EVALUATION OF BULBOUS BOWS ON AN INSHORE FISHING VESSEL

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Evaluation of Bulbous Bows on an Inshore Fishing Vessel

by

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ABSTRACT

The Newfoundland and Labrador inshore fishing fleet is in a unique situation in that they fish up to 350 miles offshore. The industry evolved from a fleet fishing for cod in short trips close to home, until the collapse of that species in 1992, to a fleet fishing multiple species wherever they can. Unfortunately, the small fishing boat regulation did not evolve with the vessels. This gave rise, because of a number of factors, to vessels becoming wider and higher but not longer. In an effort to design a vessel more appropriate for the conditions and species being harvested an unrestricted vessel was designed for the fleet under a separate project (Friis, et al. 2007).

This thesis describes the results of experiments conducted on this unrestricted vessel. The thesis looks specifically at four different bulbous bow options and how they compare to a conventional bow. Resistance, self-propulsion and head seas resistance, pitch and heave motion experiments were completed for the thesis. The intent is to contribute to the general knowledge of bulbous bow design for fishing vessels in Newfoundland and Labrador.

ACKNOWLEDGEMENTS

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List of Abbreviations

Conv	Conventional Bow
CFD	Computational Fluid Dynamics
DAS	Data Acquisition System
EHP	Effective Horse Power
HS	Head Seas
IOT	Institute for Ocean Technology
IOG	Industrial Outreach Group
ITTC	International Tow Tank Conference
K & R	Kempf & Remmers
LVDT	Linear Variable Differential Transformer
MUN	Memorial University of Newfoundland
NRC	National Research Council
OERC	Ocean Engineering Research Centre
RVDT	Rotary Variable Differential Transformer
SP	Self-Propulsion
SS3	Sea State 3
SS5	Sea State 5
SSA	Single Significant Amplitude

List of symbols

General

g	Local acceleration due to gravity
λ	Scale factor
ν_f	Kinematic viscosity of fresh water at 15 ° C
ν_m	Kinematic viscosity of water in model test conditions
ν_s	Kinematic viscosity of salt water at 15 ° C
ρ_f	Mass density of fresh water at 15° C
ρ_m	Mass density of water in model test conditions
ρ_s	Mass density of salt water at 15° C

Geometry

AP	Aft perpendicular
B	Beam [m]
C_B	Block coefficient
C_M	Midship section coefficient
C_P	Prismatic coefficient
C_W	Waterplane coefficient
D	Propeller Diameter [m]
D_M	Propeller Diameter, model [m]
D_S	Propeller Diameter, ship [m]
FP	Forward perpendicular
LBP	Length between perpendiculars [m]
LOA	Length overall [m]
LWL	Length on the waterline [m]
L_M	Length on the waterline, model [m]
L_S	Length on the waterline, ship [m]
LCB	Longitudinal center of buoyancy aft of amidships [m]
LCF	Longitudinal center of floatation aft of amidships [m]
LCG	Longitudinal center of gravity aft of amidships [m]
S	Wetted surface area [m^2]
S_S	Ship wetted surface area [m^2]
S_M	Model wetted surface area [m^2]
T	Draft [m]
VCB	Vertical center of buoyancy [m]
VCG	Vertical center of gravity [m]
z_v	Sinkage [mm]
V	Speed [m/s]
V_m	Speed of model [m/s]
V_s	Speed of ship [knots]
F_n	Froude number
Δ	Mass displacement [tonnes]
θv	Trim angle [deg]

∇	Volume displacement [m^3]
Z	Number of Blades

Resistance, Self-Propulsion, and Head Seas Experiments

ΔC_T	Blockage correction
C_A	Ship-Model correlation allowance
C_F	Frictional resistance coefficient
C_{FD}	Skin friction correction coefficient in propulsion test (based on V_M and S_M)
C_{FM}	Frictional resistance coefficient for the model
C_{FMP}	Frictional resistance coefficient for model at the propulsion test temperature
C_{FS}	Frictional resistance coefficient for the ship
C_R	Residuary resistance coefficient
C_{TM}	Total resistance coefficient for model at test temperature
$C_{TMCorrected}$	Total resistance coefficient corrected for blockage
C_{TM15}	Total resistance coefficient for model at 15°C
C_{TMP}	Total resistance coefficient of the model at the propulsion test temperature
C_{TS}	Total resistance coefficient for the ship at test temperature
C_{TS15}	Total resistance coefficient for ship at 15°C
F	Measured tow force [N]
F_D	Skin friction correction in propulsion test [N]
H_S	Significant wave height
η_D	Quasi-propulsive efficiency
η_R	Relative rotative efficiency
η_H	Hull efficiency
η_{OPEN}	Open water efficiency
J	Advance coefficient
J_{OPEN}	Advance coefficient for open water propeller
J_{SP}	Advance coefficient at equivalent self-propulsion point
K_{FD}	Skin friction correction coefficient in propulsion test
K_Q	Propeller torque coefficient
K_T	Propeller thrust coefficient
n	Propeller rate of rotation [rps]

n_M	Propeller rate of rotation for model [rps]
n_S	Propeller rate of rotation for ship [rps]
Q	Propeller torque [Nm]
Q_M	Propeller torque, model [Nm]
$Q_{MCorrected}$	Propeller torque corrected for friction test [Nm]
Q_S	Propeller torque, ship [Nm]
QPC	Quasi-propulsive efficiency
$Q_{FRICTION}$	Torque during friction tests [Nm]
R_{nM}	Reynolds Number, model
R_{nS}	Reynolds Number , ship
R_{TS}	Total resistance, ship [N]
R_{TM}	Total resistance, model [N]
P/D	Pitch/Diameter ratio
P_E	Effective power [kW]
T	Propeller thrust [N]
T_M	Thrust at model scale [N]
T_S	Thrust at ship scale [N]
Tp	Mean Peak Period
t	Thrust deduction fraction
V_A	Propeller speed of advance [m/s]
w	Taylor wake fraction

Uncertainty Analysis

B	Bias limit
P	Precision limit
U	Uncertainty limit

1 Introduction

The subject of this thesis work is the design of more efficient and safer vessels through the use of bulbous bows. The bulbous bow has been used for many years as a means of reducing calm water resistance at design speeds. This thesis compares the effectiveness of 4 different bulbous bow designs for the Newfoundland and Labrador fishing industry.

1.1 Bulbous Bow Background

Ship resistance is mainly comprised of four components, wind drag, frictional drag and wave and eddy making resistance. At lower speeds the largest component of resistance is the frictional resistance. As the vessel increases in speed, by far the greatest source of resistance comes from the creation of waves and eddies. As the bow penetrates the water it creates a pressure on the water creating the "bow wave". This phenomenon is very recognizable for anyone that has seen a vessel in motion or has seen a picture of dolphins jumping in front of a vessel at its bow. The image below shows Froude's sketch of a characteristic wave created by a vessel (Lewis 1988).

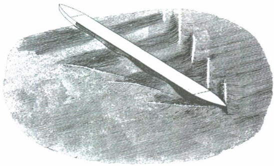

Figure 1: Froude's Sketch of a Characteristic Wave Created by a Vessel

The traditional concept of a bulbous bow is used mainly on longer vessels than those looked at in this thesis. Generally it is used to produce a wave in front of the bow so that the trough of the bulbous bow wave aligns with the crest of the bow wave thus cancelling the wave through interference. This would essentially minimize the wave creation, thus reducing the resistance of the vessel. In the perfect situation the size and shape of the bow wave would be exactly the same as the bulb wave. This never happens but with the right design the resistance can be reduced greatly.

This approach was and is still used on larger vessels because the bow waves are very predictable and only change slightly with different sea conditions. It was considered to be less cost effective for smaller vessels because they spend less time steaming at higher speeds than the larger vessels.

1.2 Purpose of Research

The work that has been completed for this thesis and through projects involving MUN's Industrial Outreach and the Ocean Engineering Research Centre (OERC) investigates the added value of bulbs on smaller vessels, which is mainly in the reduction of pitch motion in different sea states and the reduction of resistance.

The direct implication to Newfoundland and Labrador is that the proper bulbous bow design would help to reduce resistance for the inshore fishing fleet and to reduce at sea motions. This has a direct impact on the fuel efficiency of the vessel but also the reduced motions have an effect on the crew. The impact of accelerations combined with large amplitude of motion over a long duration of time increase fatigue which reduces productivity of the fisher people and will also increase the risk of accidents. It therefore also increases the window of opportunity for carrying out fishing operations. Studies have been done on what level of motion is the comfortable limit which people can withstand over a period of time. Dr. Don Bass at MUN has done extensive investigation on these motions, quantified as Motion Induced Interrupts (MII), which are a combination of accelerations and amplitudes. MII are explained as an instance in which an individual must stop and hold onto something to stabilize themselves. To quantify this, greater than 1.0 MII/minute would be considered a significant level of risk of accidents occurring (Bass, et al. n.d.).

This thesis investigates pitch and heave motions in head seas and also energy efficiency of a number of bulbous bows. Initially, six different bulbs were considered along with the conventional bow. This was reduced to four for the purposes of this thesis as the resistance data showed that two of the similar shaped bulbs were not significantly different in effect. This was determined from a previous report (Friis, et al. 2007).

Some of the work completed prior to this thesis that influenced the decision to pursue this topic included the concept design of two multi-species fishing vessels; one 65' vessel and the unrestricted fishing vessel described in this thesis. The design of these vessels indicated the need for a reduction in resistance and a reduction of pitch motions. Also, under the supervision of Professor Dag Friis a number of different bulbous bow concepts were completed for a shipyard in Québec. These were based on work that had been completed by Prof. Friis and the bulbs were built into vessels being fabricated. An example of this is shown below in Figure 2. These early stage bulbs showed some very good vessel characteristics, if only anecdotally. Testing and quantification of these benefits needed to be completed.

Figure 2: Fabrication of Concept Bulbous bow

2 Literature Review

The literature on the subject of bulbous bows has been documented at length. However, there are many different types of vessels and, as shown in this thesis, there are different effects from the bulbs. A number of papers were reviewed for this research, a sample of the papers are listed below:

'Tow tank results of bulbous bow retrofits on New England Trawler Hulls'

The first paper found during the literature review was entitled: "Tow tank results of bulbous bow retrofits on New England trawler hulls". This paper was authored by Angelos D. Heliotis and Clifford A. Goudey (1985). The paper was the closest research that could be found to the vessel size and application from the vessels described in this thesis. This paper analyzed experiments of a 23.2m (76') and a 35.4m (119') trawler engaged in the fishing industry in eastern United States.

The Heliotis paper explored cylindrical bulbous bows being retrofitted to existing vessels. The 23.2m (76') and 35.4m (119') vessel bulbous bow configurations are shown below in Figure 3 and Figure 4. These bulbs are similar to the Bulb D configuration from this thesis, though the top 'beach' area of the bulb is much different. Bulb D is shown in full detail in section 3.

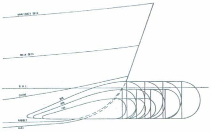

Figure 3: 23.2 (76') Trawler Bulb Experiments

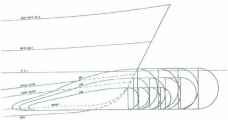

Figure 4: 35.4m (119') Trawler bulb experimentation

The 35.4m (119') vessel had a beam of 8.53m (28'), a displacement of 436 tons and a wetted surface area of 315 m^2 in the paper; this is similar to the vessel in this thesis which is 33.5m (110') long, 8.14m (26.7') of beam, 387 tonnes and a wetted surface area of $326m^2$.

The bulbs were categorized as 10, 20 or 30% of the mid ship area and as 0, 0.5, 1.0, and 1.5 diameters long, which is the distance from the bow stem to the tip of the bulb. The results showed that the bulbs became useful from a calm water resistance perspective at the 9 to 10.5 knot range depending on the configuration in the 119 ft vessel. Figure 5 and Figure 6 below shows the EHP comparison of the length and diameter to the conventional bow for the 119' vessel experiments.

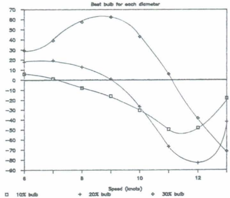

Figure 5: Bulb Diameter Comparison

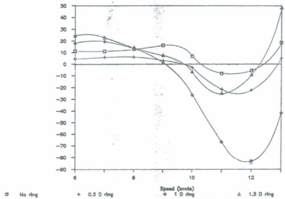

Figure 6: Bulb Length Comparison

The authors of the paper also used a creative way of simulating real life forces while at trawling speeds shown below in Figure 7.

