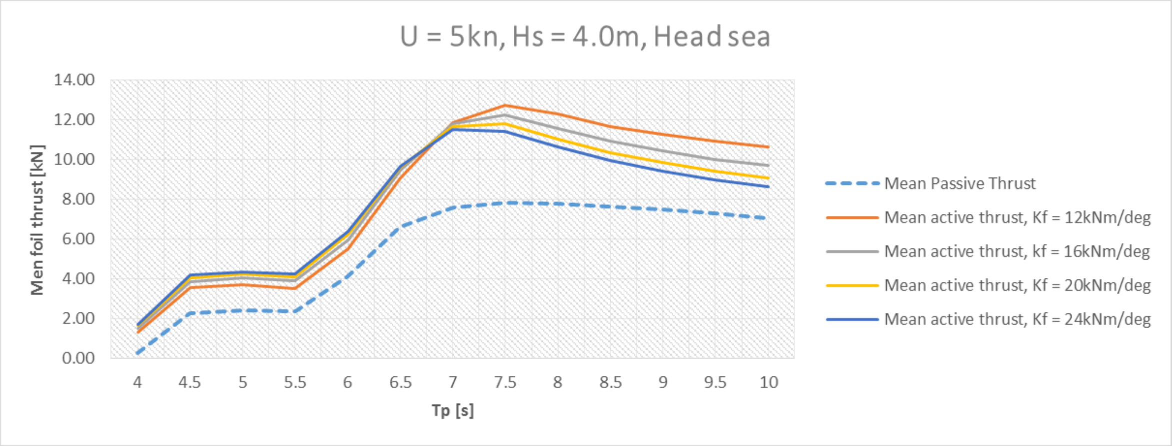


Figure 10-13: Mean thrust dependence of peak wave period T_P at U=4kn

10.2.3.2 U = 5kn





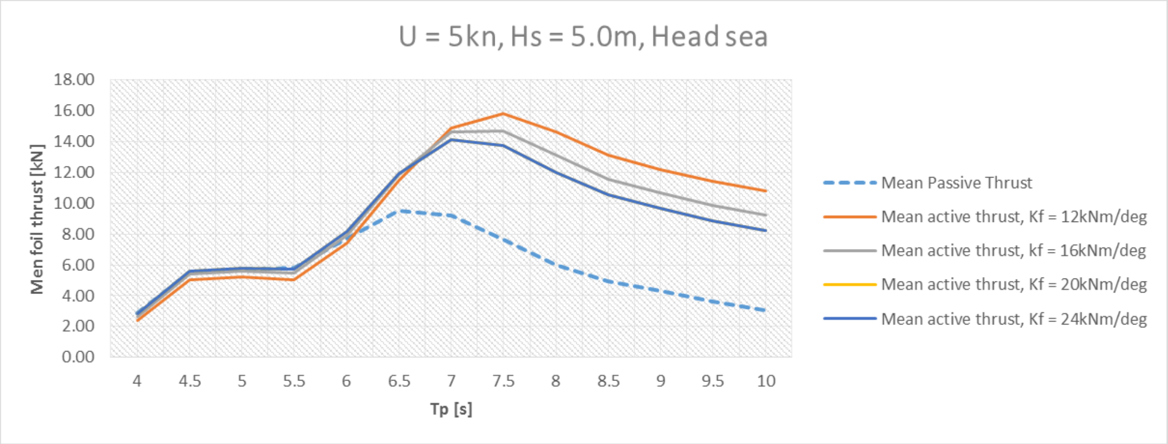
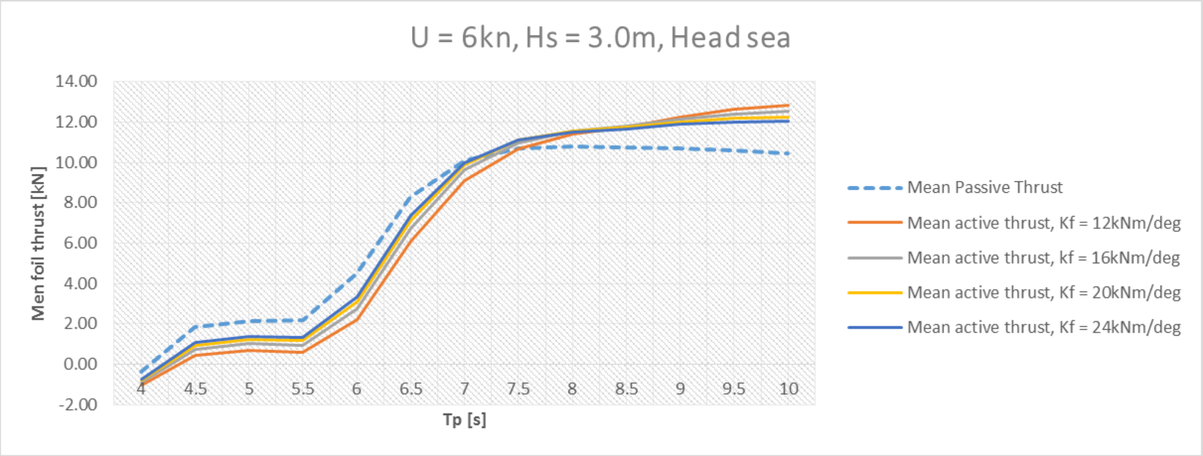
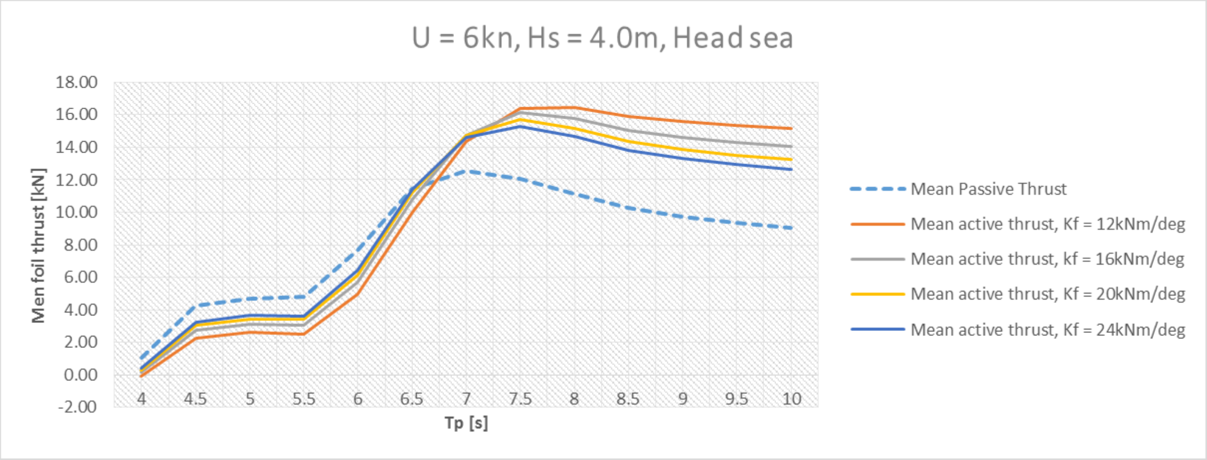


Figure 10-14: Mean thrust dependence of peak wave period T_P at U=5kn

10.2.3.3 U = 6kn





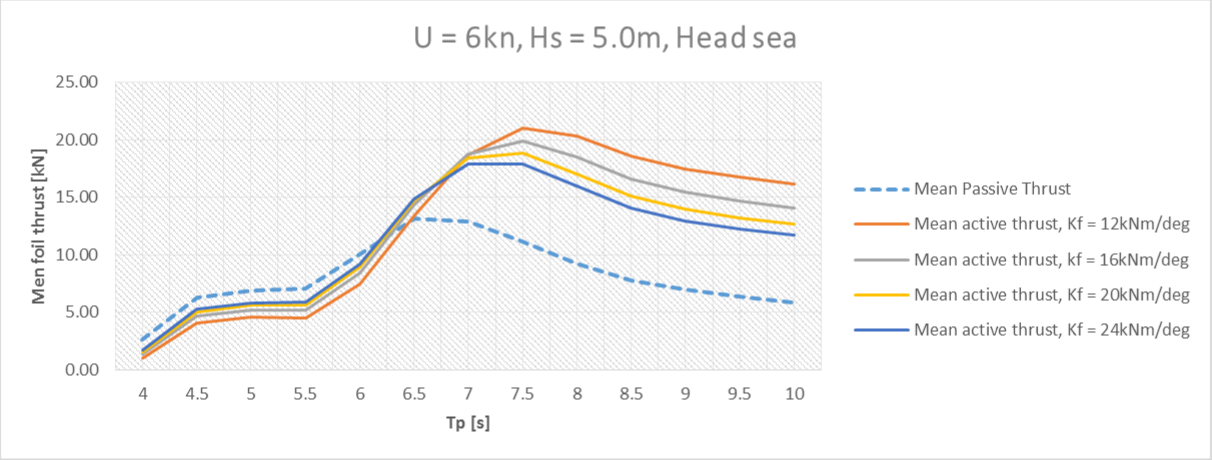
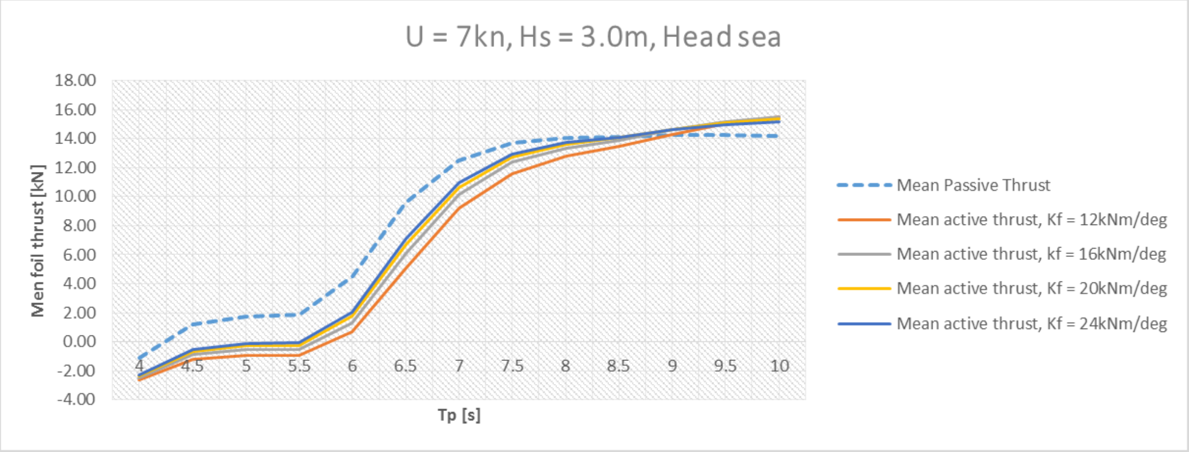
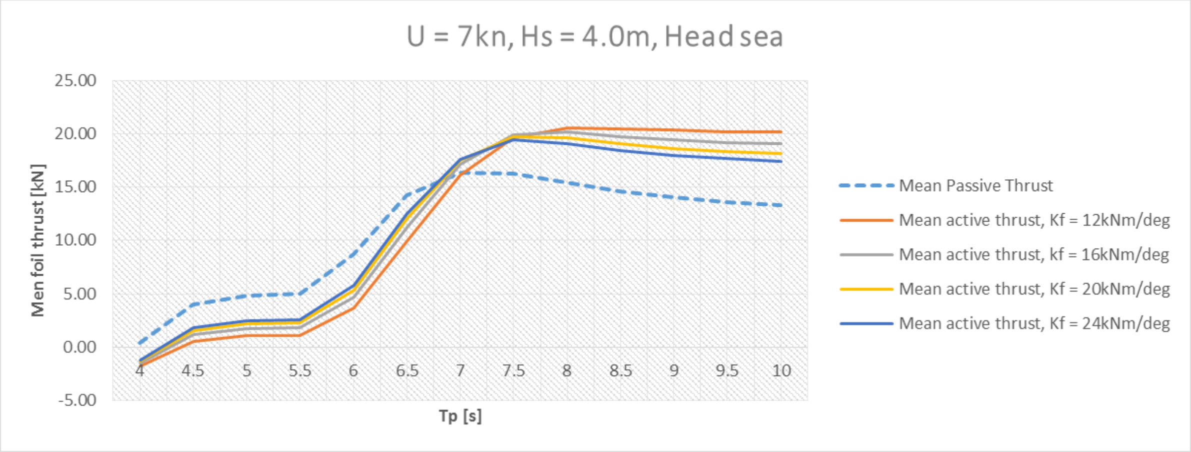


Figure 10-15: Mean thrust dependence of peak wave period T_P at U=6kn

10.2.3.4 U = 7kn





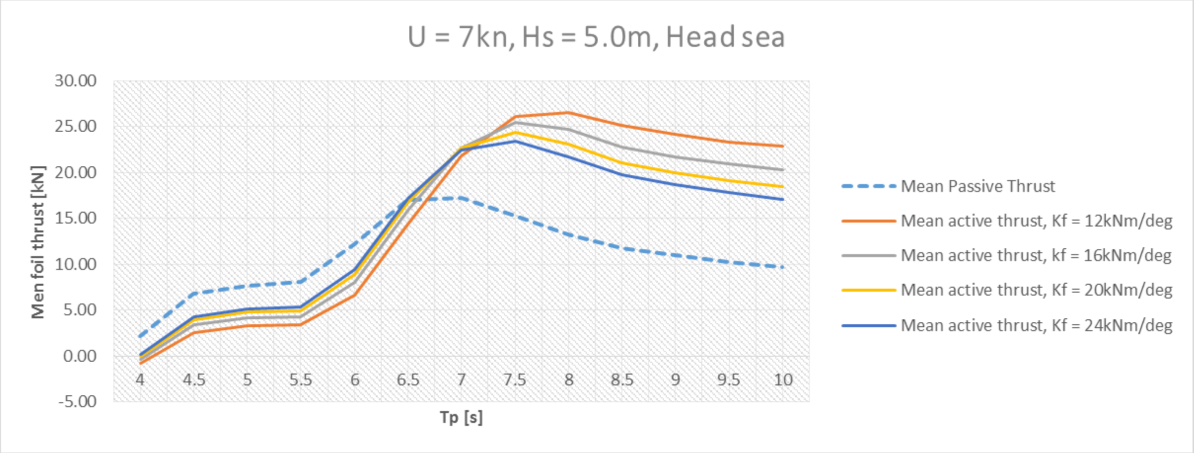
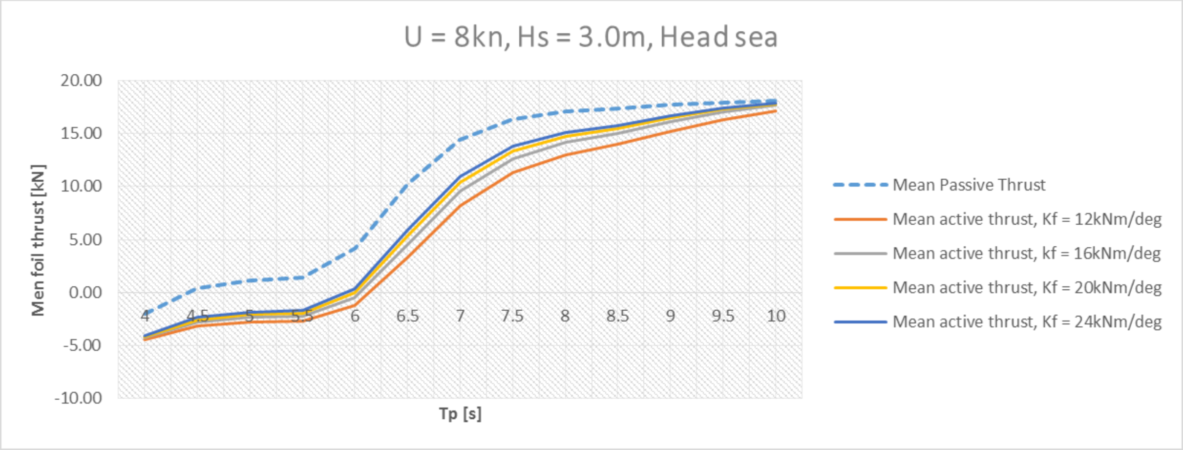
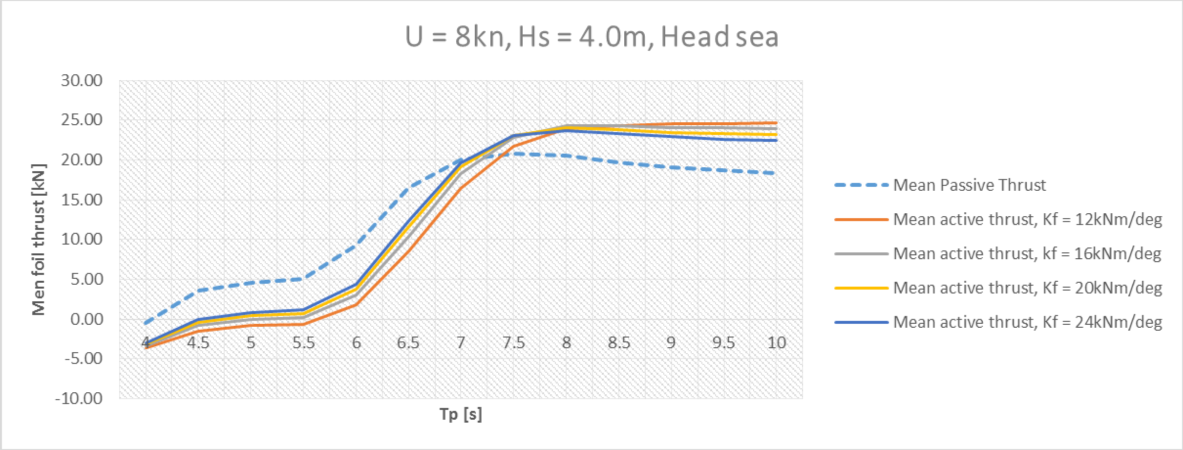


Figure 10-16: Mean thrust dependence of peak wave period T_P at U=7kn

10.2.3.5 U = 8kn





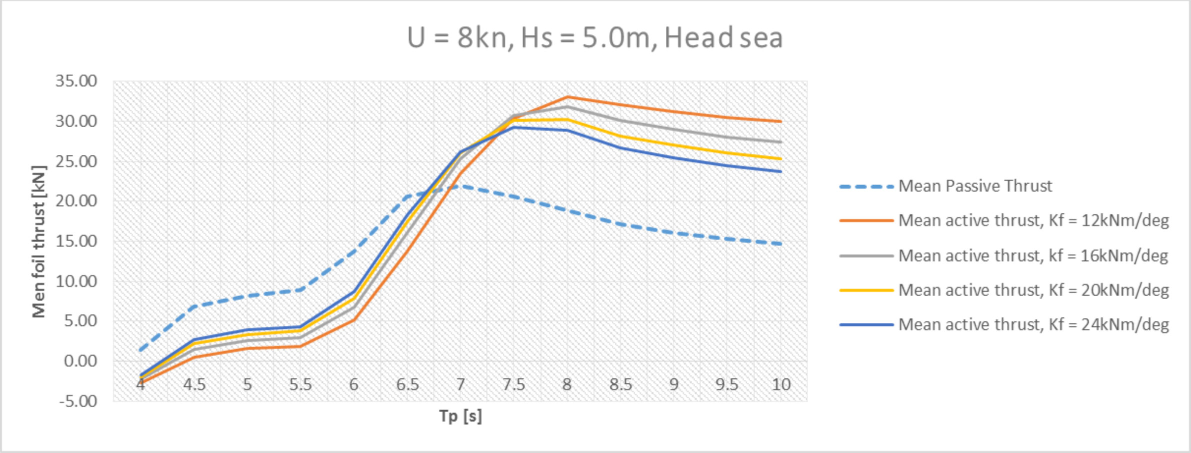


Figure 10-17: Mean thrust dependence of peak wave period T_P at U=8kn

10.2.4 Discussion: Peak wave period simulation

Looking to our results with varying peak wave period T_P, we see that with increasing T_P, a decreasing value for k_f is optimal. For lower T_P (shorter waves) a stiffer spring will be more optimal. This could be explained by the shorter waves causing a higher occurrence of high inflow angles; long waves oscillate more slowly than short waves. Thus, if the wave amplitude is equal for a long and a short wave, the vertical component of the orbital fluid motion will generally have a greater velocity for the short waves than for the long waves. Depending on the vessel motion, this could cause higher inflow angles.

We also see that if the pitching foil performance is lesser than the passive, a stiffer k_f is better. This is logical, as the thrust should go towards passive thrust when k_f goes towards infinity.

Based on the results in this and the previous section, we can say that determining an "all-inclusive" optimal spring stiffness is difficult – the optimal spring stiffness will change with the sea state encountered. Thus, if pitching foils should be used, it would be recommendable to be able to control the spring stiffness, to optimize the spring stiffness to the encountered sea state.

If the stiffness control mechanism in addition is able to let $k_f \rightarrow \infty$, effectively making the foils passive, one would be able to maximize the benefits in a sea state where passive foils have the best performance – while still having a foil system where foil pitching is possible when applicable.

Should one choose to equip ReVolt with a pitching foil system, this ability of making the foils passive is highly recommended based on our calculations, as much of the route of ReVolt futures sea states where passive foils are the most beneficial.

10.3 Working range of passive foils

The sea states where the foils give a net positive thrust can be defined as the *working range*. As the foils are only beneficial in certain sea states, it is important to have a good overview of which sea states yield a positive net thrust, and which ones do not. The answer could be found in by examining the vast amount of tabulated data in the appendix, but we seek to provide a better overview than can be found using tabulated data. As sea states are determined by H_s and T_P, we produce three-dimensional plots of the thrust as functions of H_s and T_P. We will first look at a constant speed of 6knots, and see how the working range changes with wave heading angle in the following section.

10.3.1 Wave heading dependence, constant speed U = 6kn.

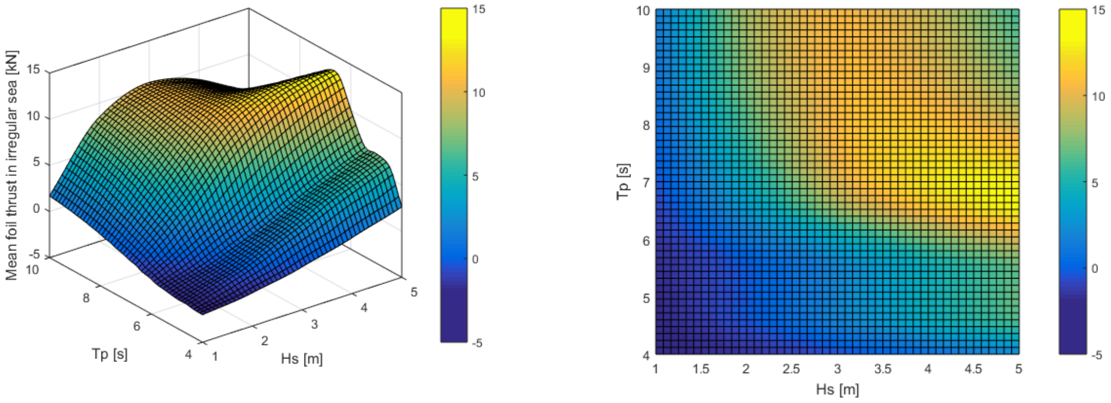


Figure 10-18: Working range for passive foils at 6 knots, wave heading β = 0°

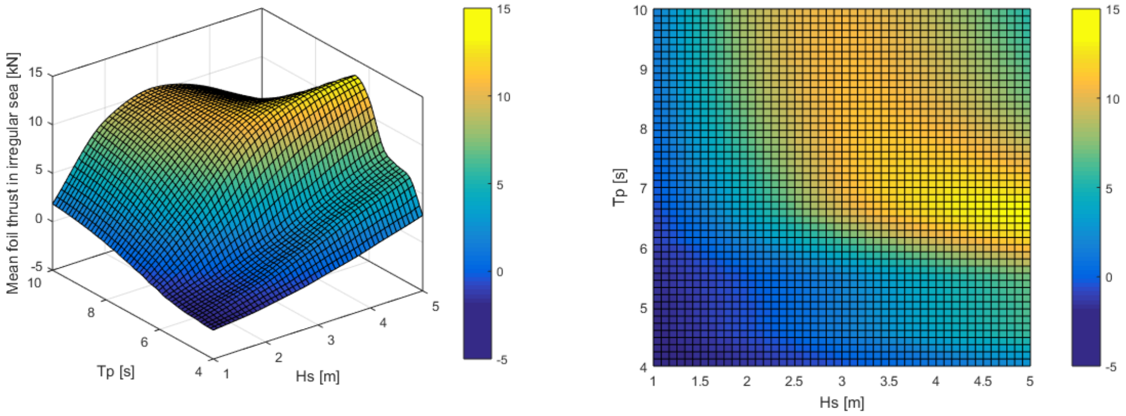


Figure 10-19: Working range for passive foils at 6 knots, wave heading β = 22.5°

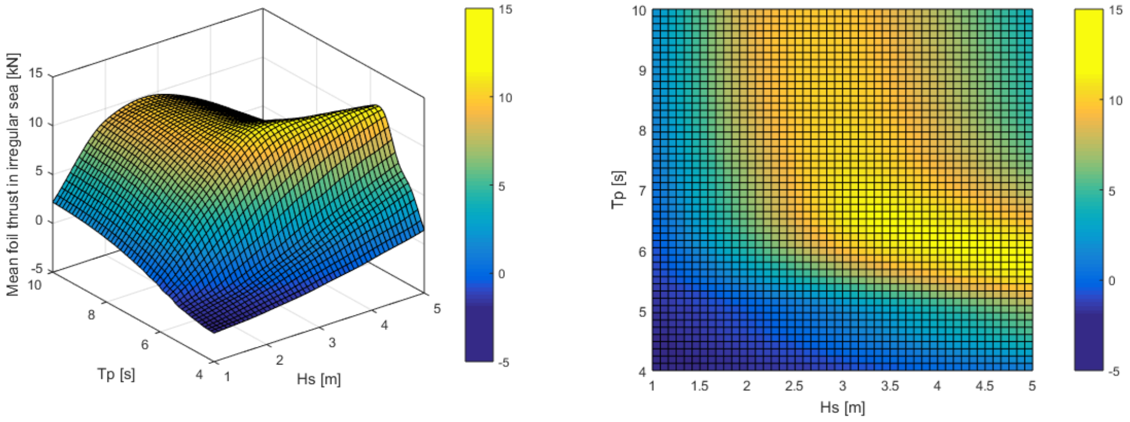


Figure 10-20: Working range for passive foils at 6 knots, wave heading β = 45°

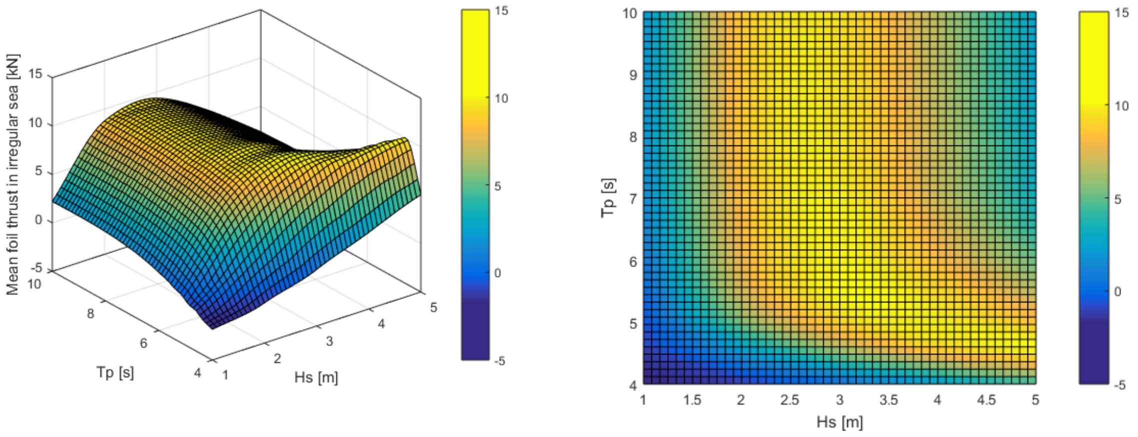


Figure 10-21: Working range for passive foils at 6 knots, wave heading β = 67.5°

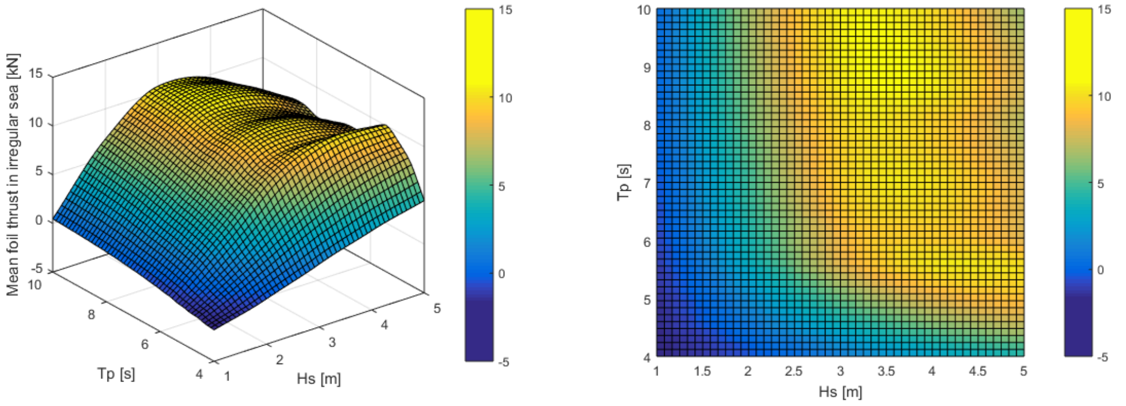


Figure 10-22: Working range for passive foils at 6 knots, wave heading β = 90°

In the figures, a deep blue color indicates a negative net thrust. We see that at all heading angles, the foils produce a net positive thrust for most of the range examined in this thesis.

We see that the positive net thrust producing range is larger for increasing wave heading angle. We know that in head sea and for low peak periods, the encounter frequency will be high, and the ship will not have a large pitch motion. However, as the waves start hitting the vessel from the side, roll motion will occur. As the vessel is longer than its width, roll motion response occurs at earlier peak periods than pitch motion. Thus, thrust inducing vertical flow components at the foil are induced for a larger range at higher wave heading angles when waves are meeting the ship from the side.

We can see a “wave pattern” emerging in Figure 10-21 and Figure 10-22. We expect this to be due to several peak wave frequencies inducing resonance in roll, but the claim is not backed by calculations.

10.3.2 Speed dependence: Wave heading 0°

We have established how the foils perform for different wave heading angles, but we have only looked at a vessel speed of 6 knots. It is also of interest to get a better overview of how the working range changes at different ship speeds in different wave heights. The H_s axis is switched with the ship speed, U, and four plots for 2.0m > H_s > 5.0m are shown below. We omit H_s = 1.0m as the net foil thrust is generally low or negative here.

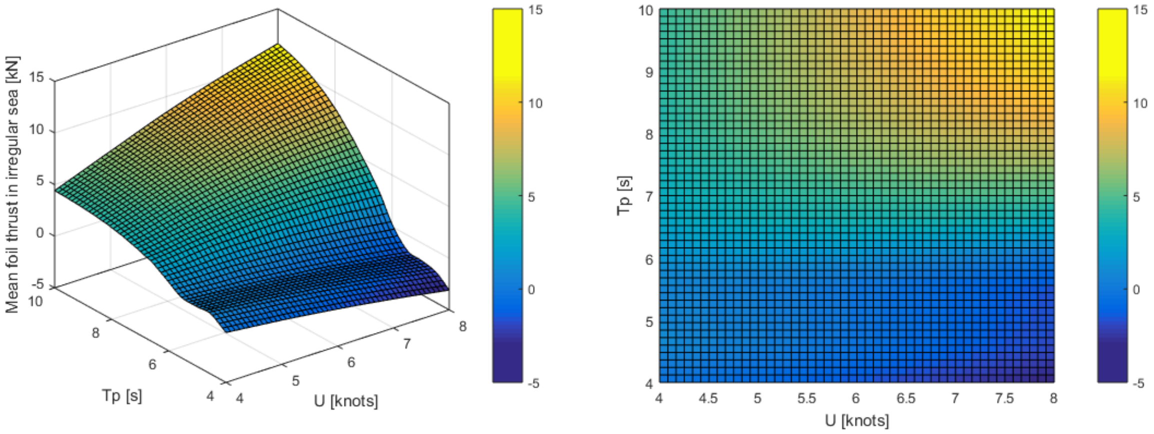


Figure 10-23: Mean thrust at $H_s = 2m$, varying T_P and U

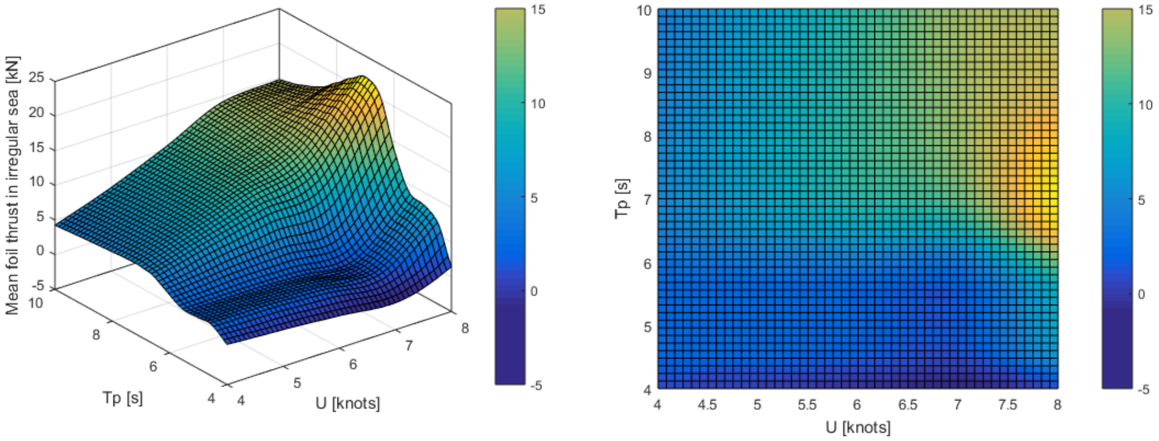


Figure 10-24: Figure 10-25: Mean thrust at $H_s = 3m$, varying T_P and U

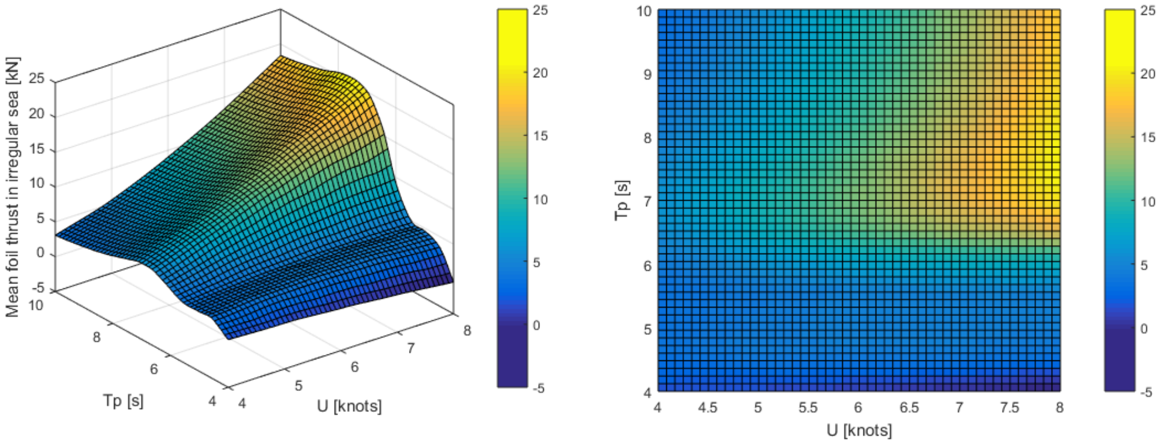


Figure 10-26: Figure 10-27: Mean thrust at $H_s = 4m$, varying T_P and U

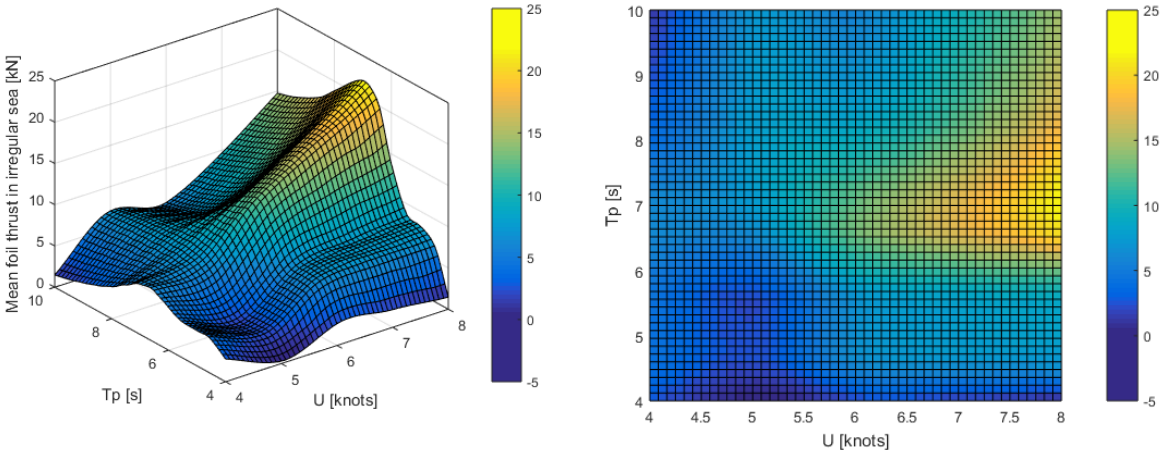


Figure 10-28: Figure 10-29: Mean thrust at $H_s = 5m$, varying T_P and U

We see that increasing the ship speed generally increases the working area of the foils. We also see that the working area generally reduces when H_s goes very large, which is expected to be due to foil stalling. A thrust peak occurs in the region 7.0s > T_P> 9.0s for high waves, but at lower waves the thrust is strictly increasing with increasing T_P, within the domain assessed.

11 Results: Brake power and battery dimensioning

11.1 Passive foils: Brake power

The brake power delivered from the engines are for all our conditions with H_s = 3.0m shown in graphical form in this section in Figure 11-1 through Figure 11-5. We only show the data for H_s =3.0m here, as this will be the dimensioning significant wave height. Tabulated data for all examined wave heights is shown in Appendix G. The brake power is shown in the appendix both with and with wind resistance – the latter to better see the effects of the wave foil without cluttering up the picture with wind resistance.