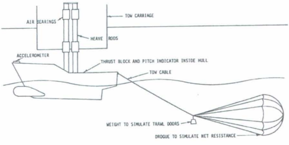

Figure 7: Simulated Trawling Speed

'Design of Bulbous Bows'

One of the most well known papers which discusses bulbous bow designs was Kracht (1978). This paper published in the SNAME transactions was the basis for some of the preliminary work completed in bulbous bow research at MUN (Friis, et al. 1998). The Kracht paper uses a series of experiments completed as the source for a non-dimensional analysis of six variables. Three are linear: length, breadth, and depth of the bulb; and three are non-linear: transverse cross-sectional area, longitudinal cross-sectional area, and volume of the bulb. The paper presents the data from a design guideline point of view. Dependent on the vessels geometric properties and speed range a basis for design can be selected from a perspective of reducing the residual power required. The data is taken from full and model scale experiments to validate the assumptions of the paper and therefore makes this paper a useful tool in designing a bulbous bow for a given hull form.

Tests with Bulbous Bow on Trawlers

This paper completed by Johnson (1958) for the Chalmers University of Technology in Sweden is the result of model testing completed in the Swedish State Shipbuilding Experimental Tank in Gothenburg. The model testing was completed on 4 hulls; one baseline hull had a conventional bow and the other 3 bows were fitted with alternate bulbs. The aim of the report was to compare the benefits of the bulbs while keeping the displacement the same throughout the bulbous bow hulls. This was accomplished by reducing the sectional area of the vessel from midship forward to offset the bulb volumes. Figure 8 below shows the three bulbs discussed in the paper.

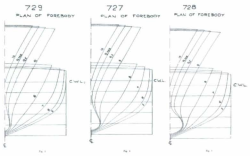

Figure 8: Bulb Plan Views from Johnson (1958)

Resistance and self-propulsion experiments were completed for the paper. The resistance experiments were completed with three different displacements at two trim conditions: even keel and 4% by the stern. The resistance experiments showed that there were reductions in resistance for speeds higher than about 8-9 kts (Froude numbers between ~0.25 to ~0.29) by using a bulbous bow, in one case up to 20% reduction.

In almost all of the experiments (draft and initial trim) the trim of the vessel by the bow increased as the vessel increased in speed and then at approximately 11 kts (Fn ~0.35) the vessel changes and starts a trim by the stern. Also, the average sinkage increased as the speed increased for all conditions.

During the self-propulsion experiments one displacement was tested at each of the two trim conditions. Unfortunately, the baseline model was a different scale than the three bulbous bow models and therefore the same propeller couldn't be used on all of the models, though there can be a comparative look between the different bulbs. The results of these comparisons show that the thrust deduction fraction gets larger as the size of the bulb increases. The lower thrust deduction fraction in the smaller bulbs leads to better efficiencies.

'Intensive Study on Bulbous Bow of Slow Full Form Ship'

During the research for this thesis there were many papers on more traditional larger vessels, such as the "Intensive study on bulbous bow of slow full form ship" a paper by Kwi-Joo Lee et. al. completed at the Hyundai Maritime Research Institute in 1989. This paper examined 23 different bulb designs with interesting results but the vessels, though having a "full form", were still approximately 280m long with a L/B ratio of 6.5. It was also interesting that the test program was completed using flume tank or "Circulating Water Channel" as the author refers to it (Lee, et al. 1989).

'A Bulbous Bow Design Methodology for High Speed Ships'

A paper written by Jeff W. Hoyle et. al. entitled "A Bulbous Bow Design Methodology for High Speed Ships" for SNAME in 1986 summarized numerical and physical testing of a number of bulbs. Though these are high-speed vessels and faster than the vessel discussed in this thesis the results were intriguing at least. The physical experiment, first of all, validated the numerical model. But the authors concluded that:

> *"...bulbous bows did tend to qualitatively degrade the seakeeping performance..."* and that *"These resistance reductions, while not substantial*

> *enough to warrant retrofitting existing ships of this type, do indicate that serious consideration should be given to installing a bow bulb on future ships."*

These statements are, of course, related to the high speed vessels. The benefit to smaller, slower vessels may or may not follow the same trend.

'Bulbous bows are not only for big vessels'

Finally, an article written for the magazine: Fishing News International, December 1984 entitled "Bulbous bows are not only for big vessels" reviews fuel savings of four fishing vessels. These vessels were retrofitted with four different types of bulbs shown below in Figure 9. Three of the bulbs are more unconventional with one, retrofitted in the "Osttysker" was a more conventional cylindrical shape. The article showed that the three unconventional bows increased fuel consumption substantially, in some cases over 30%. While the conventional bulb actually increased fuel consumption in some situations. It should be noted that the design waterline on the cylindrical bulb looks too low on the bulb to get the desired effect in enabling the bulb to get the water up over the top to create the out-of-phase wave.

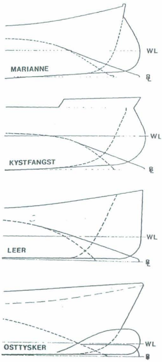

Figure 9: Four Bulbs Using in Retrofit Experiments

These articles, papers and reports have all contributed to general knowledge of bulbous bow design and efficiencies. Though all of the papers contributed to this general knowledge, the most relevant papers to this thesis were by Heliotis (1985) and Johnson (1958). One main variable of this thesis is the beach area on the top of the bulbs; Heliotis discussed similar sized vessels to this thesis and had one bulb configuration that could be used as a direct comparison without a beach area. Also, the additional bulb configurations in this thesis could add to or improve on the knowledge gained from that paper.

The Johnson paper compared similar vessels but most importantly did comparable self-propulsion experiments that could contribute to the results of this thesis. This thesis will hopefully contribute to the better understanding of how bulbous bows work and how we can use them to the greatest advantage.

3 Model Design Criteria

The initial design of the vessel was to develop the most efficient size multi-species capable vessel for the Newfoundland and Labrador fishery if the length regulations were not an obstacle. This optimized vessel has a bulbous bow and was 33.5 metres long (110ft). With the inclusion of a bulbous bow it is intended to make the vessel more efficient and, maybe more importantly, safer. The bulbs are illustrated below in Figure 10 to Figure 15 with the conventional bow in Figure 16. The bulbous bow options have come from research that has been ongoing at Memorial University of Newfoundland and headed-up by Professor Dag A. Friis.

Two distinct bulb geometry variables are looked at in this thesis. First, and most obvious, is how the bulb is faired into the hull. This is most easily seen in the top view showing the waterlines at the mid bulb height, illustrated below in Figure 10. The second variable is the difference in width of the bulbs; Bulb H was reduced in size to show the effect of bulb diameter, shown in Figure 11. Bulb H was reduced by 13% of its diameter; Bulb H is 2 metres in diameters and Bulb G is 1.75 metres full scale. A comparison of the geometric parameters of the individual bulbs is given is Table 1 below.

The rationale behind deciding which bulb shapes to test first stems from industry and then research. The Newfoundland and Labrador fishing fleet had been using cylindrical bulbs (similar to Bulb D) as the preferred type for new and retrofitted construction. The work that was completed by Friis et al. in 1998 on the M/V Newfoundland Tradition started to show the merit in a tangential bulb (Bulb C), initially there was a consideration that the bulb maybe used in the seal fishery and hence, in ice. The top of the bulb was designed to act as a snow plow, lifting and pushing ice to the sides, to accommodate this, the waterlines below the snow plow were made straight, i.e. tangential. The most logical middle ground between the two designs is an S-Shape bisecting the two designs. The length of the bulbs was derived from the work completed by Friis, et. al. (1998). They used the methods prescribed by Kracht discussed in the literature review to design one of the bulbs.

This multi-species fishing vessel has different criteria under which it was designed. Mobile fishing gear (i.e. bottom or mid-water trawls) requires the vessel to travel at slower speeds 0-3.5kts. The vessels stability at these low speeds is the biggest consideration. Getting to and from the fishing grounds is also a priority whether they are using fixed or mobile gear. Typically the fishing vessels in the Newfoundland and Labrador inshore fishing fleet will steam at speeds between 8-11kts. Though it is thought that the 'faster the better' if the vessel is not consuming vast quantities of energy. The fuel price increase has also led to a slower steaming speed in order to save fuel since significant saving can be had by monitoring speed. The design cruising speed of this vessel is 12kts.

Table 1: Bulb Geometric Parameters

		Bulb C	Bulb D	Bulb G	Bulb H
Bulb Type	[-]	Tangent	Straight	S-Type	S-Type
Width at front end of bulb	[m]	2.01	2.01	1.75	2.01
Length in Front of Forward Perpendicular	[m]	4.19	4.19	4.19	4.19
Slope at Top of Bulb	[deg]	15	10	10	10
Radius, Top of Bulb Intersect Bow Stem	[m]	2.10	1.14	1.21	1.13

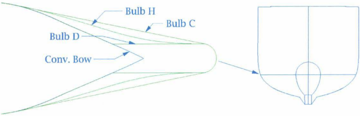

Figure 10: Bulb Fairing Comparison

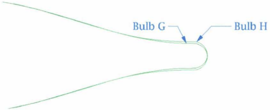

Figure 11: Width Comparison between two S-type bulbs

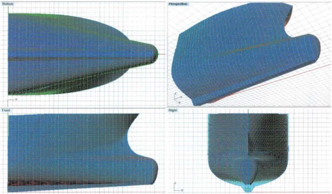

Figure 12: Bulb C – Tangent

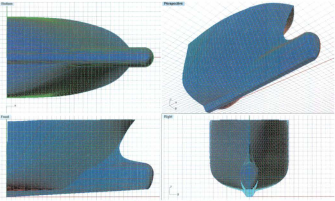

Figure 13: Bulb D – Cylindrical

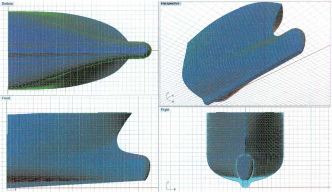

Figure 14: Bulb G - S-Type 1

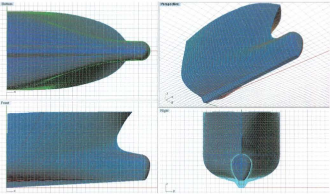

Figure 15: Bulb H – S - Type 2

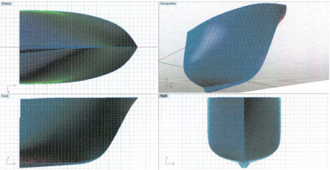

Figure 16: Conventional Bow

4 Experimental Set-Up

4.1 Facilities (OERC)

The 58-meter Towing Tank is located at the Memorial University's Ocean Engineering Research Centre (OERC) in St. John's, Newfoundland and Labrador, Canada. Table 2 gives particulars of the towing tank, and Figure 17 shows the tank layout. This facility was used for all phases of experimentation.

Table 2: 58-meter Towing Tank Particulars

Particular	Data
Length	58 m
Width	4.5 m
Maximum Still Water Depth	2.2 m
Maximum Carriage Speed	5 m/s
Useable Test Run Length	~ 35 m
Maximum Wave Height (regular)	0.7 m
Range of Wavelengths	0.9-17 m
Maximum Hs (irregular waves)	0.2 m

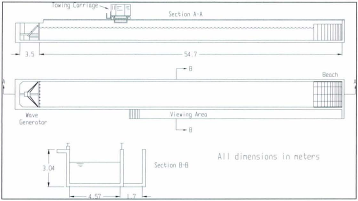

Figure 17: 58-meter Towing Tank Layout

4.2 Model Construction

The model was built to have removable bows; this was designed to reduce the cost of manufacturing. This also reduced the probability of error as the vessel's stern section was consistent for all experiments. The model was fabricated at a scale of 1:18.333. The topsides or superstructure of the vessel was not included in the model because there was no wind loading considered in this study.

The principle particulars of the model and its 18.333 scale ship are shown in Table 3. This scale vessel was the effective product of a study completed by the Industrial Outreach Group (IOG)(Friis, et al. 2007). There were a number of bow options looked at during the initial stages of this study but the options were reduced to four different bulb configurations. These four were deemed to produce the most information with the time and resources that were available. Table 4 below shows the full scale principal particulars. Bbecause the bulbs are considered appendages the length, beam, or draft does not change. Table 5 shows the model mass properties used for the head seas experiments.

Table 3: Principal particulars of vessel with conventional bow

Conventional Bow	Draft [m]	Overall Length [m]	Beam [m]	Wetted Surface Area [m^2]	Displacement [m^3]
Full Scale	4.108	33.53	9.14	326.8	398.0
Model Scale	0.224	1.829	0.499	0.972	0.063

Table 4: Principal particulars with various bulbous bows

	Wetted Surface Area [m^2]		Displacement [m^3]	
	Full Scale	Model Scale	Full Scale	Model Scale
Bulb C	377.3	1.1226	447.5	0.07263
Bulb D	368.5	1.0964	437.1	0.07094
Bulb G	371.8	1.1062	441	0.07157
Bulb H	372.9	1.1095	442.3	0.07178

Table 5: Model Mass Properties

	LCG [m]	VCB [m]	VCG [m]	Zyy [m]
Conv	0.775	0.167	0.259	0.351
Bulb C	0.879	0.166	0.262	0.370
Bulb D	0.830	0.166	0.258	0.361
Bulb G	0.854	0.166	0.259	0.366
Bulb H	0.878	0.166	0.259	0.366

The models were fabricated from numerically controlled (NC) milled foam plugs sheathed in fibreglass and epoxy resin. *Renshape®* inserts were embedded into the foam to provide anchor points in high load areas. These areas include the connection point for the bows to the stern and the entire box-keel. Figure 18 below is a rendering of the bows and the stern section assembly.

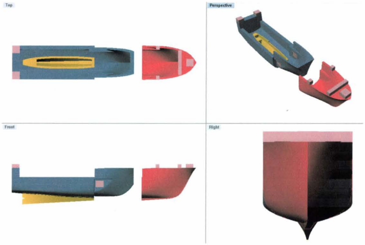

Figure 18: Connection points between bows and stern section

Three millimetre diameter by three millimetre high cylindrical studs were applied to the hull as specified by the International Towing Tank Conference (ITTC) turbulence stimulation (Butt 2004). The turbulence stimulators were applied at 2.5 cm intervals from the baseline up and at 2.5 cm from the bow stem along the hull. On the bulbous bows where the stem intersects the bulb, the studs are extended perpendicular to the baseline. Also, on the bulbous bow, another row of studs are placed at 25% of the length of the bulb from the forward most point perpendicular to the baseline. An example of this is shown in Figure 19 below.

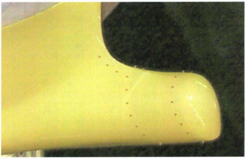

Figure 19: Example of Turbulence Studs

5 Instrumentation Calibration

5.1 Co-ordinate System

The coordinate system used for testing was in accordance with IOT Standard Test Methods (Butt 2004). The coordinate system was based on the right hand rule. The positive sense for the X, Y, and Z axes were forward, to starboard, and down, respectively. Positive moments and rotations were clockwise when looking from the origin along the positive direction of the respective axis. Thus positive pitch is bow up, positive roll is to starboard, and positive yaw is bow to starboard. Figure 20 provides a diagram illustrating the coordinate system used.

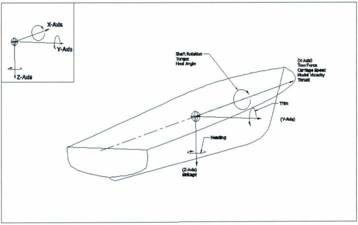

Figure 20: Coordinate System

5.2 Resistance experiments

All instrumentation was calibrated prior to testing using a laptop running IOtech DAQview 9.0.0 using a DAQbook 200 16-bit 200 kHZ processor data acquisition system. Pictures of some the calibrations are shown in Appendix A. Instrumentation employed for the resistance and self-propulsion tests is shown in Table 6.

Table 6: Calm Water Testing Instrumentation

Measurement	Instrumentation	Units
Carriage Speed	5th Wheel Encoder	m/s
Inline (calibration)	S-type Load Cell	N
Model Heave	LVDT	M
Heave Post Force (Resistance)	Beam Type Load Cell	N
Trim Angle	Inclinometer	Deg
Pitch Angle	RVDT	Deg

The model force (resistance) load cell was calibrated by applying known weights to the calibration rig and recording the results with the data acquisition system. These were plotted against each other and the slope and intercept of the linear equation was applied to the voltage output from the sensor. The heave (sinkage) sensor was physically calibrated locking the heave post at known heights and measuring the output from the sensor. Pitch angle was calibrated by using pre-machined wedges placed under the mounting bracket and recording the output values. These were placed on the rails in the tank as a reference. The pitch encoder was calibrated physically in a calibration jig.

5.3 Self-Propulsion Experiments

The self-propulsion experiments used three more channels; propeller torque, propeller thrust, and propeller speed. The propeller speed was acquired using an optical tachometer; this was calibrated by using a handheld optical tachometer. The handheld was a lab control and was factory calibrated. The torque and thrust were calibrated physically using specialized calibration tools. Appendix A shows images of these calibration tools. The complete list of instrumentation used is given below in Table 7

Table 7: SP instrumentation

Measurement	Instrumentation	Units
Carriage Speed	5th Wheel Encoder	m/s
Inline (calibration)	S-type Load Cell	N
Model Heave	LVDT	M
Heave Post Force (Resistance)	Beam Type Load Cell	N
Trim Angle	Inclinometer	Deg
Pitch Angle	RVDT	Deg
Propeller Torque	K&R torque	Nm
Propeller Thrust	K&R thrust	N
Propeller speed	Optical tachometer	Rps

5.4 Head Seas Experiments

The head seas experiments incorporated three accelerometer channels, a wave probe, and removed the propeller components from the acquisition (i.e. Propeller torque, thrust and speed). The list of instrumentation is shown below in Table 8. The 3 axis accelerometer (shown in Figure 21) was calibrated using three points. Using the carriage rails as a level surface, the accelerometer was placed with each axis perpendicular or parallel to the rail and the acquired value would be 1, 0, or -1 g's. This method was used to calibrate each direction's acceleration. The capacitance wave probe was calibrated by lowering the probe vertically into the water at known intervals using the K&R tow post.

Table 8: Head Seas Instrumentation List

Measurement	Instrumentation	Units
Carriage Speed	5^{th} Wheel Encoder	m/s
Inline	S-type Load Cell	N
Model Heave	LVDT	M
Heave Post Force	Beam Type Load Cell	N
Trim Angle	Inclinometer	Deg
Wave Height	Capacitance probe	cm
Pitch Angle	RVDT	Deg
XAccel	3-axis accelerometer	g
YAccel	3-axis accelerometer	g
ZAccel	3-axis accelerometer	g

Head seas tests were carried out in two irregular sea states for all bows at the design displacement. The JONSWAP spectral model was used to model the sea states. The principal characteristics of the sea states are tabulated below in Table 9. Only two sea states were used in the experiments because of the time constraints imposed on the project. Sea state 3 was selected as a very common condition in which the vessels would be fishing and sea state 5 was selected as a more extreme condition but where fishing may still be done if the vessel is sufficiently well behaved from a sea keeping standpoint.

Table 9: As-Tested Wave Conditions

Spectrum	JONSWAP			
Gamma	3.3			
Scale	18.333			
	Full Scale		**Model Scale**	
Sea State	Hs(m)	Tp(s)	Hs(cm)	Tp(s)
3	1.08	8.29	5.87	1.94
5	3.97	10.72	21.67	2.50

Figure 21: Location of Accelerometer

5.5 *In-Situ Calibration Checks*

In-situ checks were made before the start and end of each test program as well as at the beginning and end of the day. This was accomplished by using an inline dedicated load cell. Generally for the majority of experiments this was used in what is called an `x-pull`. A known weight was added in the x-direction and the resistance load cell output is compared to the applied force. There should be a direct linear relationship with the slope between the inline and resistance load cells equal to 1. The graph below in Figure 22 is an example showing that there was a linear relationship between the values given by the resistance load cell and inline x-pull force.

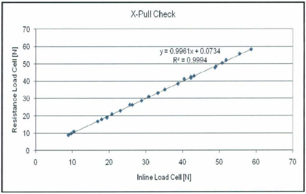

Figure 22: X-Pull Check

6 Test Methodology

The experiments in this thesis were completed using the NRC-IOT (National Research Council – Institute for Ocean Technology) standards as a guide and reference. The standards were written using information published in the proceeding at the ITTC, International Tow Tank Conference. The ITTC is an international association of physical and numerical experimentation facilities working in the field of predicting hydrodynamic performance of ships and marine installations. These ITTC methods are widely accepted in the research world.

6.1 Model Installation

Before the model could be installed in the tank basin the model was weighted and trimmed in the trim tank with a weight to represent the tow post. The model was also fully outfitted before the installation. Select pictures of the model installation are in Appendix B

6.2 Resistance Experimentation

The resistance data was collected using standard testing procedures developed for tow tank experiments (D. Murdey 2005).

The individual experiments were completed by first starting the data acquisition, recording a sample as a tare segment, starting the carriage, and then changing the speed of the carriage to obtain as many data points as possible. Each experiment was planned to minimize the number of runs and planned with established standards in mind.

6.3 *Self-Propulsion Experiments*

The self-propulsion experiments are designed to obtain the self-propulsion points, the thrust deduction and wake fraction, as well as relative rotative and propulsive efficiencies. Knowing the wake and thrust deduction fractions will allow one to optimize a propeller design to fit the average flow conditions that the propeller will experience. To fully optimize the propeller design to the flow conditions would also require a full wake survey to adjust blade area distribution and blade skew.

6.3.1 *Friction Test*

In preparation of the actual test each day's experiments started and ended with a friction test and a bollard experiment. Also, if the experiments were postponed or delayed for more than one hour the friction and bollard experiments were also redone. The purpose of the friction test was to obtain the friction in the system between the stuffing box and the shaft, and any other joints or gears that were in the system between the propeller and the torque measuring device. In this case a K&R dynamometer is used to measure the torque of the propellers.

The friction test was completed by placing a hub without propeller blades that has the same weight as the propeller in place of the propeller on the shaft. Figure 23 below shows a time trace of a friction test. The data was recorded at 50 Hz and the samples were shown in the x axis.

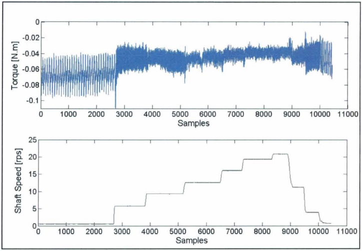

Figure 23: Time Trace of Friction Test

6.3.2 Bollard Experiment

The weighted hub was replaced by the propeller and the bollard experiments were completed. This was accomplished by moving the carriage to the centre of the tank and running the propeller up at different interval steps. Figure 24 shows an example of the time trace of one of the bollard experiments. From the data shown in this graph the torque and thrust can be checked to ensure that equipment is working properly. Figure 25 shows how this was done, the thrust and torque values should have a linear relationship with the shaft speed squared. The graph shows that this is indeed the case.

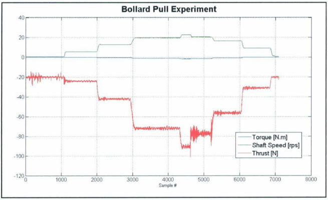

Figure 24: Time Trace of Bollard Pull Experiment

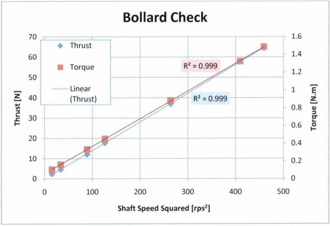

Figure 25: Bollard Check

6.3.3 Self Propulsion Experiments

The experiment started with a calm water period, the propeller was turned on, this bollard section was recorded then the carriage started to move at a predetermined speed. Depending on the speed of the carriage there may have been more than one shaft speed used per run. The graphs shown below in Figure 26 shows the time trace of an experiment. The sampling was recorded at 50 Hz. This particular experiment was completed at a full scale speed of 15 knots.

The benefit of getting a bollard on each run was that it can be tested against the earlier bollard check experiment. If there were any inconsistencies in the bollards the SP data would have to be questioned.

After each experiment the resistance data was checked to determine the next run's shaft speed. For models, there is a model-to-ship scale correction (F_D). This value was calculated from the resistance experiments and became the target self-propulsion point for the SP experiments. The model-to-ship correction coefficient was calculated from the difference in the frictional coefficient from the model tests (corrected to 15°C) and the ship frictional resistance. This calculation is completed because the frictional coefficient is a function of Reynolds number which doesn't follow the Froude scaling laws. Once this coefficient was found, F_D can be obtained. F_D is measured directly from the tow post resistance data. Usually three points above and three points below this value were acquired through testing. A graph was created to determine the self propulsion point shaft speed through interpolation. This will be discussed further in section 7.2 of the data analysis and reduction.