11.1.1.1 Wave heading = 0° (head sea), H_s = 3.0m, all speeds and peak periods

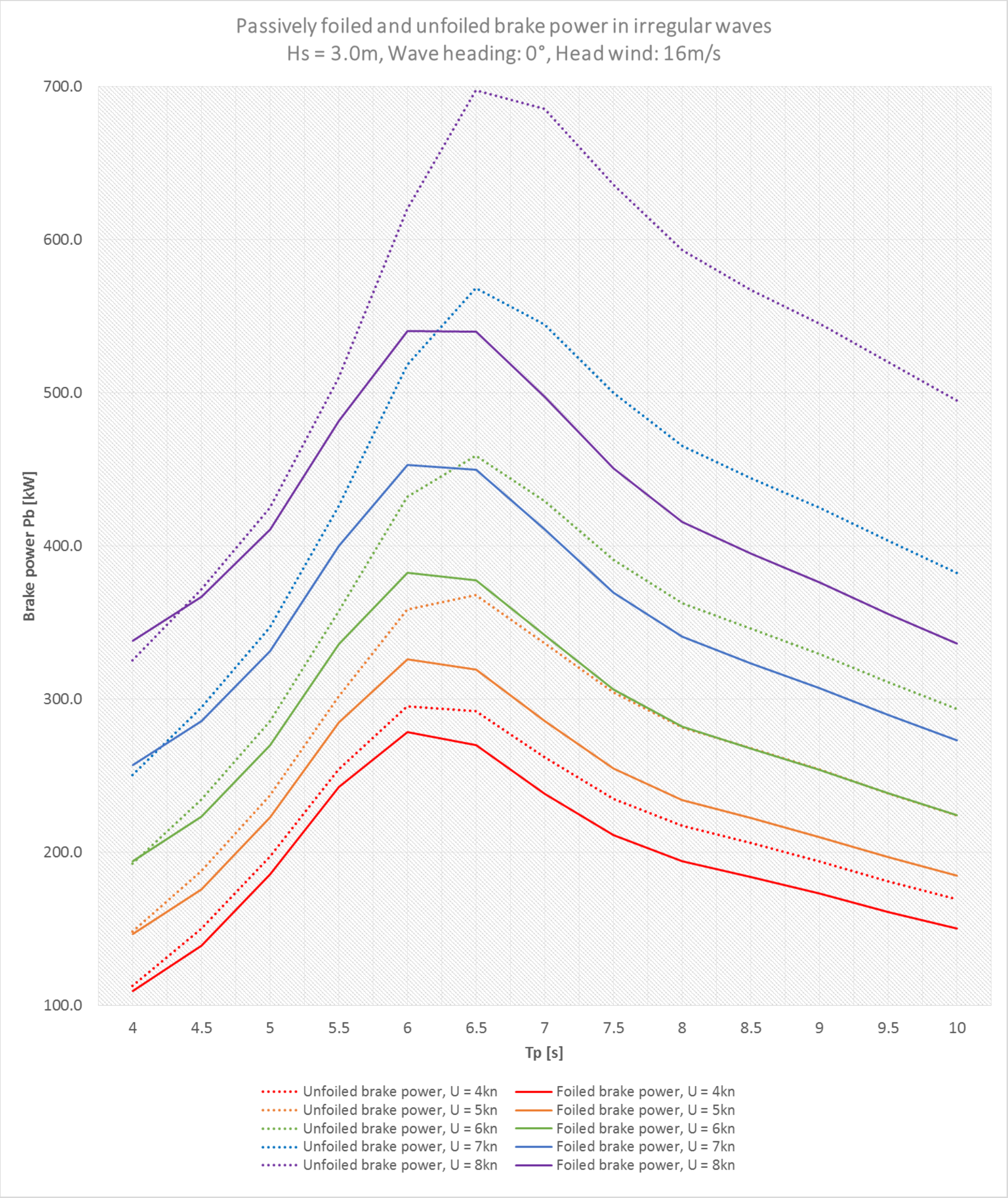


Figure 11-1: P_B for passive foils: $\beta = 0°$, H_s = 3.0m, all speeds and peak periods

11.1.1.2 Wave heading = 22.5°, H_s = 3.0m, all speeds and peak periods

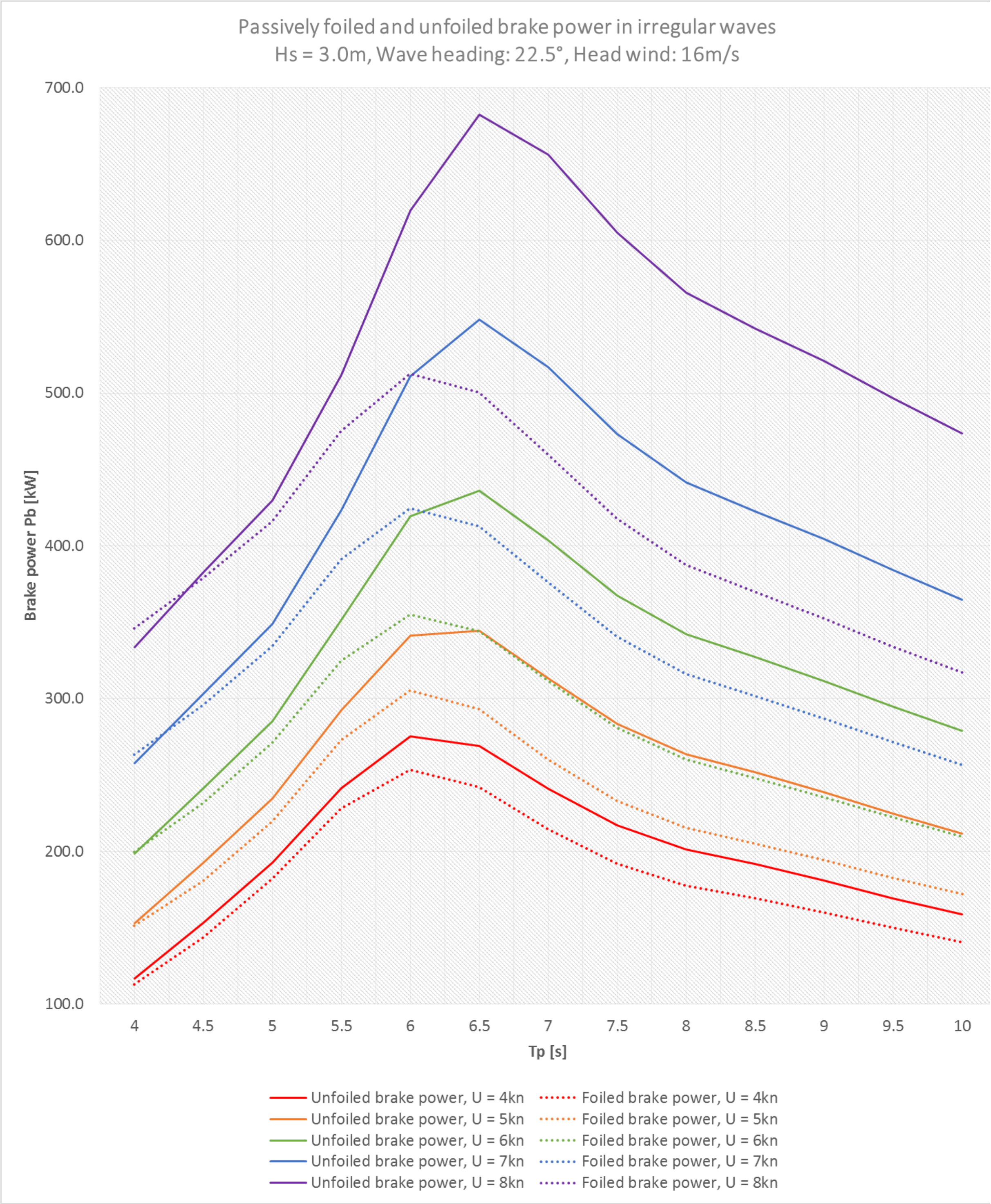


Figure 11-2: P_B for passive foils: β = 22.5°, H_s = 3.0m, all speeds and peak periods

11.1.1.3 Wave heading = 45° (bow quartering sea), H_s = 3.0m, all speeds and peak periods

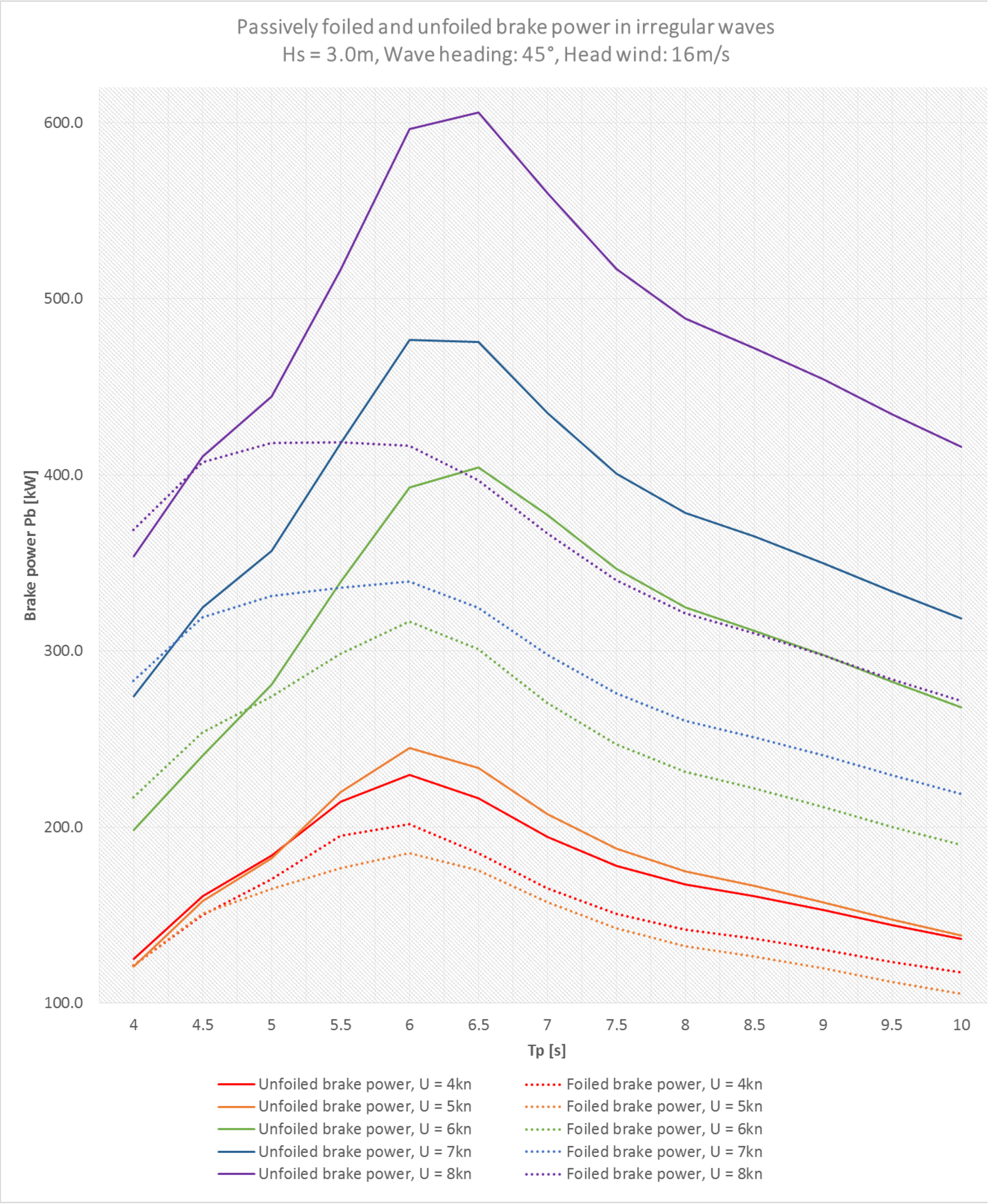


Figure 11-3: P_B for passive foils: β = 45°, H_s = 3.0m, all speeds and peak periods

11.1.1.4 Wave heading = 67.5°, H_S = 3.0m, all speeds and peak periods

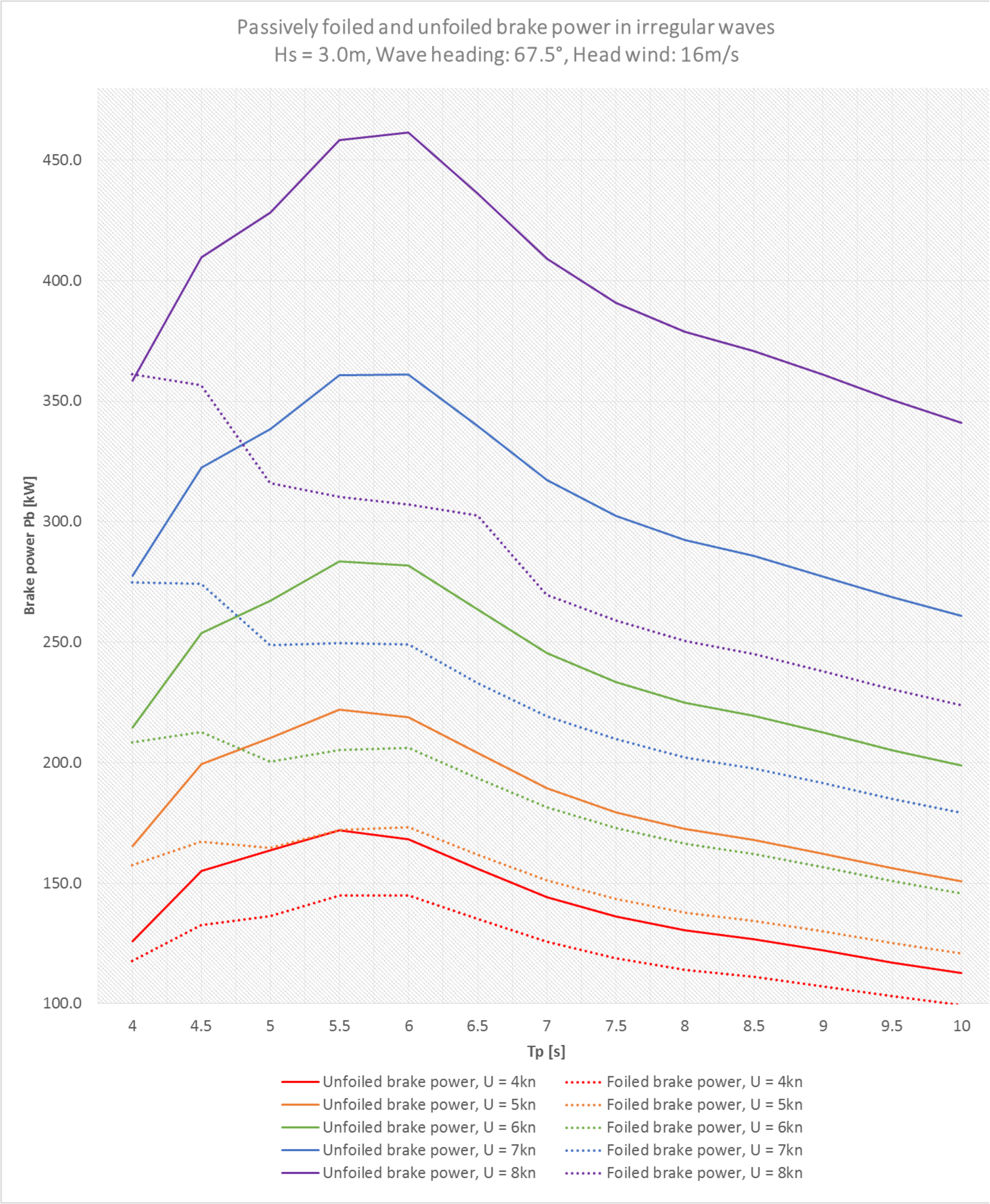


Figure 11-4: P_B for passive foils: β = 67.5°, H_S = 3.0m, all speeds and peak periods

11.1.1.5 Wave heading = 90° (beam sea), H_s = 3.0m, all speeds and peak periods

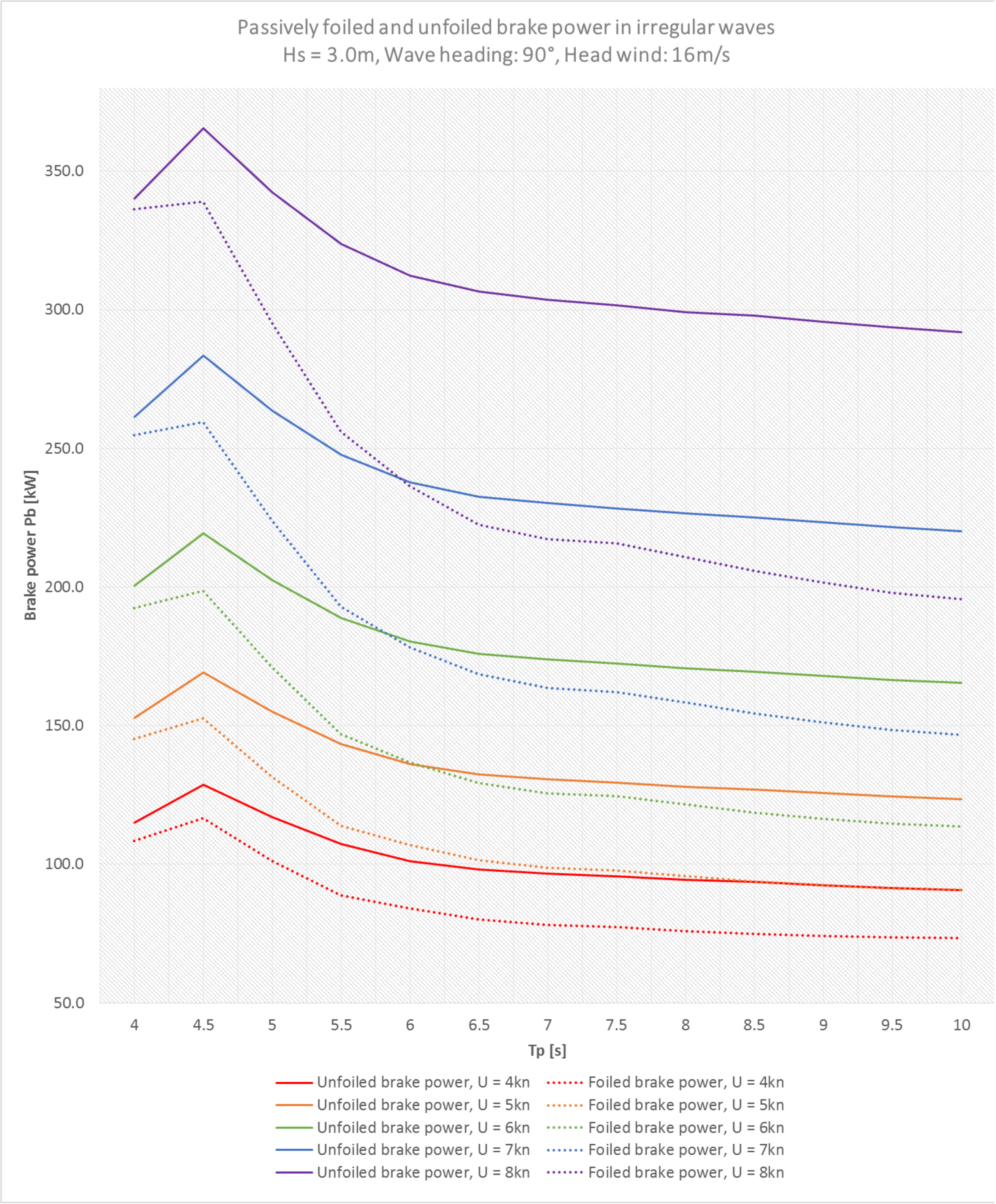


Figure 11-5: P_B for passive foils: β = 90°, H_s = 3.0m, all speeds and peak periods

11.1.2 Discussion: Brake power using passive foils

We see that for H_s = 3.0m, a reduction in brake power is observed for nearly all conditions within. We see that the magnitude of the reduction is generally larger for larger ship speeds, meaning that a larger percentage of the brake power is saved for higher speeds – or in other words, the *relative break power reduction* is higher at higher speeds.

We note that the largest relative decrease in brake power occurs for peak wave periods longer than the peak wave period at the worst case scenario. This is not optimal in a CAPEX point of view, but as wave foils are known to perform best in long waves (Steen, 2015), this is hardly unexpected. Although the brake power reduction is lower than for higher peak periods, the reduction is still quite large at the peak period that induces the WCS. As the peak period turns lower than at the WCS, the relative break power reduction reduces quickly. It seems likely, then, that the WCS with foils deployed will occur at a peak period lower than where the WCS without wave foils occurs.

The figures present some interesting notions: We see, for example, in Figure 11-1 that at head sea, $H_S = 3.0$m and T_P = 6.5s, the brake power for a passively foiled ReVolt at 7 knots is roughly equal to the brake power of an unfoiled ReVolt at 6 knots. At the same conditions, but at higher peak frequencies, the 7kn brake power of a passively foiled ReVolt is actually *lower* than the 6kn unfoiled break power.

11.2 Pitching (feathered) foils: Brake power

With the results for brake power for passive foils in place, we are ready to explore the worst case scenarios for ReVolt and potential benefits by utilization of passive foils. However, it is of also interest to examine the benefits of a pitching (feathered) foil system relative to a passive one, to determine the relative benefits of such a system (if any). Referring to Section 10.2.1, a spring stiffness k_f of ~20kNm/deg seems most benefitial at the T_p containing the WCS. This value for the spring stiffness is used throughout this section. As we only have calculated data for the pitching foils in head sea, only head sea results are presented in Figure 11-6 through Figure 11-10

11.2.1 Discussion: Brake power for pitching foils

Utilizing pitching foils rather than passive foils certainly gives a benefit for the brake power for many sea states. Generally though, H_S needs to be large and T_P needs to be long for pitching foils to have any benefits compared to passive foils. Only at U = 4kn and 5kn does the pitching foils outperform the passive foils for all H_S considered at the WCS inducing peak wave period.

As we will discover in Section 12.2, we do not recommend slowing down the vessel to a speed lower than 6knots to reduce the needed size of the battery pack. Therefore, pitching foils only have a potential benefit with respect to CAPEX if the vessel is intended to sail in speeds U ≥ 6kn and H_s > 3.0m.

11.2.1.1 *U = 4kn*

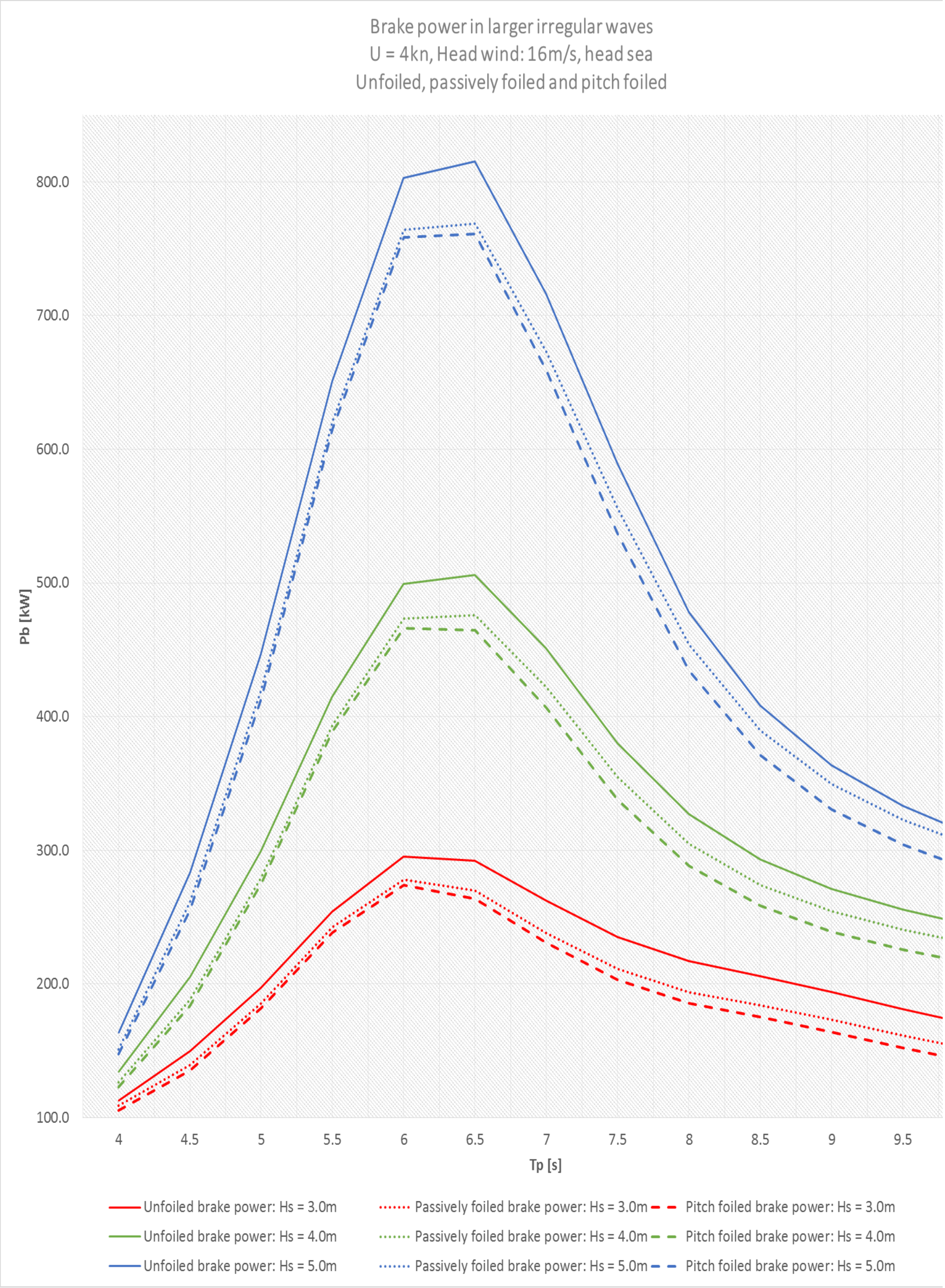


Figure 11-6: Unfoiled, foiled and pitch foiled P_B in higher, irregular seas, head sea, U = 4kn

11.2.1.2 U = 5kn

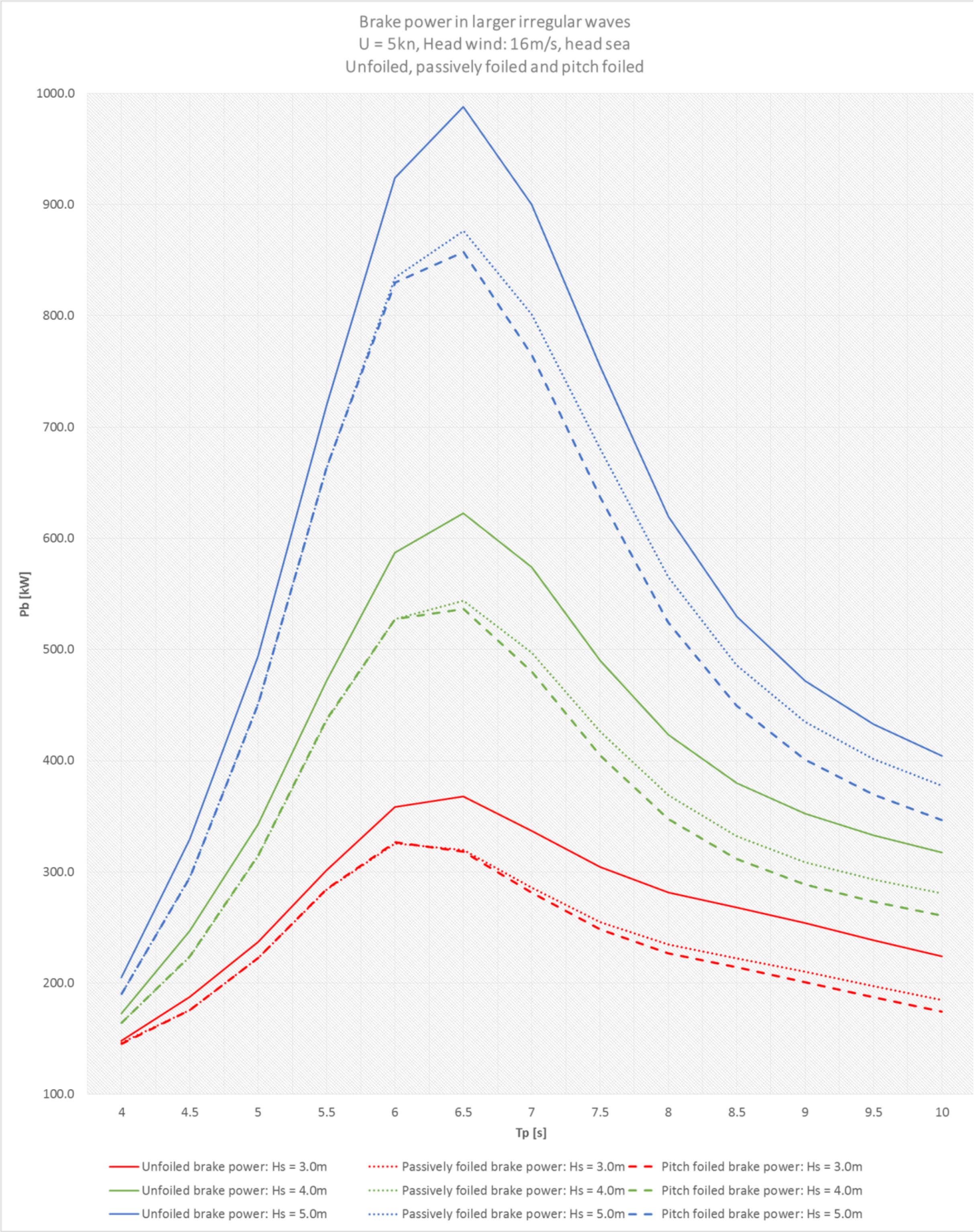


Figure 11-7: Unfoiled, foiled and pitch foiled P_B in higher, irregular seas, head sea, U = 5kn

11.2.1.3 U = 6kn

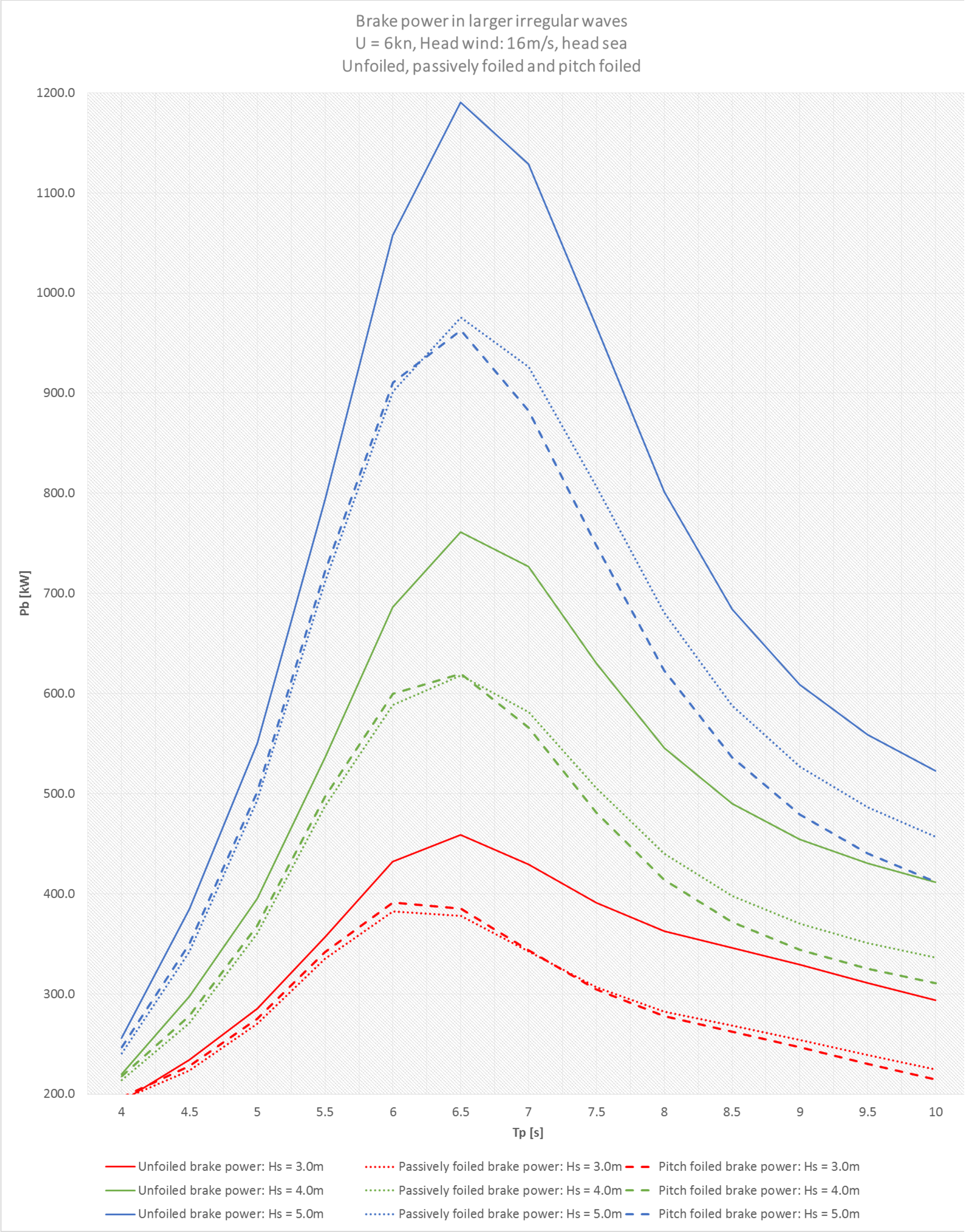


Figure 11-8: Unfoiled, foiled and pitch foiled P_B in higher, irregular seas, head sea, U = 6kn

11.2.1.4 U = 7kn

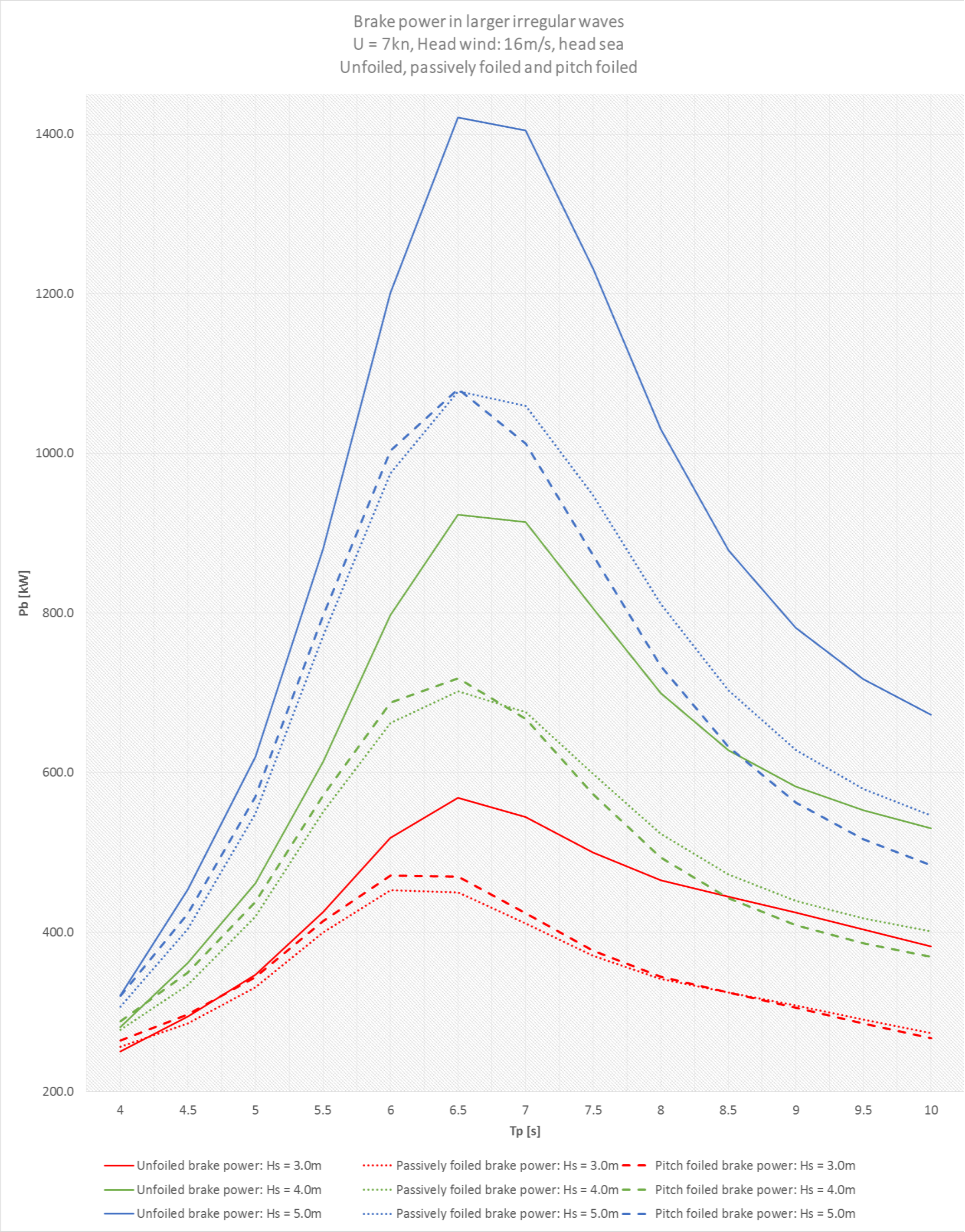


Figure 11-9: Unfoiled, foiled and pitch foiled P_B *in higher, irregular seas, head sea, U = 7kn*

11.2.1.5 U = 8kn

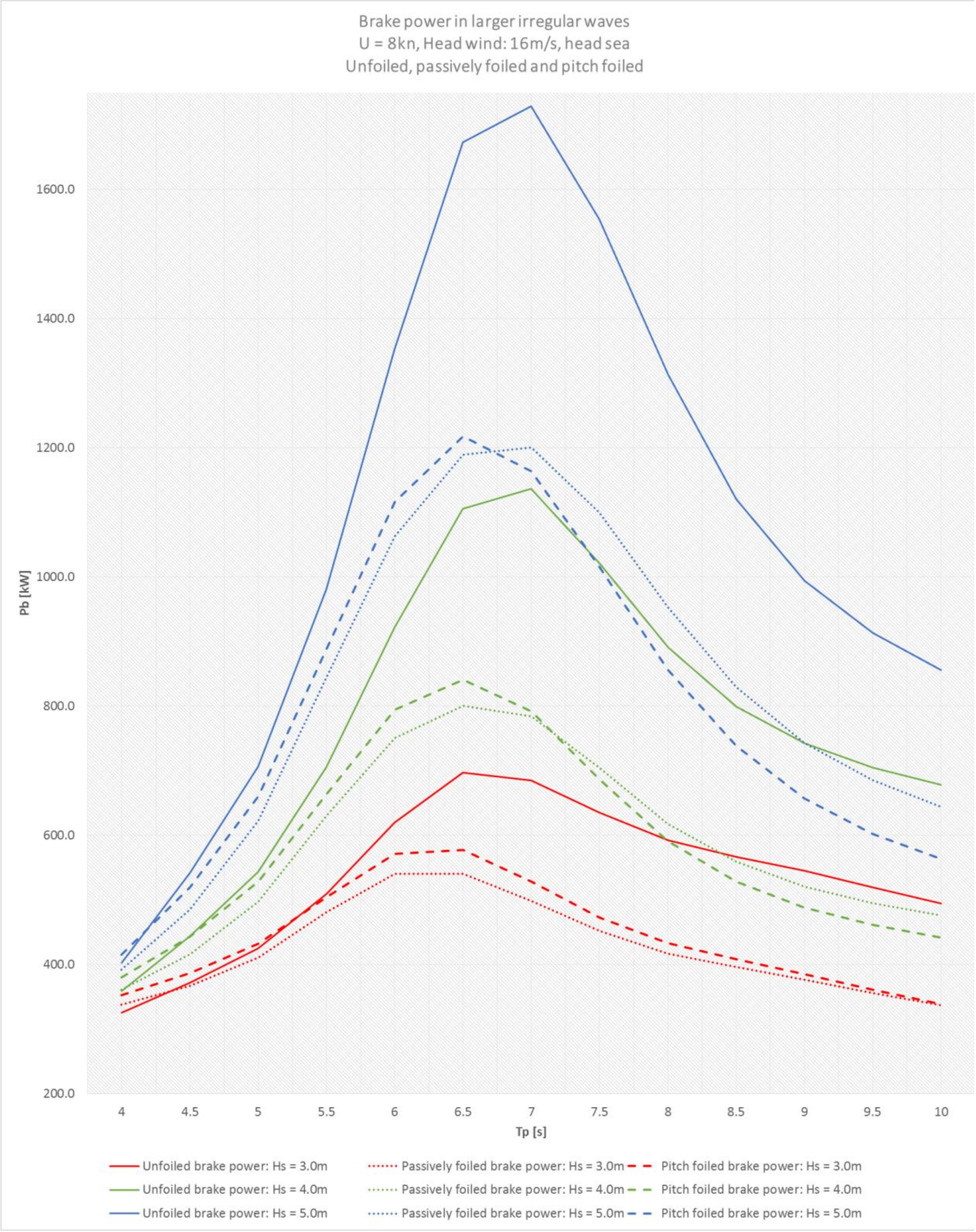


Figure 11-10: Unfoiled, foiled and pitch foiled P_B in higher, irregular seas, head sea, U = 8kn

12 Results: Reduced energy demands and effect on CAPEX

12.1 Energy demands: passive foils

The sailing time for completion of a dimensioning route leg at constant ship speed is given in Table 10 below:

Table 10: Sailing time for dimensioning route leg

Ship speed [kn]	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
Sailing time [hrs]	25.0	20.0	16.7	14.3	12.5

Thus, we can look at the worst case scenarios at different ship speeds. For an unfoiled and passively foiled ReVolt, and for each ship speed, we pick the three worst case scenarios (that is, the scenario where the brake power P_B is highest). We choose to pick three P_B values because the dimensioning process is very conservative, and hence the dimensioning energy values will be very high. Picking three values will give us an indication as to whether the highest P_B value will be much larger than the other two, lesser, P_B values, and thus it gives an indication whether the absolute worst case scenario will be unrealistically large.