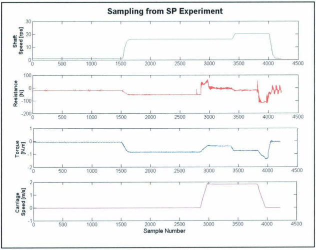

Figure 26: SP Experiment Time Trace

While the testing was being completed there were experimental checks that have to be completed. The main SP data check was plotting the raw thrust and torque data against the shaft speed. The graph below in Figure 27 shows this. The graph being linear shows that there were no outside influences on the measurements. These checks were done while the data was being collected and were completed for all of the experiments.

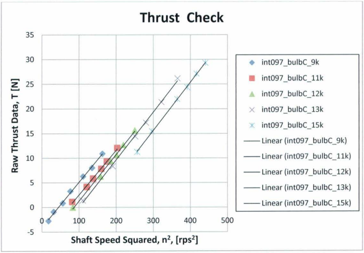

Figure 27: Raw Thrust Data Check

6.4 Head Seas Experiments

The experiments were conducted by initially recording calm water data, starting the wave boards creating waves, and then starting the speed at the same point in the wave train for each of the wave experiments. The picture below (Figure 28) shows the model attached to the tow post and at the beginning the run in the calm portion. Figure 29 shows the model traveling through the waves at 11kts full scale (1.32m/s model scale).

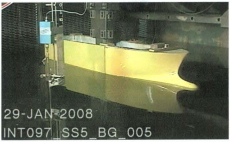

Figure 28: Calm Portion of Test Run, 0kts

Figure 29: In Waves Traveling at 11 knots

The data was collected using a data acquisition system (DAS) at a frequency of 50 Hz. There were 10 channels collecting at the time of the experiments. For illustration purposes, below is a graph that shows the collected data for the Z acceleration (Figure 30). The units are in g's, so while the vessel was at rest, at the start of the experiment, the value is 1 g or the acceleration due to gravity.

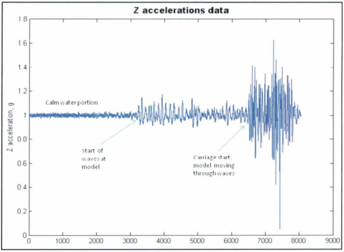

Figure 30: Z Acceleration Data

Because of time constraints, one run per speed per sea state per bulb configuration was completed. i.e. 5 bulb configurations (4 bulbs and 1 conventional bow), 5 different speeds (3, 5, 7, 9,and 11 knots) and 2 sea states (3 and 5). This is 50 different data points with an extra 20 runs for repeats and resistance data checks.

The entire length of the tank was utilized for each run but as the speed increased, obviously, the length of wave encounter time decreased. The shortest encounter time was 22 seconds model scale or 94 seconds full scale at 11 knots. The longest encounter time was 92 seconds model scale and 392 seconds full scale at 3 knots. It should be noted that the wave train was started at the same point for each test and the vessel speed started at the same point in the wave train each test.

7 Data Reduction and Analysis

As mentioned above, the data is collected using the DAQBook Software. The data is saved as an ascii file which is then reduced using Matlab routines to obtain basic statistics and to tare the individual channels. The statistics are exported into excel to be further analysed. These Matlab routines can be found in Appendix C

7.1 Resistance Calculations

Time histories were analyzed to produce basic summary statistics for each time trace. This data included: minimum, maximum, mean and standard deviation values. For the resistance experiments the steady state mean values are used for the analysis. The International Towing Tank Conference (ITTC) 1957 method of extrapolation was used [Murdey, 2004] for the resistance predictions. The primary equations used in this resistance extrapolation method are presented below. Maple was used to do most of the data analysis for the resistance experiments along with Excel and Matlab. The Maple routines for the resistance experiments can be found in Appendix D. A blockage correction was applied using a simplified version of Scott's method [Scott, 1976]. A standard correlation allowance (C_A) of 0.0004 was applied to all predictions as the vessel is less than 150m. The correlation allowance is a factor used to account for variances between model tests and full scale trials.

Froude number:

$$F_n = \frac{V}{\sqrt{g \times L}} \tag{7.1.1}$$

Model Reynold's number:

$$Rn_M = \frac{V_M \times L_M}{\upsilon_M} \tag{7.1.2}$$

Model total resistance coefficient:

$$C_{TM} = \frac{R_{TM}}{0.5 \times \rho_M \times V_M^2 \times S_M} \tag{7.1.3}$$

Model frictional resistance coefficient:

$$C_{FM} = \frac{0.075}{(log_{10}(Rn_M) - 2)^2} \tag{7.1.4}$$

Change in model total resistance coefficient due to the blockage correction is shown below in equation 7.1.5. A blockage correction is sometimes required in tanks when there is a possible influence from the walls or bottom of the tank. There are many variables that are obtained for this equation; the individual variable can be found in the Maple routines in Appendix D.

$$\Delta C_{TM} = \frac{n_t \times C_{TM} \times b \times \nabla_M \times A_T{}^{-3/2} + \frac{k \times f \times C_{R_{Tank}}}{1 + k \times f}}{1 - c \times Fr_T^2} \tag{7.1.5}$$

The corrected model total resistance coefficient given blockage correction is shown below:

$$C_{TM_{Corrected}} = C_{TM} - \Delta C_{TM} \tag{7.1.6}$$

Residuary resistance coefficient shown below is the difference between the frictional resistance, calculated easily with Rn_M above in equation 7.1.4, and the corrected total resistance coefficient. In calm water resistance test this C_R is a coefficient that describes the wave-making and eddy making resistance.

$$C_R = C_{TM_{Corrected}} - C_{FM} \tag{7.1.7}$$

Ship velocity:

$$V_S = V_M \times \sqrt{\lambda} \tag{7.1.8}$$

Ship Reynold's number; ν_S is calculated using salt water at 15°C:

$$Rn_S = \frac{V_S \times L_S}{\upsilon_S} \tag{7.1.9}$$

Ship frictional resistance coefficient:

$$C_{FS} = \frac{0.075}{(log_{10}(Rn_S) - 2)^2} \tag{7.1.10}$$

Ship total resistance coefficient:

$$C_{TS} = C_{FS} + C_R + C_A \tag{7.1.11}$$

Ship total resistance

$$R_{TS} = C_{TS} \times 0.5 \times \rho_S \times V_S^2 \times S_S \tag{7.1.12}$$

Ship effective power

$$P_{ES} = R_{TS} \times V_S \tag{7.1.13}$$

The ships effective power, as shown from the equation, gives an indication of the power required to achieve specified vessel speeds. This isn't to be confused with delivered power, P_D, which gives a better indication of actually how much power is required to be delivered by the engines to the propellers. This is to be discussed further in the self-propulsion section.

The routines developed to analyze the data can be found in Appendix D

7.2 *Self-Propulsion Experimentation Calculations*

The self-propulsion analysis followed the IOT standard (D. Murdey 2005) and used the results from the calm water resistance experiments. The ship self-propulsion point at each speed was found when the tow post tow force was equal to the model-to-ship scale corrections. Once the self propulsion point has been found the thrust deduction, wake fraction, quasi-propulsive efficiency, relative rotative efficiency, hull efficiency and ship delivered power can be found. The process of finding the self-propulsion point is laid out in this section.

The data collected for this analysis was the model speed (carriage speed), V_M, the tow post resistance, F_{DM}, the shaft speed, n_M, and the thrust, T_M, and torque, Q_M, seen by the K&R dynamometer.

7.2.1 *Raw Data and Checks*

The first task completed was to remove the friction component of the torque seen by the torque sensor of the K&R dynamometer during the experiments. Friction experiments, as discussed above, were completed regularly and it is important to use friction data from the same day in the correction process. During the experiments the shaft is continually rotating at a very slow speed, in our case this is approximately 0.75 rps. This ensures that the shaft doesn't stick at any point giving false torque readings.

$$Q_{M_{Corrected}} = Q_M - Q_{Friction} \tag{7.2.1}$$

The non-dimensionalized thrust, torque, speeds and tow force is now calculated, as shown below in equations 7.2.2 through 7.2.5.

Hull advance speed coefficient:

$$J = \frac{V_M}{n_M \times D_M} \tag{7.2.2}$$

Drag force coefficient:

$$K_{FD} = \frac{F_{DM}}{\rho_M \times n_M^2 \times D_M^4} \tag{7.2.3}$$

The propeller torque coefficient uses the corrected torque values.

$$K_Q = \frac{|Q_{M\,Corrected}|}{\rho_M \times n_M^2 \times D_M^5} \tag{7.2.4}$$

Propeller thrust coefficient:

$$\mathrm{K_T} = \frac{\mathrm{T_M}}{\rho_\mathrm{M} \times \mathrm{n_M^2} \times \mathrm{D_M^4}} \tag{7.2.5}$$

At this point data checks are completed to check for any outliers. The first completed is plot K_Q vs. K_T, using the raw data collected. Also on this graph, the opens K_Q Vs. K_T is plotted to give reference. This is a good test of data as errant data is easily picked out. The graph below in Figure 31 shows this check. The data follows the opens K_QK_T curve and no data is to be removed from this set. This graph is taken directly from the Maple routine.

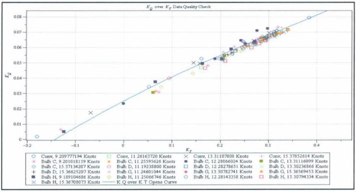

Figure 31: Data Check During SP analysis

7.2.2 Model-Ship Self Propulsion Point

If the model was a 1:1 scale the self-propulsion point would be achieved when the tow post resistance was zero. Scaling factors affect the self propulsion point at model scale. The drag force at the self propulsion point was found by subtracting the total resistance coefficient at full scale, C_{TS}, from the total resistance coefficient at model scale, C_{TM}. This yields a model drag force coefficient shown below in equation 7.2.6.

$$C_{FD} = C_{TM} - C_{TS} \qquad \textbf{(7.2.6)}$$

It should be noted that the C_{TM} is corrected to account for the difference in temperature between when the resistance experiments were completed and when the self-propulsion experiments were completed. Equation 7.2.7 shows the C_{TM15}, which is the total resistance coefficient taken from the resistance experiment calculated to 15°C, combined with the difference of the frictional resistance from the self-propulsion experiments normalized to 15°C. The associated tools from Maple are used again here; the complete list of equations and the routines are available in Appendix E.

$$C_{TM} = C_{TM15} - C_{FM15} + C_{FM} \qquad (7.2.7)$$

Now that the drag force coefficient is found for the SP point the drag force can be found at the SP point, shown in equation 7.2.8. Using this value, obtained for each condition, the self-propulsion point can be interpolated with respect to advance coefficient at the SP point, J_{SP}, and this is shown below in equation 7.2.9.

$$F_{DM} = 0.5 \times \rho_M \times V_{M_{avg}}^2 \times S_M \times C_{FD} \qquad (7.2.8)$$

$$\frac{K_{FD}}{J_{SP}^2} = \frac{C_{FD} \times S_S}{2 \times DP_S^2} \qquad (7.2.9)$$

Now that the self-propulsion point has been found the K_T and K_Q curves, which are plotted against J, can be used to calculate the thrust and torque at the self-propulsion point. The K_Q and K_T curves were evaluated at the J_{SP} points.

Given the thrust required at the self-propulsion point, the equivalent advance coefficient can be found with the propeller opens data, i.e. J_{OPEN}. Essentially the propeller wouldn't need to turn as fast to obtain the same level of thrust when the flow in front of it is unobstructed.

7.2.3 Full Scale Performance Calculations

The self propulsion points for each condition have been obtained. From here the vessels full scale performance can be quantified. The shaft speed needs to be determined at full scale and at the SP point. Using the standard advance coefficient equation the shaft speed can be determined (equation 7.2.16). The ship propeller thrust and torque values at the individual conditions can now be found. Equations 7.2.17 and 7.2.18 accomplish this.

$$\mathbf{n_S = \frac{V_S}{J_{SP} \times D_S}} \quad \mathbf{(7.2.10)}$$

$$\mathbf{T_S = \rho_S \times n_S^2 \times D_S^4 \times K_{TSP}} \quad \mathbf{(7.2.11)}$$

$$\mathbf{Q_S = \rho_S \times n_S^2 \times D_S^5 \times K_{QSP}} \quad \mathbf{(7.2.12)}$$

The ship delivered power equation (7.2.19) is derived from the torque and shaft speed at each individual SP point condition.

$$\mathbf{P_{DS} = 2 \times n_S \times Q_S} \quad \mathbf{(7.2.13)}$$

Using the calm water resistance data we find, as shown above in section 7.1, the total ship resistance and effective power.

The ship's quasi-propulsive efficiency, normally denoted as QPC or η_D, is calculated as the ratio of effective power to delivered power (equation 7.2.22).

$$\mathbf{\eta_D = \frac{P_{ES}}{P_{DS}}} \quad \mathbf{(7.2.14)}$$

The Taylor wake fraction is a ratio of the ship speed and the speed of advance; this gives an indication of the water flow at the propeller. Equation 7.2.23 shows this relationship in terms of J. The thrust deduction fraction (equation 7.2.16) is the relationship between the resistance of the vessel and the thrust developed by the propellers at given speeds.

$$w = 1 - \frac{J_{Open}}{J_{SP}} \qquad (7.2.15)$$

$$t = 1 - \frac{R_{TS}}{T_S} \qquad (7.2.16)$$

The torque values obtained during open water experiments will be different than at the SP point behind the vessel. This relationship of torque values, essentially how much more torque is required when the propeller is 'behind the hull', is shown below in equation 7.2.17 as a relationship between K_{QO} and K_{QSP}. This can also just be expressed as Q_O and Q_S. This relationship is known as the relative rotative efficiency η_R. Another useful efficiency term used is the hull efficiency, η_H. The hull efficiency is the relationship between the effective power and the thrust power. The effective power, discussed above, is the product of the vessel resistance and the ship speed. The thrust power is the work done by the propeller to deliver the thrust at the speed of advance. This is described in equation 7.2.18 below in Taylor notation.

$$\eta_R = \frac{K_{QO}}{K_{QSP}} \qquad (7.2.17)$$

$$\eta_H = \frac{1-t}{1-w} \qquad (7.2.18)$$

The open water shaft speed at the open water advance coefficient can be used to find the propeller open water efficiency. This is a valuable piece of information which will give the efficiency of the propeller at the SP points. The propeller open water efficiency is calculated using equation 7.2.19 or 7.2.20.

$$n_{open} = \frac{V_S}{J_{Open} \times D_S} \tag{7.2.19}$$

$$\eta_{open} = \frac{V_S}{2 \times \pi \times n_{Open} \times D_S} \times \frac{K_{TO}}{K_{QO}} \tag{7.2.20}$$

7.3 Head Seas

The head seas portion of this analysis was completed by taking the raw statistics from the individual experiments and presenting the data in terms of modified single significant amplitudes (SSA) shown below in equation 7.3.1. The results of the analysis in Matlab were compiled in excel and are presented below in section 8.3.1

$$SSA_{Mod} = 2\sigma + \mu \tag{7.3.1}$$

The resistance comparison is completed by taking the mean values from the tow post resistance and running the same analysis as described in section 7.1. The Maple routines can be found in Appendix F.

8 Results and Discussion

8.1 Resistance Experiments

The tabulated, analyzed resistance experiment data can be found in Appendix G.

8.1.1 Effective Ppower

An effective power comparison of each bulbous bow to the conventional bow is given below in Figure 32. From the graph, the conventional bow has the highest resistance of the bow options. Bulb C's PE appears to be slightly elevated at the higher speeds compared to the other bulbs, though the difference isn't as great as the conventional bow. There seems to be very little difference from an effective power standpoint between Bulb G and Bulb H.

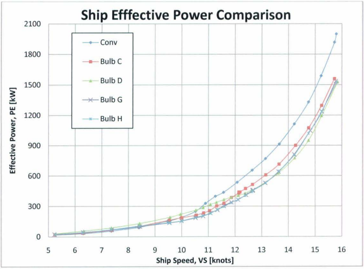

Figure 32: Ship Effective Power Vs. Speed

8.1.2 Residuary Resistance

These results can be broken down to show the components: residuary resistance and frictional resistance. At lower speeds the main component of resistance is the frictional resistance but as the speed increases the residuary resistance is the largest component. During resistance experiments the residuary portions of the total resistance is the difference between the total and the frictional. In some cases where the testing is done at extremely high speeds there is also a wind resistance component, this isn't the case for any of these experiments. The residuary resistance coefficient plotted against Froude number is shown in Figure 33, this is the non-dimensionalized form. From this plot it is seen that at lower Froude numbers Bulb D has the larger residuary resistance, while at the larger Froude numbers the conventional bow does generate more residuary resistance. As discussed above, the residuary resistance is everything other than frictional resistance.

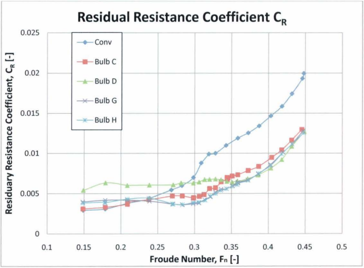

Figure 33: Residuary Resistance Coefficient vs. Froude number

8.1.3 Sinkage and Trim

The resistance experiments also record sinkage and trim. The graph below in Figure 34 shows the sinkage as a ratio of length. This gives a non-dimensional representation of the sinkage. The graph does show that as the speed increases sinkage increases. All of the bows appear to sink at the same rates until the higher end of the speed range where the conventional bow doesn't sink as much as Bulb C.

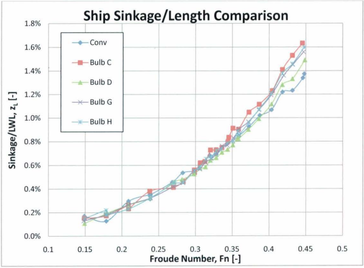

Figure 34: Sinkage/Length comparison

The ship dynamic trim graph, shown in Figure 35, illustrates how the largest bulb (by volume) trims down by the bow early as the speed increases and the conventional bow doesn't trim until an approximate F_n of 0.32. This result shows that the larger the volume of the bulb the more the vessel will trim by the bow.

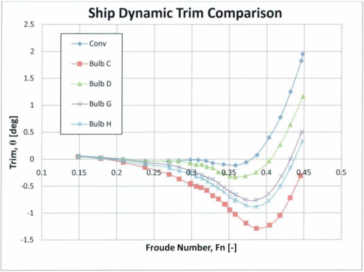

Figure 35: Trim Angle Comparison

It appears that if one were to consider the trim angle graph and the sinkage graph it shows that the vessel squats and trims by the bow as the speed increases until a point at which the bow stops sinking and the vessel starts to trim more and more by the stern. This occurs at an F_n of approximately 0.36 for the conventional bow and near 0.38 for Bulb C.

8.1.4 Resistance Comparison

A good comparison of the effectiveness of the individual bulbs is to plot the relative effective power as it compares to the conventional bow. Figure 36 below is this comparison. It shows that the bulbs become effective at speeds between approximately 9 and 10.5 knots. This is an interesting result because of the paper by Heliotis (1985) discussed in the literature review which came to the same conclusions. The Bulb D is the closest to the 20% x 1.5D configuration that Heliotis tested. The difference is that in those experiments as the speed increased past ~12.5 kts the bulbs became ineffective (see Figure 4) and the curve crossed 0% again. In these experiments the effects do not diminish as the speed increases. The difference in the bulbs was the 'beach area' on top of the bulb which decreases the abrupt intersection between the stem of the bow and the top of the bulb (see Figure 4 and Figure 13).

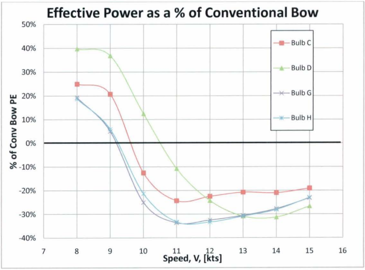

Figure 36: Effective power as a % of Conventional Bow

8.2 Self-Propulsion

The self-propulsion experiments, as noted above, are completed using the guidance of the IOT standards and ITTC methodologies. A complete list of source data and analyzed data for the SP experiments can be found in Appendix H. The propeller used in the experiments was a stock propeller that NRC-IOT graciously lent to the project. The propeller was the only one that was suitable for the scale and size of the model that was constructed. In this respect, a more optimal propeller may have been constructed if time and finances had permitted.

8.2.1 Torque Values

As discussed in the data reduction and analysis section, the first thing that has to be done to the data is that the torque has to be corrected for friction in the system. The graph below in Figure 37 shows the friction during each day of testing as well as January 23rd where there was a big enough time lapse between the sets of experiments to warrant a second friction test for that day. This data is applied only to the tests that were completed during these days. The result of the friction experiments shows that there was very little friction in the system. Expected values for friction experiments can be as high as 0.2-0.3 N-m. The main reason for this was the lack of complicated joints or gears; the dynamometer was in line with the shaft with good alignment and only the stern tube, stuffing box and one universal joint between them.

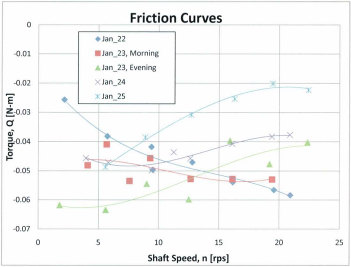

Figure 37: Friction Curves for SP Experiments

8.2.2 Data Checks

As discussed above, the data was checked at this point for outliers. Figure 31 above in section 7.2.1 shows the first check of plotting the thrust and torque coefficients against one another. The second check is to plot the KT and KQ collected data against the open water KT and KQ curves; this will also give an indication if the data isn't realistic. This is shown below in Figure 38; this graph is also taken directly from Maple. The data follows the general slope and shape of the open curves as expected.

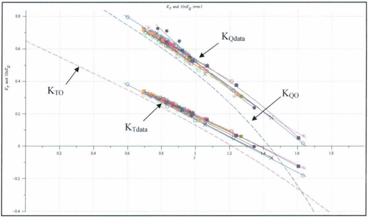

Figure 38: KT KQ Data Check

8.2.3 Delivered Power

The delivered power curve is shown below in Figure 39. This graph shows the power required to be delivered to this propeller to propel the vessel. Though there is a difference between installed power and delivered power this gives a much better concept of how much will be needed. The installed power is determined by the losses in the gears and delivery system between the engine and the propeller. An estimate of these losses is 2-3% depending on the location of the engine (Lewis 1988). Similar to the effective power graph (Figure 32) the conventional bow required more delivered power. This is also seen in Figure 40 showing a comparison of the delivered power of the bulbs as a percentage of the conventional bow. Though the order of the other bows have changed slightly. As the delivered power is calculated using the required torque values the difference in these values has given a clearer picture of power required than the effective power graph.

Figure 39: Ship Delivered Power, P_D

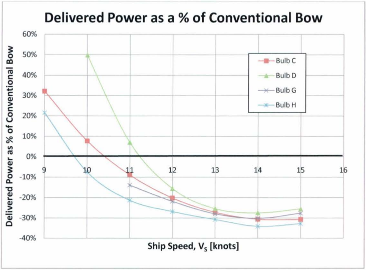

Figure 40: Delivered Power as % of Conventional Bow

8.2.4 Wake Fraction

The wake fraction gives an indication of the flow of water in the wake of the vessel. Essentially, the lower the value the closer the speed of advance of the propeller through the water is to the ship speed. Figure 41 below shows the wake fraction comparisons. The conventional bow has the lowest values with Bulb C being the second lowest. There is a trend in the data that shows an increase in the values at the ~13kts speed. This hump in the data suggests a disturbance in the flow at the propellers. As the hump occurs with each of the bow configuration it implies that the disturbance is caused by the shape of the hull behind the bow. This could be a result of the transom immersion or eddy making off the box keel interacting at the propeller or something to do with the wave patterns along the length of the vessel, i.e. as the wave length equals the ship length the vessel reaches its hull speed. Another possibility is the effect of trim on the flow. Using Figure 42 below, the trim is overlaid on the wake fraction. It shows that the hump in the wake data occurs in the same area that the trim by the head is at its greatest. Flow visualization experiment or CFD modeling would add a clearer picture of this phenomenon.

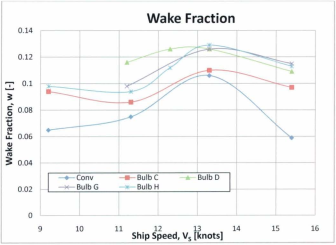

Figure 41: Taylor Wake Fraction

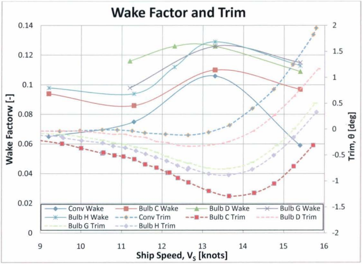

Figure 42: Wake fraction with Trim Overlay

8.2.5 Thrust Deduction Fraction

The thrust deduction fraction, t, shown below in the Figure 43, quantifies the decrease in the pressure at the stern (and thus an increase in drag) arising from flow induced by the propeller, i.e. as the t increases the thrust must increase for the same resistance. The graph shows that at the lower speeds the conventional bow utilizes the thrust more efficiently.