Table 11: Energy savings by passive foils for U = 4-5kn

	Hs	**Tp**	**Beta**	**Pb**	**Energy requirement**	$E_{unfoiled} - E_{foiled}$
	[m]	**[s]**	**[deg]**	**[kW]**	**[kWh]**	
U = 4kn Unfoiled	3.0	6.0	0	295.2	7380	Energy savings [kWh]
	3.0	6.5	0	292.4	7310	
	3.0	6.0	22.5	275.2	6880	415
U = 4kn Foiled	3.0	6.0	0	278.6	6965	Energy savings [%]
	3.0	6.5	0	270.1	6753	
	3.0	6.0	23	253.5	6338	5.6%
U = 5kn Unfoiled	3.0	6.5	0	367.9	7358	Energy savings [kWh]
	3.0	6.0	0	358.5	7170	
	3.0	6.5	23	344.3	6886	838
U = 5kn Foiled	3.0	6.0	0	326.0	6520	Energy savings [%]
	3.0	6.5	0	319.4	6388	
	3.0	6.0	23	305.5	6110	11.4%

Table 12: Energy savings by passive foils for U = 6-8kn

	Hs	Tp	Beta	Pb	Energy requirement	$E_{unfoiled} - E_{foiled}$
	[m]	[s]	[deg]	[kW]	[kWh]	
U = 6kn Unfoiled	3.0	6.5	0	458.8	7647	Energy savings [kWh]
	3.0	6.5	23	436.2	7270	
	3.0	6.0	0	431.9	7198	1270
U = 6kn Foiled	3.0	6.0	0	382.6	6377	Energy savings [%]
	3.0	6.5	0	377.2	6287	
	3.0	6.0	23	355.1	5918	16.6%
U = 7kn Unfoiled	3.0	6.5	0	568.3	8119	Energy savings [kWh]
	3.0	6.5	23	548.1	7830	
	3.0	7.0	0	544.7	7781	1650
U = 7kn Foiled	3.0	6.0	0	452.8	6469	Energy savings [%]
	3.0	6.5	0	449.7	6424	
	3.0	6.0	23	424.6	6066	20.3%
U = 8kn Unfoiled	3.0	6.5	0	697.6	8720	Energy savings [kWh]
	3.0	7.0	0	685.3	8566	
	3.0	6.5	23	682.2	8528	1968
U = 8kn Foiled	3.0	6.0	0	540.2	6753	Energy savings [%]
	3.0	6.5	0	539.8	6748	
	3.0	6.0	23	512.6	6408	22.6%

12.2 Potential consequences for CAPEX and ship speed: passive foils

Looking to Table 11 and Table 12, we see that the utilization of passive foils has beneficial effects at all speeds tested. We note that the WCS is in head sea for all speeds. For our speed range, the energy savings increase with increasing ship speed, both in absolute values [kWh], but also in relative savings; that is, at higher speeds, the share (in per cent) of the unfoiled dimensioned battery size one can reduce by utilising passive foils is larger than for lower speeds.

Thus, the potential energy savings depends on the ship speed strategy used for tackling sea states with high waves. The planned sailing speed of ReVolt is 6 knots. The energy savings at the WCS for this speed is 1270 kWh, which at a price of $1000/kWh corresponds to a CAPEX saving of 1.27MUSD, or 10.1MNOK using exchange rates from June 2015. The building and fitting costs of the foils have not been included in this calculation.

Some other interesting notes can be made concerning the energy consumption in completing the WCS route leg at different speeds. We see that at a speed of 8 knots (foiled), the energy requirement is only slightly higher than that of 6 knots (foiled). Also, at a speed of 8 knots (foiled), the energy requirement for completing a route leg is actually *less than at four knots (foiled).* This is very interesting, as the main reason for the low planned sailing speed for ReVolt is being able to tackle the added resistance by wind and waves (as we know, the calm water brake power of ReVolt is a mere 50kW).

In the work task description of this thesis, it was stated that "it is recommended that relaxing the requirement of keeping a speed of six knots". Looking to our results for passive foils, it does not look like reducing the speed of ReVolt to tackle the worst case scenario is a good strategy – in fact, it actually looks like *increasing* the sailing speed in waves yields equal or only slightly higher total energy requirement than if the ship speed is kept constant. This is very interesting because the cruising speed of six knots is quite low; the average cruising speed in the short sea shipping segment in Norway is eight knots according to DNV GL. If fitting wave foils to ReVolt could mean that the average cruising speed of ReVolt could be jacked up to, say, 8 knots, this could make the concept of ReVolt significantly more attractive.

12.3 Energy demands and CAPEX: Pitching vs. passive foils

Looking at the brake power results in Figure 11-6 through Figure 11-10, which compares pitching foils to passive foils at higher sea states, we see that for ship speeds U ≥ 6kn, in head seas, for the peak period T_p giving the largest added resistance, and as long as $H_s \leq 3.0$m, the pitching foils are outperformed by passive foils. Put more simply, at the worst case scenario found within our limitations of sea states, passive foils will be more beneficial than pitching foils for ship speeds U ≥ 6kn.

Therefore, as we do not recommend decreasing the vessel speed below six knots to tackle the worst case scenario (see Section 12.2), neither do we recommend the utilization of pitching foils for purely CAPEX reduction purposes. This claim is aggregated further by the assumption that pitching foils will be more expensive to build and maintain than the simpler passive foils.

12.4 Energy demands and OPEX: Pitching foils vs. passive foils

Even though no benefits are seen for ReVolt using passive foils in a CAPEX point of view, looking at Figure 11-6 through Figure 11-10 indicates that ReVolt generally could reap greater energy saving benefits by utilizing pitching foils, rather than passive foils, when the peak period exceeds the T_P where the added resistance is largest, or at low speeds.

Even though a large portion of the sailing route of ReVolt is in sheltered or semi-sheltered areas, we observe in the wave scatter diagrams for ReVolts route that the T_P values often exceeds the WCS peak period. As a consequence, pitching foils will produce more thrust and thus reduce the brake power more than passive foil will, for a large portion of the sea states encountered by ReVolt. This makes pitching foils generally superior to passive foils in an OPEX point of view. Even though the yearly OPEX (from energy consumption) is rather low for ReVolt, it is of interest to examine how much one could save in OPEX by the use of wave foils.

Giving a complete overview of leg completion energy consumption in higher peak period sea states would be far too time- and space consuming in this thesis. Instead, we will look for high values of peak periods which often occurs in our wave scatter diagrams. We find that peak periods of 8.0s, 9.0s and 10.0s are abundant in ReVolts sailing route. In order to not produce too much data, we choose looking at a T_P = 9.0s. Using this, we will examine the unfoiled, passively foiled and pitch foiled break power performance in head sea, for all ship speeds and H_s = 3.0, 4.0 and 5.0m. This will give an indication, however not complete, as to how large energy savings one could expect in a typical route leg containing long(er), high waves.

Full break power data is only produced in this thesis for a spring stiffness k_f value of 20kNm/deg; therefore this spring stiffness is also used in this section. With reference to Section 10.2.3, we note that a less stiff spring stiffness will perform better in long waves; thus, the calculated thrust is slightly lower than it optimally could be, and hence the break power calculated is slightly higher than it could be with a stiffer spring.

The results of this analysis is shown in Table 13 and Table 14.

Table 13: Comparison of foil mechanisms with respect to OPEX in higher waves. U=4-6kn

Ship speed	Foil configuration	Tp [s]	Hs [m]	Pb [kW]	Energy consumption [kWh]	Savings rel. to unfoiled [kWh]	Savings rel. to unfoiled [%]
U=4kn	Unfoiled	9	3	194.0	4850	-	-
	Passive	9	3	173.1	4328	523	10.8%
	Pitch	9	3	164.1	4103	748	15.4%
	Unfoiled	9	4	271.4	6785	-	-
	Passive	9	4	254.2	6355	430	6.3%
	Pitch	9	4	239.1	5978	808	11.9%
	Unfoiled	9	5	363.5	9088	-	-
	Passive	9	5	349.3	8733	355	3.9%
	Pitch	9	5	330.5	8263	825	9.1%
U=5kn	Unfoiled	9	3	254.1	5082	-	-
	Passive	9	3	210.3	4206	876	17.2%
	Pitch	9	3	201.0	4020	1062	20.9%
	Unfoiled	9	4	352.4	7048	-	-
	Passive	9	4	308.8	6176	872	12.4%
	Pitch	9	4	288.6	5772	1276	18.1%
	Unfoiled	9	5	471.7	9434	-	-
	Passive	9	5	434.8	8696	738	7.8%
	Pitch	9	5	400.9	8018	1416	15.0%
U=6kn	Unfoiled	9	3	329.3	5488	-	-
	Passive	9	3	254.1	4235	1253	22.8%
	Pitch	9	3	246.5	4108	1380	25.1%
	Unfoiled	9	4	454.3	7572	-	-
	Passive	9	4	370.0	6167	1405	18.6%
	Pitch	9	4	344.1	5735	1837	24.3%
	Unfoiled	9	5	608.9	10148	-	-
	Passive	9	5	527.0	8783	1365	13.5%
	Pitch	9	5	478.9	7982	2167	21.3%

Table 14: Comparison of foil mechanisms with respect to OPEX in higher waves. U=7-8kn

Ship speed	Foil configuration	Tp [s]	Hs [m]	Pb [kW]	Energy consumption [kWh]	Savings rel. to unfoiled [kWh]	Savings rel. to unfoiled [%]
U=7kn	Unfoiled	9	3	424.9	6070	-	-
	Passive	9	3	307.9	4399	1671	27.5%
	Pitch	9	3	305.2	4360	1710	28.2%
	Unfoiled	9	4	582.9	8327	-	-
	Passive	9	4	439.5	6279	2049	24.6%
	Pitch	9	4	408.8	5840	2487	29.9%
	Unfoiled	9	5	781.5	11164	-	-
	Passive	9	5	628.2	8974	2190	19.6%
	Pitch	9	5	562.5	8036	3129	28.0%
U=8kn	Unfoiled	9	3	545.1	6814	-	-
	Passive	9	3	376.9	4711	2103	30.9%
	Pitch	9	3	385.3	4816	1998	29.3%
	Unfoiled	9	4	742.7	9284	-	-
	Passive	9	4	520.7	6509	2775	29.9%
	Pitch	9	4	488.6	6108	3176	34.2%
	Unfoiled	9	5	994.5	12431	-	-
	Passive	9	5	743.2	9290	3141	25.3%
	Pitch	9	5	657.0	8213	4219	33.9%

Two (rather expected) points can be drawn out from this analysis. First, the energy savings both for passive and active foils will both in relative and absolute values generally increase with increasing ship speed. Secondly, active foils seem to always outperform passive foils in long waves with a large enough height.

Trying to make an estimate of actual OPEX savings throughout, say, a year, is pointless without doing a thorough analysis of ReVolts entire route and the distribution of sea states within. Our sample analysis does, however, point towards how much energy can be saved in a "typical" situation. In high seas with long waves, the savings for a route leg is found to range between 0.5-4.0MWh. With todays prices of electricity this cannot be associated with great economic savings for a single trip – however, the fleet of ReVolt with its so-called conveyor belt approach to shipping, will contain many vessels. Accumulating all trips for the entire fleet throughout the year, though, could yield energy savings, and thus OPEX savings, of significance. Trying to find what that number might add up to is a complex task, and out of the CAPEX directed scope of this thesis, so the subject of OPEX savings will not be examined further.

13 Discussion

13.1 Potential sources for error in calculation method

Numerous potential error sources have been mentioned throughout the modelling sections, and we will give a briefly summarize them here.

- For linear theory to be applied in the frequency domain, a requirement is that the waves are far from breaking. The breaking limit of a wave is $\frac{2\zeta_a}{\lambda} < \frac{1}{7}$ (Myrhaug, 2006). This value is exceeded in some of our sea states examined where H_s is high and T_P is low, and results should be treated with caution for this region. In any case. these unphysical sea states (logically) do not occur in the scatter diagrams, and no emphasis needs to be put on the results in this region.
- The problem is solved in the frequency domain, meaning that no transient effects are considered. This might especially be of significance in with respect to the pitching motion of the pitching foils, as the mechanism is assumed to work perfectly for each time instant, while in reality, a delay of the foil pitch displacement will occur as the foils cannot rotate instantly.
- The mass of the foils is not taken into account in the foil pitching calculations.
- Again for the pitching calculation, the lift resultant is assumed to always be working in the quarter-chord measured from the nose. As the inflow angle exceeds the linear foil theory-range, the lift resultant typically shifts further away from the nose, which will increase the foil pitching moment imposed by the lift (Steen, 2015).
- The increased mass in the bow due to foil system and decreased mass in stern due to a smaller battery pack will influence the motions and thus RAOs. In this thesis we have used the same RAO's for a foiled and unfoiled ReVolt.
- ShipX is only able to produce RAO's for passive foils.
- ShipX is only able to produce added resistance results for passive foils.
- ShipX VERES seems unable to predict any added resistance loss due to wave foil motion dampening in purely beam sea.
- The ship speed is assumed constant. This will not be the case in reality, as the resistance will not be constant, thus inducing accelerations in surge.

- The modifications of lift and drag coefficient should be correct in the linear foil theory range of the inflow angle, but the validity of the final span correction is unknown for inflow angles exceeding this value.
- The OPEX assessment done in Section 12.4 was done with a head sea wind of 16m/s, corresponding to the WCS. In retrospect, it would be more interesting in an OPEX point of view to assess the brake power without, or with a lesser, wind resistance. The result would have been a greater relative and absolute total energy saving.
- Free surface effects are not taken into consideration. When the foils are close to the surface, a wave making resistance is induced.
- Hull interaction has been neglected.

13.2 Comparison with previous work on wave foils

Comparing our energy savings results to those of (Borgen, 2010), we are not even close to the very optimistic results produced in his master thesis, which in some cases showed energy savings *larger* than 100%. This is hardly surprising, though, for several reasons:

- Borgen did not include any effects of stalling.
- Borgen used a generally less conservative method for modelling the unsteady lift effect than the Theodorsen approach in our thesis (Steen, 2015)
- The foils assessed were generally larger compared to the size of the vessel.
- The assessments were performed at higher ship speeds, where the effect of the foils is greater.
- Only active foils were assessed, with more or less perfect pitch control (the mechanism meant to perform this perfect pitching motion is not described in his thesis).
- Borgen found w_{REL} by using a RAO for relative velocity produced by ShipX, which as it turns out only predicts w_{REL} at the surface. This will overestimate w_{REL}, and as linear foil theory was applied with no way of assessing stalling, this surely leads to an overprediction of thrust.
- Borgens thrust results were multiplied by a factor (larger than 1) to account for the beneficial effect of flexible foils.

Arguably, it is more interesting to look to the results of the PhD thesis of Eirik Bøckmann, as model trials were performed in his thesis. As mentioned in the Previous Work Section of this thesis, Bøckmann performed model trials of a supply ship utilizing wave foils conceptually very similar to those modelled in our thesis (his foils were, as ours are, fixed to the hull by struts). A sample of his results with regards to ship resistance is seen in Table 2. In this sample, he reports a reduction of R_{TS} of 20-60%, depending on the wave period. In our thesis, the largest observed reduction of R_{TS} is roughly 20% (at 6 knots) in the worst case scenario, and up to 30% if all scenarios at 6 knots are included.

Based on this comparison with model trials, it seems we can claim that the results from our thesis do not overestimate the foil thrust or energy savings – or in other words, it looks like the results in our thesis are trustworthy. It should be noted, though, that Bøckmanns trials were performed in regular waves, while our results are valid for irregular waves. It should also be noted that the foil size relative to vessel size utilized by Bøckmann was larger than our foil. The vessel speed was slightly higher in his model trials than in our analysis. Both of these differences will yield slightly better foil performance for Bøckmanns results than ours.

(Veritec, 1985) and (Veritec, 1986) performed did calculations in the frequency domain to find the potential fuel savings on a 70m container vessel. Fuel savings up to 43% was reported at a speed of 10.6 knots. Our energy savings is found to be 10-20% lower than those found by Veritec, which seems right when taking into account that the vessel speed in our analysis is lower.

(Nagata, 2010) indicates that wave lengths of 1.5-2.2 times the ship length being optimal for foil thrust production in head seas. Related to ReVolt, this corresponds to a wave period of 7.6-9.2s. Looking to our thrust results, we see that this corresponds well with the peak period region yielding largest thrust in our thrust result.

Conclusion

We have assessed the potential CAPEX savings when equipping ReVolt with wave foils mounted. We have created numerous time series for the thrust produced by the foils in irregular seas by simulating a vast amount of sea states. The thrust has been found using a frequency domain approach, and a time averaged value is calculated. From this the applicable brake power has been found, and through defining a worst case scenario route leg distance of 100nm, the dimensioning battery capacity has been examined.

Within the use of linear theory, we have modelled the effect of stalling. The effects of unsteady lift, additional resistance imposed by the foil and struts, calm water resistance and wind resistance have also been modelled.

Both passive and pitching (spring-controlled) foils have been modelled, the latter only at head sea. A domain for applicable sea states for ReVolt to sail in has been defined, and calculations has been done within this domain. For pitching foils, the range of wave heights examined has been increased.

Various configurations for retracting the foils has been sketched. Due to its simplicity, a configuration mounting the foil to struts in front of the bow was chosen in our analysis.

The required battery capacity to complete a worst case scenario route leg, which have been found to be at head sea at H_s = 3.0m for all vessel speeds simulated, is shown in Table 15 for an unfoiled and passively foiled ReVolt.

Table 15: WCS performance and potential CAPEX savings

Ship speed U [kn]	Worst case energy consumption w/o foils [MWh]	Worst case energy consumption w/ passive foils [MWh]	Savings [MWh]	Relative savings [%]	CAPEX savings [MUSD]
4.0	7380	6965	415	5.6%	0.4
5.0	7358	6520	838	11.4%	0.8
6.0	7647	6377	1270	16.6%	1.3
7.0	8119	6469	1650	20.3%	1.7
8.0	8720	6753	1967	22.6%	2.0

At the design speed of ReVolt, six knots, we see that the battery pack size could be reduced by 16.6% if ReVolt was equipped with passive wave foils, corresponding to a CAPEX saving of 1.27MUSD at a battery price of 1000USD/kWh.

The benefits in potential CAPEX savings increase with increasing ship speed. Thus, we do not recommend sailing at a lower speed to minimize the WCS energy consumption if foils are fitted. Rather, increasing the speed seems like a good strategy; the total energy consumption for completing a WCS route leg is only slightly higher at eight knots than at six knots – and the leg completion energy consumption is actually *lower at eight knots than at four knots*. It seems then, that with wave foils equipped, ReVolt could increase its designed sailing speed without increasing the capacity of the battery pack by any significant value.

We have found that for a large amount of the sea states contained in the allowable sailing domain for ReVolt, the wave foils produce a net positive thrust. The thrust benefits are dependent on significant wave height, the peak wave period, wave heading angle and ship speed. The foil thrusting performance is generally low at low speed, and increasing with increasing vessel speed. In high waves, stalling will play an important factor in reducing the thrust if passive foils are used. We have found that the largest thrust is produced in the wave heading range 22.5°-67.5. This can be explained by the roll motions induced, which helps create an angle of attack on the foil.

We have found that pitching foils outperform passive foils in some sea states, but generally the wave height has to be large, or the ship speed very low, for pitching foils to have any benefits compared to passive ones. For the domain defined as allowable for ReVolt to sail in, pitching foils only outperform passive foils for low speeds.

We have also tried to look at the potential for wave foils as an OPEX saving device. Wave foils seem able to reduce the OPEX in the sailing route of ReVolt, but no exact figure as to how much one could save has been calculated.

Wave foils seem like a good concept for reducing the CAPEX associated with battery capacity for ReVolt. Indeed, based on our results, we believe wave foils will be a good concept for reducing the dimensioning battery capacity for all fully battery powered vessels experiencing a large added resistance in waves.

14 Further work

In the following, we will mention suggestions for further work by the author.

To validate the results produced in this thesis, model tests of ReVolt with wave foils mounted could be done. DNV GL already has a 4m model of the vessel, fully equipped to sail autonomously.

The wave foil concept is sometimes referred to as a “whale tail foil” – the reason for this is that the wave foil concept creates propulsion by vertically oscillating foils, as do aquatic mammals like whales and dolphins. No animals have foils, or rather fins, that are completely stiff. Rather, the foil flexes when oscillating, typically towards the tail of the fin. This makes the foil able to produce thrust more efficiently, as shown in for example (Yamaguchi, 1992). It would be interesting, then, to see the potential added benefits by utilizing a flexing foil if fitted to ReVolt.

The foil thickness profile chosen in this thesis (NACA0015) is not necessarily the best profile. Other foil profiles could be assessed to determine an optimal foil profile.

Time-domain simulations could be done in, for example, the MARINTEK software ShipX VeSim to validate our results. Eirik Bøckmann has implemented relevant theory to VeSim to assess the performance of wave foils in the time domain. In a time domain-simulation, one would be able to reproduce the effect of the ship speed not being constant.

We have used a foil with a rectangular planform in this thesis. One could probably increase the foil performance by using elliptical or other non-rectangular shaped foils.

To assess potential OPEX savings, one should also consider values for wave heading β.

One could assess smaller incremental values of $H_S hs$ and U to find more accurately predict the “tipping points” where pitching foils become more beneficial than passive foils.

The strut size needs to be determined more accurately than in this thesis.

The building materials of the foils and struts have not been determined. They could, for instance, be made out of steel, aluminium or a composite material. A material selection should be done with emphasis on fatigue and weight of the concept.

A fatigue analysis should be done, both for the struts and the foil itself.

It is possible that the weight of the bow-mounted foil system and reduced battery weight in the stern will cause a pitching moment of significance, making the stern rise and bow sink deeper.

We know that ReVolts keel line is inclined by 3° to account for a heavy stern. This inclination could be reduced in order to counter effect the pitching moment imposed by the foils system and reduced battery size.

The risk of foils cavitating, however improbable due to the low speed, should be assessed.

Assessing of the slamming risk should be done further, as this is of utmost importance for the structural integrity of the foil system.

14.1.1 Further work: Utilizing abundant wind energy for propulsion

We have seen that the wave foils is an effective means of utilizing the abundant energy contained in waves, which usually counteracts the forward speed of the vessel, to propel the ship forward. We have also observed that the maximum added resistance peak wave period shifts towards lower peak periods when wave foils are mounted. As waves typically dissipate towards waves with longer periods with time (Myrhaug, 2006), it seems probable that sea states with short peak periods will contain wind, which depending on the wind heading will induce (as we have seen, rather significant) wind resistance. It is tempting then, to propose a concept where one not only utilizes the wave energy, but also the abundant wind energy to propel the vessel forward.

Eirik Bøckmann did his MSc. Thesis at NTNU, Trondheim on the concept of propelling a 150m tanker vessel by the utilization of a wind turbine to create energy for propulsion, summarized in (Bøckmann & Steen, 2011). His results were promising, indicating a fuel saving of 33.1% in the route assessed. The concept was found to give marginally better results than wing sails. It was also found that the vessel was able to propel itself against head waves with no more energy delivered to the propeller than that supplied by the turbine.

It should be possible to find a mechanism for a wind turbine with foldable blades to be able to easily retract into the bulkhead compartment of ReVolt, which with the strut solution for wave foils mounted should have ample space for a wind turbine with diameter of 15m.

Without going into great detail, we will perform a simple moment theory calculation here to show the potential power that can be gained from equipping a wind turbine to show the potential. The turbine will of course also impose an extra resistance component in applicable wind headings, but this will not be modelled here, referencing Bøckmanns results that a net benefit was found by equipping a wind turbine, even with the additional, imposed drag.

The power contained in the wind, travelling with a speed U in an area A can simply be expressed

$$P(U) = \frac{1}{2}\rho_{air}AU^3 \qquad \text{Eq. 72}$$

The maximum power output from a wind turbine is limited by what we call the Betz limit. (Quaschning, 2013). The Betz limit is derived from the principles of conservation of mass and momentum of the air stream flowing through an area A. According to this law, no turbine can capture more than 59.2% of the kinetic energy in wind. Modern wind turbines are able to achieve maximum 75-80% of the Betz limit. Our wind turbine can be expected to move due to ship motions, thus we do not believe that we can achieve such a high efficiency for a wind turbine mounted to the bow of ReVolt. We guess a Betz limit achievement of 50% when equipped to ReVolt.

Thus, we can define a power coefficient C_P:

$$C_P = Betz\ limit * Betz\ limit\ achievement \qquad \text{Eq. 73}$$

C_P will then become 59.2%*50% = 29.6%. The power that can be generated by a wind turbine with the same cross-sectional area A as defined above, can be expressed by

$$P(U) = \frac{1}{2}\rho_{air}AU^3C_P \qquad \text{Eq. 74}$$

When the ship is in motion, we can express the relative wind speed as defined in Eq. 62, so

$$P(U_{rel,wind}) = \frac{1}{2}\rho_{air}A\left(U_{rel,wind}\right)^3C_P \qquad \text{Eq. 75}$$

The wind will not be constant. If one does not have a wind histogram for the region, one can use a statistical distribution to find the distribution of wind velocities. As this is merely supposed to be a crude approach, we look to the Rayleigh distribution (Quaschning, 2013), defined by

$$p_{Rayleigh}\left(U_{rel,wind}\right) = \frac{\pi}{2}\frac{U_{rel,wind}}{\bar{u}^2}exp\left(-\frac{\pi}{4}\frac{{U_{rel,wind}}^2}{\bar{u}^2}\right) \qquad \text{Eq. 76}$$

Here, $\bar{u}^2$ is the mean wind speed of the area where the ship is travelling squared. To find the total mean power output, we can calculate the average power generated by the turbine as

$$\bar{P} = \int_{0}^{\infty} P(U_{rel,wind}) * p_{Rayleigh}(U_{rel,wind}) * dU_{rel,wind} \quad \text{Eq. 77}$$

Using this, we will examine mean relative wind speed of 19m/s, corresponding to head wind of 16m/s (and ship speed ~3.0m/s)to find the obtainable power output from wind turbine diameters D of 12m, 15m and 18m. Results are shown in

Table 16: Mean power output from wind turbines

D [m]	**12**	**15**	**18**
$\bar{P}$ [kW]	264	412.5	594.0

Referencing our “standard” WCS condition at head sea, T_P = 6.5s and H_S = 3.0m and 6 knots, the unfoiled break power is 458.8kW. The passively foiled break power is 377.7kW. We see that the potential for power output by a wind turbine is huge, even with a fairly conservative Betz limit. Remember that the wind velocity input is rather large in this calculation. The figure might look unrealistically large, but considering that Bøckmanns tanker was able to sail against fairly strong head winds solely powered by wind, so should ReVolt. Note that the turbine simulated here is smaller than that of the tanker, but so is ReVolt. The power delivered with a wind turbine of diameter 15m is only slightly lower than the WCS at 6 knots, indicating that ReVolt could sail a speed of roughly 4-5 knots against such head winds, solely powered by wind. Thus, the concept seems very promising, and the author recommends the concept to be investigated further.

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Appendix

Appendix A: Assessment of scatter diagrams provided by DNVGL

Wavehist no.	8	9	10	11	12	13	14	15	16	17	18	19	20	21
% Sea states w/ Hs > 2m	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%	0.63%
% Sea states w/ Hs > 3m	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%	0.08%

Wavehist no.	22	23	24	25	26	27	28	29	30	31	32	33	34	35
% Sea states w/ Hs > 2m	0.01	0.01	0.63%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%	2.31%
% Sea states w/ Hs > 3m	0.00	0.00	0.08%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%	0.53%

Wavehist no.	36	37	38	39	40	41	42	43	44	45	46	47	48	49
% Sea states w/ Hs > 2m	2.31%	2.31%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	5.11%	2.97%
% Sea states w/ Hs > 3m	0.53%	0.53%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	0.59%

Wavehist no.	50	51	52	53	54	55	56	57	58	59	60	61	62	63
% Sea states w/ Hs > 2m	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%	2.97%
% Sea states w/ Hs > 3m	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%	0.59%

Wavehist no.	64	65	66	67	68	71	72	81	82	83	85	86	87	88
% Sea states w/ Hs > 2m	2.97%	2.97%	2.97%	2.97%	2.97%	21.35%	21.35%	21.35%	21.35%	21.35%	21.35%	21.35%	21.35%	21.35%
% Sea states w/ Hs > 3m	0.59%	0.59%	0.59%	0.59%	0.59%	8.34%	8.34%	8.34%	8.34%	8.34%	8.34%	8.34%	8.34%	8.34%

Wavehist no.	89	90	91	92	93	94	95	96	97	98	99	100	101	102
% Sea states w/ Hs > 2m	21.35%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%
% Sea states w/ Hs > 3m	8.34%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%

Wavehist no.	103	105	106	107	108	109	110	111	112	113	114	115	116	117
% Sea states w/ Hs > 2m	27.96%	27.96%	27.96%	27.96%	27.96%	27.96%	21.46%	21.46%	21.46%	21.46%	21.46%	21.46%	21.46%	21.46%
% Sea states w/ Hs > 3m	12.71%	12.71%	12.71%	12.71%	12.71%	12.71%	8.57%	8.57%	8.57%	8.57%	8.57%	8.57%	8.57%	8.57%

Wavehist no.	**118**	**119**	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**
% Sea states w/ Hs > 2m	21.46%	21.46%	21.46%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%	18.19%
% Sea states w/ Hs > 3m	8.57%	8.57%	8.57%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%	6.88%

Appendix B: Added resistance in waves, foiled and unfoiled

It is important to note that the results in this section do not include the effects of foil thrust, only the reduction in added resistance due to damping of vessel movements.

4kn

Added resistance in waves [kN] at wave heading 0, 4 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%
4	0.7	0.7	0.0%	2.9	2.9	0.0%	6.5	6.5	0.0%
4.5	1.5	1.5	0.0%	6.6	6.6	0.1%	14.9	14.9	0.1%
5	2.2	2.2	-0.3%	11.1	11.1	0.0%	24.9	24.9	0.0%
5.5	3.0	3.0	-0.6%	15.2	15.3	-0.4%	36.1	36.2	-0.3%
6	3.5	3.5	-0.8%	16.8	16.9	-0.8%	43.6	43.9	-0.7%
6.5	3.7	3.7	-1.0%	16.1	16.3	-1.1%	43.1	43.7	-1.3%
7	3.7	3.7	-1.1%	14.9	15.1	-1.1%	37.5	38.1	-1.5%
7.5	3.6	3.6	-1.2%	14.2	14.4	-1.2%	32.4	32.8	-1.4%
8	3.3	3.3	-1.2%	13.2	13.3	-1.2%	28.9	29.2	-1.3%
8.5	3.0	3.0	-1.3%	12.0	12.2	-1.3%	26.7	27.0	-1.2%
9	2.7	2.7	-1.2%	10.8	10.9	-1.2%	24.3	24.6	-1.2%
9.5	2.4	2.4	-1.2%	9.6	9.7	-1.2%	21.6	21.9	-1.2%
10	2.1	2.1	-1.2%	8.5	8.6	-1.2%	19.1	19.3	-1.2%

Added resistance in waves [kN] at wave heading 22.5, 4 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.6%	0.6	0.6	0.6%	1.4	1.4	0.6%
4	0.8	0.8	0.1%	3.3	3.3	0.1%	7.4	7.4	0.1%
4.5	1.5	1.5	0.3%	7.0	7.0	0.3%	15.7	15.7	0.3%
5	2.2	2.2	0.3%	10.7	10.6	0.3%	24.0	23.9	0.3%
5.5	2.8	2.8	0.3%	14.2	14.2	0.4%	33.6	33.5	0.4%
6	3.2	3.2	0.1%	15.4	15.4	0.3%	40.0	39.8	0.4%
6.5	3.4	3.4	0.0%	14.6	14.6	0.0%	38.8	38.8	-0.1%
7	3.4	3.4	0.0%	13.5	13.5	0.0%	33.5	33.6	-0.3%
7.5	3.2	3.2	-0.1%	12.8	12.8	-0.1%	28.8	28.9	-0.3%
8	3.0	3.0	-0.1%	11.8	11.8	-0.1%	25.7	25.7	-0.2%
8.5	2.7	2.7	-0.1%	10.7	10.7	-0.1%	23.8	23.8	-0.1%
9	2.4	2.4	-0.2%	9.6	9.6	-0.2%	21.6	21.6	-0.2%
9.5	2.1	2.1	-0.2%	8.5	8.5	-0.2%	19.1	19.2	-0.2%
10	1.9	1.9	-0.1%	7.5	7.5	-0.1%	16.9	16.9	-0.1%

Appendix B: Added resistance in waves, foiled and unfoiled

Added resistance in waves [kN] at wave heading 45, 4 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.5%	0.8	0.8	0.5%	1.8	1.8	0.5%
4	1.0	1.0	0.9%	4.2	4.2	0.6%	9.4	9.4	0.6%
4.5	1.6	1.6	2.1%	7.7	7.6	1.3%	17.3	17.0	1.3%
5	2.0	1.9	3.5%	9.8	9.5	3.3%	22.1	21.4	3.3%
5.5	2.4	2.3	3.9%	12.0	11.4	4.9%	28.3	26.9	5.1%
6	2.6	2.5	4.0%	12.3	11.7	4.7%	31.3	29.7	5.1%
6.5	2.7	2.6	4.0%	11.3	10.8	4.1%	28.8	27.5	4.2%
7	2.6	2.5	3.9%	10.3	9.9	3.9%	24.3	23.5	3.7%
7.5	2.4	2.3	3.8%	9.6	9.3	3.8%	21.0	20.2	3.5%
8	2.2	2.1	3.7%	8.7	8.4	3.7%	18.7	18.1	3.6%
8.5	2.0	1.9	3.6%	7.8	7.5	3.6%	17.3	16.7	3.6%
9	1.7	1.7	3.5%	6.9	6.7	3.5%	15.6	15.0	3.5%
9.5	1.5	1.5	3.5%	6.1	5.9	3.5%	13.7	13.2	3.5%
10	1.3	1.3	3.3%	5.3	5.2	3.3%	12.0	11.6	3.3%

Added resistance in waves [kN] at wave heading 67.5, 4 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	1.8%	0.8	0.8	1.8%	1.8	1.8	1.8%
4	1.0	1.0	2.4%	4.2	4.2	1.8%	9.5	9.4	1.8%
4.5	1.4	1.3	4.7%	7.1	6.9	3.9%	16.1	15.4	3.9%
5	1.6	1.5	6.0%	8.0	7.4	7.5%	17.9	16.6	7.5%
5.5	1.7	1.6	6.4%	8.4	7.7	7.9%	19.7	18.0	8.3%
6	1.8	1.7	6.4%	7.8	7.2	6.8%	18.9	17.6	7.1%
6.5	1.7	1.6	6.3%	6.9	6.5	6.2%	16.2	15.3	5.8%
7	1.6	1.5	6.1%	6.3	5.9	6.0%	13.7	12.9	5.3%
7.5	1.4	1.3	5.9%	5.7	5.4	5.9%	11.9	11.3	5.3%
8	1.3	1.2	5.6%	5.0	4.8	5.6%	10.6	10.0	5.5%
8.5	1.1	1.0	5.6%	4.4	4.2	5.6%	9.8	9.2	5.5%
9	1.0	0.9	5.4%	3.9	3.7	5.4%	8.7	8.2	5.4%
9.5	0.8	0.8	5.2%	3.4	3.2	5.2%	7.5	7.1	5.2%
10	0.7	0.7	5.1%	2.9	2.8	5.1%	6.5	6.2	5.1%

Added resistance in waves [kN] at wave heading 90, 4 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.4	1.4	0.0%
4	0.7	0.7	0.0%	3.1	3.1	0.0%	7.0	7.0	0.0%
4.5	0.8	0.8	0.0%	4.5	4.5	0.0%	10.2	10.2	0.0%
5	0.7	0.7	0.0%	3.3	3.3	0.0%	7.5	7.5	0.0%
5.5	0.6	0.6	0.0%	2.4	2.4	0.0%	5.2	5.2	0.0%
6	0.6	0.6	0.0%	1.9	1.9	0.0%	3.8	3.8	0.0%
6.5	0.5	0.5	0.0%	1.7	1.7	0.0%	3.0	3.0	0.0%
7	0.4	0.4	0.0%	1.5	1.5	0.0%	2.6	2.6	0.0%
7.5	0.3	0.3	0.0%	1.3	1.3	0.0%	2.3	2.3	0.0%
8	0.3	0.3	0.0%	1.0	1.0	0.0%	2.1	2.1	0.0%
8.5	0.2	0.2	0.0%	0.9	0.9	0.0%	1.9	1.9	0.0%
9	0.2	0.2	0.0%	0.7	0.7	0.0%	1.6	1.6	0.0%
9.5	0.1	0.1	0.0%	0.6	0.6	0.0%	1.3	1.3	0.0%
10	0.1	0.1	0.0%	0.5	0.5	0.0%	1.1	1.1	0.0%

U = 4kn, β=0°, Higher Hs

Added resistance in higher waves									
Head seas									
U = 4kn									
Tp [s]	Hs = 3.0m			Hs = 4.0m			Hs = 5.0m		
	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings
3	0.2	0.2	0.0%	0.3	0.3	0.0%	0.4	0.4	0.0%
3.5	1.2	1.2	0.0%	2.2	2.2	0.0%	3.4	3.4	0.0%
4	6.5	6.5	0.1%	11.5	11.5	0.1%	18.0	18.0	0.1%
4.5	14.9	14.9	0.2%	26.6	26.5	0.2%	41.5	41.4	0.2%
5	24.9	24.9	0.1%	44.3	44.3	0.1%	69.3	69.2	0.1%
5.5	36.1	36.1	-0.1%	64.1	64.2	-0.1%	100.2	100.3	-0.1%
6	43.6	43.8	-0.6%	77.5	77.9	-0.6%	121.1	121.8	-0.6%
6.5	43.1	43.6	-1.2%	78.6	79.5	-1.2%	122.7	124.3	-1.2%
7	37.5	38.1	-1.5%	70.0	71.2	-1.8%	109.3	111.2	-1.8%
7.5	32.4	32.9	-1.5%	58.4	59.4	-1.8%	91.1	92.8	-1.8%
8	28.9	29.3	-1.4%	49.2	50.0	-1.6%	74.3	75.6	-1.7%
8.5	26.7	27.0	-1.3%	43.2	43.8	-1.4%	63.0	64.0	-1.5%
9	24.3	24.6	-1.3%	39.2	39.7	-1.3%	55.6	56.3	-1.3%
9.5	21.6	21.9	-1.3%	36.3	36.8	-1.3%	50.4	51.0	-1.3%
10	19.1	19.4	-1.3%	34.0	34.4	-1.3%	46.4	47.0	-1.3%

5kn

Added resistance in waves [kN] at wave heading 0, 5 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%
4	0.7	0.7	0.4%	2.9	2.9	0.3%	6.5	6.4	0.3%
4.5	1.5	1.4	0.9%	6.4	6.4	0.6%	14.5	14.4	0.6%
5	2.2	2.2	1.7%	10.7	10.5	1.0%	24.0	23.7	1.0%
5.5	3.0	3.0	2.1%	15.1	14.8	1.8%	35.5	34.9	1.7%
6	3.6	3.5	2.4%	17.4	16.9	2.7%	45.1	43.8	2.9%
6.5	3.9	3.8	2.5%	17.2	16.7	2.8%	46.7	45.2	3.3%
7	4.0	3.9	2.6%	16.0	15.6	2.6%	41.5	40.3	2.9%
7.5	3.9	3.8	2.6%	15.5	15.0	2.6%	36.0	35.0	2.7%
8	3.6	3.5	2.7%	14.5	14.1	2.7%	32.0	31.2	2.6%
8.5	3.3	3.2	2.6%	13.3	13.0	2.6%	29.6	28.8	2.6%
9	3.0	2.9	2.6%	12.0	11.7	2.6%	27.1	26.4	2.6%
9.5	2.7	2.6	2.6%	10.8	10.5	2.6%	24.2	23.6	2.6%
10	2.4	2.3	2.6%	9.6	9.3	2.6%	21.5	21.0	2.6%