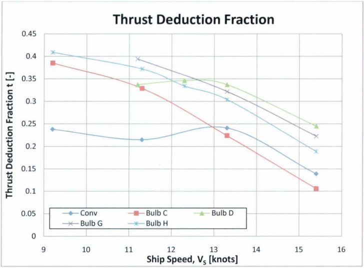

Figure 43: Thrust Deduction Fraction

8.2.6 Efficiencies

The relative rotative, propeller open water, hull and quasi-propulsive efficiencies are shown in this section.

The relative rotative efficiency quantifies how much more torque is required of the propeller when it is behind the hull relative to open water. The relative rotative does not generally stray too far from unity, nominally in the range of 0.95 to 1.1 (Lewis 1988). The graph below in Figure 44 shows that Bulb H requires less torque when the propeller is behind the hull than when it is in open water.

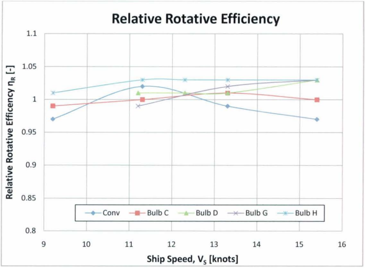

Figure 44: Relative Rotative Efficiency

The propeller geometry is shown below in Table 10. In Figure 45 the data from the open water experiments is presented for the propeller #110R for this NRC-IOT stock propeller. The range of K_T , K_Q and open water propeller efficiencies used in the self-propulsion experiments is highlighted on the graph.

Table 10: Propeller Geometry

P/D	1.27
Ae/Ao	0.906
Z	4
D [m]	0.1205

The propeller open water efficiency shown below in Figure 46 is the efficiency of the propeller without being influenced by the hull. This means that the overall efficiency of the system cannot be larger than these efficiencies. As stated above, the stock propeller is used to determine the wake fraction, thrust deduction, and relative rotative efficiency. An ideal propeller would be selected for each hull configuration to determine the exact quasi-propulsive efficiency.

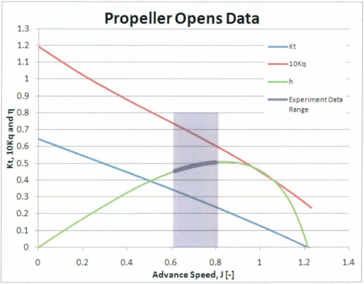

Figure 45: Opens Propeller Data

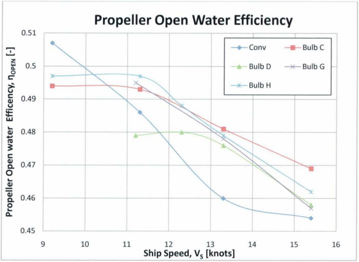

Figure 46: Propeller Open Water Efficiency

The hull efficiency is the ratio of the work done on the hull to the work done by the propeller. Figure 47 below shows the comparison of the hull efficiencies. The conventional bow is shown to have the higher efficiency at lower speeds while Bulb C passes the conventional bow at a higher speed for this propeller.

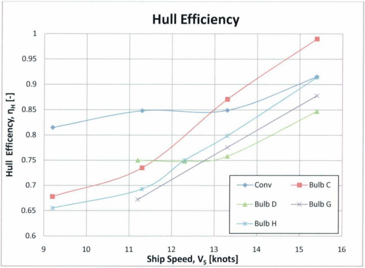

Figure 47: Hull Efficiency

The overall propulsive efficiency of the system, known as the quasi-propulsive efficiency, η_D, is shown below in Figure 48. The graph shows that the conventional bow has a better η_D at the lower speeds and, again, the Bulb C is better at the higher speeds, above ~13kts. It is possible that this propeller isn't perfectly suited for either of these hull forms but may be more suited to one than another. A true comparison of QPC would include an analysis with an ideally selected propeller. Though the consistent trends in the data shows that Bulb C is more effective at the higher speeds.

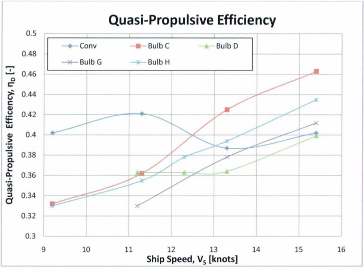

Figure 48: Quasi-Propulsive Efficiency

8.3 Head Seas

The head seas experiments are broken down into two sections: the motions and the resistance. Both sets of data are tabulated and presented in Appendix I

8.3.1 Motions

The relative accelerations between each bow are evaluated through the data from the head seas experiments. A useful way of looking at acceleration data is to use the modified SSA's (single significant amplitudes) method. The formula is two times the standard deviation plus the mean of the data set. The modified refers to the "+ mean". This insures that if there is bias in motion it isn't removed from the results.

The z accelerations, pitch motions, and x accelerations is shown below in Figure 49 to Figure 54 in terms of modified SSA against Ship Speed. All of these graphs show trends to which bow performs best in the sea conditions.

The z accelerations are an indication of the vertical motions that are experienced at the specified location. Figure 49 shows the effectiveness of the bulbous bow over the conventional bow at sea state 3. The sea state conditions that we are discussing are significant wave height, H_S, of 1.08m and a mean peak period, T_P, of 8.29s. Even at this smaller sea state a trend does emerge, though at the larger sea state 5 (H_S=3.97m, T_P =10.72s) it is more obvious. Figure 50 shows that the conventional bow has the higher accelerations and Bulb C has the lowest.

It should be noted that the accelerations recorded are x and z acceleration with respect to the body axes. As the vessel is fixed in absolute surge, the x acceleration is an indication of the pitching and heaving together. In other words the x acceleration is in reality the x component of the heave acceleration.

The trend continues when the pitch motions are captured in Figure 51 and Figure 52. Figure 51 shows the pitch motions during sea state 3 and Figure 52 shows sea state 5. These results suggest that Bulb C has the lowest pitch motions across the speed range tested and that the conventional bow has the worst.

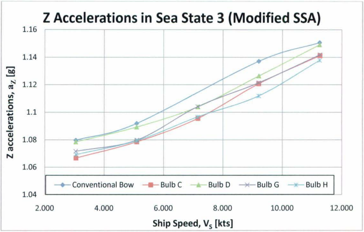

Figure 49: Z-acceleration in Sea State 3

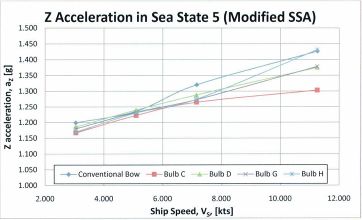

Figure 50: Z-acceleration in Sea State 5

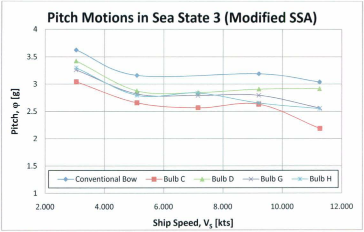

Figure 51: Pitch Motions in Sea State 3

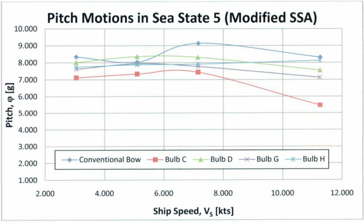

Figure 52: Pitch Motions in Sea State 5

The x accelerations were also recorded during the experiments. These are interesting results as the vessel was not free to surge during the experiments. The graphs in Figure 53 and Figure 54 show the same trend as the other results; Bulb C has lower accelerations and the conventional bow has the most. These results suggest that Bulb C is surging less and therefore maintaining speed more than the other bows. These phenomena should be studied more accurately with a `free-to-surge` tow post.

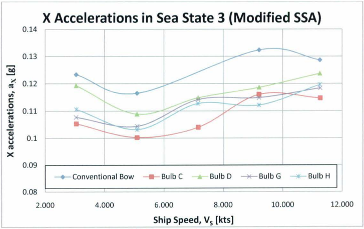

Figure 53: X-acceleration in Sea State 3

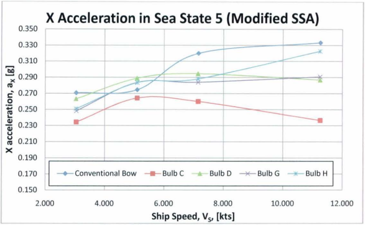

Figure 54: X-acceleration in Sea State 5

8.3.2 Added Resistance in Waves

Along with the motion characteristics, a qualitative comparison can be made between the resistance of each bulb at calm water and at sea state 3 and sea state 5. Figure 55 to Figure 58 shows the comparison of each bulb against the conventional bow. Interestingly the same pattern arises from the sea state 3 data as the calm water data that the bulbs become effective in the 9 to 11 knot speed range. This is not the case for sea state 5. For Bulbs C, G and H, the resistance is either equal to or better than the conventional bow. The only exception is Bulb D, which follows the same pattern as sea state 3 and the calm water resistance. Figure 59 and Figure 60 show this phenomenon in sea state 5. In particular Figure 60 should be compared to Figure 36 from the resistance experiments to show the benefits of bulb design for heavier sea states.

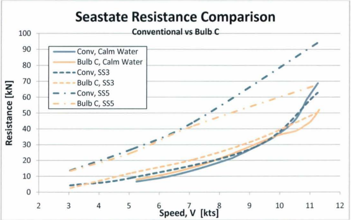

Figure 55: Head Seas Resistance – Conventional Vs Bulb C

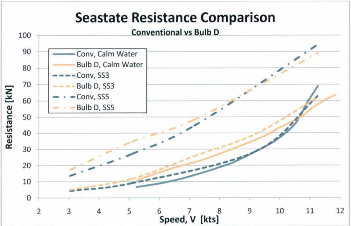

Figure 56: Head Seas Resistance – Conventional Vs Bulb D

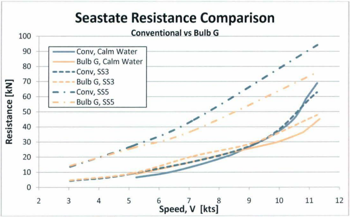

Figure 57: Head Seas Resistance – Conventional Vs Bulb G

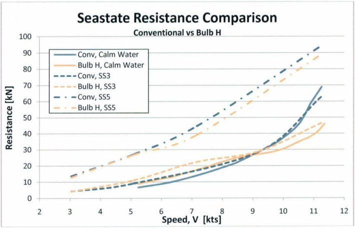

Figure 58: Head Seas Resistance – Conventional Vs Bulb H

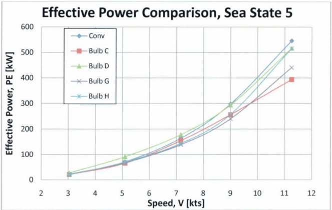

Figure 59: Effective Power Comparison in SS5

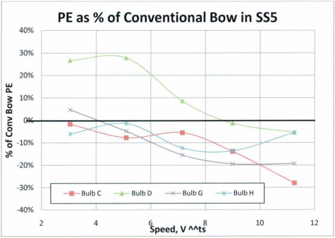

Figure 60: Effective Power as a % of Conventional Bow in SS5

9 Uncertainty Analysis

This section examines the error involved in the experimentation completed in this thesis. This uncertainty analysis is completed for the resistance and self-propulsion experiments. A brief overview of the methodology employed to complete this analysis is given below. The results of the uncertainty analysis are given with a review of where improvements in the system could be seen.

9.1 Methodology

The methodology used in this thesis is taken from the International Tow Tank Conference (ITTC) procedures 7.5-02-02-02: Uncertainty Analysis, Example for Resistance Test and 7.5-02-03-01.2: Propulsion, Performance Uncertainty Analysis, Example for Propulsion Test. The full results can be found in Appendix J.

The Total Uncertainty (U) of the individual variables of the experiments is given by the root sum square of the two main components: Bias Limit (B) and Precision Limit (P).

$$(U)^2 = (B)^2 + (P)^2 \quad (9.1)$$

The Bias Limit is taken as the elementary error sources; they can be broken into sub categories of: data acquisition, data reduction, and conceptual bias. The precision limit is determined by completing repeat experiments and using the standard deviation of these repeats. When it was not possible to perform repeat tests an estimate was used with the best information available.

9.1.1 Resistance

By collecting data for tow post resistance, model speed, water temperature, model principle parameters, including wetted surface area, the resistance coefficients can be found (equations 9.2-9.4). These equations are the basis for the bias error calculations.

$$C_T = \frac{R_x}{0.5 \times \rho \times V^2 \times S} \tag{9.2}$$

$$C_F = \frac{0.075}{(log_{10}(Rn) - 2)^2} \tag{9.3}$$

$$C_R = C_T - C_F \tag{9.4}$$

9.1.1.1 Bias Limit

The bias limit of the total resistance coefficient can be found using the equation below:

$$\left(B_{C_T}\right)^2 = \left(\frac{\partial C_T}{\partial S} \times B_S\right)^2 + \left(\frac{\partial C_T}{\partial V} \times B_V\right)^2 + \left(\frac{\partial C_T}{\partial R_x} \times B_{R_x}\right)^2 + \left(\frac{\partial C_T}{\partial \rho} \times B_\rho\right)^2 \tag{9.5}$$

Where: S is Wetted Surface Area
v is Viscosity
Rx is Resistance
ρ is density

Likewise with the frictional resistance coefficient the equation can be broken down into its bias components and shown in equation 9.6 below:

$$\left(B_{C_F}\right)^2 = \left(\frac{\partial C_F}{\partial V} \times B_V\right)^2 + \left(\frac{\partial C_F}{\partial L} \times B_L\right)^2 + \left(\frac{\partial C_F}{\partial v} \times B_v\right)^2 \tag{9.6}$$

Where: L is Vessel Length

Using the ITTC57 method Residuary resistance coefficient reduction can be found using the equation:

$$(B_{C_R})^2 = \left(\frac{\partial B_{C_R}}{\partial B_{C_T}} \times B_{C_T}\right)^2 + \left(\frac{\partial B_{C_F}}{\partial B_{C_T}} \times B_{C_F}\right)^2 \quad (9.7)$$

9.1.1.2 Precision Limit

The precision limit is calculated by completing repeat experiments and comparing an end-to-end analysis. The precision limit is taken from the equation below.

$$P = \frac{K \times Std.Dev.}{\sqrt{M}} \quad (9.8)$$

Where: K = 2, coverage factor according to the ITTC methodology.
Std.Dev. is the standard deviation of the variable being considered
M is the number of repeats.

9.1.2 Self-Propulsion

Using the measurements from the resistance test along with measuring thrust, torque, tow post resistance, model speed, shaft speed, and water temperature the wake fraction, thrust deduction fraction and relative rotative efficiency can be calculated. These variables are indicated under the ITTC procedure 7.5-02-03-01.2 as the validating components of the propulsion experiments.

9.1.2.1 Bias Limit

The equations used to define the bias limit in the self propulsion experiments are the thrust and torque coefficients shown in equations 9.9 and 9.10 along with the bias equations in 9.11 and 9.12:

$$K_T = \frac{T}{\rho \times n^2 \times D^4} \quad (9.9)$$

$$K_Q = \frac{Q}{\rho \times n^2 \times D^5} \tag{9.10}$$

$$\left(B_{K_T}\right)^2 = \left(\frac{\partial K_T}{\partial T} \times B_T\right)^2 + \left(\frac{\partial K_T}{\partial \rho} \times B_\rho\right)^2 + \left(\frac{\partial K_T}{\partial n} \times B_n\right)^2 + \left(\frac{\partial K_T}{\partial D} \times B_D\right)^2 \tag{9.11}$$

$$\left(B_{K_Q}\right)^2 = \left(\frac{\partial K_Q}{\partial Q} \times B_Q\right)^2 + \left(\frac{\partial K_Q}{\partial \rho} \times B_\rho\right)^2 + \left(\frac{\partial K_Q}{\partial n} \times B_n\right)^2 + \left(\frac{\partial K_Q}{\partial D} \times B_D\right)^2 \tag{9.12}$$

Where: T is thrust
n is shaft speed
D is propeller Diameter
Q is torque

The wake fraction, thrust deduction fraction and relative rotative efficiency equations are given below in equation 9.13 – 9.15. The bias limits are given in equation 9.16 – 9.18

$$w = 1 - \frac{J_T \times D}{V} \tag{9.13}$$

$$t = \frac{T - F_D - R_x}{T} \tag{9.14}$$

$$\eta_R = \frac{K_{Q_o}}{K_Q} \tag{9.15}$$

$$(B_w)^2 = \left(\frac{\partial w}{\partial J_T} \times B_{J_T}\right)^2 + \left(\frac{\partial w}{\partial D} \times B_D\right)^2 + \left(\frac{\partial w}{\partial n} \times B_n\right)^2 + \left(\frac{\partial w}{\partial V} \times B_V\right)^2 \tag{9.16}$$

$$(B_t)^2 = \left(\frac{\partial t}{\partial J_T} \times B_{J_T}\right)^2 + \left(\frac{\partial t}{\partial D} \times B_D\right)^2 + \left(\frac{\partial t}{\partial n} \times B_n\right)^2 \tag{9.17}$$

$$\left(B_{\eta_R}\right)^2 = \left(\frac{\partial \eta_R}{\partial K_{Q_o}} \times B_{K_{Q_o}}\right)^2 + \left(\frac{\partial \eta_R}{\partial K_Q} \times B_{K_Q}\right)^2 \tag{9.18}$$

Where: J_T is open water advance coefficient
V is speed

9.1.2.2 Precision Limit

The nature of the self-propulsion experiments are such that it is very difficult to repeat an individual experiment. The F_D is obtained by acquiring numerous data points above and below the predicted F_D and interpolating the self-propulsion point and subsequent shaft speed thrust and torque. Thus, as repeats affect the line that the F_D is interpolated from and, in the end, affects the overall result obtained. The precision error can be calculated by the statistical variance in the overall results. This is how the precision error is calculated.

9.1.3 Seakeeping

Unfortunately a full uncertainty analysis could not be completed for the seakeeping experiments because the wave calibration data cannot be found. As well under the ITTC procedure there were not enough wave encounters per test to constitute a statistically significant result. However, there is enough data to give a qualitative evaluation of the results. All of the experiments were completed under the same conditions that are all comparable to self-propulsion and resistance experiments which suggest that the level of confidence in the acquired data is reasonable.

9.2 Results

The results presented in this section will include the main components of the resistance and self-propulsion experiments. All of the uncertainty analysis can be found in appendix J which will also cover all of the uncertainty associated with temperature, viscosity, density, model speed and propeller and model geometry.

9.2.1 Resistance

The results of the resistance uncertainty analysis are shown below for Bulb C as an example. All of the data for the different bow options and different speeds are given in appendix J. The data presented below in Table 11 is the individual bias error estimates for one bow and at one speed as well as the total bias limit.

Table 11: Sample Bias Limit

Bulb C at 11.25 knots full scale						
Variable		Bias Error				Bias Limit
Length	B_L	Data Acquisition	±	0.002	m	
Temperature	B_{t^oC}	Calibration	±	0.5	°C	
Density	B_ρ	Calibration	±	0.0511136	kg/m^3	0.086675257 kg/m^3
		Data Reduction	±	0.07	kg/m^3	
Viscosity	B_ν	Calibration	±	1.7273E-08	m^2/s	1.72805E-08 m^2/s
		Data Reduction	±	5.08E-10	m^2/s	
Resistance	B_{Rx}	Conceptual	±	0.024159241	N	0.02576672 N
		Calibration	±	0.007444358	N	
		Data Acquisition	±	0.000498445	N	
Wetted Surface Area	B_S	Data Acquisition	±	0.002342259	m^2	0.002351598 m^2
		Calibration	±	0.000209366	m^2	
Speed	B_V	Pulses	±	2.358495283	pulses	0.004640822 m/s
		Wheel Diameter	±	0.0001	m	
		Time Basis	±	0.00001025	s	

Using this data in combination with equations 9.5 – 9.7 the resistance coefficients bias can be calculated.

B_{CT}	0.000255585
B_{CF}	1.16357E-05
B_{CR}	0.00025585

Using multiple repeat runs during the resistance experiments the precision error can be calculated using equation 9.8 above.

P_{CT}	0.000184633
P_{CF}	9.87256E-08
P_{CR}	0.000184633

Subsequently the total uncertainty can be ascertained by using equation 9.1 giving:

U_{CT}	0.000315298
U_{CF}	1.16361E-05
U_{CR}	0.000301705

Using the uncertainty values found here we can compare against the calculated resistance coefficients to find the level of uncertainty in the data. The data below is the total uncertainty of the data for Bulb C. The values above are used in the Bulb C - 11.3 knots only, a complete analysis for each speed and bulb in the appendix J. From this data it can be seen that the data is within a 95% confidence level.

Table 12: Uncertainty in Total Resistance Coefficient

V	C_T	U_{CT}	
knots	[-]	[±]	[%]
6.3	0.007882	0.000277	3.509%
8.4	0.008585	0.000289	3.366%
9.5	0.008925	0.000296	3.315%
10.5	0.008595	0.000289	3.367%
11.3	0.009795	0.000315	3.219%
11.9	0.010696	0.000336	3.145%
12.4	0.011287	0.000352	3.115%
13.1	0.011951	0.000370	3.100%
14.3	0.013666	0.000424	3.099%
15.7	0.017301	0.000564	3.261%

9.2.2 Self-Propulsion

The self-propulsion uncertainty analysis is more complicated as the number of variable and collected channels increase. The measured data was first broken down into individual bias errors. These are shown below in Table 13. This data only applies to Bulb C at 11.25 knots full scale equivalent. Each bow and each speed will have its own bias error and is shown in appendix J.

Table 13: Individual Bias Limits for Measured Variables

Bulb C at 11.25 knots full scale							
Variable		Bias Error				Bias Limit	
Length	B_L	Data Acquisition	±	0.002	m		
Density	B_ρ	Calibration	±	0.0511136	kg/m^3	0.086675257	kg/m^3
		Data Reduction	±	0.07	kg/m^3		
Viscosity	B_ν	Calibration	±	1.7273E-08	m^2/s	1.72805E-08	m^2/s
		Data Reduction	±	5.08E-10	m^2/s		
FD	B_{FD}	Weight Error	±	0.000996306	N	0.030523536	N
		Calibration	±	0.007444358	N		
		Data Acquisition	±	0.000498445	N		
		Curve Fit Error	±	0.017076482	N		
Speed	B_V	Pulses	±	2.358495283	pulses	0.004640822	m/s
		Wheel Diameter	±	0.0001	m		
		Time Basis	±	0.00001025	s		
Thrust	B_T	Calibration	±	0.000600188	N	0.031018649	N
		Data Acquisition	±	0.015115491	N		
		AD Conversion	±	0.02707985	N		
Torque	B_Q	Calibration	±	0.000278079	N.m	0.002599433	N.m
		Data Acquisition	±	7.75164E-06	N.m		
		AD Conversion	±	0.002584505	N.m		
Opens Advance Coefficient	B_{JT}	Data Acquisition	±	0.002032	[-]	0.004813283	[-]
		Calibration	±	0.00002107	[-]		
		Curve Fit Error	±	-0.00436328	[-]		
Opens Torque Coefficient	B_{KQT}	Data Acquisition	±	0.0002628	[-]	0.000781034	[-]
		Calibration	±	0.000733026	[-]		
		Curve Fit Error	±	6.01919E-05	[-]		

The individual bias errors were employed to give the bias limits for the thrust coefficient, torque coefficient, wake fraction, thrust deduction and relative rotative efficiency using equations 9.11 – 9.12 and equations 9.16 – 9.18. Table 14 and Table 15 below are the bias limits for the thrust and torque coefficients. The results are for Bulb C, all speeds. This gives an example of how the bias changes over the speed range for a bow.