Appendix B: Added resistance in waves, foiled and unfoiled

Added resistance in waves [kN] at wave heading 22.5, 5 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.6%	0.6	0.6	0.6%	1.4	1.4	0.6%
4	0.8	0.8	0.5%	3.3	3.3	0.3%	7.5	7.5	0.3%
4.5	1.5	1.5	1.3%	6.9	6.8	0.9%	15.5	15.4	0.9%
5	2.2	2.1	2.7%	10.4	10.3	1.6%	23.5	23.1	1.6%
5.5	2.9	2.8	3.4%	14.4	13.9	3.2%	33.9	32.8	3.1%
6	3.4	3.3	3.8%	16.3	15.6	4.3%	42.3	40.3	4.8%
6.5	3.6	3.5	4.0%	15.9	15.2	4.4%	42.8	40.7	5.0%
7	3.7	3.5	4.1%	14.7	14.1	4.1%	37.5	35.8	4.5%
7.5	3.5	3.4	4.1%	14.1	13.5	4.1%	32.4	31.0	4.1%
8	3.3	3.1	4.1%	13.1	12.6	4.1%	28.8	27.6	4.0%
8.5	3.0	2.9	4.1%	12.0	11.5	4.1%	26.6	25.5	4.1%
9	2.7	2.6	4.0%	10.8	10.4	4.0%	24.3	23.3	4.0%
9.5	2.4	2.3	4.0%	9.6	9.2	4.0%	21.7	20.8	4.0%
10	2.1	2.0	3.9%	8.5	8.2	3.9%	19.2	18.4	3.9%

Added resistance in waves [kN] at wave heading 45, 5 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.9%	0.8	0.8	0.9%	1.9	1.8	0.9%
4	1.0	1.0	1.4%	4.3	4.3	1.0%	9.8	9.7	1.0%
4.5	1.6	1.6	3.7%	7.9	7.7	2.2%	17.8	17.4	2.2%
5	2.1	2.0	6.6%	10.1	9.5	5.6%	22.7	21.4	5.6%
5.5	2.6	2.4	7.8%	12.7	11.6	9.3%	30.0	27.1	9.6%
6	2.9	2.6	8.4%	13.5	12.2	9.8%	34.6	30.9	10.7%
6.5	2.9	2.7	8.6%	12.5	11.4	9.0%	32.5	29.3	9.8%
7	2.9	2.6	8.6%	11.5	10.5	8.6%	27.6	25.2	8.6%
7.5	2.7	2.5	8.5%	10.8	9.8	8.5%	23.7	21.8	8.2%
8	2.5	2.2	8.4%	9.8	9.0	8.4%	21.2	19.4	8.1%
8.5	2.2	2.0	8.2%	8.8	8.1	8.2%	19.5	17.9	8.2%
9	2.0	1.8	8.1%	7.8	7.2	8.1%	17.6	16.2	8.1%
9.5	1.7	1.6	8.0%	6.9	6.4	8.0%	15.6	14.3	8.0%
10	1.5	1.4	7.8%	6.1	5.6	7.8%	13.7	12.6	7.8%

Added resistance in waves [kN] at wave heading 67.5, 5 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	2.8%	0.1	0.1	2.8%	0.3	0.3	2.8%
3.5	0.2	0.2	2.2%	0.8	0.8	2.2%	1.9	1.9	2.2%
4	1.0	1.0	3.0%	4.5	4.3	2.3%	10.0	9.8	2.3%
4.5	1.5	1.4	6.4%	7.5	7.1	5.1%	16.8	15.9	5.1%
5	1.6	1.5	8.7%	8.4	7.5	10.4%	18.9	16.9	10.4%
5.5	1.8	1.7	9.5%	9.0	7.9	11.9%	21.1	18.5	12.4%
6	1.9	1.7	9.7%	8.4	7.5	10.6%	20.6	18.3	11.3%
6.5	1.8	1.7	9.7%	7.5	6.8	9.7%	17.7	16.0	9.6%
7	1.7	1.5	9.6%	6.8	6.2	9.5%	14.8	13.5	8.9%
7.5	1.5	1.4	9.3%	6.2	5.6	9.3%	12.9	11.7	8.7%
8	1.4	1.2	9.2%	5.4	4.9	9.2%	11.5	10.5	8.8%
8.5	1.2	1.1	9.0%	4.8	4.4	9.0%	10.6	9.6	8.9%
9	1.0	1.0	8.8%	4.2	3.8	8.8%	9.4	8.6	8.8%
9.5	0.9	0.8	8.6%	3.6	3.3	8.6%	8.1	7.4	8.6%
10	0.8	0.7	8.5%	3.1	2.9	8.5%	7.0	6.4	8.5%

Added resistance in waves [kN] at wave heading 90, 5 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.4	1.4	0.0%
4	0.7	0.7	0.0%	3.3	3.3	0.0%	7.5	7.5	0.0%
4.5	0.9	0.9	0.0%	4.8	4.8	0.0%	10.8	10.8	0.0%
5	0.7	0.7	0.0%	3.5	3.5	0.0%	7.9	7.9	0.0%
5.5	0.7	0.7	0.0%	2.5	2.5	0.0%	5.5	5.5	0.0%
6	0.6	0.6	0.0%	2.0	2.0	0.0%	3.9	3.9	0.0%
6.5	0.5	0.5	0.0%	1.8	1.8	0.0%	3.1	3.1	0.0%
7	0.4	0.4	0.0%	1.6	1.6	0.0%	2.8	2.8	0.0%
7.5	0.3	0.3	0.0%	1.4	1.4	0.0%	2.5	2.5	0.0%
8	0.3	0.3	0.0%	1.1	1.1	0.0%	2.2	2.2	0.0%
8.5	0.2	0.2	0.0%	0.9	0.9	0.0%	2.0	2.0	0.0%
9	0.2	0.2	0.0%	0.7	0.7	0.0%	1.7	1.7	0.0%
9.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.4	1.4	0.0%
10	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%

U = 5kn, β=0°, Higher Hs

Added resistance in higher waves									
Head seas									
U = 5kn									
Tp [s]	Hs = 3.0m			Hs = 4.0m			Hs = 5.0m		
	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings
3	0.2	0.2	0.0%	0.3	0.3	0.0%	0.4	0.4	0.0%
3.5	1.2	1.2	0.0%	2.1	2.1	0.0%	3.3	3.3	0.0%
4	6.5	6.4	0.4%	11.5	11.4	0.4%	17.9	17.9	0.4%
4.5	14.5	14.4	0.7%	25.8	25.6	0.7%	40.3	40.0	0.7%
5	24.0	23.7	1.1%	42.6	42.1	1.1%	66.6	65.8	1.1%
5.5	35.5	34.9	1.9%	63.2	62.0	1.9%	98.7	96.9	1.9%
6	45.1	43.8	3.1%	80.3	77.8	3.1%	125.4	121.6	3.1%
6.5	46.7	45.2	3.3%	85.3	82.5	3.3%	133.3	128.9	3.3%
7	41.5	40.4	2.8%	78.3	76.1	2.9%	122.4	118.9	2.9%
7.5	36.0	35.1	2.5%	66.0	64.4	2.4%	103.5	101.0	2.4%
8	32.0	31.2	2.5%	55.6	54.4	2.3%	84.9	83.1	2.2%
8.5	29.6	28.9	2.5%	48.7	47.6	2.3%	71.8	70.3	2.2%
9	27.1	26.4	2.5%	44.1	43.1	2.3%	63.2	61.7	2.3%
9.5	24.2	23.6	2.4%	40.9	39.9	2.4%	57.2	55.8	2.3%
10	21.5	21.0	2.4%	38.3	37.4	2.4%	52.7	51.4	2.4%

6kn

Added resistance in waves [kN] at wave heading 0, 6 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%
4	0.7	0.7	0.5%	2.9	2.9	0.4%	6.5	6.4	0.4%
4.5	1.4	1.4	1.7%	6.3	6.2	1.1%	14.1	14.0	1.1%
5	2.2	2.1	3.8%	10.2	10.0	2.1%	23.0	22.5	2.1%
5.5	3.1	2.9	5.1%	14.9	14.3	4.1%	34.9	33.6	3.8%
6	3.8	3.5	6.1%	18.0	16.8	6.4%	46.5	43.4	6.7%
6.5	4.2	3.9	6.6%	18.4	17.0	7.2%	50.6	46.4	8.3%
7	4.3	4.0	6.9%	17.4	16.1	7.0%	46.2	42.5	8.0%
7.5	4.2	3.9	7.0%	16.9	15.7	7.0%	40.2	37.2	7.4%
8	4.0	3.7	7.1%	16.0	14.9	7.1%	35.8	33.2	7.1%
8.5	3.7	3.4	7.1%	14.8	13.8	7.1%	33.1	30.7	7.1%
9	3.4	3.1	7.0%	13.5	12.5	7.0%	30.4	28.2	7.0%
9.5	3.0	2.8	7.0%	12.2	11.3	7.0%	27.3	25.4	7.0%
10	2.7	2.5	6.9%	10.9	10.1	6.9%	24.4	22.7	6.9%

Added resistance in waves [kN] at wave heading 22.5, 6 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.4	1.4	0.0%
4	0.8	0.8	0.7%	3.4	3.4	0.5%	7.6	7.5	0.5%
4.5	1.5	1.5	2.4%	6.8	6.7	1.5%	15.4	15.2	1.5%
5	2.2	2.1	5.1%	10.2	9.9	3.0%	23.0	22.3	3.0%
5.5	3.0	2.8	6.7%	14.5	13.6	6.0%	34.0	32.0	5.8%
6	3.6	3.3	7.8%	17.2	15.8	8.6%	44.6	40.5	9.2%
6.5	3.9	3.6	8.4%	17.2	15.7	9.1%	47.2	42.3	10.4%
7	4.0	3.7	8.7%	16.1	14.7	8.7%	42.2	38.1	9.7%
7.5	3.9	3.6	8.7%	15.6	14.2	8.7%	36.5	33.2	9.0%
8	3.7	3.3	8.8%	14.6	13.4	8.8%	32.4	29.6	8.7%
8.5	3.4	3.1	8.7%	13.5	12.3	8.7%	30.0	27.4	8.7%
9	3.0	2.8	8.6%	12.2	11.1	8.6%	27.4	25.1	8.6%
9.5	2.7	2.5	8.5%	10.9	10.0	8.5%	24.6	22.5	8.5%
10	2.4	2.2	8.4%	9.7	8.9	8.4%	21.9	20.0	8.4%

Added resistance in waves [kN] at wave heading 45, 6 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.3	-50.0%
3.5	0.2	0.2	0.4%	0.8	0.8	0.4%	1.4	1.9	-35.7%
4	1.1	1.0	1.8%	4.5	4.4	1.3%	7.5	10.1	-34.7%
4.5	1.7	1.6	5.1%	8.1	7.9	3.0%	15.2	18.3	-20.4%
5	2.2	2.0	9.6%	10.3	9.5	7.7%	22.3	23.2	-4.0%
5.5	2.8	2.4	11.6%	13.5	11.7	13.2%	32.0	31.6	1.3%
6	3.1	2.7	12.7%	14.8	12.6	14.7%	40.5	38.1	5.9%
6.5	3.2	2.8	13.1%	13.9	12.0	13.9%	42.3	36.8	13.0%
7	3.2	2.8	13.2%	12.8	11.1	13.3%	38.1	31.4	17.6%
7.5	3.0	2.6	13.2%	12.1	10.5	13.2%	33.2	26.9	19.0%
8	2.8	2.4	13.1%	11.0	9.6	13.1%	29.6	23.9	19.3%
8.5	2.5	2.2	12.9%	10.0	8.7	12.9%	27.4	22.1	19.3%
9	2.2	1.9	12.7%	8.9	7.8	12.7%	25.1	20.0	20.3%
9.5	2.0	1.7	12.4%	7.9	6.9	12.4%	22.5	17.7	21.3%
10	1.7	1.5	12.3%	6.9	6.1	12.3%	20.0	15.6	22.0%

Added resistance in waves [kN] at wave heading 67.5, 6 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	2.5%	0.9	0.9	2.5%	2.0	2.0	2.5%
4	1.1	1.0	3.5%	4.7	4.5	2.8%	10.5	10.2	2.8%
4.5	1.6	1.4	7.9%	7.8	7.3	6.1%	17.6	16.5	6.1%
5	1.7	1.5	11.4%	8.8	7.7	13.2%	19.9	17.3	13.2%
5.5	2.0	1.7	12.5%	9.7	8.1	15.7%	22.7	19.0	16.4%
6	2.0	1.8	13.0%	9.1	7.8	14.5%	22.4	18.9	15.5%
6.5	2.0	1.7	13.2%	8.1	7.0	13.3%	19.3	16.7	13.5%
7	1.8	1.6	13.0%	7.4	6.4	13.0%	16.1	14.1	12.4%
7.5	1.7	1.5	12.8%	6.7	5.8	12.8%	13.9	12.2	12.2%
8	1.5	1.3	12.7%	5.9	5.1	12.7%	12.4	10.9	12.3%
8.5	1.3	1.1	12.5%	5.2	4.5	12.5%	11.4	10.0	12.4%
9	1.1	1.0	12.3%	4.5	4.0	12.3%	10.2	8.9	12.3%
9.5	1.0	0.9	12.1%	3.9	3.4	12.1%	8.8	7.7	12.1%
10	0.8	0.7	11.9%	3.4	3.0	11.9%	7.6	6.7	11.9%

Added resistance in waves [kN] at wave heading 90, 6 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.7	0.7	0.0%	1.5	1.5	0.0%
4	0.8	0.8	0.0%	3.5	3.5	0.0%	7.9	7.9	0.0%
4.5	0.9	0.9	0.0%	5.1	5.1	0.0%	11.4	11.4	0.0%
5	0.8	0.8	0.0%	3.7	3.7	0.0%	8.3	8.3	0.0%
5.5	0.7	0.7	0.0%	2.6	2.6	0.0%	5.8	5.8	0.0%
6	0.6	0.6	0.0%	2.1	2.1	0.0%	4.1	4.1	0.0%
6.5	0.5	0.5	0.0%	1.9	1.9	0.0%	3.3	3.3	0.0%
7	0.4	0.4	0.0%	1.7	1.7	0.0%	2.9	2.9	0.0%
7.5	0.4	0.4	0.0%	1.4	1.4	0.0%	2.6	2.6	0.0%
8	0.3	0.3	0.0%	1.1	1.1	0.0%	2.3	2.3	0.0%
8.5	0.2	0.2	0.0%	0.9	0.9	0.0%	2.1	2.1	0.0%
9	0.2	0.2	0.0%	0.8	0.8	0.0%	1.8	1.8	0.0%
9.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.5	1.5	0.0%
10	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%

U = 6kn, β=0°, Higher Hs

Added resistance in higher waves									
Head seas									
U = 6kn									
Tp [s]	Hs = 3.0m			Hs = 4.0m			Hs = 5.0m		
	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings
3	0.2	0.2	0.0%	0.3	0.3	0.0%	0.5	0.5	0.0%
3.5	1.2	1.2	0.0%	2.1	2.1	0.0%	3.3	3.3	0.0%
4	6.5	6.4	0.4%	11.5	11.4	0.4%	17.9	17.9	0.4%
4.5	14.1	13.9	1.2%	25.1	24.8	1.2%	39.2	38.7	1.2%
5	23.0	22.5	2.2%	41.0	40.0	2.2%	64.0	62.6	2.2%
5.5	34.9	33.5	4.0%	62.1	59.6	4.0%	97.0	93.2	4.0%
6	46.5	43.4	6.8%	82.7	77.1	6.8%	129.3	120.4	6.8%
6.5	50.6	46.5	8.2%	92.7	84.9	8.4%	144.8	132.7	8.4%
7	46.2	42.6	7.8%	88.1	80.9	8.2%	137.7	126.4	8.2%
7.5	40.2	37.3	7.2%	75.2	69.7	7.4%	118.4	109.7	7.4%
8	35.8	33.3	6.9%	63.3	59.0	6.8%	97.8	91.2	6.7%
8.5	33.1	30.8	6.8%	55.2	51.6	6.6%	82.4	77.2	6.4%
9	30.4	28.3	6.8%	50.0	46.7	6.6%	72.2	67.6	6.3%
9.5	27.3	25.5	6.7%	46.3	43.2	6.6%	65.2	61.0	6.4%
10	24.4	22.8	6.6%	43.4	40.5	6.6%	60.1	56.2	6.5%

U=7kn

Added resistance in waves [kN] at wave heading 0, 7 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.1	0.1	0.7%	0.5	0.5	0.7%	1.2	1.2	0.7%
4	0.7	0.7	0.5%	2.9	2.9	0.5%	6.5	6.5	0.5%
4.5	1.4	1.3	2.5%	6.1	6.0	1.6%	13.8	13.6	1.6%
5	2.2	2.1	5.8%	9.8	9.5	3.3%	22.2	21.4	3.3%
5.5	3.1	2.9	8.2%	14.7	13.8	6.3%	34.1	32.2	5.8%
6	3.9	3.5	9.9%	18.5	16.7	10.1%	47.5	42.7	10.3%
6.5	4.4	3.9	10.8%	19.6	17.3	11.7%	54.5	47.3	13.3%
7	4.6	4.1	11.4%	18.8	16.6	11.5%	51.2	44.4	13.3%
7.5	4.6	4.1	11.7%	18.5	16.3	11.7%	45.0	39.4	12.4%
8	4.4	3.9	11.8%	17.7	15.6	11.8%	40.0	35.2	11.8%
8.5	4.1	3.6	11.7%	16.5	14.6	11.7%	36.9	32.6	11.7%
9	3.8	3.3	11.6%	15.1	13.4	11.6%	34.1	30.1	11.6%
9.5	3.4	3.0	11.5%	13.7	12.1	11.5%	30.8	27.3	11.5%
10	3.1	2.7	11.4%	12.3	10.9	11.4%	27.7	24.5	11.4%

Appendix B: Added resistance in waves, foiled and unfoiled

Added resistance in waves [kN] at wave heading 22.5, 7 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.6	0.6	0.0%	1.4	1.4	0.0%
4	0.8	0.8	0.8%	3.4	3.4	0.6%	7.7	7.6	0.6%
4.5	1.5	1.4	3.3%	6.8	6.6	2.0%	15.3	15.0	2.0%
5	2.2	2.1	7.4%	10.0	9.6	4.3%	22.5	21.6	4.3%
5.5	3.1	2.8	10.1%	14.6	13.3	8.6%	33.9	31.1	8.2%
6	3.8	3.3	11.8%	18.1	15.8	12.7%	46.5	40.4	13.3%
6.5	4.2	3.7	12.7%	18.6	16.1	13.8%	51.7	43.6	15.6%
7	4.4	3.8	13.2%	17.6	15.3	13.3%	47.3	40.2	15.1%
7.5	4.3	3.7	13.4%	17.2	14.9	13.4%	41.1	35.4	14.0%
8	4.1	3.5	13.5%	16.3	14.1	13.5%	36.5	31.6	13.4%
8.5	3.8	3.3	13.4%	15.1	13.1	13.4%	33.7	29.2	13.3%
9	3.4	3.0	13.3%	13.8	11.9	13.3%	31.0	26.9	13.3%
9.5	3.1	2.7	13.1%	12.4	10.8	13.1%	27.9	24.2	13.1%
10	2.8	2.4	12.9%	11.1	9.6	12.9%	24.9	21.7	12.9%

Added resistance in waves [kN] at wave heading 45, 7 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.4%	0.9	0.9	0.4%	2.0	2.0	0.4%
4	1.1	1.1	2.0%	4.7	4.6	1.5%	10.5	10.3	1.5%
4.5	1.7	1.6	6.3%	8.3	8.0	3.6%	18.7	18.0	3.6%
5	2.3	2.0	12.3%	10.5	9.5	9.4%	23.7	21.5	9.4%
5.5	2.9	2.5	15.2%	14.1	11.8	16.7%	33.0	27.4	17.0%
6	3.4	2.8	16.7%	16.1	13.0	19.2%	41.6	32.9	21.0%
6.5	3.6	2.9	17.5%	15.4	12.6	18.6%	41.4	32.9	20.6%
7	3.5	2.9	17.7%	14.2	11.7	17.7%	35.6	28.9	18.6%
7.5	3.4	2.8	17.7%	13.5	11.1	17.7%	30.4	25.1	17.5%
8	3.1	2.6	17.6%	12.4	10.2	17.6%	27.0	22.4	17.2%
8.5	2.8	2.3	17.3%	11.2	9.3	17.3%	25.0	20.7	17.2%
9	2.5	2.1	17.0%	10.1	8.4	17.0%	22.6	18.8	17.0%
9.5	2.2	1.9	16.8%	8.9	7.4	16.8%	20.1	16.7	16.8%
10	2.0	1.6	16.5%	7.9	6.6	16.5%	17.7	14.8	16.5%

Added resistance in waves [kN] at wave heading 67.5, 7 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	2.8%	0.9	0.9	2.8%	2.1	2.0	2.8%
4	1.1	1.1	4.0%	4.9	4.8	3.1%	11.0	10.7	3.1%
4.5	1.6	1.5	9.2%	8.1	7.6	6.8%	18.3	17.1	6.8%
5	1.9	1.6	13.8%	9.3	7.8	15.6%	20.9	17.6	15.6%
5.5	2.1	1.8	15.4%	10.3	8.4	19.2%	24.4	19.5	20.1%
6	2.2	1.8	16.2%	9.8	8.1	18.2%	24.4	19.6	19.6%
6.5	2.1	1.8	16.5%	8.8	7.3	16.8%	21.0	17.4	17.4%
7	2.0	1.7	16.4%	8.0	6.6	16.4%	17.5	14.7	16.0%
7.5	1.8	1.5	16.2%	7.2	6.1	16.2%	15.1	12.8	15.6%
8	1.6	1.3	16.1%	6.4	5.4	16.1%	13.5	11.3	15.7%
8.5	1.4	1.2	15.9%	5.6	4.7	15.9%	12.4	10.4	15.8%
9	1.2	1.0	15.7%	4.9	4.1	15.7%	11.0	9.3	15.7%
9.5	1.1	0.9	15.5%	4.2	3.6	15.5%	9.6	8.1	15.5%
10	0.9	0.8	15.3%	3.7	3.1	15.3%	8.3	7.0	15.3%

Added resistance in waves [kN] at wave heading 90, 7 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.0%	0.7	0.7	0.0%	1.6	1.6	0.0%
4	0.8	0.8	0.0%	3.7	3.7	0.0%	8.3	8.3	0.0%
4.5	1.0	1.0	0.0%	5.3	5.3	0.0%	12.0	12.0	0.0%
5	0.8	0.8	0.0%	3.9	3.9	0.0%	8.7	8.7	0.0%
5.5	0.7	0.7	0.0%	2.8	2.8	0.0%	6.0	6.0	0.0%
6	0.6	0.6	0.0%	2.2	2.2	0.0%	4.3	4.3	0.0%
6.5	0.5	0.5	0.0%	2.0	2.0	0.0%	3.4	3.4	0.0%
7	0.5	0.5	0.0%	1.8	1.8	0.0%	3.0	3.0	0.0%
7.5	0.4	0.4	0.0%	1.5	1.5	0.0%	2.7	2.7	0.0%
8	0.3	0.3	0.0%	1.2	1.2	0.0%	2.4	2.4	0.0%
8.5	0.2	0.2	0.0%	1.0	1.0	0.0%	2.2	2.2	0.0%
9	0.2	0.2	0.0%	0.8	0.8	0.0%	1.8	1.8	0.0%
9.5	0.2	0.2	0.0%	0.7	0.7	0.0%	1.5	1.5	0.0%
10	0.1	0.1	0.0%	0.6	0.6	0.0%	1.3	1.3	0.0%

U = 7kn, β =0°, Higher Hs

Added resistance in higher waves									
Head seas									
U = 7kn									
Tp [s]	Hs = 3.0m			Hs = 4.0m			Hs = 5.0m		
	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings
3	0.2	0.2	0.0%	0.3	0.3	0.0%	0.5	0.5	0.0%
3.5	1.2	1.2	0.7%	2.2	2.1	0.7%	3.4	3.3	0.7%
4	6.5	6.5	0.5%	11.5	11.5	0.5%	18.0	17.9	0.5%
4.5	13.8	13.6	1.7%	24.5	24.1	1.7%	38.3	37.7	1.7%
5	22.2	21.4	3.3%	39.4	38.1	3.3%	61.5	59.5	3.3%
5.5	34.1	32.1	5.9%	60.7	57.1	5.9%	94.8	89.2	5.9%
6	47.5	42.6	10.3%	84.5	75.8	10.3%	132.0	118.4	10.3%
6.5	54.5	47.3	13.1%	99.9	86.5	13.4%	156.1	135.2	13.4%
7	51.2	44.5	13.1%	98.8	85.3	13.7%	154.4	133.2	13.7%
7.5	45.0	39.5	12.1%	85.6	74.8	12.6%	135.5	118.3	12.7%
8	40.0	35.3	11.5%	72.0	63.7	11.6%	112.6	99.6	11.5%
8.5	36.9	32.7	11.4%	62.6	55.7	11.1%	94.5	84.3	10.8%
9	34.1	30.2	11.3%	56.5	50.3	11.0%	82.5	73.7	10.7%
9.5	30.8	27.4	11.2%	52.4	46.6	11.1%	74.3	66.4	10.7%
10	27.7	24.6	11.1%	49.2	43.8	11.1%	68.4	61.1	10.7%

8kn

Added resistance in waves [kN] at wave heading 0, 8 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.1	0.1	0.0%	0.5	0.5	0.0%	1.2	1.2	0.0%
4	0.7	0.7	0.7%	2.9	2.9	0.5%	6.5	6.5	0.5%
4.5	1.3	1.3	3.1%	6.0	5.9	1.9%	13.5	13.3	1.9%
5	2.2	2.0	7.7%	9.5	9.1	4.3%	21.3	20.4	4.3%
5.5	3.2	2.8	11.2%	14.4	13.2	8.3%	33.2	30.7	7.6%
6	4.0	3.5	13.5%	18.9	16.4	13.5%	48.0	41.6	13.4%
6.5	4.7	4.0	15.0%	20.7	17.4	16.0%	58.0	47.6	17.8%
7	5.0	4.2	15.8%	20.2	17.0	15.9%	56.4	46.0	18.4%
7.5	5.0	4.2	16.2%	20.1	16.9	16.2%	50.0	41.3	17.4%
8	4.9	4.1	16.3%	19.5	16.3	16.3%	44.5	37.1	16.5%
8.5	4.6	3.8	16.3%	18.3	15.3	16.3%	41.0	34.3	16.3%
9	4.2	3.5	16.2%	16.9	14.2	16.2%	38.0	31.9	16.2%
9.5	3.8	3.2	16.0%	15.4	12.9	16.0%	34.6	29.1	16.0%
10	3.5	2.9	15.8%	13.9	11.7	15.8%	31.2	26.3	15.8%

Added resistance in waves [kN] at wave heading 22.5, 8 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.2	0.2	0.0%
3.5	0.2	0.2	0.0%	0.7	0.7	0.0%	1.5	1.5	0.0%
4	0.8	0.8	0.9%	3.5	3.5	0.7%	7.8	7.8	0.7%
4.5	1.5	1.4	3.9%	6.7	6.6	2.4%	15.2	14.8	2.4%
5	2.2	2.0	9.5%	9.8	9.3	5.4%	22.0	20.8	5.4%
5.5	3.2	2.8	13.2%	14.5	12.9	10.9%	33.5	30.1	10.3%
6	4.0	3.4	15.6%	18.8	15.7	16.3%	47.9	39.9	16.8%
6.5	4.5	3.7	16.9%	20.0	16.4	18.2%	56.0	44.6	20.4%
7	4.7	3.9	17.6%	19.2	15.8	17.7%	52.7	42.1	20.2%
7.5	4.7	3.9	17.9%	18.9	15.5	17.9%	46.1	37.4	18.8%
8	4.5	3.7	18.0%	18.1	14.8	18.0%	40.8	33.5	18.0%
8.5	4.2	3.5	17.9%	16.9	13.8	17.9%	37.7	31.0	17.8%
9	3.9	3.2	17.7%	15.5	12.7	17.7%	34.8	28.6	17.7%
9.5	3.5	2.9	17.5%	14.0	11.5	17.5%	31.5	25.9	17.5%
10	3.1	2.6	17.3%	12.5	10.4	17.3%	28.2	23.3	17.3%

Added resistance in waves [kN] at wave heading 45, 8 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.4%	0.9	0.9	0.4%	2.0	2.0	0.4%
4	1.1	1.1	2.1%	4.8	4.8	1.6%	10.9	10.7	1.6%
4.5	1.8	1.7	7.2%	8.5	8.2	4.2%	19.2	18.4	4.2%
5	2.4	2.0	14.7%	10.7	9.6	10.8%	24.1	21.5	10.8%
5.5	3.1	2.5	18.4%	14.7	11.8	19.6%	34.2	27.4	19.9%
6	3.6	2.9	20.4%	17.3	13.3	23.3%	44.9	33.6	25.3%
6.5	3.9	3.0	21.4%	17.0	13.1	22.9%	46.2	34.5	25.4%
7	3.9	3.0	21.8%	15.6	12.2	21.9%	40.1	30.7	23.3%
7.5	3.7	2.9	21.8%	14.9	11.7	21.8%	34.2	26.8	21.8%
8	3.5	2.7	21.7%	13.8	10.8	21.7%	30.3	23.9	21.3%
8.5	3.2	2.5	21.5%	12.6	9.9	21.5%	28.0	22.0	21.3%
9	2.8	2.2	21.1%	11.3	8.9	21.1%	25.5	20.1	21.1%
9.5	2.5	2.0	20.9%	10.1	8.0	20.9%	22.7	17.9	20.9%
10	2.2	1.8	20.6%	8.9	7.1	20.6%	20.0	15.9	20.6%

Added resistance in waves [kN] at wave heading 67.5, 8 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.2	0.2	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	3.0%	1.0	0.9	3.0%	2.2	2.1	3.0%
4	1.2	1.1	4.3%	5.1	5.0	3.3%	11.6	11.2	3.3%
4.5	1.7	1.5	10.4%	8.5	7.9	7.4%	19.1	17.7	7.4%
5	2.0	1.6	16.0%	9.7	8.0	17.6%	21.8	18.0	17.6%
5.5	2.2	1.8	18.2%	11.1	8.6	22.6%	26.0	19.9	23.5%
6	2.3	1.9	19.2%	10.6	8.3	21.7%	26.5	20.3	23.5%
6.5	2.3	1.8	19.6%	9.5	7.6	20.2%	22.9	18.1	21.1%
7	2.1	1.7	19.7%	8.6	6.9	19.7%	19.0	15.3	19.4%
7.5	2.0	1.6	19.6%	7.8	6.3	19.6%	16.4	13.3	18.8%
8	1.7	1.4	19.5%	6.9	5.6	19.5%	14.6	11.8	19.0%
8.5	1.5	1.2	19.2%	6.1	4.9	19.2%	13.4	10.9	19.1%
9	1.3	1.1	19.0%	5.3	4.3	19.0%	11.9	9.7	19.0%
9.5	1.2	0.9	18.8%	4.6	3.7	18.8%	10.4	8.4	18.8%
10	1.0	0.8	18.6%	4.0	3.2	18.6%	9.0	7.3	18.6%

Added resistance in waves [kN] at wave heading 90, 8 knots									
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]	Foilless	Foiled	Reduction [%]
3	0.0	0.0	0.0%	0.1	0.1	0.0%	0.3	0.3	0.0%
3.5	0.2	0.2	0.0%	0.8	0.8	0.0%	1.7	1.7	0.0%
4	0.9	0.9	0.0%	3.9	3.9	0.0%	8.8	8.8	0.0%
4.5	1.0	1.0	0.0%	5.6	5.6	0.0%	12.6	12.6	0.0%
5	0.8	0.8	0.0%	4.1	4.1	0.0%	9.1	9.1	0.0%
5.5	0.8	0.8	0.0%	2.9	2.9	0.0%	6.3	6.3	0.0%
6	0.7	0.7	0.0%	2.3	2.3	0.0%	4.5	4.5	0.0%
6.5	0.6	0.6	0.0%	2.1	2.1	0.0%	3.6	3.6	0.0%
7	0.5	0.5	0.0%	1.9	1.9	0.0%	3.2	3.2	0.0%
7.5	0.4	0.4	0.0%	1.6	1.6	0.0%	2.8	2.8	0.0%
8	0.3	0.3	0.0%	1.2	1.2	0.0%	2.5	2.5	0.0%
8.5	0.3	0.3	0.0%	1.0	1.0	0.0%	2.3	2.3	0.0%
9	0.2	0.2	0.0%	0.9	0.9	0.0%	1.9	1.9	0.0%
9.5	0.2	0.2	0.0%	0.7	0.7	0.0%	1.6	1.6	0.0%
10	0.1	0.1	0.0%	0.6	0.6	0.0%	1.3	1.3	0.0%

U = 8kn, β =0°, Higher Hs

Added resistance in higher waves									
Head seas									
U = 8kn									
Tp [s]	Hs = 3.0m			Hs = 4.0m			Hs = 5.0m		
	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings	Unfoiled	Foiled	Savings
3	0.2	0.2	0.0%	0.3	0.3	0.0%	0.5	0.5	0.0%
3.5	1.2	1.2	0.7%	2.2	2.2	0.7%	3.4	3.4	0.7%
4	6.5	6.5	0.5%	11.6	11.6	0.5%	18.2	18.1	0.5%
4.5	13.5	13.2	2.0%	24.0	23.6	2.0%	37.5	36.8	2.0%
5	21.3	20.4	4.3%	37.9	36.2	4.3%	59.2	56.6	4.3%
5.5	33.2	30.7	7.7%	59.1	54.5	7.7%	92.3	85.2	7.7%
6	48.0	41.6	13.4%	85.3	73.9	13.4%	133.3	115.5	13.4%
6.5	58.0	47.7	17.7%	106.3	87.2	18.0%	166.1	136.3	18.0%
7	56.4	46.2	18.1%	109.8	88.9	19.1%	171.6	138.9	19.1%
7.5	50.0	41.5	17.0%	97.0	79.7	17.8%	154.0	126.3	18.0%
8	44.5	37.3	16.2%	81.6	68.3	16.4%	129.1	107.9	16.5%
8.5	41.0	34.5	15.9%	70.7	59.7	15.6%	108.0	91.4	15.3%
9	38.0	32.0	15.8%	63.6	53.8	15.4%	93.8	79.8	14.9%
9.5	34.6	29.2	15.7%	59.0	49.9	15.4%	84.3	71.7	14.9%
10	31.2	26.4	15.5%	55.5	46.9	15.5%	77.5	65.9	15.0%

Appendix C: Total ship resistance

Appendix C-I: Wind resistance included

U = 4kn

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	26.7	27.5	28.9	29.1	32.5	31.7
4.5	27.5	28.2	32.7	31.9	41.0	38.6
5	28.3	28.9	37.1	36.3	51.0	48.6
5.5	29.0	29.5	41.2	40.5	62.1	59.9
6	29.5	29.8	42.8	41.3	69.6	66.6
6.5	29.7	29.7	42.1	39.7	69.1	65.0
7	29.7	29.4	40.9	38.0	63.6	59.0
7.5	29.6	29.0	40.2	36.9	58.4	53.7
8	29.3	28.5	39.2	35.5	54.9	50.3
8.5	29.0	27.9	38.0	34.1	52.7	48.2
9	28.7	27.4	36.8	32.7	50.3	45.9
9.5	28.4	26.9	35.6	31.4	47.6	43.4
10	28.2	26.5	34.5	30.2	45.1	41.1

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	26.8	27.6	29.3	29.5	33.5	32.6
4.5	27.6	28.2	33.0	32.4	41.7	39.6
5	28.2	28.8	36.7	36.1	50.0	47.8
5.5	28.8	29.2	40.2	39.3	59.7	57.1
6	29.2	29.4	41.5	39.4	66.0	61.9
6.5	29.4	29.3	40.7	37.7	64.8	59.8
7	29.4	28.9	39.5	36.1	59.5	54.4
7.5	29.2	28.4	38.8	35.0	54.9	49.9
8	29.0	27.9	37.8	33.8	51.7	46.9
8.5	28.7	27.4	36.7	32.5	49.8	45.2
9	28.4	26.9	35.6	31.3	47.6	43.2
9.5	28.2	26.5	34.5	30.2	45.2	41.0
10	27.9	26.1	33.5	29.1	42.9	38.9

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	27.0	27.9	30.2	30.7	35.4	34.5
4.5	27.6	28.4	33.7	33.6	43.3	41.0
5	28.0	28.5	35.9	35.2	48.2	45.3
5.5	28.4	28.5	38.0	35.8	54.3	50.5
6	28.7	28.3	38.3	34.9	57.3	51.8
6.5	28.7	28.0	37.3	33.3	54.8	48.5
7	28.6	27.5	36.4	32.2	50.4	44.3
7.5	28.4	27.1	35.7	31.3	47.0	41.2
8	28.2	26.6	34.8	30.3	44.8	39.2
8.5	28.0	26.2	33.8	29.4	43.3	38.0
9	27.8	25.9	32.9	28.5	41.6	36.6
9.5	27.6	25.6	32.1	27.7	39.7	35.0
10	27.4	25.3	31.4	27.0	38.0	33.6

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	27.0	27.6	30.3	29.9	35.6	33.7
4.5	27.4	27.3	33.2	30.2	42.1	37.1
5	27.6	26.9	34.0	29.2	44.0	38.0
5.5	27.8	26.5	34.4	29.2	45.7	39.9
6	27.8	26.2	33.8	28.7	45.0	39.9
6.5	27.7	25.8	33.0	28.0	42.3	37.7
7	27.6	25.5	32.4	27.5	39.7	35.5
7.5	27.5	25.3	31.8	26.9	37.9	34.0
8	27.3	25.1	31.1	26.3	36.7	32.8
8.5	27.1	24.9	30.5	25.8	35.8	32.1
9	27.0	24.7	29.9	25.3	34.7	31.2
9.5	26.9	24.6	29.4	24.8	33.6	30.2
10	26.8	24.5	28.9	24.4	32.6	29.3

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	26.7	27.3	29.2	28.7	33.1	31.5
4.5	26.8	27.3	30.6	29.2	36.3	33.4
5	26.7	27.0	29.4	27.3	33.5	29.8
5.5	26.7	26.7	28.4	25.6	31.2	26.7
6	26.6	26.4	28.0	24.8	29.8	25.5
6.5	26.5	26.1	27.7	24.3	29.0	24.5
7	26.4	25.9	27.6	24.0	28.6	24.0
7.5	26.4	25.7	27.3	23.5	28.4	23.8
8	26.3	25.5	27.1	23.0	28.1	23.4
8.5	26.2	25.3	26.9	22.7	27.9	23.1
9	26.2	25.2	26.7	22.4	27.6	22.9
9.5	26.2	25.1	26.6	22.2	27.4	22.8
10	26.2	25.0	26.5	22.1	27.1	22.7

Total ship resistance at higher seas: Unfoiled, passively foiled and pitch foiled U = 4kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Rts Tp [s]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled
4	32.5	31.7	30.8	2.5%	5.2%	37.5	35.7	34.9	4.9%	7.1%	44.0	41.3	40.5	6.2%	8.1%
4.5	41.0	38.6	37.8	5.8%	7.8%	52.6	49.1	48.1	6.7%	8.4%	67.5	63.4	62.2	6.1%	7.9%
5	51.0	48.6	47.8	4.7%	6.2%	70.4	66.8	65.9	5.1%	6.3%	95.3	91.0	89.9	4.5%	5.7%
5.5	62.1	59.8	59.1	3.6%	4.8%	90.1	86.7	85.9	3.8%	4.7%	126.2	121.8	121.0	3.4%	4.1%
6	69.6	66.5	65.7	4.5%	5.6%	103.5	99.5	98.4	3.9%	5.0%	147.1	142.0	141.1	3.5%	4.1%
6.5	69.1	65.0	63.9	6.0%	7.6%	104.6	99.9	98.2	4.5%	6.1%	148.8	142.6	141.5	4.2%	4.9%
7	63.6	59.0	57.6	7.2%	9.5%	96.0	91.3	88.8	4.9%	7.5%	135.4	129.2	127.3	4.5%	6.0%
7.5	58.4	53.8	52.1	8.0%	10.8%	84.4	80.0	77.1	5.2%	8.6%	117.1	112.1	109.3	4.3%	6.7%
8	54.9	50.3	48.5	8.4%	11.6%	75.3	71.3	68.4	5.2%	9.1%	100.3	96.4	93.3	3.9%	7.0%
8.5	52.7	48.2	46.4	8.5%	12.0%	69.3	65.7	62.8	5.1%	9.3%	89.1	86.0	82.8	3.4%	7.0%
9	50.3	46.0	44.0	8.6%	12.4%	65.3	62.1	59.2	4.9%	9.3%	81.6	79.2	75.9	3.0%	7.0%
9.5	47.6	43.5	41.5	8.8%	13.0%	62.3	59.5	56.6	4.6%	9.3%	76.4	74.5	71.2	2.5%	6.8%
10	45.1	41.1	39.1	8.9%	13.4%	60.0	57.4	54.4	4.4%	9.2%	72.4	70.9	67.7	2.1%	6.6%

14.1.1.2 U = 5kn

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	30.7	32.1	32.9	33.6	36.5	36.2
4.5	31.5	32.7	36.5	36.1	44.5	42.2
5	32.3	33.4	40.7	40.2	54.0	51.4
5.5	33.1	34.0	45.1	44.4	65.6	62.6
6	33.6	34.2	47.4	45.3	75.2	69.8
6.5	34.0	34.2	47.2	43.6	76.7	68.6
7	34.0	33.8	46.1	41.7	71.6	62.8
7.5	33.9	33.3	45.5	40.3	66.0	57.2
8	33.7	32.7	44.5	38.7	62.1	53.5
8.5	33.4	32.1	43.3	37.1	59.6	51.2
9	33.0	31.6	42.1	35.6	57.1	48.9
9.5	32.7	31.0	40.8	34.2	54.3	46.3
10	32.4	30.6	39.6	32.9	51.6	44.0

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	30.8	32.2	33.4	34.1	37.5	37.2
4.5	31.6	32.8	36.9	36.6	45.6	43.2
5	32.2	33.3	40.5	39.9	53.5	50.7
5.5	32.9	33.8	44.4	43.5	63.9	60.5
6	33.4	34.0	46.4	44.0	72.4	66.2
6.5	33.7	33.8	45.9	42.1	72.8	64.1
7	33.7	33.5	44.8	40.2	67.5	58.3
7.5	33.6	32.9	44.1	38.8	62.4	53.2
8	33.3	32.4	43.2	37.2	58.8	49.9
8.5	33.0	31.8	42.0	35.7	56.7	47.9
9	32.7	31.2	40.8	34.2	54.3	45.8
9.5	32.4	30.7	39.7	32.9	51.7	43.5
10	32.2	30.3	38.6	31.7	49.2	41.4

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	31.1	32.5	34.4	35.3	30.6	30.8
4.5	31.7	32.9	37.9	38.1	38.6	37.0
5	32.1	33.0	40.1	39.3	43.5	39.9
5.5	32.6	32.9	42.8	39.1	50.8	42.4
6	32.9	32.7	43.5	37.8	55.4	44.1
6.5	33.0	32.2	42.6	36.1	53.3	42.1
7	32.9	31.7	41.5	34.8	48.4	38.4
7.5	32.7	31.1	40.8	33.8	44.5	35.3
8	32.5	30.6	39.8	32.6	42.0	33.2
8.5	32.2	30.2	38.9	31.6	40.3	31.9
9	32.0	29.8	37.9	30.7	38.4	30.4
9.5	31.8	29.5	37.0	29.8	36.4	28.7
10	31.6	29.2	36.1	29.0	34.5	27.1

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	31.1	32.2	34.5	34.6	40.1	38.5
4.5	31.5	31.9	37.5	34.4	46.8	40.5
5	31.7	31.4	38.4	32.3	48.9	39.9
5.5	31.9	30.9	39.0	31.8	51.2	41.5
6	31.9	30.4	38.4	31.1	50.6	41.6
6.5	31.9	30.0	37.5	30.2	47.7	39.4
7	31.7	29.6	36.9	29.6	44.9	37.2
7.5	31.6	29.2	36.2	29.0	42.9	35.5
8	31.4	29.0	35.5	28.3	41.5	34.3
8.5	31.2	28.8	34.8	27.7	40.6	33.6
9	31.1	28.6	34.2	27.2	39.4	32.6
9.5	30.9	28.5	33.7	26.7	38.2	31.6
10	30.8	28.4	33.2	26.3	37.1	30.6

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	30.8	31.9	33.4	33.2	37.5	35.9
4.5	30.9	31.8	34.8	33.6	40.8	37.4
5	30.8	31.5	33.5	31.4	37.9	33.0
5.5	30.7	31.1	32.5	29.3	35.5	29.1
6	30.6	30.8	32.1	28.3	34.0	27.5
6.5	30.5	30.5	31.8	27.6	33.2	26.2
7	30.5	30.2	31.7	27.2	32.8	25.6
7.5	30.4	30.0	31.4	26.6	32.5	25.4
8	30.3	29.8	31.1	26.0	32.2	24.9
8.5	30.3	29.6	30.9	25.5	32.0	24.5
9	30.2	29.5	30.8	25.2	31.7	24.1
9.5	30.2	29.4	30.7	24.9	31.4	23.9
10	30.2	29.3	30.6	24.7	31.2	23.8

Total ship resistance at higher seas: Unfoiled, passively foiled and pitch foiled U = 5kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Rts Tp [s]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled
4	36.5	36.2	35.9	0.9%	1.7%	41.5	39.9	39.8	3.9%	4.1%	48.0	45.0	45.1	6.1%	6.0%
4.5	44.5	42.2	42.2	5.3%	5.4%	55.8	51.5	51.6	7.7%	7.6%	70.3	64.5	64.4	8.2%	8.4%
5	54.0	51.3	51.3	5.0%	5.0%	72.7	67.8	67.9	6.6%	6.5%	96.6	90.1	90.1	6.7%	6.8%
5.5	65.6	62.6	62.6	4.6%	4.5%	93.2	87.7	87.9	5.9%	5.7%	128.8	121.1	121.2	6.0%	5.9%
6	75.2	69.7	69.9	7.3%	7.1%	110.3	101.6	101.6	7.9%	7.9%	155.5	143.9	143.5	7.4%	7.7%
6.5	76.7	68.6	68.4	10.6%	10.8%	115.4	104.0	102.9	9.9%	10.8%	163.4	149.4	147.0	8.6%	10.0%
7	71.6	62.8	62.0	12.2%	13.4%	108.4	97.1	94.5	10.4%	12.8%	152.4	139.7	134.8	8.3%	11.6%
7.5	66.0	57.3	56.0	13.2%	15.1%	96.0	86.1	82.7	10.4%	13.9%	133.6	123.4	117.4	7.6%	12.1%
8	62.1	53.5	52.1	13.8%	16.1%	85.7	76.9	73.4	10.2%	14.4%	115.0	107.2	101.2	6.8%	12.0%
8.5	59.6	51.3	49.7	14.0%	16.7%	78.8	70.8	67.3	10.1%	14.6%	101.9	95.4	89.8	6.4%	11.9%
9	57.1	48.9	47.2	14.3%	17.4%	74.2	66.8	63.3	9.9%	14.7%	93.2	87.5	82.1	6.2%	11.9%
9.5	54.3	46.4	44.5	14.5%	18.1%	70.9	64.1	60.5	9.7%	14.6%	87.2	82.2	77.0	5.7%	11.7%
10	51.6	44.0	42.0	14.7%	18.7%	68.3	61.9	58.4	9.4%	14.6%	82.7	78.4	73.2	5.2%	11.5%

14.1.1.3 U = 6kn

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	35.3	37.3	37.5	38.9	41.1	41.4
4.5	36.0	37.9	40.9	41.2	48.7	46.8
5	36.8	38.6	44.9	44.8	57.7	55.0
5.5	37.7	39.1	49.5	49.0	69.5	66.0
6	38.4	39.4	52.6	50.1	81.2	73.6
6.5	38.8	39.3	53.0	48.3	85.3	72.8
7	38.9	39.0	52.0	46.1	80.8	67.0
7.5	38.9	38.4	51.5	44.6	74.8	61.2
8	38.6	37.8	50.6	42.8	70.4	57.1
8.5	38.3	37.1	49.5	41.0	67.7	54.6
9	38.0	36.5	48.1	39.3	65.0	52.2
9.5	37.7	36.0	46.8	37.7	62.0	49.5
10	37.3	35.5	45.5	36.2	59.1	46.9

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	35.4	37.5	38.0	39.3	42.2	42.4
4.5	36.1	38.0	41.5	41.9	50.0	48.2
5	36.8	38.5	44.9	44.9	57.7	55.2
5.5	37.6	39.0	49.1	48.2	68.6	64.2
6	38.2	39.1	51.9	48.3	79.2	69.2
6.5	38.5	38.8	51.9	46.2	81.9	67.4
7	38.6	38.4	50.8	44.1	76.8	62.0
7.5	38.5	37.8	50.2	42.5	71.1	56.9
8	38.3	37.2	49.3	40.8	67.1	53.3
8.5	38.0	36.5	48.1	39.1	64.6	51.1
9	37.7	36.0	46.8	37.5	62.1	48.9
9.5	37.4	35.5	45.6	36.1	59.2	46.5
10	37.1	35.0	44.4	34.8	56.5	44.2

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	35.7	37.7	39.1	40.7	42.1	45.6
4.5	36.3	38.2	42.7	43.4	49.8	52.1
5	36.8	38.2	45.0	44.4	56.9	55.7
5.5	37.4	38.2	48.1	43.9	66.6	59.8
6	37.7	37.8	49.4	42.3	75.1	62.9
6.5	37.9	37.3	48.6	40.2	76.9	60.3
7	37.8	36.7	47.4	38.7	72.7	55.1
7.5	37.6	36.1	46.7	37.4	67.8	51.0
8	37.4	35.5	45.7	36.1	64.2	48.2
8.5	37.1	35.0	44.6	34.9	62.0	46.5
9	36.8	34.6	43.5	33.8	59.7	44.6
9.5	36.6	34.3	42.5	32.8	57.1	42.5
10	36.4	34.0	41.6	31.9	54.6	40.5

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	35.7	37.5	39.3	40.0	45.1	44.0
4.5	36.2	37.1	42.4	39.5	52.2	44.8
5	36.4	36.5	43.5	36.4	54.5	42.6
5.5	36.6	36.0	44.3	35.3	57.3	43.4
6	36.7	35.4	43.7	34.4	57.0	43.6
6.5	36.6	34.9	42.7	33.4	53.9	41.3
7	36.5	34.4	42.0	32.6	50.7	39.0
7.5	36.3	34.1	41.3	31.9	48.6	37.3
8	36.1	33.8	40.5	31.0	47.0	36.0
8.5	35.9	33.5	39.8	30.4	46.1	35.2
9	35.8	33.4	39.1	29.8	44.8	34.1
9.5	35.6	33.3	38.5	29.3	43.4	33.0
10	35.5	33.2	38.0	28.8	42.2	32.0

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	35.4	37.2	38.1	38.5	42.5	41.1
4.5	35.5	37.1	39.7	38.7	46.0	42.2
5	35.4	36.7	38.3	36.2	42.9	36.9
5.5	35.3	36.3	37.3	33.8	40.4	32.2
6	35.2	35.9	36.8	32.6	38.8	30.2
6.5	35.1	35.6	36.5	31.8	37.9	28.6
7	35.1	35.3	36.3	31.3	37.5	27.8
7.5	35.0	35.0	36.1	30.5	37.2	27.6
8	34.9	34.8	35.8	29.9	36.9	27.0
8.5	34.9	34.6	35.6	29.3	36.7	26.4
9	34.8	34.5	35.4	28.9	36.4	25.9
9.5	34.8	34.4	35.3	28.5	36.1	25.5
10	34.8	34.3	35.2	28.3	35.8	25.3

Total ship resistance at higher seas: Unfoiled, passively foiled and pitch foiled U = 6kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Rts Tp [s]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled [%]	Savings pitch foiled [%]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled [%]	Savings pitch foiled [%]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled [%]	Savings pitch foiled [%]
4	41.1	41.4	41.8	-0.8%	-1.8%	46.1	45.0	45.8	2.4%	0.7%	52.6	49.9	50.9	5.1%	3.1%
4.5	48.7	46.7	47.6	4.1%	2.3%	59.7	55.2	56.4	7.6%	5.6%	73.9	67.0	68.3	9.2%	7.5%
5	57.7	55.0	55.9	4.7%	3.0%	75.6	70.0	71.2	7.5%	5.8%	98.6	90.3	91.6	8.4%	7.1%
5.5	69.5	66.0	67.0	5.1%	3.7%	96.7	89.4	90.8	7.5%	6.1%	131.6	120.7	122.2	8.3%	7.2%
6	81.2	73.5	74.9	9.4%	7.7%	117.4	104.0	105.6	11.3%	10.1%	163.9	145.0	146.2	11.5%	10.8%
6.5	85.3	72.8	74.0	14.6%	13.3%	127.3	108.1	108.3	15.1%	14.9%	179.5	154.1	152.6	14.1%	15.0%
7	80.8	67.1	67.3	17.0%	16.7%	122.8	103.0	100.8	16.1%	17.9%	172.3	148.1	142.7	14.0%	17.2%
7.5	74.8	61.3	60.9	18.1%	18.7%	109.8	92.2	88.6	16.0%	19.3%	153.1	133.1	125.5	13.0%	18.0%
8	70.4	57.1	56.4	18.8%	19.9%	97.9	82.5	78.5	15.8%	19.9%	132.4	116.6	108.8	11.9%	17.8%
8.5	67.7	54.7	53.7	19.2%	20.7%	89.9	75.9	71.8	15.5%	20.0%	117.0	104.0	96.6	11.2%	17.4%
9	65.0	52.2	50.9	19.6%	21.7%	84.6	71.6	67.4	15.4%	20.3%	106.8	95.3	88.3	10.8%	17.4%
9.5	62.0	49.5	48.0	20.1%	22.6%	80.9	68.5	64.3	15.3%	20.5%	99.8	89.3	82.4	10.5%	17.4%
10	59.1	47.0	45.2	20.5%	23.5%	78.1	66.1	61.9	15.3%	20.7%	94.7	84.9	78.1	10.3%	17.5%

14.1.1.4 U = 7kn

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	41.0	43.8	43.1	45.3	46.8	47.8
4.5	41.6	44.3	46.4	47.4	54.1	52.6
5	42.4	44.9	50.1	50.7	62.4	60.0
5.5	43.4	45.5	54.9	54.7	74.4	70.6
6	44.2	45.8	58.8	56.0	87.8	78.4
6.5	44.7	45.7	59.8	54.3	94.8	77.9
7	44.9	45.3	59.0	51.9	91.5	72.2
7.5	44.9	44.7	58.7	50.1	85.2	66.0
8	44.7	44.0	58.0	48.1	80.2	61.5
8.5	44.4	43.4	56.8	46.1	77.2	58.7
9	44.0	42.7	55.4	44.2	74.3	56.1
9.5	43.7	42.1	54.0	42.5	71.1	53.3
10	43.3	41.6	52.6	41.0	67.9	50.6

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	41.1	43.9	43.7	45.8	47.9	48.9
4.5	41.7	44.4	47.0	48.2	55.5	54.3
5	42.5	44.9	50.3	50.9	62.8	60.4
5.5	43.4	45.3	54.8	54.1	74.1	69.3
6	44.1	45.4	58.3	54.3	86.8	74.3
6.5	44.5	45.2	58.9	52.1	92.0	72.5
7	44.6	44.7	57.9	49.8	87.6	67.0
7.5	44.6	44.1	57.5	48.0	81.4	61.4
8	44.3	43.4	56.6	46.0	76.7	57.5
8.5	44.0	42.8	55.4	44.2	74.0	55.2
9	43.7	42.2	54.0	42.4	71.2	52.8
9.5	43.4	41.6	52.7	40.8	68.2	50.3
10	43.0	41.2	51.3	39.4	65.2	47.8

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	41.3	44.2	44.9	47.2	50.8	52.2
4.5	42.0	44.6	48.6	49.8	59.0	58.0
5	42.6	44.6	50.8	50.7	64.0	60.0
5.5	43.2	44.5	54.4	50.0	73.3	60.7
6	43.6	44.2	56.4	48.0	81.9	61.3
6.5	43.8	43.6	55.7	45.7	81.7	58.9
7	43.8	43.0	54.5	43.9	75.8	54.7
7.5	43.6	42.3	53.7	42.3	70.7	51.1
8	43.4	41.7	52.7	40.7	67.3	48.4
8.5	43.1	41.2	51.5	39.3	65.2	46.9
9	42.8	40.7	50.3	38.0	62.9	45.1
9.5	42.5	40.3	49.2	36.9	60.4	43.1
10	42.2	40.0	48.1	36.0	58.0	41.3

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	41.4	44.0	45.2	46.7	51.3	50.9
4.5	41.9	43.6	48.4	46.0	58.6	50.7
5	42.1	42.9	49.5	41.8	61.1	46.5
5.5	42.4	42.3	50.6	40.2	64.6	46.6
6	42.4	41.7	50.1	39.1	64.7	46.5
6.5	42.4	41.1	49.0	37.8	61.3	43.8
7	42.3	40.6	48.2	37.0	57.8	41.4
7.5	42.1	40.2	47.5	36.1	55.4	39.7
8	41.9	39.9	46.6	35.2	53.7	38.4
8.5	41.7	39.7	45.9	34.5	52.6	37.5
9	41.5	39.5	45.2	33.9	51.3	36.4
9.5	41.3	39.4	44.5	33.4	49.8	35.3
10	41.2	39.3	43.9	33.0	48.5	34.2

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	41.1	43.6	44.0	45.0	48.6	47.5
4.5	41.2	42.7	45.6	45.0	52.3	48.3
5	41.1	43.1	44.1	42.2	49.0	42.2
5.5	41.0	42.9	43.0	39.6	46.3	36.7
6	40.9	42.4	42.5	38.2	44.6	34.1
6.5	40.8	42.1	42.2	37.3	43.7	32.2
7	40.7	41.7	42.1	36.7	43.3	31.3
7.5	40.6	41.4	41.8	35.9	43.0	31.0
8	40.6	41.2	41.5	35.1	42.6	30.3
8.5	40.5	41.0	41.2	34.6	42.4	29.6
9	40.5	40.8	41.1	34.1	42.1	28.9
9.5	40.4	40.7	40.9	33.7	41.8	28.4
10	40.4	40.6	40.8	33.4	41.5	28.1

Total ship resistance at higher seas: Unfoiled, passively foiled and pitch foiled U = 6kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Rts Tp [s]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled
4	46.8	47.8	49.1	-2.3%	-5.0%	51.8	51.4	53.1	0.8%	-2.4%	58.3	56.1	58.2	3.8%	0.1%
4.5	54.1	52.6	54.5	2.7%	-0.8%	64.8	60.3	62.8	6.9%	3.0%	78.6	71.2	74.0	9.5%	5.8%
5	62.4	60.0	61.9	3.9%	0.8%	79.6	73.5	76.2	7.7%	4.4%	101.8	92.0	95.0	9.6%	6.7%
5.5	74.4	70.5	72.6	5.2%	2.4%	101.0	92.3	95.1	8.6%	5.8%	135.1	121.4	124.6	10.2%	7.8%
6	87.8	78.4	81.1	10.7%	7.6%	124.8	107.4	110.7	14.0%	11.3%	172.3	146.4	149.8	15.0%	13.1%
6.5	94.8	78.0	80.9	17.7%	14.6%	140.2	112.6	114.8	19.7%	18.1%	196.4	158.5	158.7	19.3%	19.2%
7	91.5	72.3	74.1	21.0%	19.0%	139.1	109.2	108.0	21.5%	22.3%	194.7	156.2	150.8	19.8%	22.6%
7.5	85.2	66.1	67.1	22.4%	21.3%	125.9	98.8	95.4	21.5%	24.2%	175.7	143.2	134.1	18.5%	23.7%
8	80.2	61.6	62.0	23.2%	22.7%	112.3	88.5	84.3	21.1%	24.9%	152.9	126.6	116.8	17.2%	23.6%
8.5	77.2	58.9	58.9	23.7%	23.7%	102.9	81.3	76.9	21.0%	25.2%	134.8	112.8	103.5	16.4%	23.2%
9	74.3	56.2	55.8	24.3%	24.9%	96.8	76.5	71.9	21.0%	25.7%	122.7	102.9	94.0	16.2%	23.4%
9.5	71.1	53.4	52.5	24.9%	26.1%	92.6	73.2	68.5	21.0%	26.1%	114.6	96.3	87.5	15.9%	23.6%
10	67.9	50.7	49.5	25.4%	27.1%	89.5	70.7	65.9	21.0%	26.4%	108.7	91.7	82.9	15.7%	23.8%

14.1.1.5 U = 8kn

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	47.9	51.6	50.1	53.2	53.7	55.7
4.5	48.6	52.1	53.2	55.1	60.7	60.0
5	49.4	52.7	56.7	58.0	68.5	66.5
5.5	50.4	53.3	61.6	61.9	80.4	76.5
6	51.3	53.5	66.1	63.3	95.2	84.6
6.5	51.9	53.5	68.0	61.7	105.2	84.5
7	52.2	53.1	67.4	59.2	103.6	78.8
7.5	52.2	52.5	67.3	57.3	97.2	72.2
8	52.1	51.8	66.7	55.1	91.7	67.2
8.5	51.8	51.1	65.5	52.9	88.2	64.2
9	51.4	50.4	64.1	50.9	85.2	61.4
9.5	51.1	49.8	62.6	48.9	81.8	58.3
10	50.7	49.3	61.1	47.2	78.4	55.4

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	48.0	51.7	50.7	53.7	55.0	56.9
4.5	48.7	52.2	54.0	55.9	62.4	61.8
5	49.4	52.7	57.0	58.3	69.3	67.2
5.5	50.4	53.1	61.7	61.4	80.8	75.7
6	51.2	53.2	66.0	61.8	95.1	80.8
6.5	51.7	53.0	67.2	59.6	103.2	79.1
7	51.9	52.5	66.4	57.1	99.9	73.5
7.5	51.9	51.9	66.1	55.1	93.3	67.5
8	51.7	51.2	65.3	52.9	88.0	63.1
8.5	51.4	50.5	64.1	50.9	84.9	60.5
9	51.1	49.9	62.7	48.9	82.0	57.9
9.5	50.7	49.3	61.2	47.2	78.7	55.1
10	50.3	48.8	59.7	45.7	75.4	52.4

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	48.3	52.1	52.0	55.2	58.1	60.3
4.5	49.0	52.5	55.7	57.8	66.4	66.0
5	49.6	52.5	57.9	58.4	71.3	67.5
5.5	50.3	52.4	61.9	57.6	81.4	67.6
6	50.8	52.0	64.6	55.5	92.1	67.3
6.5	51.1	51.4	64.2	52.9	93.4	64.5
7	51.1	50.8	62.9	50.9	87.3	60.0
7.5	50.9	50.1	62.1	49.0	81.4	56.0
8	50.7	49.4	61.0	47.1	77.5	53.1
8.5	50.4	48.9	59.8	45.5	75.2	51.4
9	50.0	48.4	58.5	44.1	72.7	49.4
9.5	49.7	48.0	57.3	42.9	69.9	47.3
10	49.4	47.7	56.1	41.9	67.3	45.3

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	48.4	51.9	52.3	54.7	58.8	59.2
4.5	48.9	51.5	55.7	54.0	66.3	58.5
5	49.2	50.8	56.9	49.1	69.0	52.3
5.5	49.5	50.1	58.3	47.0	73.3	51.4
6	49.6	49.5	57.8	45.7	73.7	50.9
6.5	49.5	48.8	56.7	44.2	70.1	65.3
7	49.4	48.3	55.8	43.2	66.2	45.0
7.5	49.2	47.9	55.0	42.1	63.6	43.3
8	48.9	47.6	54.1	41.1	61.8	41.9
8.5	48.7	47.3	53.3	40.3	60.6	41.0
9	48.5	47.1	52.5	39.7	59.2	39.8
9.5	48.4	47.0	51.8	39.2	57.6	38.6
10	48.2	46.9	51.2	38.8	56.2	37.5

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	48.1	51.5	51.1	52.9	56.0	55.4
4.5	48.2	51.3	52.8	52.9	59.8	55.8
5	48.0	50.9	51.3	49.8	56.3	49.1
5.5	48.0	50.5	50.1	46.9	53.5	42.8
6	47.9	50.0	49.6	45.4	51.7	39.6
6.5	47.8	49.6	49.3	44.5	50.8	50.8
7	47.7	49.3	49.1	43.8	50.4	36.4
7.5	47.6	49.0	48.8	42.9	50.1	36.2
8	47.5	48.8	48.5	42.1	49.7	35.3
8.5	47.5	48.6	48.2	41.5	49.5	34.5
9	47.4	48.5	48.1	41.0	49.1	33.8
9.5	47.4	48.4	47.9	40.6	48.8	33.1
10	47.4	48.3	47.8	40.3	48.5	32.7

Total ship resistance at higher seas: Unfoiled, passively foiled and pitch foiled U = 6kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Rts Tp [s]	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled	Unfoiled [kN]	Passively foiled [kN]	Pitching foiled [kN]	Savings passive foiled	Savings pitch foiled
4	53.7	55.7	57.9	-3.6%	-7.7%	58.8	59.2	61.9	-0.6%	-5.3%	65.4	63.8	67.2	2.4%	-2.8%
4.5	60.7	60.0	63.0	1.1%	-3.8%	71.2	67.2	71.1	5.6%	0.1%	84.7	77.1	81.8	9.0%	3.5%
5	68.5	66.5	69.6	3.0%	-1.7%	85.1	78.8	83.0	7.4%	2.5%	106.4	95.6	100.4	10.1%	5.6%
5.5	80.4	76.5	79.8	4.9%	0.8%	106.3	96.6	101.0	9.1%	5.0%	139.5	123.5	128.6	11.5%	7.8%
6	95.2	84.6	88.8	11.1%	6.7%	132.5	111.9	117.3	15.5%	11.5%	180.5	148.9	154.8	17.5%	14.3%
6.5	105.2	84.6	89.6	19.5%	14.8%	153.5	118.0	122.9	23.1%	20.0%	213.3	162.9	166.0	23.6%	22.2%
7	103.6	78.9	83.0	23.8%	19.9%	157.1	116.0	117.0	26.1%	25.5%	218.8	164.1	160.0	25.0%	26.9%
7.5	97.2	72.4	75.4	25.6%	22.5%	144.2	106.1	103.8	26.4%	28.0%	201.3	152.9	143.4	24.0%	28.8%
8	91.7	67.4	69.7	26.5%	23.9%	128.8	95.0	91.4	26.3%	29.1%	176.3	136.2	124.8	22.7%	29.2%
8.5	88.2	64.4	66.2	27.0%	25.0%	117.9	87.2	83.1	26.0%	29.5%	155.2	121.5	110.4	21.7%	28.8%
9	85.2	61.5	62.8	27.8%	26.4%	110.8	81.9	77.5	26.1%	30.0%	141.0	110.9	100.0	21.3%	29.1%
9.5	81.8	58.4	59.1	28.6%	27.8%	106.2	78.4	73.8	26.2%	30.5%	131.5	103.7	92.9	21.2%	29.4%
10	78.4	55.5	55.8	29.2%	28.9%	102.7	75.8	70.9	26.2%	30.9%	124.7	98.4	87.8	21.1%	29.6%

Appendic C-II: Wind resistance omitted

14.1.1.6 U = 4kn

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	7.1	7.9	9.2	9.4	12.8	12.0
4.5	7.9	8.5	13.0	12.2	21.3	18.9
5	8.6	9.2	17.4	16.7	31.3	28.9
5.5	9.3	9.8	21.6	20.8	42.4	40.2
6	9.8	10.1	23.1	21.6	50.0	46.9
6.5	10.1	10.1	22.4	20.0	49.5	45.3
7	10.1	9.8	21.3	18.3	43.9	39.3
7.5	9.9	9.3	20.6	17.2	38.7	34.1
8	9.7	8.8	19.5	15.8	35.2	30.6
8.5	9.4	8.3	18.4	14.4	33.0	28.5
9	9.1	7.7	17.1	13.0	30.6	26.3
9.5	8.8	7.3	16.0	11.7	28.0	23.8
10	8.5	6.8	14.8	10.5	25.5	21.4

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	7.2	8.0	9.7	9.8	13.8	12.9
4.5	7.9	8.6	13.3	12.7	22.1	19.9
5	8.5	9.1	17.0	16.4	30.4	28.2
5.5	9.2	9.6	20.6	19.6	40.0	37.4
6	9.6	9.7	21.8	19.7	46.3	42.3
6.5	9.7	9.6	21.0	18.1	45.2	40.1
7	9.7	9.2	19.9	16.5	39.8	34.7
7.5	9.6	8.8	19.2	15.4	35.2	30.2
8	9.3	8.2	18.2	14.1	32.1	27.2
8.5	9.0	7.7	17.1	12.8	30.1	25.5
9	8.8	7.3	15.9	11.6	27.9	23.5
9.5	8.5	6.8	14.9	10.5	25.5	21.3
10	8.2	6.5	13.9	9.5	23.2	19.3

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	7.3	8.2	10.5	11.0	15.8	14.8
4.5	7.9	8.7	14.0	13.9	23.6	21.3
5	8.3	8.8	16.2	15.6	28.5	25.7
5.5	8.8	8.9	18.4	16.1	34.7	30.8
6	9.0	8.7	18.7	15.2	37.7	32.1
6.5	9.0	8.3	17.7	13.7	35.1	28.8
7	8.9	7.9	16.7	12.6	30.7	24.6
7.5	8.8	7.4	16.0	11.7	27.3	21.5
8	8.5	6.9	15.1	10.6	25.1	19.6
8.5	8.3	6.5	14.2	9.7	23.7	18.4
9	8.1	6.2	13.3	8.8	21.9	16.9
9.5	7.9	5.9	12.4	8.0	20.1	15.4
10	7.7	5.6	11.7	7.3	18.4	14.0

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	7.3	7.9	10.6	10.2	15.9	14.1
4.5	7.8	7.6	13.5	10.5	22.4	17.5
5	7.9	7.2	14.3	9.6	24.3	18.3
5.5	8.1	6.9	14.7	9.5	26.0	20.2
6	8.1	6.5	14.1	9.1	25.3	20.2
6.5	8.1	6.2	13.3	8.3	22.6	18.1
7	7.9	5.9	12.7	7.8	20.0	15.9
7.5	7.8	5.6	12.1	7.3	18.3	14.3
8	7.6	5.4	11.4	6.7	17.0	13.2
8.5	7.5	5.2	10.8	6.1	16.1	12.5
9	7.3	5.0	10.2	5.6	15.1	11.6
9.5	7.2	4.9	9.7	5.1	13.9	10.6
10	7.1	4.8	9.3	4.7	12.9	9.7

	Total ship resistance [kN]					
	Ship speed: 4kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	7.1	7.7	9.5	9.0	13.4	11.9
4.5	7.2	7.6	10.9	9.6	16.6	13.8
5	7.0	7.3	9.7	7.6	13.9	10.1
5.5	7.0	7.0	8.7	5.9	11.6	7.0
6	6.9	6.7	8.3	5.1	10.1	5.8
6.5	6.8	6.4	8.1	4.7	9.3	4.8
7	6.8	6.2	7.9	4.3	9.0	4.3
7.5	6.7	6.0	7.7	3.8	8.7	4.1
8	6.6	5.8	7.4	3.4	8.4	3.7
8.5	6.6	5.7	7.2	3.0	8.2	3.4
9	6.5	5.5	7.1	2.7	7.9	3.2
9.5	6.5	5.4	6.9	2.5	7.7	3.1
10	6.5	5.3	6.9	2.4	7.5	3.1

14.1.1.7 U = 5kn

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	9.9	11.3	12.1	12.8	15.7	15.4
4.5	10.7	11.9	15.7	15.3	23.7	21.4
5	11.5	12.6	19.9	19.4	33.2	30.6
5.5	12.3	13.2	24.3	23.6	44.8	41.8
6	12.8	13.4	26.6	24.5	54.4	49.0
6.5	13.2	13.4	26.4	22.8	55.9	47.8
7	13.2	13.0	25.3	20.9	50.8	42.0
7.5	13.1	12.5	24.7	19.5	45.2	36.4
8	12.9	11.9	23.7	17.9	41.3	32.7
8.5	12.6	11.3	22.5	16.3	38.8	30.4
9	12.2	10.8	21.3	14.8	36.3	28.1
9.5	11.9	10.2	20.0	13.4	33.5	25.5
10	11.6	9.8	18.8	12.1	30.8	23.2

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	10.0	11.4	12.6	13.3	16.7	16.4
4.5	10.7	11.9	16.1	15.8	24.8	22.4
5	11.4	12.5	19.7	19.1	32.7	29.9
5.5	12.1	13.0	23.6	22.7	43.1	39.7
6	12.6	13.2	25.6	23.2	51.6	45.4
6.5	12.9	13.0	25.1	21.3	52.0	43.3
7	12.9	12.7	24.0	19.4	46.7	37.5
7.5	12.8	12.1	23.3	18.0	41.6	32.4
8	12.5	11.5	22.3	16.4	38.0	29.1
8.5	12.2	11.0	21.2	14.9	35.9	27.1
9	11.9	10.4	20.0	13.4	33.5	25.0
9.5	11.6	9.9	18.9	12.1	30.9	22.7
10	11.4	9.5	17.8	10.9	28.4	20.6

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	10.2	11.7	13.6	14.5	9.8	10.0
4.5	10.9	12.1	17.1	17.3	17.8	16.2
5	11.3	12.2	19.3	18.5	22.7	19.1
5.5	11.8	12.1	22.0	18.3	30.0	21.6
6	12.1	11.8	22.7	17.0	34.6	23.3
6.5	12.2	11.4	21.8	15.3	32.5	21.3
7	12.1	10.9	20.7	14.0	27.6	17.6
7.5	11.9	10.3	20.0	12.9	23.7	14.5
8	11.7	9.8	19.0	11.8	21.2	12.4
8.5	11.4	9.4	18.0	10.8	19.5	11.1
9	11.2	9.0	17.1	9.9	17.6	9.6
9.5	11.0	8.6	16.1	9.0	15.6	7.9
10	10.7	8.4	15.3	8.2	13.7	6.3

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	10.3	11.4	13.7	13.8	19.2	17.7
4.5	10.7	11.1	16.7	13.6	26.0	19.7
5	10.9	10.5	17.6	11.5	28.1	19.1
5.5	11.1	10.1	18.2	11.0	30.4	20.7
6	11.1	9.6	17.6	10.3	29.8	20.8
6.5	11.1	9.1	16.7	9.4	26.9	18.6
7	10.9	8.8	16.0	8.8	24.1	16.3
7.5	10.8	8.4	15.4	8.1	22.1	14.7
8	10.6	8.2	14.7	7.5	20.7	13.5
8.5	10.4	8.0	14.0	6.9	19.8	12.8
9	10.3	7.8	13.4	6.4	18.6	11.8
9.5	10.1	7.7	12.8	5.9	17.4	10.8
10	10.0	7.6	12.4	5.5	16.3	9.8

	Total ship resistance [kN]					
	Ship speed: 5kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	10.0	11.1	12.6	12.4	16.7	15.1
4.5	10.1	11.0	14.0	12.8	20.0	16.6
5	10.0	10.7	12.7	10.5	17.1	12.2
5.5	9.9	10.3	11.7	8.5	14.7	8.3
6	9.8	10.0	11.3	7.5	13.2	6.7
6.5	9.7	9.7	11.0	6.8	12.4	5.4
7	9.6	9.4	10.9	6.4	12.0	4.8
7.5	9.6	9.2	10.6	5.8	11.7	4.6
8	9.5	9.0	10.3	5.2	11.4	4.1
8.5	9.5	8.8	10.1	4.7	11.2	3.7
9	9.4	8.7	10.0	4.4	10.9	3.3
9.5	9.4	8.6	9.8	4.1	10.6	3.1
10	9.4	8.5	9.7	3.8	10.4	3.0

14.1.1.8 U = 6kn

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	13.4	15.4	15.5	16.9	19.1	19.4
4.5	14.1	15.9	18.9	19.2	26.8	24.8
5	14.9	16.6	22.9	22.9	35.7	33.0
5.5	15.7	17.2	27.6	27.0	47.6	44.1
6	16.4	17.4	30.7	28.1	59.2	51.6
6.5	16.8	17.4	31.0	26.3	63.3	50.8
7	17.0	17.0	30.0	24.2	58.8	45.0
7.5	16.9	16.4	29.6	22.6	52.9	39.2
8	16.7	15.8	28.7	20.8	48.4	35.1
8.5	16.4	15.2	27.5	19.0	45.7	32.6
9	16.0	14.5	26.1	17.3	43.0	30.2
9.5	15.7	14.0	24.8	15.7	40.0	27.5
10	15.4	13.5	23.5	14.3	37.1	24.9

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	13.5	15.5	16.0	17.4	20.2	20.5
4.5	14.2	16.0	19.5	19.9	28.0	26.3
5	14.9	16.6	22.9	23.0	35.7	33.2
5.5	15.7	17.0	27.2	26.2	46.6	42.3
6	16.2	17.1	29.9	26.3	57.3	47.2
6.5	16.6	16.9	29.9	24.2	59.9	45.5
7	16.7	16.4	28.8	22.1	54.9	40.1
7.5	16.5	15.8	28.2	20.5	49.1	34.9
8	16.3	15.2	27.3	18.8	45.1	31.4
8.5	16.0	14.6	26.1	17.1	42.6	29.2
9	15.7	14.0	24.8	15.6	40.1	27.0
9.5	15.4	13.5	23.6	14.1	37.3	24.5
10	15.1	13.0	22.4	12.9	34.5	22.3

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	13.7	15.8	17.2	18.7	20.2	23.6
4.5	14.3	16.2	20.8	21.4	27.9	30.2
5	14.9	16.2	23.0	22.4	35.0	33.7
5.5	15.4	16.2	26.1	21.9	44.7	37.9
6	15.8	15.8	27.4	20.3	53.2	40.9
6.5	15.9	15.3	26.6	18.3	55.0	38.3
7	15.8	14.7	25.4	16.7	50.8	33.1
7.5	15.7	14.1	24.7	15.4	45.9	29.0
8	15.4	13.6	23.7	14.1	42.3	26.2
8.5	15.1	13.1	22.6	12.9	40.1	24.6
9	14.9	12.6	21.5	11.8	37.8	22.6
9.5	14.6	12.3	20.5	10.8	35.2	20.5
10	14.4	12.0	19.6	9.9	32.7	18.6

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	13.7	15.5	17.3	18.1	23.2	22.1
4.5	14.2	15.2	20.5	17.5	30.2	22.8
5	14.4	14.6	21.5	14.4	32.5	20.6
5.5	14.6	14.0	22.3	13.3	35.4	21.5
6	14.7	13.4	21.8	12.5	35.1	21.6
6.5	14.6	12.9	20.7	11.4	31.9	19.3
7	14.5	12.5	20.0	10.7	28.7	17.0
7.5	14.3	12.1	19.3	9.9	26.6	15.3
8	14.1	11.8	18.5	9.1	25.1	14.0
8.5	13.9	11.6	17.8	8.4	24.1	13.2
9	13.8	11.4	17.2	7.8	22.8	12.2
9.5	13.6	11.3	16.6	7.3	21.5	11.0
10	13.5	11.2	16.0	6.9	20.3	10.0

	Total ship resistance [kN]					
	Ship speed: 6kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	13.4	15.2	16.2	16.5	20.6	19.1
4.5	13.6	15.1	17.7	16.7	24.0	20.3
5	13.4	14.7	16.3	14.2	21.0	15.0
5.5	13.4	14.3	15.3	11.8	18.4	10.2
6	13.3	13.9	14.8	10.6	16.8	8.2
6.5	13.2	13.6	14.5	9.8	15.9	6.6
7	13.1	13.3	14.4	9.3	15.5	5.8
7.5	13.0	13.0	14.1	8.6	15.2	5.6
8	12.9	12.8	13.8	7.9	14.9	5.0
8.5	12.9	12.7	13.6	7.3	14.7	4.4
9	12.8	12.5	13.4	6.9	14.4	3.9
9.5	12.8	12.4	13.3	6.6	14.1	3.5
10	12.8	12.3	13.2	6.3	13.9	3.3

14.1.1.9 U = 7kn

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	17.8	20.6	20.0	22.1	23.6	24.7
4.5	18.5	21.1	23.2	24.2	30.9	29.5
5	19.3	21.7	26.9	27.5	39.2	36.8
5.5	20.2	22.3	31.8	31.5	51.2	47.4
6	21.0	22.6	35.6	32.8	64.6	55.3
6.5	21.5	22.5	36.7	31.1	71.6	54.8
7	21.7	22.1	35.8	28.7	68.3	49.0
7.5	21.7	21.5	35.6	26.9	62.0	42.8
8	21.5	20.9	34.8	24.9	57.0	38.3
8.5	21.2	20.2	33.6	23.0	54.0	35.6
9	20.9	19.5	32.2	21.1	51.2	33.0
9.5	20.5	18.9	30.8	19.3	47.9	30.1
10	20.2	18.4	29.4	17.8	44.8	27.4

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	17.9	20.7	20.5	22.6	24.8	25.8
4.5	18.6	21.2	23.9	25.0	32.4	31.1
5	19.3	21.7	27.1	27.7	39.6	37.3
5.5	20.2	22.1	31.7	30.9	51.0	46.1
6	20.9	22.3	35.2	31.1	63.6	51.1
6.5	21.3	22.0	35.7	28.9	68.8	49.3
7	21.5	21.5	34.7	26.6	64.4	43.8
7.5	21.4	20.9	34.3	24.8	58.2	38.3
8	21.2	20.2	33.4	22.9	53.6	34.4
8.5	20.9	19.6	32.2	21.0	50.8	32.0
9	20.5	19.0	30.9	19.2	48.1	29.7
9.5	20.2	18.4	29.5	17.7	45.0	27.1
10	19.9	18.0	28.2	16.2	42.0	24.6

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	18.2	21.0	21.8	24.1	27.6	29.0
4.5	18.8	21.4	25.4	26.7	35.8	34.8
5	19.4	21.5	27.6	27.5	40.8	36.8
5.5	20.0	21.4	31.2	26.8	50.1	37.6
6	20.5	21.0	33.2	24.9	58.7	38.1
6.5	20.6	20.4	32.5	22.5	58.5	35.7
7	20.6	19.8	31.3	20.8	52.7	31.5
7.5	20.4	19.1	30.5	19.1	47.5	27.9
8	20.2	18.5	29.5	17.5	44.1	25.3
8.5	19.9	18.0	28.3	16.1	42.0	23.7
9	19.6	17.5	27.2	14.9	39.7	21.9
9.5	19.3	17.2	26.0	13.8	37.2	20.0
10	19.1	16.9	25.0	12.8	34.8	18.1

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	18.2	20.8	22.0	23.5	28.1	27.7
4.5	18.7	20.4	25.2	22.8	35.4	27.5
5	18.9	19.8	26.4	18.7	38.0	23.3
5.5	19.2	19.1	27.4	17.1	41.4	23.4
6	19.3	18.5	26.9	15.9	41.5	23.3
6.5	19.2	17.9	25.8	14.7	38.1	20.6
7	19.1	17.4	25.0	13.8	34.6	18.2
7.5	18.9	17.0	24.3	12.9	32.2	16.6
8	18.7	16.7	23.5	12.0	30.5	15.2
8.5	18.5	16.5	22.7	11.3	29.5	14.3
9	18.3	16.3	22.0	10.7	28.1	13.2
9.5	18.1	16.2	21.3	10.2	26.6	12.1
10	18.0	16.1	20.8	9.8	25.3	11.0

	Total ship resistance [kN]					
	Ship speed: 7kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	17.8	20.3	20.0	21.0	23.6	22.4
4.5	18.5	20.7	23.2	22.5	30.9	26.7
5	19.3	21.1	26.9	24.7	39.2	31.8
5.5	20.2	21.6	31.8	27.4	51.2	39.6
6	21.0	21.9	35.6	29.4	64.6	49.2
6.5	21.5	22.1	36.7	29.5	71.6	52.9
7	21.7	22.0	35.8	28.4	68.3	49.5
7.5	21.7	21.8	35.6	27.6	62.0	44.5
8	21.5	21.5	34.8	26.4	57.0	40.0
8.5	21.2	21.1	33.6	25.0	54.0	36.8
9	20.9	20.7	32.2	23.5	51.2	34.0
9.5	20.5	20.3	30.8	22.0	47.9	31.0
10	20.2	20.0	29.4	20.6	44.8	28.2

14.1.1.10 *U = 8kn*

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 0					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	23.5	27.2	25.7	28.8	29.3	31.3
4.5	24.1	27.7	28.8	30.7	36.3	35.6
5	25.0	28.3	32.3	33.6	44.1	42.1
5.5	26.0	28.8	37.2	37.4	56.0	52.1
6	26.8	29.1	41.7	38.9	70.8	60.2
6.5	27.5	29.1	43.5	37.3	80.8	60.1
7	27.8	28.7	43.0	34.8	79.2	54.4
7.5	27.8	28.1	42.9	32.9	72.8	47.8
8	27.7	27.4	42.3	30.7	67.3	42.8
8.5	27.4	26.7	41.1	28.5	63.8	39.8
9	27.0	26.0	39.7	26.4	60.8	37.0
9.5	26.6	25.4	38.2	24.5	57.4	33.9
10	26.3	24.9	36.7	22.8	54.0	31.0

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 22.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	23.6	27.3	26.3	29.3	30.6	32.5
4.5	24.3	27.8	29.5	31.5	38.0	37.4
5	25.0	28.3	32.6	33.9	44.8	42.8
5.5	26.0	28.7	37.3	37.0	56.3	51.3
6	26.8	28.8	41.6	37.4	70.7	56.4
6.5	27.3	28.6	42.8	35.2	78.8	54.7
7	27.5	28.1	42.0	32.7	75.5	49.1
7.5	27.5	27.5	41.7	30.7	68.9	43.1
8	27.3	26.8	40.9	28.5	63.6	38.7
8.5	27.0	26.1	39.7	26.4	60.5	36.1
9	26.7	25.5	38.3	24.5	57.6	33.5
9.5	26.3	24.9	36.8	22.8	54.3	30.7
10	25.9	24.4	35.3	21.3	51.0	28.0

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 45					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	23.9	27.7	27.6	30.8	33.7	35.9
4.5	24.6	28.0	31.3	33.4	42.0	41.6
5	25.2	28.1	33.5	34.0	46.9	43.1
5.5	25.9	28.0	37.5	33.2	57.0	43.2
6	26.4	27.6	40.1	31.1	67.7	42.9
6.5	26.7	27.0	39.8	28.5	69.0	40.1
7	26.7	26.3	38.4	26.5	62.9	35.6
7.5	26.5	25.7	37.7	24.6	57.0	31.6
8	26.3	25.0	36.6	22.7	53.1	28.7
8.5	26.0	24.4	35.4	21.1	50.8	27.0
9	25.6	24.0	34.1	19.7	48.3	25.0
9.5	25.3	23.6	32.9	18.5	45.5	22.9
10	25.0	23.3	31.7	17.5	42.8	20.9

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 67.5					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	24.0	27.5	27.9	30.3	34.4	34.8
4.5	24.5	27.1	31.3	29.6	41.9	34.1
5	24.8	26.4	32.5	24.7	44.6	27.9
5.5	25.0	25.7	33.9	22.6	48.8	27.0
6	25.1	25.1	33.4	21.3	49.3	26.5
6.5	25.1	24.4	32.3	19.8	45.7	23.2
7	24.9	23.9	31.4	18.8	41.8	20.6
7.5	24.8	23.5	30.6	17.7	39.2	18.9
8	24.5	23.1	29.7	16.7	37.4	17.5
8.5	24.3	22.9	28.9	15.9	36.2	16.6
9	24.1	22.7	28.1	15.3	34.7	15.4
9.5	24.0	22.6	27.4	14.8	33.2	14.2
10	23.8	22.5	26.8	14.3	31.8	13.1

	Total ship resistance [kN]					
	Ship speed: 8kn					
	Wave heading: 90					
	Hs = 1m		Hs = 2m		Hs = 3m	
Tp [s]	Unfoiled	Foiled	Unfoiled	Foiled	Unfoiled	Foiled
4	23.7	27.1	26.7	28.5	31.6	31.0
4.5	23.8	26.9	28.4	28.5	35.4	31.4
5	23.6	26.5	26.9	25.4	31.9	24.7
5.5	23.6	26.1	25.7	22.5	29.1	18.4
6	23.5	25.6	25.1	21.0	27.3	15.2
6.5	23.4	25.2	24.9	20.1	26.4	13.1
7	23.3	24.9	24.7	19.4	26.0	12.0
7.5	23.2	24.6	24.4	18.5	25.6	11.8
8	23.1	24.4	24.0	17.7	25.3	10.9
8.5	23.1	24.2	23.8	17.1	25.1	10.1
9	23.0	24.1	23.7	16.6	24.7	9.4
9.5	23.0	24.0	23.5	16.2	24.4	8.7
10	22.9	23.9	23.4	15.9	24.1	8.3

Appendix D: Foil thrust: Passive

U = 4kn

Mean thrust at 4kn, beta = 0					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-0.80	-0.16	0.79	1.83	2.74
4.5	-0.67	0.80	2.35	3.49	4.14
5	-0.62	0.79	2.37	3.54	4.27
5.5	-0.47	0.82	2.30	3.53	4.34
6	-0.24	1.65	3.36	4.50	5.18
6.5	0.03	2.56	4.67	5.66	6.21
7	0.33	3.10	5.15	5.95	6.11
7.5	0.62	3.55	5.15	5.40	5.05
8	0.89	3.88	5.00	4.71	3.89
8.5	1.13	4.11	4.83	4.15	3.07
9	1.34	4.27	4.66	3.72	2.45
9.5	1.52	4.36	4.46	3.36	1.90
10	1.66	4.43	4.26	3.08	1.49

Mean thrust at 4kn, beta = 22.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-0.80	-0.13	0.86	1.93	2.86
4.5	-0.69	0.61	2.10	3.30	4.08
5	-0.62	0.60	2.11	3.36	4.19
5.5	-0.42	0.91	2.42	3.66	4.47
6	-0.15	2.02	3.92	5.06	5.73
6.5	0.17	2.93	5.09	5.93	6.26
7	0.49	3.40	5.23	5.57	5.30
7.5	0.80	3.80	5.08	4.78	3.98
8	1.07	4.07	4.87	4.14	2.89
8.5	1.30	4.24	4.66	3.64	2.29
9	1.49	4.34	4.45	3.23	1.77
9.5	1.65	4.38	4.22	2.90	1.29
10	1.77	4.40	4.01	2.64	0.95

Mean thrust at 4kn, beta = 45					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-0.87	-0.47	0.18	0.99	1.83
4.5	-0.74	0.14	1.37	2.61	3.61
5	-0.48	0.64	2.20	3.53	4.45
5.5	-0.10	2.26	4.23	5.32	5.82
6	0.32	3.47	5.16	5.27	4.77
6.5	0.73	3.99	5.10	4.30	3.08
7	1.08	4.15	4.67	3.34	1.91
7.5	1.37	4.34	4.39	2.80	1.17
8	1.60	4.43	4.20	2.45	0.56
8.5	1.77	4.47	4.02	2.18	0.29
9	1.89	4.46	3.81	1.98	0.13
9.5	1.99	4.43	3.61	1.76	-0.17
10	2.06	4.40	3.44	1.55	-0.46

Mean thrust at 4kn, beta = 67.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-0.63	0.31	1.66	2.96	3.93
4.5	0.06	2.68	4.33	4.70	4.23
5	0.59	4.18	4.63	3.58	2.06
5.5	1.11	4.54	4.17	2.50	0.65
6	1.51	4.53	3.74	1.85	-0.11
6.5	1.79	4.55	3.59	1.43	-0.65
7	1.97	4.51	3.44	1.17	-0.92
7.5	2.09	4.49	3.32	1.19	-0.82
8	2.17	4.46	3.23	1.05	-1.04
8.5	2.22	4.44	3.13	0.90	-1.25
9	2.24	4.42	3.03	0.75	-1.41
9.5	2.25	4.39	2.95	0.62	-1.58
10	2.25	4.37	2.88	0.50	-1.71

Mean thrust at 4kn, beta = 90					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-0.60	0.50	1.54	2.29	2.76
4.5	-0.41	1.35	2.81	3.65	3.86
5	-0.25	2.05	3.75	4.21	3.82
5.5	-0.02	2.81	4.57	4.54	3.55
6	0.20	3.15	4.31	3.64	2.34
6.5	0.39	3.42	4.55	3.56	1.97
7	0.56	3.59	4.67	3.46	1.64
7.5	0.70	3.81	4.60	3.28	1.48
8	0.81	4.01	4.68	3.25	1.35
8.5	0.92	4.19	4.78	3.31	1.14
9	1.00	4.33	4.72	3.10	0.75
9.5	1.08	4.42	4.59	2.76	0.41
10	1.14	4.46	4.42	2.48	0.05

U = 5kn

Mean thrust at 5kn, beta = 0					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.36	-0.73	0.29	1.57	2.88
4.5	-1.22	0.30	2.26	4.13	5.48
5	-1.17	0.38	2.41	4.32	5.72
5.5	-0.97	0.45	2.36	4.31	5.82
6	-0.68	1.64	4.11	6.24	7.67
6.5	-0.32	3.09	6.58	8.52	9.52
7	0.08	3.99	7.60	9.04	9.20
7.5	0.47	4.78	7.82	8.35	7.65
8	0.83	5.40	7.77	7.48	5.97
8.5	1.14	5.84	7.64	6.82	4.96
9	1.40	6.15	7.50	6.33	4.30
9.5	1.62	6.35	7.29	5.89	3.64
10	1.79	6.48	7.06	5.50	3.09

Mean thrust at 5kn, beta = 22.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.36	-0.69	0.36	1.66	2.98
4.5	-1.25	0.12	1.95	3.77	5.20
5	-1.16	0.17	2.06	3.94	5.42
5.5	-0.91	0.58	2.54	4.55	6.11
6	-0.57	2.17	5.07	7.24	8.66
6.5	-0.15	3.62	7.30	8.99	9.56
7	0.27	4.42	7.87	8.63	8.12
7.5	0.67	5.12	7.81	7.70	6.41
8	1.03	5.65	7.62	6.89	4.97
8.5	1.32	5.99	7.40	6.22	4.12
9	1.57	6.22	7.21	5.76	3.53
9.5	1.76	6.36	6.98	5.37	2.97
10	1.92	6.45	6.77	5.05	2.50

Mean thrust at 5kn, beta = 45					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.42	-0.99	-0.28	0.67	1.75
4.5	-1.27	-0.31	1.16	2.84	4.40
5	-0.98	0.29	2.30	4.34	6.01
5.5	-0.52	2.50	5.55	7.56	8.60
6	0.01	4.44	7.61	8.25	7.70
6.5	0.53	5.39	8.05	7.33	5.59
7	0.99	5.74	7.63	6.01	3.80
7.5	1.37	6.14	7.28	5.29	2.83
8	1.67	6.38	7.07	4.92	2.08
8.5	1.89	6.51	6.87	4.61	1.77
9	2.06	6.58	6.65	4.37	1.60
9.5	2.18	6.61	6.45	4.10	1.27
10	2.26	6.63	6.28	3.86	0.93

Mean thrust at 5kn, beta = 67.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.18	-0.21	1.35	3.10	4.70
4.5	-0.44	2.72	5.50	6.89	7.04
5	0.19	5.22	7.04	6.50	4.86
5.5	0.83	6.16	7.09	5.44	3.03
6	1.36	6.42	6.65	4.49	1.80
6.5	1.74	6.59	6.64	4.02	1.01
7	2.02	6.62	6.39	3.51	0.48
7.5	2.19	6.69	6.23	3.44	0.48
8	2.30	6.71	6.17	3.34	0.19
8.5	2.37	6.70	6.08	3.23	0.04
9	2.39	6.68	5.98	3.12	-0.04
9.5	2.39	6.65	5.90	3.02	-0.16
10	2.38	6.62	5.85	2.91	-0.28

Mean thrust at 5kn, beta = 90					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.13	0.16	1.61	2.82	3.69
4.5	-0.90	1.27	3.39	4.94	5.73
5	-0.71	2.19	4.96	6.30	6.31
5.5	-0.43	3.25	6.44	7.28	6.48
6	-0.17	3.80	6.46	6.29	4.78
6.5	0.06	4.19	6.93	6.41	4.51
7	0.26	4.46	7.19	6.45	4.25
7.5	0.42	4.82	7.10	6.12	3.94
8	0.55	5.13	7.28	6.11	3.71
8.5	0.66	5.40	7.54	6.48	3.78
9	0.76	5.62	7.58	6.36	3.46
9.5	0.83	5.79	7.55	5.97	2.93
10	0.90	5.90	7.44	5.65	2.43

U = 6kn

Mean thrust at 6kn, beta = 0					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.03	-1.41	-0.35	1.05	2.63
4.5	-1.89	-0.36	1.83	4.24	6.32
5	-1.82	-0.19	2.17	4.72	6.87
5.5	-1.60	-0.07	2.18	4.80	7.09
6	-1.26	1.39	4.49	7.67	10.07
6.5	-0.82	3.35	8.28	11.44	13.17
7	-0.33	4.64	10.10	12.53	12.89
7.5	0.14	5.77	10.70	12.06	11.19
8	0.57	6.70	10.79	11.15	9.22
8.5	0.94	7.39	10.73	10.30	7.81
9	1.25	7.89	10.70	9.74	6.99
9.5	1.50	8.24	10.60	9.34	6.34
10	1.70	8.49	10.46	9.02	5.86

Mean thrust at 6kn, beta = 22.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.03	-1.37	-0.28	1.17	2.79
4.5	-1.91	-0.51	1.54	3.87	5.99
5	-1.81	-0.38	1.81	4.28	6.51
5.5	-1.53	0.09	2.42	5.16	7.60
6	-1.12	2.08	5.94	9.31	11.69
6.5	-0.63	4.08	9.51	12.33	13.40
7	-0.11	5.24	10.67	12.26	11.70
7.5	0.37	6.32	10.92	11.34	9.64
8	0.80	7.18	10.92	10.49	7.86
8.5	1.16	7.80	10.86	9.81	6.89
9	1.45	8.22	10.76	9.37	6.27
9.5	1.67	8.50	10.60	8.96	5.65
10	1.85	8.69	10.43	8.62	5.13

Mean thrust at 6kn, beta = 45					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.08	-1.63	-0.86	0.19	1.45
4.5	-1.92	-0.88	0.79	2.84	4.93
5	-1.60	-0.23	2.11	4.73	7.12
5.5	-1.09	2.39	6.38	9.41	11.23
6	-0.48	4.98	9.81	11.42	11.18
6.5	0.14	6.39	11.11	10.95	8.94
7	0.68	7.00	10.93	9.60	6.79
7.5	1.14	7.69	10.56	8.68	5.50
8	1.50	8.16	10.35	8.23	4.63
8.5	1.76	8.45	10.18	7.85	4.25
9	1.96	8.63	10.01	7.64	4.10
9.5	2.09	8.73	9.83	7.38	3.75
10	2.17	8.78	9.68	7.17	3.40

Mean thrust at 6kn, beta = 67.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.85	-0.86	0.83	2.90	5.04
4.5	-1.08	2.47	6.31	8.92	9.99
5	-0.37	5.93	9.33	9.69	8.23
5.5	0.37	7.48	10.17	9.02	6.31
6	0.98	7.98	9.94	8.01	4.78
6.5	1.45	8.28	10.03	7.44	3.73
7	1.78	8.40	9.76	6.83	3.02
7.5	2.00	8.60	9.56	6.69	2.92
8	2.14	8.72	9.51	6.63	2.66
8.5	2.21	8.78	9.44	6.51	2.53
9	2.24	8.80	9.40	6.42	2.52
9.5	2.23	8.80	9.38	6.39	2.44
10	2.21	8.77	9.37	6.35	2.39

Mean thrust at 6kn, beta = 90					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-1.78	-0.35	1.46	3.13	4.47
4.5	-1.52	1.01	3.79	6.06	7.52
5	-1.29	2.16	5.98	8.43	9.14
5.5	-0.97	3.46	8.17	10.25	10.01
6	-0.68	4.20	8.60	9.38	7.96
6.5	-0.42	4.70	9.32	9.80	7.90
7	-0.21	5.05	9.70	10.06	7.80
7.5	-0.03	5.51	9.62	9.54	7.32
8	0.11	5.91	9.90	9.53	6.96
8.5	0.23	6.25	10.31	10.30	7.51
9	0.32	6.52	10.50	10.38	7.42
9.5	0.40	6.73	10.58	9.98	6.75
10	0.46	6.89	10.57	9.69	6.14

U = 7kn

Mean thrust at 7kn, beta = 0					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.82	-2.19	-1.11	0.38	2.15
4.5	-2.68	-1.13	1.20	4.03	6.79
5	-2.60	-0.89	1.72	4.80	7.72
5.5	-2.36	-0.70	1.85	5.04	8.13
6	-1.97	0.92	4.49	8.68	12.22
6.5	-1.47	3.30	9.59	14.23	17.00
7	-0.91	4.99	12.50	16.35	17.24
7.5	-0.37	6.49	13.69	16.25	15.36
8	0.13	7.75	14.02	15.41	13.27
8.5	0.55	8.71	14.09	14.61	11.79
9	0.90	9.40	14.22	14.07	11.06
9.5	1.17	9.88	14.25	13.61	10.30
10	1.37	10.21	14.19	13.29	9.67

Mean thrust at 7kn, beta = 22.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.81	-2.16	-1.04	0.49	2.30
4.5	-2.69	-1.26	0.93	3.62	6.33
5	-2.58	-1.05	1.39	4.36	7.29
5.5	-2.28	-0.53	2.11	5.48	8.75
6	-1.82	1.73	6.34	10.94	14.52
6.5	-1.26	4.22	11.40	15.80	17.79
7	-0.67	5.76	13.49	16.53	16.34
7.5	-0.12	7.19	14.19	15.89	14.16
8	0.37	8.35	14.30	15.01	12.13
8.5	0.77	9.18	14.25	14.19	10.84
9	1.09	9.78	14.29	13.63	10.10
9.5	1.34	10.20	14.25	13.24	9.48
10	1.52	10.49	14.17	12.92	9.00

Mean thrust at 7kn, beta = 45					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.86	-2.39	-1.57	-0.41	1.01
4.5	-2.69	-1.57	0.29	2.67	5.27
5	-2.35	-0.89	1.74	4.91	8.06
5.5	-1.79	2.03	6.93	11.20	14.10
6	-1.12	5.21	11.84	14.80	15.25
6.5	-0.43	7.10	14.27	15.36	13.49
7	0.19	8.00	14.53	14.19	11.09
7.5	0.71	9.02	14.31	13.19	9.49
8	1.12	9.77	14.20	12.70	8.40
8.5	1.42	10.27	14.07	12.24	7.90
9	1.63	10.58	13.97	11.99	7.81
9.5	1.77	10.76	13.84	11.76	7.54
10	1.86	10.86	13.73	11.53	7.16

Mean thrust at 7kn, beta = 67.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.64	-1.65	0.11	2.39	4.93
4.5	-1.85	1.90	6.62	10.55	12.86
5	-1.08	6.25	11.42	13.14	12.29
5.5	-0.28	8.39	13.14	12.98	10.38
6	0.41	9.20	13.39	12.20	8.80
6.5	0.93	9.70	13.86	11.87	7.73
7	1.31	9.91	13.59	11.32	6.99
7.5	1.56	10.23	13.29	10.93	6.72
8	1.71	10.41	13.25	10.98	6.55
8.5	1.79	10.47	13.19	10.89	6.48
9	1.81	10.48	13.12	10.77	6.46
9.5	1.80	10.44	13.08	10.68	6.39
10	1.76	10.38	13.05	10.65	6.32

Mean thrust at 7kn, beta = 90					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-2.55	-1.01	1.11	3.24	5.07
4.5	-2.26	0.57	3.99	7.05	9.31
5	-2.00	1.92	6.76	10.50	12.22
5.5	-1.66	3.43	9.62	13.26	13.98
6	-1.34	4.31	10.55	12.72	11.81
6.5	-1.06	4.90	11.50	13.48	12.02
7	-0.83	5.31	12.01	14.02	12.20
7.5	-0.64	5.85	11.93	13.30	11.49
8	-0.50	6.31	12.32	13.29	10.99
8.5	-0.38	6.69	12.84	14.47	12.17
9	-0.29	6.99	13.15	14.78	12.46
9.5	-0.22	7.22	13.36	14.46	11.66
10	-0.16	7.41	13.44	14.24	10.96

U = 8kn

Mean thrust at 8kn, beta = 0					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-3.72	-3.09	-1.99	-0.43	1.48
4.5	-3.58	-2.02	0.43	3.55	6.88
5	-3.50	-1.70	1.10	4.62	8.23
5.5	-3.24	-1.46	1.38	5.09	8.92
6	-2.83	0.23	4.16	9.17	13.77
6.5	-2.28	2.93	10.29	16.44	20.60
7	-1.67	4.98	14.44	20.09	22.00
7.5	-1.07	6.82	16.37	20.82	20.64
8	-0.52	8.40	17.08	20.50	18.84
8.5	-0.05	9.62	17.33	19.67	17.10
9	0.32	10.53	17.70	19.12	16.08
9.5	0.62	11.18	17.95	18.66	15.27
10	0.84	11.64	18.05	18.34	14.73

Mean thrust at 8kn, beta = 22.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-3.72	-3.06	-1.92	-0.31	1.65
4.5	-3.59	-2.12	0.19	3.19	6.44
5	-3.47	-1.84	0.83	4.22	7.81
5.5	-3.15	-1.28	1.63	5.52	9.56
6	-2.67	1.11	6.25	11.92	16.72
6.5	-2.06	3.97	12.61	18.71	21.92
7	-1.41	5.85	15.80	20.57	21.13
7.5	-0.80	7.63	17.12	20.53	19.17
8	-0.26	9.10	17.56	19.95	17.25
8.5	0.18	10.21	17.69	19.26	15.99
9	0.53	11.00	17.95	18.77	15.20
9.5	0.79	11.55	18.09	18.29	14.42
10	0.98	11.91	18.10	17.94	13.83

Mean thrust at 8kn, beta = 45					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-3.76	-3.26	-2.40	-1.15	0.41
4.5	-3.59	-2.38	-0.36	2.33	5.38
5	-3.23	-1.68	1.18	4.79	8.60
5.5	-2.65	1.39	6.98	12.37	16.44
6	-1.93	5.05	13.47	18.13	19.68
6.5	-1.18	7.37	17.19	20.13	18.87
7	-0.51	8.53	17.92	19.22	16.30
7.5	0.06	9.87	17.94	18.27	14.51
8	0.50	10.89	17.94	17.83	13.38
8.5	0.83	11.57	17.88	17.37	12.78
9	1.06	12.00	17.89	17.11	12.64
9.5	1.21	12.25	17.86	16.85	12.30
10	1.29	12.37	17.79	16.68	12.08

Mean thrust at 8kn, beta = 67.5					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-3.55	-2.56	-0.77	1.64	4.46
4.5	-2.76	1.08	6.41	11.53	15.22
5	-1.95	6.08	12.88	16.28	16.53
5.5	-1.10	8.77	15.69	17.04	15.08
6	-0.37	9.87	16.56	16.79	13.78
6.5	0.20	10.56		17.02	12.90
7	0.61	10.87	17.55	16.57	12.05
7.5	0.88	11.36	17.19	15.91	11.38
8	1.04	11.65	17.11	15.88	11.25
8.5	1.13	11.78	17.06	15.78	11.23
9	1.15	11.81	17.05	15.73	11.30
9.5	1.13	11.78	17.02	15.75	11.25
10	1.09	11.69	16.99	15.79	11.27

Mean thrust at 8kn, beta = 90					
	Hs = 1m	Hs = 2m	Hs = 3m	Hs = 4m	Hs = 5m
Tp [s]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]	Thrust [kN]
4	-3.45	-1.83	0.54	3.13	5.51
4.5	-3.13	-0.06	3.99	7.96	11.25
5	-2.85	1.49	7.24	12.37	15.37
5.5	-2.48	3.16	10.72	16.11	18.17
6	-2.14	4.16	12.17	16.08	16.14
6.5	-1.84	4.80		17.22	16.72
7	-1.60	5.25	13.96	18.08	17.24
7.5	-1.41	5.85	13.88	17.10	16.25
8	-1.27	6.35	14.37	17.16	15.59
8.5	-1.15	6.75	14.97	18.73	17.49
9	-1.07	7.06	15.37	19.24	18.21
9.5	-1.00	7.30	15.68	18.99	17.28
10	-0.95	7.49	15.84	18.87	16.55

Appendix E: Spring stiffness optimization: Irregular waves, head sea, WC wave period

U = 4kn

Active foil thrust at U=4kn Tp = 6.5s, Hs = 3.0m, beta = 0 Passive foil thrust for this condition: 4.67kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	5.5	16.8%
14.0	5.6	20.9%
17.5	5.7	22.9%
20.9	5.8	23.9%
24.4	5.8	24.4%
27.9	5.8	24.7%
31.4	5.8	24.9%
34.9	5.8	25.0%
38.4	5.8	25.0%
41.9	5.8	25.0%
45.4	5.8	25.0%
48.9	5.8	25.0%
52.4	5.8	25.0%
55.9	5.8	25.0%
59.3	5.8	24.9%
62.8	5.8	24.9%
66.3	5.8	24.9%
69.8	5.8	24.9%

Active foil thrust at U=4kn Tp = 6.5s, Hs = 4.0m, beta = 0 Passive foil thrust for this condition: 5.66kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	7.2	27.2%
14.0	7.4	30.0%
17.5	7.4	30.7%
20.9	7.4	30.5%
24.4	7.4	30.0%
27.9	7.3	29.4%
31.4	7.3	28.9%
34.9	7.3	28.3%
38.4	7.2	27.8%
41.9	7.2	27.4%
45.4	7.2	26.9%
48.9	7.2	26.6%
52.4	7.1	26.2%
55.9	7.1	25.9%
59.3	7.1	25.6%
62.8	7.1	25.3%
66.3	7.1	25.1%
69.8	7.1	24.9%

Active foil thrust at U=4kn Tp = 6.5s, Hs = 5.0m, beta = 0 Passive foil thrust for this condition: 6.21kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	8.7	39.9%
14.0	8.8	42.3%
17.5	8.8	42.0%
20.9	8.7	40.8%
24.4	8.7	39.4%
27.9	8.6	37.9%
31.4	8.5	36.6%
34.9	8.4	35.4%
38.4	8.3	34.3%
41.9	8.3	33.3%
45.4	8.2	32.4%
48.9	8.2	31.6%
52.4	8.1	30.9%
55.9	8.1	30.2%
59.3	8.0	29.6%
62.8	8.0	29.1%
66.3	8.0	28.6%
69.8	8.0	28.1%

U = 5kn

Active foil thrust at U=5kn Tp = 6.5s, Hs = 3.0m, beta = 0 Passive foil thrust for this condition: 6.58kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	6.0	-9.2%
14.0	6.4	-2.4%
17.5	6.7	1.3%
20.9	6.8	3.5%
24.4	6.9	4.9%
27.9	7.0	5.9%
31.4	7.0	6.6%
34.9	7.0	7.1%
38.4	7.1	7.5%
41.9	7.1	7.8%
45.4	7.1	8.0%
48.9	7.1	8.2%
52.4	7.1	8.3%
55.9	7.1	8.5%
59.3	7.1	8.6%
62.8	7.1	8.7%
66.3	7.2	8.7%
69.8	7.2	8.8%

Active foil thrust at U=5kn Tp = 6.5s, Hs = 4.0m, beta = 0 Passive foil thrust for this condition: 8.52kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	8.8	3.2%
14.0	9.3	9.0%
17.5	9.5	11.6%
20.9	9.6	12.8%
24.4	9.7	13.3%
27.9	9.7	13.4%
31.4	9.7	13.3%
34.9	9.6	13.2%
38.4	9.6	13.0%
41.9	9.6	12.8%
45.4	9.6	12.6%
48.9	9.6	12.3%
52.4	9.6	12.1%
55.9	9.5	12.0%
59.3	9.5	11.8%
62.8	9.5	11.6%
66.3	9.5	11.4%
69.8	9.5	11.3%

Active foil thrust at U=5kn Tp = 6.5s, Hs = 5.0m, beta = 0 Passive foil thrust for this condition: 9.52kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	11.2	17.6%
14.0	11.7	23.2%
17.5	11.9	25.0%
20.9	11.9	25.2%
24.4	11.9	24.7%
27.9	11.8	23.9%
31.4	11.7	23.0%
34.9	11.6	22.2%
38.4	11.6	21.3%
41.9	11.5	20.6%
45.4	11.4	19.8%
48.9	11.3	19.2%
52.4	11.3	18.5%
55.9	11.2	18.0%
59.3	11.2	17.5%
62.8	11.1	17.0%
66.3	11.1	16.5%
69.8	11.1	16.1%

U = 6kn

Active foil thrust at U=6kn Tp = 6.5s, Hs = 3.0m, beta = 0 Passive foil thrust for this condition: 8.28kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	5.7	-31.1%
14.0	6.5	-21.9%
17.5	6.9	-16.5%
20.9	7.2	-12.9%
24.4	7.4	-10.5%
27.9	7.6	-8.8%
31.4	7.7	-7.5%
34.9	7.7	-6.5%
38.4	7.8	-5.7%
41.9	7.9	-5.1%
45.4	7.9	-4.6%
48.9	7.9	-4.1%
52.4	8.0	-3.8%
55.9	8.0	-3.5%
59.3	8.0	-3.2%
62.8	8.0	-3.0%
66.3	8.0	-2.8%
69.8	8.1	-2.6%

Active foil thrust at U=6kn Tp = 6.5s, Hs = 4.0m, beta = 0 Passive foil thrust for this condition: 11.44kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	9.5	-17.0%
14.0	10.5	-8.5%
17.5	11.0	-4.0%
20.9	11.3	-1.4%
24.4	11.5	0.2%
27.9	11.6	1.1%
31.4	11.6	1.7%
34.9	11.7	2.1%
38.4	11.7	2.3%
41.9	11.7	2.4%
45.4	11.7	2.5%
48.9	11.7	2.5%
52.4	11.7	2.5%
55.9	11.7	2.5%
59.3	11.7	2.5%
62.8	11.7	2.4%
66.3	11.7	2.4%
69.8	11.7	2.3%

Active foil thrust at U=6kn Tp = 6.5s, Hs = 5.0m, beta = 0 Passive foil thrust for this condition: 13.17kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	12.8	-2.7%
14.0	13.9	5.7%
17.5	14.5	9.8%
20.9	14.7	11.7%
24.4	14.8	12.5%
27.9	14.8	12.7%
31.4	14.8	12.5%
34.9	14.8	12.2%
38.4	14.7	11.8%
41.9	14.7	11.3%
45.4	14.6	10.9%
48.9	14.5	10.4%
52.4	14.5	10.0%
55.9	14.4	9.6%
59.3	14.4	9.2%
62.8	14.3	8.9%
66.3	14.3	8.5%
69.8	14.3	8.2%

U = 7kn

Active foil thrust at U=7kn Tp = 6.5s, Hs = 3.0m, beta = 0 Passive foil thrust for this condition: 9.59kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	4.6	-52.4%
14.0	5.6	-41.2%
17.5	6.3	-34.0%
20.9	6.8	-29.1%
24.4	7.1	-25.6%
27.9	7.4	-23.0%
31.4	7.6	-21.0%
34.9	7.7	-19.4%
38.4	7.8	-18.2%
41.9	7.9	-17.1%
45.4	8.0	-16.3%
48.9	8.1	-15.5%
52.4	8.2	-14.9%
55.9	8.2	-14.4%
59.3	8.3	-13.9%
62.8	8.3	-13.5%
66.3	8.3	-13.1%
69.8	8.4	-12.8%

Active foil thrust at U=7kn Tp = 6.5s, Hs = 4.0m, beta = 0 Passive foil thrust for this condition: 14.23kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	9.2	-35.6%
14.0	10.7	-25.0%
17.5	11.6	-18.6%
20.9	12.2	-14.6%
24.4	12.5	-11.9%
27.9	12.8	-10.0%
31.4	13.0	-8.7%
34.9	13.1	-7.7%
38.4	13.2	-7.0%
41.9	13.3	-6.5%
45.4	13.4	-6.1%
48.9	13.4	-5.8%
52.4	13.4	-5.5%
55.9	13.5	-5.3%
59.3	13.5	-5.1%
62.8	13.5	-5.0%
66.3	13.5	-4.9%
69.8	13.5	-4.8%

Active foil thrust at U=7kn Tp = 6.5s, Hs = 5.0m, beta = 0 Passive foil thrust for this condition: 17.00kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	13.4	-21.0%
14.0	15.3	-10.3%
17.5	16.3	-4.2%
20.9	16.9	-0.7%
24.4	17.2	1.3%
27.9	17.4	2.4%
31.4	17.5	3.1%
34.9	17.6	3.4%
38.4	17.6	3.5%
41.9	17.6	3.5%
45.4	17.6	3.4%
48.9	17.6	3.3%
52.4	17.5	3.1%
55.9	17.5	3.0%
59.3	17.5	2.8%
62.8	17.4	2.6%
66.3	17.4	2.4%
69.8	17.4	2.2%

U = 8kn

Active foil thrust at U=8kn Tp = 6.5s, Hs = 3.0m, beta = 0 Passive foil thrust for this condition: 10.29kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	2.6	-74.5%
14.0	4.0	-61.5%
17.5	4.9	-52.8%
20.9	5.5	-46.6%
24.4	6.0	-42.0%
27.9	6.3	-38.5%
31.4	6.6	-35.8%
34.9	6.8	-33.6%
38.4	7.0	-31.8%
41.9	7.2	-30.3%
45.4	7.3	-29.0%
48.9	7.4	-27.9%
52.4	7.5	-27.0%
55.9	7.6	-26.2%
59.3	7.7	-25.5%
62.8	7.7	-24.9%
66.3	7.8	-24.3%
69.8	7.8	-23.8%

Active foil thrust at U=8kn Tp = 6.5s, Hs = 4.0m, beta = 0 Passive foil thrust for this condition: 16.44kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	7.6	-53.7%
14.0	9.6	-41.5%
17.5	10.9	-33.6%
20.9	11.8	-28.2%
24.4	12.4	-24.4%
27.9	12.9	-21.6%
31.4	13.2	-19.6%
34.9	13.5	-18.0%
38.4	13.7	-16.7%
41.9	13.9	-15.8%
45.4	14.0	-15.0%
48.9	14.1	-14.3%
52.4	14.2	-13.8%
55.9	14.3	-13.3%
59.3	14.3	-12.9%
62.8	14.4	-12.6%
66.3	14.4	-12.3%
69.8	14.5	-12.1%

Active foil thrust at U=8kn Tp = 6.5s, Hs = 5.0m, beta = 0 Passive foil thrust for this condition: 20.60kN		
Kf [kNm/deg]	Active foil thrust [kN]	Relative increase
10.5	12.5	-39.2%
14.0	15.1	-26.7%
17.5	16.7	-18.9%
20.9	17.7	-13.9%
24.4	18.4	-10.6%
27.9	18.9	-8.4%
31.4	19.2	-6.9%
34.9	19.4	-5.9%
38.4	19.5	-5.2%
41.9	19.6	-4.7%
45.4	19.7	-4.4%
48.9	19.7	-4.2%
52.4	19.8	-4.0%
55.9	19.8	-3.9%
59.3	19.8	-3.9%
62.8	19.8	-3.9%
66.3	19.8	-3.9%
69.8	19.8	-3.9%

Appendix F: Brake power: passively foiled. Wind included

U = 4kn

	Brake power [kW] at 4 knots								
	beta = 0, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	89.0	92.2	-3.6%	97.7	98.3	-0.7%	112.6	109.3	3.0%
4.5	92.1	94.8	-2.9%	113.3	109.9	3.0%	149.9	139.1	7.2%
5	95.1	97.7	-2.7%	132.5	129.0	2.7%	197.3	185.8	5.8%
5.5	98.0	100.0	-2.1%	151.1	147.6	2.3%	254.2	242.8	4.5%
6	100.1	101.2	-1.1%	158.2	151.2	4.4%	295.2	278.6	5.6%
6.5	101.1	101.1	0.0%	155.1	144.1	7.1%	292.4	270.1	7.6%
7	101.1	99.9	1.2%	149.7	136.5	8.8%	262.1	238.0	9.2%
7.5	100.4	98.0	2.4%	146.5	131.4	10.4%	235.0	211.2	10.1%
8	99.3	95.9	3.5%	141.9	125.4	11.6%	217.1	194.0	10.6%
8.5	98.2	93.8	4.5%	136.6	119.3	12.7%	206.0	183.9	10.7%
9	97.0	91.7	5.4%	131.1	113.4	13.6%	194.0	173.0	10.9%
9.5	95.8	89.8	6.2%	126.0	107.9	14.4%	181.0	161.2	11.0%
10	94.6	88.1	6.9%	121.2	102.9	15.1%	169.2	150.5	11.0%

	Brake power [kW] at 4 knots								
	beta = 22.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	89.3	92.5	-3.6%	99.4	99.9	-0.5%	116.7	112.9	3.2%
4.5	92.3	95.0	-3.0%	114.7	112.1	2.3%	153.4	143.7	6.4%
5	94.8	97.3	-2.6%	130.7	127.9	2.2%	192.7	182.1	5.5%
5.5	97.3	99.0	-1.7%	146.5	142.1	3.0%	241.5	228.3	5.5%
6	99.0	99.7	-0.6%	152.1	142.7	6.2%	275.2	253.5	7.9%
6.5	99.7	99.0	0.7%	148.4	135.2	8.9%	269.1	242.2	10.0%
7	99.7	97.7	2.0%	143.3	128.3	10.5%	240.8	214.4	11.0%
7.5	99.0	95.8	3.2%	140.1	123.4	11.9%	216.9	191.9	11.5%
8	98.0	93.6	4.4%	135.7	118.0	13.1%	201.1	177.6	11.7%
8.5	96.8	91.6	5.4%	130.8	112.6	13.9%	191.5	169.3	11.6%
9	95.7	89.7	6.2%	125.9	107.5	14.7%	180.9	160.0	11.5%
9.5	94.7	88.1	7.0%	121.2	102.8	15.2%	169.3	149.9	11.5%
10	93.6	86.6	7.5%	116.9	98.6	15.6%	158.8	140.6	11.4%

	Brake power [kW] at 4 knots								
	beta = 45, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	90.1	93.6	-3.9%	103.0	105.0	-1.9%	125.2	121.2	3.2%
4.5	92.5	95.5	-3.2%	117.7	117.1	0.5%	160.7	149.9	6.7%
5	94.1	96.0	-2.0%	127.1	124.3	2.2%	183.7	170.2	7.4%
5.5	95.8	96.2	-0.5%	136.6	126.6	7.3%	214.2	194.9	9.0%
6	96.7	95.4	1.3%	137.9	122.7	11.0%	229.5	201.7	12.1%
6.5	96.8	93.9	3.0%	133.4	116.1	13.0%	216.5	185.3	14.4%
7	96.4	92.1	4.5%	129.2	111.4	13.8%	194.4	165.1	15.1%
7.5	95.8	90.3	5.7%	126.1	107.6	14.7%	178.1	150.9	15.3%
8	94.9	88.5	6.7%	122.2	103.5	15.3%	167.5	141.9	15.3%
8.5	93.9	86.9	7.5%	118.3	99.6	15.8%	160.7	136.6	15.0%
9	93.0	85.5	8.1%	114.4	96.0	16.1%	152.8	130.3	14.7%
9.5	92.2	84.4	8.5%	110.9	92.8	16.4%	144.3	123.4	14.5%
10	91.5	83.3	8.9%	107.8	89.8	16.7%	136.5	117.3	14.1%

	Brake power [kW] at 4 knots								
	beta = 67.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	90.0	92.5	-2.7%	103.2	101.6	1.6%	125.7	117.8	6.3%
4.5	91.8	91.3	0.5%	115.4	103.0	10.7%	155.0	132.5	14.5%
5	92.3	89.6	3.0%	118.9	99.0	16.8%	163.7	136.4	16.7%
5.5	93.0	88.1	5.3%	120.8	98.9	18.1%	171.8	145.0	15.6%
6	93.2	86.7	6.9%	118.2	97.0	17.9%	168.3	144.9	13.9%
6.5	93.0	85.4	8.1%	114.5	93.9	18.0%	155.9	135.3	13.2%
7	92.5	84.2	8.9%	111.9	91.8	17.9%	144.1	125.6	12.8%
7.5	91.8	83.3	9.3%	109.5	89.7	18.0%	136.2	118.9	12.7%
8	91.1	82.3	9.7%	106.5	87.3	18.0%	130.5	114.1	12.6%
8.5	90.6	81.6	9.9%	104.1	85.1	18.2%	126.8	111.0	12.5%
9	90.0	81.0	10.0%	101.7	83.2	18.2%	122.1	107.2	12.2%
9.5	89.4	80.4	10.1%	99.6	81.4	18.3%	117.1	103.1	12.0%
10	89.0	80.1	10.1%	97.7	79.8	18.3%	112.8	99.4	11.9%

	Brake power [kW] at 4 knots								
	beta = 90, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	88.9	91.3	-2.7%	98.7	96.7	2.1%	115.0	108.5	5.6%
4.5	89.4	91.0	-1.8%	104.5	99.0	5.3%	128.7	116.6	9.4%
5	88.8	89.9	-1.2%	99.6	91.3	8.4%	116.9	101.2	13.4%
5.5	88.7	88.8	-0.1%	95.6	84.5	11.6%	107.3	88.7	17.4%
6	88.3	87.5	0.9%	93.8	81.4	13.3%	101.2	84.0	17.1%
6.5	88.0	86.5	1.8%	92.9	79.5	14.5%	98.1	80.0	18.4%
7	87.7	85.5	2.5%	92.3	78.2	15.3%	96.6	78.2	19.0%
7.5	87.4	84.7	3.1%	91.3	76.4	16.3%	95.5	77.4	18.9%
8	87.2	84.0	3.7%	90.2	74.6	17.3%	94.4	76.0	19.5%
8.5	87.0	83.4	4.1%	89.5	73.3	18.1%	93.6	74.9	19.9%
9	86.9	82.9	4.5%	89.0	72.2	18.8%	92.5	74.0	19.9%
9.5	86.7	82.5	4.9%	88.5	71.4	19.3%	91.4	73.5	19.5%
10	86.7	82.2	5.2%	88.1	70.9	19.5%	90.6	73.4	19.0%

U = 5kn

	Brake power [kW] at 5 knots								
	beta = 0, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	121.4	127.5	-5.1%	131.3	134.6	-2.5%	148.1	146.6	1.0%
4.5	124.8	130.3	-4.4%	148.1	146.4	1.1%	187.6	175.8	6.3%
5	128.3	133.5	-4.1%	168.3	166.0	1.4%	237.2	223.0	6.0%
5.5	132.0	136.1	-3.1%	190.4	186.9	1.9%	301.6	284.8	5.6%
6	134.7	137.5	-2.1%	202.3	191.5	5.3%	358.5	326.0	9.1%
6.5	136.1	137.2	-0.8%	201.2	183.0	9.0%	367.9	319.4	13.2%
7	136.4	135.5	0.7%	195.4	173.2	11.4%	336.7	285.5	15.2%
7.5	135.8	133.2	1.9%	192.4	166.4	13.5%	304.2	254.7	16.3%
8	134.7	130.4	3.2%	187.5	158.8	15.3%	281.5	234.1	16.8%
8.5	133.4	127.7	4.3%	181.6	151.1	16.8%	267.9	222.3	17.0%
9	131.9	125.1	5.1%	175.2	143.9	17.9%	254.1	209.9	17.4%
9.5	130.4	122.7	5.9%	168.9	137.2	18.8%	238.5	196.8	17.5%
10	129.1	120.6	6.5%	163.1	131.1	19.6%	224.1	184.7	17.6%

	Brake power [kW] at 5 knots								
	beta = 22.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	121.8	128.0	-5.1%	133.4	136.8	-2.5%	153.0	151.5	1.0%
4.5	125.1	130.5	-4.4%	150.2	148.5	1.1%	192.8	180.8	6.3%
5	128.1	133.2	-4.0%	167.3	164.6	1.6%	234.5	219.6	6.3%
5.5	131.4	135.4	-3.1%	187.0	182.4	2.5%	292.2	272.8	6.6%
6	133.7	136.2	-1.9%	196.8	184.9	6.1%	341.3	305.5	10.5%
6.5	134.8	135.6	-0.6%	194.5	175.4	9.8%	344.3	293.2	14.8%
7	134.9	133.8	0.8%	188.8	165.8	12.2%	313.0	260.4	16.8%
7.5	134.3	131.4	2.2%	185.4	158.9	14.3%	283.4	233.0	17.8%
8	133.1	128.7	3.3%	180.6	151.5	16.1%	263.6	215.3	18.3%
8.5	131.8	126.1	4.3%	175.0	144.3	17.5%	251.6	205.0	18.5%
9	130.4	123.6	5.3%	169.0	137.5	18.7%	238.7	194.2	18.7%
9.5	129.2	121.3	6.1%	163.4	131.3	19.6%	224.8	182.4	18.8%
10	127.9	119.4	6.7%	158.0	125.9	20.3%	211.6	171.9	18.8%

	Brake power [kW] at 5 knots								
	beta = 45, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	122.8	129.2	-5.1%	138.1	142.6	-3.2%	120.6	121.5	-0.7%
4.5	125.6	131.2	-4.4%	155.0	155.6	-0.4%	158.1	150.6	4.8%
5	127.7	131.5	-3.0%	165.7	161.4	2.6%	182.4	164.6	9.8%
5.5	129.9	131.4	-1.1%	178.7	160.5	10.2%	220.0	176.7	19.7%
6	131.2	130.1	0.8%	182.6	154.2	15.6%	244.8	185.3	24.3%
6.5	131.6	128.0	2.7%	177.7	146.1	17.8%	233.4	175.4	24.9%
7	131.2	125.6	4.3%	172.6	140.1	18.8%	207.4	157.2	24.2%
7.5	130.4	123.1	5.6%	168.9	135.1	20.0%	187.6	142.6	24.0%
8	129.3	120.8	6.6%	164.3	130.0	20.8%	174.7	132.4	24.2%
8.5	128.2	118.8	7.3%	159.4	125.3	21.4%	166.7	126.6	24.1%
9	127.0	117.0	7.9%	154.6	121.0	21.7%	157.4	119.7	24.0%
9.5	126.0	115.6	8.2%	150.2	117.1	22.1%	147.5	112.1	24.0%
10	125.1	114.3	8.6%	146.2	113.6	22.3%	138.5	105.3	24.0%

	Brake power [kW] at 5 knots								
	beta = 67.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	122.8	128.1	-4.3%	138.6	139.0	-0.3%	165.3	157.5	4.7%
4.5	124.9	126.5	-1.3%	152.9	138.2	9.6%	199.3	167.3	16.0%
5	125.6	124.1	1.2%	157.4	128.7	18.2%	210.3	164.6	21.7%
5.5	126.6	122.0	3.6%	160.3	126.2	21.3%	221.9	172.2	22.4%
6	126.8	119.8	5.5%	157.4	123.1	21.8%	218.9	173.1	20.9%
6.5	126.5	117.8	6.9%	153.0	118.9	22.3%	203.9	161.9	20.6%
7	125.9	116.0	7.8%	149.8	116.1	22.5%	189.2	151.2	20.1%
7.5	125.1	114.7	8.4%	146.7	113.3	22.8%	179.4	143.5	20.0%
8	124.3	113.4	8.8%	143.3	110.3	23.0%	172.4	137.8	20.1%
8.5	123.6	112.5	9.0%	140.2	107.7	23.2%	167.8	134.3	20.0%
9	122.9	111.8	9.0%	137.3	105.4	23.2%	162.1	129.9	19.9%
9.5	122.3	111.2	9.0%	134.7	103.4	23.2%	156.0	125.1	19.8%
10	121.7	110.8	9.0%	132.5	101.6	23.3%	150.8	120.8	19.9%

	Brake power [kW] at 5 knots								
	beta = 90, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	121.5	126.7	-4.2%	133.3	132.6	0.5%	152.9	145.3	5.0%
4.5	122.1	126.2	-3.3%	140.2	134.3	4.2%	169.1	152.6	9.8%
5	121.5	124.7	-2.7%	134.2	124.1	7.5%	155.0	131.6	15.1%
5.5	121.2	123.2	-1.7%	129.5	114.8	11.3%	143.4	113.9	20.6%
6	120.8	121.5	-0.6%	127.4	110.3	13.4%	136.2	107.0	21.5%
6.5	120.5	120.1	0.3%	126.3	107.6	14.8%	132.5	101.4	23.4%
7	120.0	118.9	0.9%	125.5	105.6	15.9%	130.7	98.7	24.5%
7.5	119.7	117.9	1.6%	124.3	103.0	17.2%	129.4	97.8	24.4%
8	119.4	116.9	2.1%	123.1	100.4	18.4%	128.0	95.8	25.1%
8.5	119.2	116.2	2.5%	122.3	98.4	19.5%	127.0	93.9	26.1%
9	119.0	115.6	2.9%	121.5	96.8	20.3%	125.7	92.4	26.5%
9.5	118.9	115.2	3.1%	121.0	95.5	21.0%	124.5	91.4	26.6%
10	118.8	114.8	3.4%	120.6	94.6	21.5%	123.5	90.9	26.4%

Appendix F: Brake power: passively foiled. Wind included

U = 6kn

	Brake power [kW] at 6 knots								
	beta = 0, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	162.7	173.1	-6.4%	173.7	181.1	-4.2%	192.6	194.4	-0.9%
4.5	166.3	175.9	-5.8%	191.6	193.2	-0.8%	234.4	223.3	4.7%
5	170.4	179.4	-5.2%	212.9	212.7	0.1%	285.4	270.1	5.4%
5.5	174.9	182.5	-4.3%	238.8	235.8	1.3%	357.3	335.8	6.0%
6	178.4	183.8	-3.0%	256.2	241.9	5.6%	431.9	382.6	11.4%
6.5	180.6	183.4	-1.6%	258.4	231.9	10.3%	458.8	377.7	17.7%
7	181.2	181.4	-0.1%	252.6	219.8	13.0%	429.5	341.7	20.5%
7.5	180.8	178.6	1.3%	250.1	211.3	15.5%	390.9	306.1	21.7%
8	179.6	175.3	2.4%	245.0	201.7	17.7%	362.7	281.9	22.3%
8.5	178.2	172.0	3.5%	238.3	192.2	19.3%	346.0	267.8	22.6%
9	176.5	168.7	4.4%	230.9	183.1	20.7%	329.3	253.7	23.0%
9.5	174.7	165.8	5.0%	223.5	174.8	21.8%	311.1	238.5	23.4%
10	173.0	163.3	5.6%	216.3	167.4	22.6%	293.6	224.2	23.6%

	Brake power [kW] at 6 knots								
	beta = 22.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	163.3	173.6	-6.3%	176.3	183.4	-4.0%	198.6	199.8	-0.6%
4.5	166.8	176.5	-5.8%	194.6	196.8	-1.1%	241.4	231.5	4.1%
5	170.4	179.2	-5.2%	212.9	213.4	-0.2%	285.4	270.9	5.1%
5.5	174.5	181.4	-3.9%	236.7	231.2	2.3%	351.7	324.7	7.7%
6	177.5	181.9	-2.5%	251.8	231.9	7.9%	419.2	355.1	15.3%
6.5	179.2	180.8	-0.9%	251.8	220.3	12.5%	436.2	344.4	21.1%
7	179.6	178.4	0.7%	245.6	208.9	14.9%	403.6	311.6	22.8%
7.5	179.1	175.4	2.1%	242.6	200.4	17.4%	367.4	281.0	23.5%
8	177.9	172.1	3.3%	237.2	191.1	19.5%	342.2	260.4	23.9%
8.5	176.3	168.9	4.2%	230.7	182.3	21.0%	327.0	247.8	24.2%
9	174.8	166.0	5.0%	223.7	174.1	22.1%	311.6	235.4	24.5%
9.5	173.1	163.3	5.7%	216.7	166.7	23.1%	294.7	222.0	24.7%
10	171.6	161.0	6.2%	210.2	160.2	23.8%	278.7	209.6	24.8%

	Brake power [kW] at 6 knots								
	beta = 45, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	164.5	175.0	-6.4%	182.3	190.6	-4.6%	198.2	216.9	-9.5%
4.5	167.7	177.3	-5.7%	201.4	204.9	-1.7%	240.4	253.5	-5.4%
5	170.3	177.5	-4.2%	213.5	210.3	1.5%	281.0	274.0	2.5%
5.5	173.2	177.3	-2.3%	230.7	207.8	9.9%	339.3	298.4	12.0%
6	175.0	175.4	-0.2%	238.1	198.9	16.5%	392.8	316.7	19.4%
6.5	175.7	172.8	1.6%	233.3	188.1	19.4%	404.3	301.2	25.5%
7	175.4	169.7	3.3%	227.1	180.2	20.7%	377.4	270.5	28.3%
7.5	174.5	166.7	4.5%	222.8	173.4	22.2%	346.8	246.9	28.8%
8	173.2	163.8	5.5%	217.4	166.4	23.4%	324.7	231.2	28.8%
8.5	171.8	161.2	6.2%	211.4	160.3	24.2%	311.4	222.2	28.6%
9	170.4	159.0	6.7%	205.7	154.7	24.8%	297.7	211.6	28.9%
9.5	169.2	157.2	7.1%	200.1	149.9	25.1%	282.3	200.1	29.1%
10	167.9	155.9	7.2%	195.1	145.5	25.4%	267.8	189.8	29.1%

Appendix F: Brake power: passively foiled. Wind included

	Brake power [kW] at 6 knots								
	beta = 67.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	164.6	173.9	-5.6%	183.3	187.0	-2.0%	214.5	208.5	2.8%
4.5	167.1	172.0	-2.9%	199.8	184.2	7.8%	253.7	212.7	16.2%
5	168.1	168.9	-0.5%	205.4	168.1	18.2%	267.2	200.5	24.9%
5.5	169.2	166.1	1.8%	209.7	162.4	22.5%	283.6	205.2	27.6%
6	169.6	163.2	3.8%	206.8	158.2	23.5%	281.9	206.1	26.9%
6.5	169.2	160.5	5.1%	201.3	152.8	24.1%	263.6	193.5	26.6%
7	168.6	158.2	6.2%	197.4	149.1	24.5%	245.4	181.5	26.0%
7.5	167.7	156.3	6.8%	193.8	145.2	25.1%	233.3	172.8	25.9%
8	166.6	154.8	7.1%	189.6	141.3	25.5%	224.9	166.2	26.1%
8.5	165.7	153.7	7.3%	185.9	138.0	25.8%	219.5	162.1	26.2%
9	164.9	152.8	7.3%	182.3	135.1	25.9%	212.6	156.7	26.3%
9.5	164.1	152.2	7.3%	179.2	132.6	26.0%	205.2	150.9	26.5%
10	163.4	151.8	7.1%	176.5	130.4	26.1%	198.7	145.7	26.7%

	Brake power [kW] at 6 knots								
	beta = 90, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	163.0	172.2	-5.6%	177.1	179.0	-1.0%	200.4	192.5	3.9%
4.5	163.8	171.4	-4.7%	185.2	179.9	2.9%	219.4	198.7	9.4%
5	162.9	169.6	-4.1%	178.0	166.9	6.2%	202.5	170.9	15.6%
5.5	162.7	167.7	-3.1%	172.6	154.9	10.2%	188.9	147.0	22.2%
6	162.2	165.7	-2.2%	170.1	148.8	12.5%	180.4	136.9	24.2%
6.5	161.7	163.9	-1.3%	168.7	145.0	14.1%	175.9	129.3	26.5%
7	161.4	162.3	-0.6%	167.8	142.4	15.1%	173.9	125.5	27.8%
7.5	160.9	161.1	-0.1%	166.4	138.8	16.6%	172.3	124.5	27.8%
8	160.5	159.9	0.4%	164.9	135.4	17.9%	170.7	121.6	28.8%
8.5	160.3	159.1	0.7%	163.9	132.8	19.0%	169.6	118.7	30.0%
9	160.1	158.4	1.0%	163.0	130.7	19.8%	168.1	116.4	30.7%
9.5	159.9	157.9	1.2%	162.4	129.0	20.6%	166.6	114.6	31.2%
10	159.8	157.5	1.5%	161.8	127.8	21.0%	165.3	113.6	31.3%

U = 7kn

	Brake power [kW] at 7 knots								
	beta = 0, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	216.9	232.9	-7.4%	229.4	242.1	-5.5%	250.4	256.8	-2.5%
4.5	220.7	236.1	-6.9%	248.4	254.3	-2.4%	294.3	285.7	2.9%
5	225.3	239.8	-6.4%	270.4	273.9	-1.3%	346.8	331.3	4.5%
5.5	230.7	243.0	-5.3%	299.8	298.5	0.4%	425.6	399.9	6.0%
6	235.4	244.6	-3.9%	323.9	306.3	5.4%	518.1	452.8	12.6%
6.5	238.3	244.0	-2.4%	330.3	295.6	10.5%	568.3	449.7	20.9%
7	239.6	241.9	-1.0%	325.2	281.1	13.6%	544.7	410.6	24.6%
7.5	239.4	238.5	0.4%	323.5	270.4	16.4%	499.8	369.6	26.1%
8	238.3	234.5	1.6%	318.4	258.5	18.8%	465.2	340.8	26.7%
8.5	236.6	230.6	2.6%	311.2	246.8	20.7%	444.2	323.5	27.2%
9	234.7	226.8	3.3%	302.7	235.7	22.1%	424.9	307.3	27.7%
9.5	232.6	223.5	3.9%	293.9	225.7	23.2%	403.5	289.7	28.2%
10	230.6	220.6	4.3%	285.3	216.9	24.0%	382.4	273.3	28.5%

	Brake power [kW] at 7 knots								
	beta = 22.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	217.5	233.6	-7.4%	232.4	244.9	-5.4%	257.6	263.3	-2.2%
4.5	221.4	236.6	-6.9%	252.1	258.9	-2.7%	303.4	295.8	2.5%
5	225.7	239.6	-6.2%	271.4	275.1	-1.3%	349.1	334.3	4.3%
5.5	230.6	242.1	-5.0%	299.1	294.7	1.5%	423.6	391.2	7.7%
6	234.7	242.6	-3.4%	320.8	296.0	7.7%	511.2	424.6	16.9%
6.5	237.1	241.3	-1.8%	324.4	282.5	12.9%	548.1	412.8	24.7%
7	238.0	238.5	-0.2%	318.2	268.5	15.6%	516.9	376.1	27.2%
7.5	237.6	234.8	1.2%	315.4	257.6	18.3%	473.1	340.6	28.0%
8	236.2	230.9	2.3%	309.8	246.2	20.5%	441.5	316.1	28.4%
8.5	234.5	227.2	3.1%	302.5	235.4	22.2%	422.4	301.6	28.6%
9	232.6	223.7	3.8%	294.3	225.2	23.5%	404.4	287.0	29.0%
9.5	230.7	220.6	4.4%	285.9	216.2	24.4%	384.1	271.2	29.4%
10	228.7	218.0	4.7%	277.8	208.2	25.0%	364.7	256.6	29.6%

	Brake power [kW] at 7 knots								
	beta = 45, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	219.1	235.4	-7.4%	239.8	253.4	-5.7%	274.3	282.9	-3.2%
4.5	222.9	237.8	-6.7%	261.2	268.8	-2.9%	324.9	318.9	1.8%
5	226.0	238.0	-5.3%	274.5	273.9	0.2%	356.8	331.3	7.1%
5.5	229.7	237.5	-3.4%	296.5	269.8	9.0%	417.9	336.0	19.6%
6	232.3	235.4	-1.3%	308.6	258.1	16.4%	476.8	339.6	28.8%
6.5	233.3	232.1	0.5%	304.5	244.4	19.7%	475.3	324.4	31.7%
7	233.1	228.4	2.0%	296.9	234.0	21.2%	435.1	298.0	31.5%
7.5	232.1	224.7	3.2%	292.3	224.7	23.1%	400.8	276.1	31.1%
8	230.6	221.1	4.1%	285.9	215.4	24.7%	378.4	260.4	31.2%
8.5	229.0	218.1	4.8%	278.8	207.5	25.6%	364.9	251.0	31.2%
9	227.3	215.4	5.2%	271.6	200.4	26.2%	349.9	240.6	31.2%
9.5	225.7	213.4	5.5%	264.9	194.2	26.7%	333.8	229.4	31.3%
10	224.2	211.6	5.6%	258.7	188.9	27.0%	318.7	218.9	31.3%

	Brake power [kW] at 7 knots								
	beta = 67.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	219.3	234.3	-6.9%	241.2	249.9	-3.6%	277.5	274.9	1.0%
4.5	222.2	231.9	-4.4%	260.2	245.7	5.6%	322.5	274.1	15.0%
5	223.5	228.2	-2.1%	267.1	221.9	16.9%	338.5	248.8	26.5%
5.5	224.8	224.7	0.1%	273.5	212.7	22.2%	360.8	249.5	30.9%
6	225.3	221.1	1.9%	270.4	206.4	23.7%	361.1	249.0	31.1%
6.5	225.0	217.7	3.3%	263.9	199.3	24.5%	339.6	232.9	31.4%
7	224.2	214.9	4.1%	259.1	194.5	24.9%	317.3	219.3	30.9%
7.5	223.2	212.6	4.8%	254.7	189.6	25.6%	302.5	209.9	30.6%
8	222.0	210.9	5.0%	249.9	184.7	26.1%	292.3	202.2	30.8%
8.5	220.9	209.5	5.2%	245.3	180.9	26.3%	285.7	197.4	30.9%
9	219.9	208.5	5.2%	241.0	177.6	26.3%	277.3	191.4	31.0%
9.5	218.9	207.8	5.1%	237.3	175.0	26.3%	268.6	185.0	31.1%
10	218.1	207.3	5.0%	234.0	172.6	26.2%	261.0	179.3	31.3%

	Brake power [kW] at 7 knots								
	beta = 90, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	217.7	232.3	-6.7%	234.2	240.1	-2.5%	261.4	254.9	2.5%
4.5	218.3	226.8	-3.9%	243.7	240.3	1.4%	283.4	259.5	8.4%
5	217.5	229.0	-5.3%	235.0	224.0	4.7%	263.5	224.0	15.0%
5.5	217.2	227.8	-4.9%	228.7	209.1	8.5%	247.7	192.8	22.1%
6	216.5	225.0	-3.9%	225.7	201.3	10.8%	237.8	178.4	25.0%
6.5	216.1	223.2	-3.3%	224.2	196.6	12.3%	232.6	168.5	27.6%
7	215.4	221.2	-2.7%	223.2	193.2	13.4%	230.2	163.5	29.0%
7.5	215.1	219.6	-2.1%	221.4	188.6	14.8%	228.4	162.2	29.0%
8	214.6	218.3	-1.7%	219.8	184.3	16.1%	226.5	158.3	30.1%
8.5	214.3	217.2	-1.3%	218.5	181.2	17.1%	225.2	154.5	31.4%
9	214.0	216.2	-1.0%	217.5	178.6	17.9%	223.3	151.1	32.3%
9.5	213.8	215.6	-0.8%	216.7	176.5	18.5%	221.5	148.4	33.0%
10	213.7	214.9	-0.6%	216.1	175.0	19.0%	220.2	146.8	33.4%

U = 8kn

	Brake power [kW] at 8 knots								
	beta = 0, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	287.8	311.5	-8.2%	302.0	321.8	-6.6%	325.4	338.1	-3.9%
4.5	291.9	314.5	-7.8%	321.8	334.4	-3.9%	371.6	367.0	1.2%
5	297.1	318.5	-7.2%	344.7	353.2	-2.5%	424.9	410.9	3.3%
5.5	303.5	322.0	-6.1%	377.4	379.1	-0.4%	509.5	481.4	5.5%
6	309.2	323.9	-4.8%	408.5	389.3	4.7%	620.0	540.2	12.9%
6.5	313.3	323.5	-3.2%	421.1	378.3	10.2%	697.6	539.8	22.6%
7	315.2	321.1	-1.9%	417.1	361.3	13.4%	685.3	497.5	27.4%
7.5	315.4	317.3	-0.6%	416.8	348.5	16.4%	635.8	450.5	29.1%
8	314.5	312.7	0.6%	412.2	334.1	18.9%	592.8	415.8	29.9%
8.5	312.7	308.1	1.5%	404.3	319.9	20.9%	566.9	395.1	30.3%
9	310.4	303.8	2.1%	394.5	306.7	22.3%	545.1	376.0	31.0%
9.5	307.8	300.0	2.6%	384.2	294.5	23.3%	519.9	355.5	31.6%
10	305.6	296.7	2.9%	373.8	283.6	24.1%	494.9	336.4	32.0%

	Brake power [kW] at 8 knots								
	beta = 22.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	288.7	312.4	-8.2%	305.6	325.1	-6.4%	333.6	345.9	-3.7%
4.5	292.7	315.4	-7.7%	326.6	339.6	-4.0%	382.8	379.1	1.0%
5	297.6	318.5	-7.0%	346.7	355.5	-2.5%	429.9	415.8	3.3%
5.5	303.5	321.3	-5.9%	378.3	376.3	0.5%	511.8	475.3	7.1%
6	308.8	322.0	-4.3%	407.3	378.8	7.0%	619.5	512.6	17.3%
6.5	312.2	320.6	-2.7%	415.8	364.3	12.4%	682.2	500.5	26.6%
7	313.6	317.3	-1.2%	410.0	347.5	15.3%	656.0	459.7	29.9%
7.5	313.6	313.3	0.1%	408.2	334.1	18.1%	605.1	417.7	31.0%
8	312.2	308.8	1.1%	402.5	319.9	20.5%	565.7	387.6	31.5%
8.5	310.4	304.2	2.0%	394.3	306.7	22.2%	542.3	370.0	31.8%
9	308.1	300.2	2.6%	384.7	294.3	23.5%	521.1	352.4	32.4%
9.5	305.6	296.7	2.9%	374.6	283.4	24.4%	496.7	333.9	32.8%
10	303.3	293.6	3.2%	365.1	273.7	25.0%	473.6	316.8	33.1%

	Brake power [kW] at 8 knots								
	beta = 45, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	290.6	314.5	-8.2%	314.3	335.1	-6.6%	353.9	368.9	-4.2%
4.5	294.7	316.8	-7.5%	338.4	351.9	-4.0%	410.3	407.3	0.7%
5	298.7	317.1	-6.2%	352.9	356.3	-1.0%	444.5	418.0	6.0%
5.5	303.3	316.6	-4.4%	379.4	350.8	7.5%	516.5	418.6	18.9%
6	306.5	314.0	-2.5%	397.5	336.6	15.3%	596.4	416.4	30.2%
6.5	308.1	310.4	-0.7%	394.8	319.9	19.0%	606.0	396.9	34.5%
7	308.1	306.0	0.7%	385.9	306.9	20.5%	560.1	367.0	34.5%
7.5	307.2	301.5	1.8%	381.1	294.7	22.7%	516.8	340.4	34.1%
8	305.3	297.3	2.6%	373.8	283.0	24.3%	488.6	321.3	34.2%
8.5	303.5	293.8	3.2%	365.4	272.9	25.3%	472.2	309.9	34.4%
9	301.3	290.8	3.5%	356.8	264.3	25.9%	454.2	297.6	34.5%
9.5	299.3	288.4	3.6%	348.5	256.7	26.3%	434.4	284.0	34.6%
10	297.6	286.5	3.7%	340.9	250.5	26.5%	416.1	271.7	34.7%

	Brake power [kW] at 8 knots								
	beta = 67.5, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	290.8	313.3	-7.8%	316.1	331.7	-4.9%	358.4	361.1	-0.7%
4.5	294.3	310.8	-5.6%	338.1	327.1	3.3%	409.7	356.6	13.0%
5	295.8	306.3	-3.5%	346.2	295.6	14.6%	428.3	315.9	26.3%
5.5	297.6	302.0	-1.5%	355.0	282.1	20.5%	458.3	310.4	32.3%
6	298.2	297.8	0.1%	352.4	273.7	22.3%	461.4	307.2	33.4%
6.5	298.0	293.8	1.4%	344.4	264.7	23.1%	436.0	302.5	30.6%
7	297.1	290.4	2.3%	338.6	258.7	23.6%	409.1	269.6	34.1%
7.5	295.8	287.8	2.7%	333.6	251.8	24.5%	390.8	259.0	33.7%
8	294.3	285.7	2.9%	327.8	245.7	25.0%	378.8	250.5	33.9%
8.5	293.0	284.0	3.1%	322.3	240.8	25.3%	370.8	245.0	33.9%
9	291.9	283.0	3.1%	317.3	237.1	25.3%	361.1	237.8	34.1%
9.5	290.6	282.1	2.9%	312.9	233.9	25.2%	350.6	230.4	34.3%
10	289.7	281.7	2.8%	308.8	231.3	25.1%	341.1	223.8	34.4%

	Brake power [kW] at 8 knots								
	beta = 90, wind resistance included								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%	Unfoiled	Foiled	Savings [%]
4	288.9	311.0	-7.7%	308.3	320.1	-3.8%	340.1	336.4	1.1%
4.5	289.7	309.7	-6.9%	319.2	319.7	-0.1%	365.4	339.1	7.2%
5	288.7	306.9	-6.3%	309.2	299.8	3.1%	342.4	295.4	13.7%
5.5	288.2	304.2	-5.5%	301.8	281.7	6.6%	323.7	256.0	20.9%
6	287.8	301.3	-4.7%	298.2	272.1	8.8%	312.4	236.3	24.4%
6.5	287.0	298.7	-4.1%	296.5	266.3	10.2%	306.5	222.5	27.4%
7	286.3	296.7	-3.6%	295.4	262.3	11.2%	303.5	217.3	28.4%
7.5	285.9	294.9	-3.2%	293.4	256.7	12.5%	301.5	215.8	28.4%
8	285.5	293.4	-2.8%	291.2	251.6	13.6%	299.1	210.8	29.5%
8.5	285.1	292.3	-2.5%	289.9	247.9	14.5%	297.8	206.0	30.8%
9	284.8	291.5	-2.3%	288.9	245.0	15.2%	295.6	201.6	31.8%
9.5	284.6	290.8	-2.2%	287.8	242.6	15.7%	293.6	198.0	32.6%
10	284.4	290.4	-2.1%	287.2	240.8	16.1%	291.9	195.6	33.0%

Appendix G: Brake power: Passive foils. Wind not included

U = 4kn

	Brake power [kW] at 4 knots								
	beta = 0, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	21.3	23.6	-10.7%	27.6	28.1	-1.8%	38.7	36.2	6.5%
4.5	23.5	25.5	-8.2%	39.3	36.7	6.6%	68.1	59.5	12.7%
5	25.7	27.6	-7.3%	54.2	51.4	5.1%	107.5	97.8	9.0%
5.5	27.8	29.3	-5.2%	69.1	66.3	4.1%	156.5	146.5	6.4%
6	29.3	30.2	-2.8%	74.9	69.2	7.6%	192.5	177.8	7.7%
6.5	30.1	30.1	0.0%	72.3	63.5	12.2%	190.0	170.2	10.4%
7	30.1	29.2	2.9%	67.9	57.3	15.6%	163.4	142.4	12.9%
7.5	29.6	27.8	5.9%	65.4	53.3	18.5%	139.8	119.2	14.7%
8	28.8	26.3	8.8%	61.7	48.6	21.2%	124.2	104.6	15.8%
8.5	27.9	24.7	11.5%	57.5	43.9	23.7%	114.8	96.1	16.3%
9	27.0	23.2	14.1%	53.1	39.3	26.1%	104.7	87.1	16.9%
9.5	26.2	21.9	16.4%	49.1	35.1	28.4%	93.8	77.3	17.6%
10	25.3	20.7	18.5%	45.3	31.5	30.6%	83.9	68.6	18.3%

	Brake power [kW] at 4 knots								
	beta = 22.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	21.5	23.8	-10.6%	28.8	29.2	-1.3%	41.8	39.0	6.8%
4.5	23.6	25.6	-8.5%	40.4	38.3	5.0%	71.0	63.1	11.1%
5	25.5	27.3	-7.1%	52.8	50.5	4.2%	103.6	94.7	8.7%
5.5	27.3	28.6	-4.5%	65.4	61.9	5.4%	145.5	133.8	8.0%
6	28.6	29.0	-1.5%	69.9	62.3	10.9%	174.9	155.7	11.0%
6.5	29.1	28.6	1.8%	66.9	56.4	15.8%	169.3	145.8	13.9%
7	29.0	27.5	5.1%	62.8	50.8	19.1%	144.7	121.9	15.8%
7.5	28.5	26.2	8.3%	60.3	47.1	21.9%	124.1	102.9	17.1%
8	27.8	24.6	11.3%	56.7	42.9	24.5%	110.7	91.0	17.8%
8.5	27.0	23.2	14.0%	52.9	38.7	26.8%	102.6	84.0	18.1%
9	26.1	21.8	16.4%	49.0	34.8	28.9%	93.6	76.3	18.5%
9.5	25.3	20.6	18.5%	45.4	31.4	30.9%	84.0	68.1	19.0%
10	24.6	19.6	20.4%	42.1	28.3	32.8%	75.3	60.6	19.5%

	Brake power [kW] at 4 knots								
	beta = 45, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	22.1	24.6	-11.3%	31.5	33.0	-4.6%	48.4	45.3	6.4%
4.5	23.8	25.9	-9.0%	42.6	42.2	1.1%	76.9	68.1	11.3%
5	24.9	26.4	-5.7%	49.9	47.7	4.3%	96.1	84.7	11.8%
5.5	26.2	26.5	-1.1%	57.4	49.5	13.7%	121.8	105.5	13.4%
6	26.8	25.9	3.6%	58.5	46.5	20.5%	134.9	111.1	17.7%
6.5	27.0	24.8	7.9%	55.0	41.4	24.6%	123.8	97.3	21.4%
7	26.7	23.5	11.8%	51.6	37.8	26.7%	105.0	80.5	23.4%
7.5	26.2	22.2	15.2%	49.2	35.0	28.9%	91.3	68.9	24.5%
8	25.5	20.9	18.0%	46.1	31.8	31.0%	82.4	61.7	25.2%
8.5	24.8	19.8	20.2%	43.1	29.0	32.8%	77.0	57.5	25.3%
9	24.2	18.9	22.0%	40.2	26.3	34.4%	70.4	52.4	25.6%
9.5	23.6	18.0	23.6%	37.5	24.0	36.0%	63.5	47.1	25.9%
10	23.1	17.3	24.8%	35.1	21.9	37.6%	57.4	42.4	26.2%

	Brake power [kW] at 4 knots								
	beta = 67.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	22.0	23.8	-7.8%	31.7	30.5	3.7%	48.8	42.7	12.6%
4.5	23.3	22.9	1.6%	40.9	31.5	22.9%	72.3	54.3	24.9%
5	23.7	21.7	8.2%	43.6	28.5	34.6%	79.3	57.2	27.9%
5.5	24.2	20.7	14.4%	45.0	28.5	36.7%	86.1	64.1	25.5%
6	24.3	19.7	18.9%	43.0	27.1	37.0%	83.3	64.1	23.0%
6.5	24.1	18.8	22.2%	40.2	24.8	38.2%	73.0	56.4	22.7%
7	23.8	18.0	24.3%	38.2	23.3	38.9%	63.5	48.8	23.1%
7.5	23.3	17.3	26.0%	36.3	21.8	39.9%	57.1	43.6	23.7%
8	22.8	16.6	27.1%	34.2	20.1	41.1%	52.6	39.8	24.3%
8.5	22.4	16.1	28.0%	32.3	18.6	42.4%	49.7	37.6	24.5%
9	22.0	15.7	28.6%	30.5	17.2	43.6%	46.0	34.7	24.6%
9.5	21.6	15.4	29.0%	29.0	16.0	44.8%	42.2	31.6	25.1%
10	21.3	15.1	29.2%	27.6	14.9	45.9%	38.9	28.9	25.8%

	Brake power [kW] at 4 knots								
	beta = 90, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	21.3	23.0	-8.0%	28.3	26.8	5.3%	40.6	35.6	12.2%
4.5	21.6	22.7	-5.4%	32.6	28.5	12.6%	51.2	41.8	18.4%
5	21.2	21.9	-3.3%	28.9	22.9	20.8%	42.1	30.2	28.2%
5.5	21.1	21.1	-0.2%	26.1	18.1	30.5%	34.7	21.1	39.2%
6	20.9	20.3	2.7%	24.8	16.0	35.4%	30.2	17.8	41.1%
6.5	20.6	19.5	5.3%	24.1	14.7	39.0%	27.9	15.1	45.9%
7	20.4	18.8	7.6%	23.7	13.8	41.5%	26.8	13.8	48.4%
7.5	20.2	18.3	9.5%	22.9	12.6	45.0%	26.0	13.3	48.8%
8	20.0	17.8	11.2%	22.2	11.5	48.4%	25.1	12.4	50.8%
8.5	19.9	17.4	12.6%	21.7	10.6	51.3%	24.6	11.6	52.8%
9	19.8	17.1	13.8%	21.3	9.9	53.6%	23.8	11.1	53.4%
9.5	19.7	16.8	14.9%	20.9	9.4	55.2%	23.0	10.7	53.3%
10	19.6	16.6	15.8%	20.7	9.0	56.3%	22.4	10.6	52.5%

U = 5kn

	Brake power [kW] at 5 knots								
	beta = 0, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	37.7	42.4	-12.5%	45.3	47.9	-5.7%	58.6	57.4	2.0%
4.5	40.3	44.6	-10.6%	58.5	57.2	2.2%	90.8	81.0	10.7%
5	43.0	47.0	-9.3%	74.9	73.0	2.6%	132.6	120.5	9.1%
5.5	45.9	49.2	-7.2%	93.2	90.1	3.3%	188.8	173.9	7.9%
6	48.0	50.1	-4.5%	103.1	94.1	8.8%	239.1	210.3	12.1%
6.5	49.1	49.9	-1.6%	102.1	86.9	14.9%	247.5	204.4	17.4%
7	49.3	48.7	1.4%	97.3	78.9	18.9%	219.8	174.6	20.6%
7.5	48.9	46.8	4.2%	94.8	73.4	22.5%	191.0	147.7	22.7%
8	48.0	44.7	6.9%	90.7	67.2	25.9%	171.2	130.1	24.0%
8.5	47.0	42.6	9.4%	85.8	61.0	28.9%	159.3	119.8	24.8%
9	45.8	40.6	11.4%	80.5	55.2	31.4%	147.2	109.5	25.6%
9.5	44.7	38.7	13.3%	75.4	49.9	33.8%	133.8	98.4	26.4%
10	43.6	37.1	14.8%	70.6	45.2	36.0%	121.5	88.3	27.3%

Appendix G: Brake power: Passive foils. Wind not included

	Brake power [kW] at 5 knots								
	beta = 22.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	38.0	47.0	-23.6%	47.0	50.6	-7.7%	62.5	58.1	7.0%
4.5	40.5	48.5	-19.7%	60.3	57.8	4.0%	95.1	78.0	18.0%
5	42.9	49.9	-16.3%	74.1	65.8	11.2%	130.4	98.6	24.4%
5.5	45.4	51.1	-12.5%	90.3	74.3	17.6%	180.5	129.1	28.5%
6	47.2	51.6	-9.4%	98.5	77.5	21.3%	224.1	160.0	28.6%
6.5	48.1	51.4	-7.0%	96.5	73.4	24.0%	226.6	157.1	30.7%
7	48.2	50.6	-5.1%	91.7	67.7	26.2%	198.8	131.9	33.7%
7.5	47.6	49.5	-3.8%	89.0	63.1	29.0%	172.8	110.6	36.0%
8	46.8	48.1	-2.8%	85.0	57.8	32.0%	155.5	94.3	39.4%
8.5	45.8	46.7	-2.0%	80.3	52.3	34.8%	145.1	83.3	42.6%
9	44.7	45.3	-1.5%	75.5	47.1	37.7%	134.0	72.9	45.6%
9.5	43.7	44.1	-0.9%	70.8	42.3	40.3%	122.0	62.2	49.0%
10	42.7	43.0	-0.6%	66.5	38.0	42.9%	111.0	53.1	52.2%

	Brake power [kW] at 5 knots								
	beta = 45, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	38.8	43.7	-12.7%	50.7	54.2	-6.9%	37.1	37.7	-1.7%
4.5	40.9	45.3	-10.6%	64.0	64.6	-0.8%	66.6	60.5	9.1%
5	42.5	45.5	-7.0%	72.7	69.3	4.7%	86.5	71.9	16.9%
5.5	44.3	45.4	-2.6%	83.4	68.6	17.7%	118.0	81.8	30.7%
6	45.3	44.4	2.0%	86.5	63.5	26.6%	139.1	88.9	36.1%
6.5	45.6	42.8	6.1%	82.6	56.9	31.1%	129.4	80.7	37.7%
7	45.3	40.9	9.7%	78.3	52.2	33.3%	107.4	65.9	38.7%
7.5	44.7	39.0	12.6%	75.4	48.3	35.9%	90.7	54.1	40.3%
8	43.8	37.3	15.0%	71.5	44.3	38.0%	80.1	46.2	42.3%
8.5	42.9	35.7	16.7%	67.7	40.8	39.8%	73.6	41.7	43.4%
9	42.1	34.4	18.2%	63.9	37.4	41.4%	66.0	36.4	44.9%
9.5	41.3	33.3	19.3%	60.3	34.5	42.9%	58.0	30.7	47.1%
10	40.5	32.4	20.1%	57.1	31.8	44.3%	51.0	25.6	49.7%

	Brake power [kW] at 5 knots								
	beta = 67.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	38.8	42.9	-10.5%	51.0	51.4	-0.8%	72.4	66.1	8.6%
4.5	40.4	41.6	-3.0%	62.4	50.7	18.7%	100.5	74.1	26.3%
5	41.0	39.8	2.8%	66.0	43.3	34.4%	109.7	71.9	34.5%
5.5	41.7	38.2	8.4%	68.4	41.4	39.5%	119.7	78.0	34.8%
6	41.8	36.5	12.7%	66.0	39.0	40.9%	117.2	78.8	32.8%
6.5	41.7	35.0	16.0%	62.4	35.8	42.6%	104.3	69.6	33.3%
7	41.2	33.7	18.2%	59.9	33.7	43.7%	92.1	61.1	33.7%
7.5	40.6	32.6	19.7%	57.5	31.6	45.0%	83.9	55.0	34.5%
8	40.0	31.7	20.8%	54.8	29.4	46.3%	78.2	50.4	35.5%
8.5	39.4	31.0	21.4%	52.3	27.5	47.4%	74.5	47.7	36.0%
9	38.9	30.5	21.6%	50.0	25.8	48.5%	69.9	44.3	36.7%
9.5	38.4	30.0	21.7%	48.0	24.3	49.4%	65.0	40.6	37.5%
10	38.0	29.7	21.7%	46.2	23.0	50.3%	60.8	37.3	38.6%

	Brake power [kW] at 5 knots								
	beta = 90, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	37.8	41.7	-10.3%	46.9	46.4	1.2%	46.4	56.3	-21.5%
4.5	38.2	41.4	-8.3%	52.3	47.7	8.8%	47.7	62.2	-30.3%
5	37.7	40.2	-6.5%	47.6	39.8	16.4%	39.8	45.6	-14.5%
5.5	37.6	39.1	-4.0%	44.0	32.7	25.6%	32.7	32.0	2.2%
6	37.3	37.9	-1.6%	42.3	29.4	30.6%	29.4	26.9	8.3%
6.5	37.0	36.8	0.6%	41.5	27.3	34.1%	27.3	22.8	16.4%
7	36.7	35.8	2.4%	40.9	25.9	36.6%	25.9	20.9	19.4%
7.5	36.4	35.0	3.8%	40.0	23.9	40.2%	23.9	20.3	15.2%
8	36.2	34.3	5.1%	39.0	22.1	43.4%	22.1	18.8	14.9%
8.5	36.1	33.8	6.3%	38.4	20.7	46.1%	20.7	17.4	15.7%
9	35.9	33.4	7.1%	37.8	19.5	48.4%	19.5	16.4	15.9%
9.5	35.8	33.0	7.9%	37.4	18.6	50.2%	18.6	15.7	15.7%
10	35.7	32.7	8.4%	37.0	18.0	51.4%	18.0	15.3	14.8%

$U = 6kn$

	Brake power [kW] at 6 knots								
	beta = 0, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	61.2	69.6	-13.7%	70.2	76.1	-8.4%	85.6	87.0	-1.7%
4.5	64.2	72.0	-12.2%	84.8	86.0	-1.5%	120.6	111.3	7.8%
5	67.4	74.8	-10.9%	102.5	102.4	0.1%	164.5	151.1	8.1%
5.5	71.0	77.2	-8.7%	124.3	121.8	2.1%	227.7	208.6	8.4%
6	74.0	78.3	-5.9%	139.3	126.9	8.9%	294.5	250.3	15.0%
6.5	75.7	78.0	-3.0%	141.1	118.6	15.9%	319.0	246.0	22.9%
7	76.3	76.4	-0.2%	136.2	108.3	20.4%	292.3	213.8	26.8%
7.5	75.9	74.1	2.4%	134.0	101.1	24.5%	257.6	182.6	29.1%
8	75.0	71.4	4.8%	129.7	93.2	28.1%	232.6	161.5	30.6%
8.5	73.7	68.6	6.9%	124.0	85.3	31.2%	217.6	149.2	31.4%
9	72.3	66.1	8.6%	117.6	77.8	33.8%	202.9	137.1	32.5%
9.5	70.9	63.8	10.1%	111.3	71.0	36.2%	186.8	124.0	33.7%
10	69.6	61.8	11.2%	105.4	65.0	38.3%	171.7	111.9	34.8%

	Brake power [kW] at 6 knots								
	beta = 22.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	61.7	70.0	-13.6%	72.3	78.0	-7.9%	90.6	91.6	-1.1%
4.5	64.5	72.3	-12.1%	87.3	89.1	-2.1%	126.6	118.2	6.6%
5	67.5	74.6	-10.5%	102.5	102.8	-0.3%	164.5	151.9	7.7%
5.5	70.8	76.4	-8.0%	122.5	118.0	3.7%	222.7	198.9	10.7%
6	73.3	76.9	-4.9%	135.6	118.5	12.6%	283.2	225.9	20.2%
6.5	74.6	75.9	-1.7%	135.6	108.7	19.8%	298.6	216.3	27.6%
7	75.0	74.0	1.3%	130.3	99.1	23.9%	269.0	187.3	30.4%
7.5	74.5	71.5	4.1%	127.6	91.9	27.9%	236.7	160.8	32.1%
8	73.6	68.8	6.5%	123.0	84.4	31.4%	214.2	142.7	33.3%
8.5	72.3	66.2	8.4%	117.5	77.1	34.4%	200.8	132.1	34.2%
9	70.9	63.8	10.0%	111.6	70.4	36.9%	187.4	121.5	35.2%
9.5	69.6	61.7	11.3%	105.7	64.5	39.0%	172.6	110.2	36.2%
10	68.4	59.9	12.4%	100.2	59.2	40.9%	158.6	99.7	37.1%

	Brake power [kW] at 6 knots								
	beta = 45, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	62.7	71.2	-13.6%	77.1	84.0	-8.8%	102.0	105.8	-3.7%
4.5	65.3	73.0	-11.8%	92.9	95.8	-3.0%	140.5	136.9	2.6%
5	67.4	73.2	-8.6%	103.0	100.4	2.5%	165.6	154.7	6.6%
5.5	69.7	73.0	-4.7%	117.4	98.2	16.4%	209.6	175.8	16.1%
6	71.2	71.5	-0.5%	123.8	90.8	26.7%	245.8	191.9	21.9%
6.5	71.8	69.4	3.3%	119.7	81.9	31.6%	238.3	178.2	25.2%
7	71.5	66.9	6.5%	114.3	75.4	34.1%	208.5	151.5	27.3%
7.5	70.8	64.4	9.0%	110.8	69.8	37.0%	184.5	131.2	28.9%
8	69.7	62.1	11.0%	106.2	64.2	39.6%	169.2	117.9	30.3%
8.5	68.6	60.0	12.6%	101.3	59.3	41.5%	159.8	110.3	31.0%
9	67.5	58.3	13.6%	96.4	54.9	43.1%	149.2	101.4	32.0%
9.5	66.4	56.9	14.4%	91.8	51.0	44.4%	137.9	91.8	33.4%
10	65.4	55.7	14.8%	87.7	47.6	45.7%	127.6	83.2	34.8%

	Brake power [kW] at 6 knots								
	beta = 67.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	62.8	70.3	-12.0%	77.9	81.0	-4.1%	103.8	98.7	4.9%
4.5	64.7	68.7	-6.1%	91.5	78.6	14.1%	137.1	102.3	25.4%
5	65.5	66.2	-1.0%	96.2	65.5	31.9%	148.7	92.2	38.0%
5.5	66.5	63.9	3.9%	99.9	61.0	38.9%	162.9	96.1	41.0%
6	66.7	61.6	7.7%	97.3	57.6	40.9%	161.4	96.8	40.0%
6.5	66.5	59.4	10.6%	92.9	53.3	42.6%	145.5	86.4	40.6%
7	65.9	57.7	12.5%	89.6	50.4	43.7%	130.1	76.4	41.2%
7.5	65.2	56.2	13.8%	86.6	47.3	45.3%	119.7	69.4	42.0%
8	64.4	54.9	14.7%	83.1	44.3	46.8%	112.6	64.0	43.1%
8.5	63.7	54.0	15.1%	80.0	41.7	47.9%	108.0	60.7	43.8%
9	62.9	53.4	15.2%	77.1	39.4	48.9%	102.1	56.4	44.8%
9.5	62.4	52.8	15.3%	74.6	37.5	49.7%	96.0	51.8	46.1%
10	61.8	52.5	15.1%	72.4	35.9	50.4%	90.7	47.8	47.3%

	Brake power [kW] at 6 knots								
	beta = 90, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	61.6	68.9	-11.9%	72.9	74.4	-2.0%	92.0	85.5	7.1%
4.5	62.1	68.3	-10.1%	79.6	75.2	5.4%	107.8	90.7	15.9%
5	61.5	66.8	-8.7%	73.7	64.6	12.3%	93.8	67.9	27.6%
5.5	61.2	65.2	-6.5%	69.2	55.0	20.5%	82.5	48.8	40.9%
6	60.9	63.7	-4.5%	67.1	50.1	25.3%	75.6	40.9	45.9%
6.5	60.5	62.2	-2.8%	66.1	47.2	28.6%	72.0	35.0	51.3%
7	60.1	60.9	-1.4%	65.3	45.2	30.8%	70.3	32.1	54.3%
7.5	59.8	59.9	-0.2%	64.2	42.3	34.1%	69.0	31.3	54.6%
8	59.5	59.1	0.7%	63.0	39.7	37.0%	67.7	29.2	56.9%
8.5	59.3	58.4	1.6%	62.2	37.7	39.4%	66.8	27.0	59.6%
9	59.2	57.8	2.2%	61.5	36.1	41.4%	65.5	25.3	61.4%
9.5	59.0	57.4	2.8%	61.0	34.8	42.9%	64.3	23.9	62.8%
10	58.9	57.0	3.2%	60.5	33.8	44.1%	63.4	23.2	63.4%

U = 7kn

	Brake power [kW] at 7 knots								
	beta = 0, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	95.4	108.9	-14.2%	105.8	116.5	-10.1%	123.6	129.1	-4.4%
4.5	98.6	111.4	-13.0%	121.9	127.0	-4.2%	161.3	153.9	4.6%
5	102.4	114.5	-11.7%	140.7	143.6	-2.1%	207.1	193.5	6.6%
5.5	107.0	117.3	-9.7%	166.1	164.8	0.7%	277.1	254.2	8.3%
6	110.8	118.6	-7.1%	187.0	171.7	8.2%	360.8	301.8	16.4%
6.5	113.3	118.2	-4.3%	192.8	162.4	15.8%	406.6	298.7	26.5%
7	114.5	116.3	-1.6%	188.2	149.8	20.4%	385.0	263.7	31.5%
7.5	114.3	113.5	0.7%	186.8	140.6	24.7%	344.4	227.3	34.0%
8	113.3	110.2	2.8%	182.4	130.5	28.4%	312.8	201.9	35.5%
8.5	111.9	106.8	4.6%	176.0	120.5	31.5%	294.1	186.8	36.5%
9	110.2	103.7	5.9%	168.6	111.1	34.1%	276.7	172.5	37.7%
9.5	108.5	100.9	7.0%	160.8	102.7	36.2%	257.4	157.3	38.9%
10	106.7	98.5	7.7%	153.4	95.3	37.9%	238.7	143.2	40.0%

	Brake power [kW] at 7 knots								
	beta = 22.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	95.9	109.4	-14.1%	108.4	119.0	-9.8%	129.6	134.7	-3.9%
4.5	99.1	111.9	-12.9%	125.1	130.7	-4.5%	169.2	162.7	3.9%
5	102.7	114.5	-11.5%	141.6	144.8	-2.3%	209.3	196.1	6.3%
5.5	106.9	116.5	-9.0%	165.5	161.6	2.4%	275.5	246.6	10.5%
6	110.3	117.1	-6.2%	184.4	162.8	11.7%	354.4	276.3	22.0%
6.5	112.4	115.9	-3.2%	187.6	151.1	19.4%	388.2	265.7	31.6%
7	113.1	113.5	-0.4%	182.0	139.0	23.6%	359.8	233.1	35.2%
7.5	112.7	110.5	2.0%	179.7	129.7	27.8%	320.1	201.7	37.0%
8	111.7	107.1	4.1%	174.8	120.0	31.4%	291.5	180.1	38.2%
8.5	110.2	104.0	5.6%	168.3	110.8	34.2%	274.5	167.6	38.9%
9	108.6	101.1	6.9%	161.2	102.4	36.5%	258.1	154.9	40.0%
9.5	106.9	98.5	7.9%	154.0	94.8	38.5%	240.1	141.5	41.1%
10	105.3	96.3	8.6%	147.0	88.1	40.1%	222.9	128.9	42.2%

	Brake power [kW] at 7 knots								
	beta = 45, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	97.2	110.9	-14.1%	114.6	126.1	-10.1%	144.0	151.4	-5.1%
4.5	100.3	112.9	-12.6%	132.8	139.3	-4.9%	188.0	182.7	2.8%
5	103.0	113.1	-9.8%	144.3	143.7	0.4%	215.9	193.7	10.3%
5.5	106.1	112.7	-6.2%	163.1	140.1	14.1%	270.4	197.7	26.9%
6	108.2	110.9	-2.4%	173.7	130.1	25.1%	323.2	200.8	37.9%
6.5	109.1	108.1	0.9%	170.1	118.4	30.4%	321.8	187.5	41.7%
7	109.0	105.0	3.7%	163.5	109.7	32.9%	285.9	164.6	42.4%
7.5	108.1	101.9	5.8%	159.5	101.8	36.2%	254.9	145.6	42.9%
8	106.9	98.9	7.5%	154.0	94.2	38.9%	235.0	132.1	43.8%
8.5	105.5	96.4	8.6%	147.9	87.5	40.8%	223.0	124.1	44.3%
9	104.1	94.2	9.5%	141.8	81.7	42.4%	209.9	115.4	45.0%
9.5	102.7	92.4	10.0%	136.0	76.6	43.7%	195.7	105.8	45.9%
10	101.4	91.0	10.2%	130.6	72.2	44.7%	182.5	97.1	46.8%

	Brake power [kW] at 7 knots								
	beta = 67.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	97.4	109.9	-12.9%	115.7	123.2	-6.4%	146.9	144.5	1.6%
4.5	99.8	108.0	-8.2%	131.9	119.6	9.3%	185.8	143.8	22.6%
5	100.8	104.8	-3.9%	137.8	99.6	27.7%	199.9	122.2	38.9%
5.5	102.0	101.8	0.2%	143.3	91.9	35.9%	219.6	122.8	44.1%
6	102.4	98.8	3.6%	140.7	86.6	38.4%	219.8	122.3	44.3%
6.5	102.2	96.1	6.0%	135.1	80.8	40.2%	200.8	108.8	45.8%
7	101.6	93.7	7.7%	131.0	76.9	41.3%	181.3	97.4	46.3%
7.5	100.6	91.8	8.7%	127.3	72.7	42.9%	168.3	89.6	46.8%
8	99.6	90.3	9.4%	123.1	68.9	44.1%	159.6	83.1	48.0%
8.5	98.7	89.2	9.6%	119.3	65.8	44.9%	153.9	79.2	48.5%
9	97.8	88.3	9.7%	115.6	63.1	45.4%	146.7	74.3	49.3%
9.5	97.1	87.8	9.5%	112.4	60.9	45.8%	139.1	69.0	50.4%
10	96.4	87.4	9.3%	109.7	59.1	46.1%	132.5	64.4	51.4%

	Brake power [kW] at 7 knots								
	beta = 90, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	95.4	107.6	-12.8%	105.8	110.7	-4.6%	123.6	117.9	4.7%
4.5	98.6	109.3	-10.9%	121.9	118.5	2.7%	161.3	139.3	13.6%
5	102.4	111.6	-8.9%	140.7	129.2	8.2%	207.1	166.0	19.9%
5.5	107.0	113.9	-6.4%	166.1	143.2	13.8%	277.1	209.3	24.5%
6	110.8	115.5	-4.3%	187.0	153.7	17.8%	360.8	264.9	26.6%
6.5	113.3	116.2	-2.5%	192.8	154.0	20.1%	406.6	287.2	29.4%
7	114.5	115.9	-1.2%	188.2	148.1	21.3%	385.0	266.7	30.7%
7.5	114.3	114.8	-0.5%	186.8	143.9	22.9%	344.4	237.5	31.1%
8	113.3	113.2	0.1%	182.4	137.9	24.4%	312.8	211.5	32.4%
8.5	111.9	111.4	0.5%	176.0	130.7	25.7%	294.1	193.7	34.1%
9	110.2	109.5	0.6%	168.6	123.1	27.0%	276.7	178.4	35.5%
9.5	108.5	107.6	0.9%	160.8	115.7	28.1%	257.4	162.0	37.0%
10	106.7	105.8	0.9%	153.4	108.8	29.1%	238.7	147.1	38.4%

$U = 8kn$

	Brake power [kW] at 8 knots								
	beta = 0, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	143.7	164.4	-14.3%	156.0	173.1	-11.0%	176.2	187.4	-6.3%
4.5	147.3	166.9	-13.3%	173.3	184.0	-6.2%	216.6	212.6	1.9%
5	151.7	170.3	-12.3%	192.9	200.6	-4.0%	263.9	251.4	4.7%
5.5	157.3	173.4	-10.2%	221.9	223.4	-0.7%	340.4	314.7	7.5%
6	162.2	175.0	-7.9%	249.4	232.5	6.8%	440.9	368.1	16.5%
6.5	165.8	174.6	-5.3%	260.6	222.6	14.6%	512.2	367.5	28.2%
7	167.5	172.5	-3.0%	257.1	207.7	19.2%	500.8	329.2	34.3%
7.5	167.7	169.2	-0.9%	256.7	196.3	23.5%	455.2	287.0	37.0%
8	166.8	165.3	0.9%	252.6	184.0	27.2%	416.1	256.2	38.4%
8.5	165.3	161.3	2.4%	245.7	171.5	30.2%	392.5	237.8	39.4%
9	163.2	157.6	3.5%	237.1	159.9	32.5%	372.2	220.8	40.7%
9.5	161.1	154.2	4.2%	227.8	149.5	34.4%	349.5	202.6	42.0%
10	159.1	151.4	4.8%	218.8	140.2	35.9%	327.1	185.8	43.2%

Appendix G: Brake power: Passive foils. Wind not included

	Brake power [kW] at 8 knots								
	beta = 22.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	144.4	165.0	-14.2%	159.1	176.1	-10.7%	183.6	194.3	-5.8%
4.5	148.0	167.6	-13.2%	177.5	188.7	-6.3%	226.6	223.3	1.5%
5	152.2	170.3	-11.9%	194.9	202.6	-4.0%	268.6	256.0	4.7%
5.5	157.4	172.7	-9.7%	222.8	220.9	0.8%	342.4	309.2	9.7%
6	161.8	173.4	-7.2%	248.5	223.1	10.2%	440.3	342.9	22.1%
6.5	164.9	172.1	-4.4%	256.0	210.2	17.9%	497.9	331.9	33.3%
7	166.2	169.3	-1.9%	250.7	195.6	22.0%	473.9	295.1	37.7%
7.5	166.0	165.8	0.2%	249.0	183.9	26.2%	427.4	257.5	39.7%
8	164.9	161.8	1.9%	244.1	171.5	29.7%	391.1	230.9	40.9%
8.5	163.2	157.9	3.2%	236.7	159.9	32.4%	369.7	215.2	41.8%
9	161.2	154.5	4.1%	228.3	149.3	34.6%	350.6	200.0	43.0%
9.5	159.2	151.5	4.8%	219.4	139.9	36.3%	328.8	183.7	44.1%
10	157.2	148.7	5.4%	211.0	131.8	37.6%	307.6	168.9	45.1%

	Brake power [kW] at 8 knots								
	beta = 45, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	146.0	166.8	-14.2%	166.7	184.7	-10.8%	201.2	214.2	-6.5%
4.5	149.7	168.9	-12.8%	187.6	199.4	-6.3%	250.9	248.3	1.0%
5	153.0	169.2	-10.5%	200.3	203.3	-1.5%	281.5	257.9	8.4%
5.5	157.1	168.6	-7.4%	223.8	198.6	11.2%	346.4	258.5	25.4%
6	159.9	166.5	-4.1%	239.7	186.1	22.4%	419.2	256.6	38.8%
6.5	161.3	163.2	-1.2%	237.4	171.5	27.7%	428.0	239.2	44.1%
7	161.3	159.4	1.2%	229.4	160.3	30.1%	385.9	212.6	44.9%
7.5	160.4	155.6	3.0%	225.1	149.8	33.5%	347.0	189.3	45.4%
8	158.9	152.1	4.3%	218.6	139.7	36.1%	321.3	172.7	46.2%
8.5	157.3	149.0	5.3%	211.3	131.0	38.0%	306.3	162.8	46.8%
9	155.5	146.4	5.8%	203.8	123.6	39.3%	290.2	152.1	47.6%
9.5	153.8	144.3	6.1%	196.5	117.3	40.3%	272.5	140.4	48.5%
10	152.2	142.6	6.3%	189.9	112.0	41.0%	256.2	130.0	49.3%

	Brake power [kW] at 8 knots								
	beta = 67.5, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	146.4	165.8	-13.2%	168.4	181.9	-8.0%	205.2	207.5	-1.1%
4.5	149.3	163.6	-9.5%	187.4	177.6	5.2%	250.5	203.5	18.8%
5	150.6	159.7	-6.0%	194.4	150.4	22.6%	267.3	168.1	37.1%
5.5	152.2	156.1	-2.6%	202.2	138.9	31.3%	293.8	163.2	44.5%
6	152.8	152.3	0.3%	199.8	131.7	34.1%	296.7	160.4	45.9%
6.5	152.6	149.0	2.3%	192.9	123.9	35.8%	274.1	142.4	48.1%
7	151.7	146.0	3.7%	187.8	118.8	36.8%	250.0	128.2	48.7%
7.5	150.6	143.7	4.6%	183.6	113.2	38.3%	233.9	119.3	49.0%
8	149.5	141.9	5.0%	178.3	107.8	39.5%	223.1	111.9	49.8%
8.5	148.3	140.6	5.2%	173.7	103.8	40.2%	216.2	107.3	50.4%
9	147.2	139.5	5.2%	169.3	100.6	40.6%	207.5	101.3	51.2%
9.5	146.3	139.0	5.0%	165.4	97.9	40.8%	198.1	95.0	52.1%
10	145.4	138.5	4.7%	161.8	95.8	40.8%	190.0	89.6	52.9%

	Brake power [kW] at 8 knots								
	beta = 90, no wind resistance								
	Hs = 1m			Hs = 2m			Hs = 3m		
Tp [s]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]	Unfoiled	Foiled	Savings [%]
4	144.8	163.7	-13.1%	161.4	171.7	-6.3%	189.1	186.0	1.7%
4.5	145.5	162.7	-11.8%	171.0	171.3	-0.2%	211.3	188.1	11.0%
5	144.5	160.2	-10.8%	162.3	154.0	5.1%	191.0	150.3	21.3%
5.5	144.2	157.8	-9.4%	155.7	138.5	11.0%	174.9	116.5	33.4%
6	143.7	155.3	-8.1%	152.8	130.3	14.7%	165.0	100.0	39.4%
6.5	143.1	153.2	-7.1%	151.4	125.4	17.2%	159.8	89.4	44.1%
7	142.6	151.4	-6.1%	150.2	122.0	18.8%	157.3	84.2	46.5%
7.5	142.1	149.8	-5.4%	148.5	117.2	21.1%	155.6	83.0	46.7%
8	141.7	148.6	-4.9%	146.7	113.0	23.0%	153.5	78.8	48.7%
8.5	141.3	147.7	-4.5%	145.6	109.8	24.6%	152.3	74.8	50.9%
9	141.1	147.0	-4.2%	144.7	107.3	25.8%	150.4	71.3	52.6%
9.5	141.0	146.4	-3.8%	143.9	105.3	26.8%	148.7	68.2	54.1%
10	140.8	145.9	-3.7%	143.2	103.8	27.5%	147.3	66.2	55.0%

Appendix H: Brake power: Pitching foils vs. passive foils, higher seas

Break power in higher, irregular seas: Unfoiled, passively foiled and pitch foiled U = 4kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Pb Tp [s]	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled
4	112.6	109.2	105.5	3.1%	6.3%	134.4	126.2	122.8	6.1%	8.6%	164.0	151.2	147.5	7.8%	10.0%
4.5	149.9	139.1	135.4	7.2%	9.7%	205.5	188.1	183.6	8.5%	10.7%	283.6	261.2	254.7	7.9%	10.2%
5	197.3	185.6	181.8	5.9%	7.8%	299.1	279.6	274.9	6.5%	8.1%	446.8	420.1	413.2	6.0%	7.5%
5.5	254.2	242.4	238.7	4.7%	6.1%	414.9	393.7	388.9	5.1%	6.3%	651.0	621.0	615.3	4.6%	5.5%
6	295.2	278.1	273.9	5.8%	7.2%	499.2	473.1	466.1	5.2%	6.6%	803.1	763.9	758.4	4.9%	5.6%
6.5	292.4	269.8	263.9	7.7%	9.8%	505.8	475.6	464.6	6.0%	8.1%	815.0	768.6	761.2	5.7%	6.6%
7	262.1	238.2	230.8	9.1%	12.0%	451.0	421.8	406.4	6.5%	9.9%	716.0	672.6	658.6	6.1%	8.0%
7.5	235.0	211.4	202.9	10.1%	13.6%	379.9	354.5	337.7	6.7%	11.1%	589.3	555.3	536.6	5.8%	8.9%
8	217.1	194.0	185.5	10.6%	14.6%	327.0	304.7	288.5	6.8%	11.8%	478.2	453.9	434.3	5.1%	9.2%
8.5	206.0	184.0	175.2	10.7%	14.9%	293.2	273.9	258.3	6.6%	11.9%	408.1	389.7	370.9	4.5%	9.1%
9	194.0	173.1	164.1	10.8%	15.4%	271.4	254.2	239.1	6.3%	11.9%	363.5	349.3	330.5	3.9%	9.1%
9.5	181.0	161.3	152.0	10.9%	16.0%	255.7	240.6	225.6	5.9%	11.7%	333.4	322.5	304.1	3.3%	8.8%
10	169.2	150.6	141.2	11.0%	16.6%	243.3	229.7	214.8	5.6%	11.7%	310.9	302.6	284.4	2.7%	8.5%

Break power in higher, irregular seas: Unfoiled, passively foiled and pitch foiled U = 5kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Pb Tp [s]	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled
4	148.1	146.6	145.2	1.0%	2.0%	172.4	164.5	164.1	4.6%	4.8%	205.2	190.1	190.4	7.3%	7.2%
4.5	187.6	175.6	175.6	6.4%	6.4%	246.9	223.7	224.1	9.4%	9.3%	329.3	295.7	295.2	10.2%	10.4%
5	237.2	222.8	222.8	6.1%	6.1%	343.1	314.9	315.4	8.2%	8.1%	494.3	451.9	451.5	8.6%	8.6%
5.5	301.6	284.3	284.8	5.7%	5.6%	471.7	436.3	437.5	7.5%	7.2%	719.2	663.5	664.2	7.7%	7.7%
6	358.5	325.7	326.5	9.1%	8.9%	587.1	527.5	527.5	10.1%	10.1%	924.0	834.2	829.9	9.7%	10.2%
6.5	367.9	319.4	318.3	13.2%	13.5%	622.7	543.6	536.5	12.7%	13.8%	987.9	876.3	857.2	11.3%	13.2%
7	336.7	285.7	281.0	15.1%	16.5%	573.8	497.0	480.0	13.4%	16.3%	899.8	801.2	764.3	11.0%	15.1%
7.5	304.2	254.9	248.2	16.2%	18.4%	490.2	425.9	404.5	13.1%	17.5%	755.0	680.2	636.8	9.9%	15.7%
8	281.5	234.5	226.6	16.7%	19.5%	423.2	368.9	347.5	12.8%	17.9%	619.6	565.1	524.6	8.8%	15.3%
8.5	267.9	222.4	214.1	17.0%	20.1%	380.0	332.1	311.4	12.6%	18.0%	529.5	485.7	449.5	8.3%	15.1%
9	254.1	210.3	201.0	17.2%	20.9%	352.4	308.8	288.6	12.4%	18.1%	471.7	434.8	400.9	7.8%	15.0%
9.5	238.5	197.1	187.2	17.4%	21.5%	333.0	293.0	273.0	12.0%	18.0%	432.8	401.6	369.5	7.2%	14.6%
10	224.1	184.9	174.6	17.5%	22.1%	317.5	280.8	260.8	11.6%	17.9%	404.5	377.7	346.4	6.6%	14.4%

Appendix H: Brake power: Pitching foils vs. passive foils, higher seas

Break power in higher, irregular seas: Unfoiled, passively foiled and pitch foiled U = 6kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Pb Tp [s]	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled
4	192.6	194.4	196.7	-0.9%	-2.1%	219.7	213.8	217.9	2.7%	0.8%	255.8	240.6	246.5	5.9%	3.6%
4.5	234.4	223.3	228.1	4.7%	2.7%	297.7	270.9	278.0	9.0%	6.6%	384.7	341.9	349.8	11.1%	9.1%
5	285.4	269.9	275.3	5.4%	3.5%	395.6	359.9	367.9	9.0%	7.0%	550.6	492.9	501.6	10.5%	8.9%
5.5	357.3	335.3	341.7	6.2%	4.4%	536.8	487.3	496.6	9.2%	7.5%	794.5	711.4	722.3	10.5%	9.1%
6	431.9	382.3	391.2	11.5%	9.4%	686.1	588.8	599.5	14.2%	12.6%	1057.4	901.4	910.7	14.8%	13.9%
6.5	458.8	378.0	385.3	17.6%	16.0%	761.5	617.9	619.5	18.9%	18.6%	1190.6	975.6	962.7	18.1%	19.1%
7	429.5	342.2	343.5	20.3%	20.0%	726.8	581.3	565.7	20.0%	22.2%	1128.7	926.2	882.3	17.9%	21.8%
7.5	390.9	306.8	304.5	21.5%	22.1%	630.3	505.8	481.2	19.8%	23.6%	966.3	806.9	747.9	16.5%	22.6%
8	362.7	282.3	278.0	22.2%	23.4%	545.5	440.5	414.2	19.2%	24.1%	801.1	680.7	623.2	15.0%	22.2%
8.5	346.0	268.2	262.2	22.5%	24.2%	489.7	397.8	371.8	18.8%	24.1%	683.7	588.3	536.3	13.9%	21.6%
9	329.3	254.1	246.5	22.8%	25.1%	454.3	370.0	344.1	18.6%	24.3%	608.9	527.0	478.9	13.5%	21.4%
9.5	311.1	238.8	230.0	23.2%	26.1%	430.2	350.9	325.2	18.4%	24.4%	559	486.4	440.1	13.0%	21.3%
10	293.6	224.5	214.6	23.5%	26.9%	411.5	336.3	310.6	18.3%	24.5%	523	456.9	411.8	12.6%	21.3%

Break power in higher, irregular seas: Unfoiled, passively foiled and pitch foiled U = 7kn, Head sea, Head wind: 16m/s															
	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
Pb Tp [s]	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled
4	250.4	256.8	264.3	-2.5%	-5.5%	280.6	278.0	288.2	1.0%	-2.7%	320.6	306.8	320.1	4.3%	0.2%
4.5	294.3	285.7	296.9	2.9%	-0.9%	361.9	333.5	349.6	7.8%	3.4%	453.9	403.8	423.0	11.0%	6.8%
5	346.8	331.0	343.7	4.5%	0.9%	461.2	419.5	437.5	9.1%	5.2%	620.2	548.5	569.7	11.6%	8.1%
5.5	425.6	399.6	413.4	6.1%	2.9%	613.8	550.7	571.0	10.3%	7.0%	880.9	770.5	795.9	12.5%	9.6%
6	518.1	452.8	471.3	12.6%	9.0%	797.2	661.9	687.6	17.0%	13.7%	1200.5	975.3	1003.5	18.8%	16.4%
6.5	568.3	450.0	469.8	20.8%	17.3%	923.1	701.7	718.5	24.0%	22.2%	1420.7	1078.0	1080.9	24.1%	23.9%
7	544.7	411.2	423.6	24.5%	22.2%	913.7	676.0	667.3	26.0%	27.0%	1404.9	1059.3	1012.3	24.6%	27.9%
7.5	499.8	370.5	376.7	25.9%	24.6%	805.9	598.4	572.8	25.8%	28.9%	1231.2	947.9	872.8	23.0%	29.1%
8	465.2	341.6	344.2	26.6%	26.0%	699.4	523.3	494.1	25.2%	29.4%	1030.0	812.0	734.0	21.2%	28.7%
8.5	444.2	324.2	324.4	27.0%	27.0%	628.2	472.7	442.5	24.7%	29.6%	878.7	703.4	632.8	19.9%	28.0%
9	424.9	307.9	305.2	27.5%	28.2%	582.9	439.5	408.8	24.6%	29.9%	781.5	628.2	562.5	19.6%	28.0%
9.5	403.5	290.4	285.3	28.0%	29.3%	552.9	417.6	386.2	24.5%	30.2%	717.3	579.7	516.5	19.2%	28.0%
10	382.4	273.9	267.1	28.4%	30.2%	529.9	400.8	369.1	24.4%	30.4%	672.2	546.0	483.5	18.8%	28.1%

Appendix H: Brake power: Pitching foils vs. passive foils, higher seas

Break power in higher, irregular seas: Unfoiled, passively foiled and pitch foiled
U = 8kn, Head sea, Head wind: 16m/s

Pb Tp [s]	Hs = 3.0m					Hs = 4.0m					Hs = 5.0m				
	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled	Unfoiled [kW]	Passively foiled [kW]	Pitching foiled [kW]	Savings passive foiled	Savings pitch foiled
4	325.4	338.1	352.6	-3.9%	-8.4%	358.9	361.3	379.7	-0.7%	-5.8%	403.1	392.5	415.5	2.6%	-3.1%
4.5	371.6	367.0	387.0	1.2%	-4.1%	443.9	415.8	443.2	6.3%	0.2%	541.5	485.7	519.9	10.3%	4.0%
5	424.9	410.6	432.8	3.4%	-1.9%	543.5	497.9	528.2	8.4%	2.8%	706.8	622.8	660.5	11.9%	6.6%
5.5	509.5	481.0	505.0	5.6%	0.9%	706.2	630.9	664.6	10.7%	5.9%	981.7	845.7	888.9	13.9%	9.5%
6	620.0	540.2	571.2	12.9%	7.9%	922.1	751.4	794.8	18.5%	13.8%	1353.5	1063.8	1116.5	21.4%	17.5%
6.5	697.6	540.7	577.3	22.5%	17.2%	1105.6	801.0	841.0	27.5%	23.9%	1673	1190	1218.1	28.9%	27.2%
7	685.3	499.0	528.2	27.2%	22.9%	1137	784.3	792.3	31.0%	30.3%	1728.9	1200.9	1163.6	30.5%	32.7%
7.5	635.8	451.9	473.2	28.9%	25.6%	1022.2	704.6	686.4	31.1%	32.9%	1553.7	1099.2	1015.6	29.3%	34.6%
8	592.8	417.1	433.1	29.6%	26.9%	891.1	618.1	591.0	30.6%	33.7%	1313.9	953.7	856.4	27.4%	34.8%
8.5	566.9	396.3	408.8	30.1%	27.9%	799.8	559.3	529.0	30.1%	33.9%	1120.2	829.8	739.2	25.9%	34.0%
9	545.1	376.9	385.3	30.9%	29.3%	742.7	520.7	488.6	29.9%	34.2%	994.5	743.2	657	25.3%	33.9%
9.5	519.9	356.3	360.8	31.5%	30.6%	705.1	494.9	461.7	29.8%	34.5%	913.3	685.3	602.3	25.0%	34.1%
10	494.9	337.1	338.6	31.9%	31.6%	678	476.0	441.9	29.8%	34.8%	856.4	644.6	563.9	24.7%	34.2%