Table 14: Thrust Coefficient Bias – Bulb C

Vs	K_T	∂KT/∂T	∂KT/∂ρ	∂KT/∂n	∂KT/∂D	B_{KT}	
knots	[-]					[-]	%
9.201	0.281317	0.03607297	-0.000281	-0.04906	-9.33832	**0.00237**	**0.843%**
11.256	0.2826058	0.02354311	-0.000283	-0.03982	-9.38111	**0.002222**	**0.786%**
12.281	0.3019237	0.01883558	-0.000302	-0.03805	-10.0224	**0.002317**	**0.767%**
13.311	0.3029354	0.01591214	-0.000303	-0.03509	-10.0559	**0.002303**	**0.760%**
15.371	0.3203536	0.01048917	-0.00032	-0.03013	-10.6341	**0.002401**	**0.749%**

Table 15: Torque Coefficient Bias – Bulb C

Vs	K_Q	∂KQ/∂Q	∂KQ/∂ρ	∂KQ/∂n	∂KQ/∂D	B_{KQ}	
knots	[-]					[-]	%
9.201	0.066236	0.299361	-6.8051E-05	-0.01187	-2.823	**0.000634**	**0.95707%**
11.256	0.06599	0.195379	-6.7798E-05	-0.00955	-2.81249	**0.000631**	**0.95691%**
12.281	0.07417	0.156312	-7.6202E-05	-0.0096	-3.16113	**0.00071**	**0.95685%**
13.311	0.067567	0.132051	-6.9419E-05	-0.00804	-2.87973	**0.000646**	**0.95681%**
15.371	0.070922	0.087047	-7.2865E-05	-0.00685	-3.0227	**0.000679**	**0.95674%**

The bias error for the thrust and torque coefficients are less than 1% of the results from the experiments. Table 16 to Table 18 below shows the bias error for the wake fraction, thrust deduction fraction and relative rotative efficiency for Bulb C, all speeds tested. The wake fraction shows that the error is less than 5% of the results of the SP experiments. The thrust deduction and relative rotative efficiency bias error is less than 2% of the results from the experiments.

Table 16: Wake Fraction Bias – Bulb C

Vs	w	∂w/∂JT	∂w/∂D	∂w/∂Jn	∂w/∂JV	B_w	
Kts	[-]					[-]	%
9.201	0.093792	-0.64307	-7.52105	-0.07903	0.819871	**0.004580**	**4.8841%**
11.256	0.086119	-0.65068	-7.58473	-0.06438	0.675866	**0.0040603**	**4.7148%**
12.281	0.110725	-0.66676	-7.38051	-0.05604	0.602792	**0.0038320**	**3.4608%**
13.311	0.109872	-0.66927	-7.38759	-0.05156	0.55666	**0.0036846**	**3.3535%**
15.371	0.09655	-0.71384	-7.49816	-0.04248	0.489267	**0.0035899**	**3.7182%**

Table 17: Thrust Deduction Fraction Bias – Bulb C

Vs	t	∂t/∂T	∂t/∂FD	∂t/∂Rx	B_t	
knots	[-]				[-]	%
9.201	0.385376	0.078196	0.128228927	0.128229	**0.005644**	**1.465%**
11.256	0.32864	0.055356	0.083307235	0.083307	**0.003745**	**1.139%**
12.281	0.28641	0.044181	0.062385225	0.062385	**0.002859**	**0.998%**
13.311	0.224392	0.040539	0.052526526	0.052527	**0.002476**	**1.103%**
15.371	0.105619	0.029111	0.032742461	0.032742	**0.001664**	**1.576%**

Table 18: Relative Rotative Efficiency Bias – Bulb C

Vs	η_R	$\partial\eta_R/\partial K_{QO}$	$\partial\eta_R/\partial K_Q$	$B_{\eta R}$	
knots	[-]			[-]	%
9.201	0.992511	15.0975	14.9844378	**0.019071**	**1.921%**
11.256	0.998768	15.15389	15.13521845	**0.017025**	**1.705%**
12.281	0.922538	13.48259	12.43819558	**0.014631**	**1.586%**
13.311	1.014631	14.80006	15.01659959	**0.015942**	**1.571%**
15.371	0.998539	14.10004	14.07944287	**0.014919**	**1.494%**

The precision limit is calculated by running the complete analysis end to end with the different input data from repeat experiments. The data shown was calculated using the methods prescribed by the ITTC procedure 7.5-02-03-01.2. These values are applied to the bias limits using equation 9.1 to give the total uncertainty for each variable.

Table 19 and Table 20 summarizes the total uncertainties for each bow at each test speed.

P_{KQ}	2.30896E-05
P_{KT}	0.000498325
P_t	0.004445827
P_w	0.000707849
$P_{\eta R}$	0.000573757

Table 19: Total Uncertainty for Torque and Thrust Coefficient

	Vs	U_{KQ}		U_{KT}	
	knots	[-]	%	[-]	%
Conventional Bow	9.210	0.0010626	1.7022%	0.0022579	0.9325%
	11.262	0.0007828	1.1856%	0.0023413	0.7947%
	13.311	0.0007549	1.0356%	0.0025417	0.7680%
	15.379	0.0007468	0.9882%	0.0025772	0.7610%
Bulb C	9.201	0.0010005	1.5105%	0.0024223	0.8611%
	11.256	0.0008089	1.2257%	0.0022775	0.8059%
	12.281	0.0008169	1.1015%	0.00237	0.7850%
	13.311	0.0007314	1.0825%	0.0023563	0.7778%
	15.371	0.0007152	1.0085%	0.0024519	0.7654%
Bulb D	11.192	0.0008123	1.1892%	0.0024261	0.7938%
	12.283	0.0007698	1.1322%	0.0023951	0.7849%
	13.302	0.0007422	1.0771%	0.0024075	0.7761%
	15.366	0.0007091	1.0039%	0.0025475	0.7630%
Bulb G	11.246	0.000823	1.2493%	0.0022656	0.8114%
	13.308	0.0007353	1.0836%	0.0023922	0.7770%
	15.366	0.000711	1.0044%	0.0025543	0.7629%
Bulb H	9.189	0.0010165	1.5896%	0.0024028	0.8764%
	11.251	0.0008061	1.2793%	0.0022398	0.8145%
	12.281	0.0007552	1.1617%	0.0023085	0.7909%
	13.308	0.0007312	1.0914%	0.0023792	0.7782%
	15.367	0.0007047	1.0083%	0.0025162	0.7639%

Table 20: Total Uncertainty for Wake Fraction, Thrust Deduction Fraction and Relative Rotative Efficiency.

	Vs	U_w		U_t		$U_{\eta R}$	
	knots	[-]	%	[-]	%	[-]	%
Conventional Bow	9.210	0.0046711	7.1852%	0.0085675	3.6054%	0.0133974	1.4718%
	11.262	0.0042151	5.6563%	0.00548	2.5454%	0.014116	1.4544%
	13.311	0.0039004	3.6651%	0.004793	1.9887%	0.0134383	1.3149%
	15.379	0.0039127	6.6178%	0.0046144	3.3220%	0.0123134	1.2434%
Bulb C	9.201	0.0046352	4.9420%	0.0071847	1.8643%	0.0119019	1.2289%
	11.256	0.0041215	4.7859%	0.0058127	1.7687%	0.0134598	1.3561%
	12.281	0.0038968	3.5194%	0.0052858	1.8455%	0.0133913	1.3408%
	13.311	0.003752	3.4149%	0.0050886	2.2677%	0.011974	1.2979%
	15.371	0.003659	3.7897%	0.0047471	4.4945%	0.0131399	1.2950%
Bulb D	11.192	0.0040894	3.5376%	0.0053872	1.5995%	0.0125876	1.2606%
	12.283	0.0038441	3.0467%	0.0051535	1.4887%	0.0130556	1.2941%
	13.302	0.0037204	2.9610%	0.0049354	1.4625%	0.0130898	1.2928%
	15.366	0.0036837	3.3663%	0.0046426	1.8923%	0.0129232	1.2813%
Bulb G	11.246	0.0040596	4.1362%	0.0057067	1.4475%	0.0127117	1.2372%
	13.308	0.0037094	2.9521%	0.0049597	1.5408%	0.0134034	1.3488%
	15.366	0.0036658	3.1812%	0.0046523	2.0854%	0.0131121	1.2858%
Bulb H	9.189	0.0046	4.7161%	0.0074387	1.8186%	0.0126893	1.2357%
	11.251	0.0040639	4.3349%	0.0059713	1.6057%	0.0139348	1.3749%
	12.281	0.003853	3.4473%	0.0053015	1.5863%	0.0139983	1.3589%
	13.308	0.0036872	2.8617%	0.0049898	1.6419%	0.013623	1.3194%
	15.367	0.0036448	3.2329%	0.0046684	2.4707%	0.0132711	1.2901%

9.3 Discussion

The procedure in which the experiments were conducted are well established and are used in industry as an accepted way to conduct resistance and self-propulsion experiments. The data provided above in this uncertainty analysis shows that the experimental data has an uncertainty level of less than 5% for any of the variables. This being said, there is always room for improvement and a sensitivity analysis was completed to see the greatest bias influences in the results.

The variables discussed here are listed below in Table 21.

Table 21: Most Influence on Overall Uncertainty

Variable Affected	Bias Error	Description	Uncertainty Reduction
K_Q	B_{T3}	AD conversion x slope of curve fit calibration	up to 37%
	B_D	CNC machine and polishing error	up to21%
K_T	B_D	CNC machine and polishing error	up to 44%
	B_{Q3}	AD conversion x slope of curve fit calibration	up to 10%
w	B_c	pulse count error	up to 35%
	B_D	CNC machine and polishing error	up to 13%
t	B_{RX4}	AD conversion x slope of curve fit calibration	up to 13%
η_R	B_{Q3}	AD conversion x slope of curve fit calibration	up to 25%

The diameter of the propeller bias, B_D, has affected Kq, Kt and wake substantially. The error assumed for this thesis is based on the CNC machine having a calibration error ±0.1mm and a polishing error of ±0.1mm. If the accuracy of these elements can be increased, the total error in the project could be decreased. The analog to digital (AD) conversion error which shows up in almost all of the variables is calculated by the error in the AD converter which is 1 bit of AD accuracy of 16 bits. This is multiplied by the slope of the curve for the calibration, therefore, the larger range of voltage that the sensors can be calibrated over the lower the slope and the lower the error. For example, the torque sensor is calibrated over a range of -3.1 volts to +3.2 volts, if this were calibrated over a range -15 volts to +15 volts the uncertainty in K_Q, could be reduced, for the Bulb C 11.3

knot case, from 0.98% to 0.63% and reduced the uncertainty in relative rotative efficiency from 1.77% to 1.35%.

Overall the uncertainty analysis for the resistance and self-propulsion experiments showed that there were sources of error but the values are within acceptable levels.

In addition to the uncertainty analysis outlined in the ITTC standards, Figure 61 below shows a 95% confidence level in the delivered power graph. This shows that it is reasonable to accept the results from these experiments.

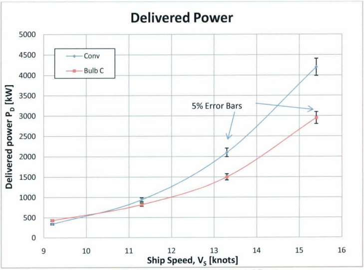

Figure 61: Confidence Level of the Delivered Power

10 Conclusions and Recommendations

The experiments show that the bulbs perform better in the higher speed ranges (Fn>0.3), where the highest resistance occurs. A closer look at the residuary resistance shows also that at the lower speeds (Fn < 0.29) Bulb D's residuary resistance is the highest. Figure 36 in Section 8.1 shows the comparison of the bulbous bows resistance against a base-line conventional bow resistance. The results are interesting especially when compared to the results of the paper by Heliotis (Heliotis and Goudey 1985). The Heliotis paper showed that the bulbs become effective in calm water, only after 9-10.5knots, regardless of the bulb used. These results are seen in Figure 6 of the literature review. This was also the result of this thesis, though where the experimental results diverge is that in Heliotis's paper, at some higher speeds, the bulbs start to become less effective, while this thesis showed a steady benefit as the speed increased. It could be concluded that the beach area on the bulbs prolong the benefits where the cylindrical bulbs of the Heliotis's experiments had no such area.

The self-propulsion experiments show that the delivered power required for a conventional bow is higher than the bulbs in the higher speed ranges (V_S>10kts). This is identified in the resistance experiment and shown again in the SP experiments.

The wake fraction results show an interesting 'hump' in the data at ~13knots. The wake fraction increases across all bows. This hump in the data suggests a disturbance in the flow at the propeller. As the hump occurs with each of the bow configuration it implies that the disturbance is caused by the shape of the hull behind the bow. This could be a result of the transom immersion or eddy making off the box keel interacting at the propeller. Also the results show that at the 'hump' the vessel is at its greatest bow down pitch values which could also affect the flow to the propeller. A flow visualization experiment would give better insight into this phenomenon.

The qualitative information from the head seas motion results shows that in all cases Bulb C's motions are less severe and the conventional bow's are the most. Because more wave encounters are required to make the experiment statistically significant, more work should be done to quantitatively validate these results.

The resistance comparison is intriguing when comparing the result to the calm water results. It was determined that in calm water the effectiveness of the bulbs starts above ~9kts, a trend that is repeated in the sea state 3 results. This is not the case for sea state 5. For Bulbs C, G and H, the resistance is either equal to or better than the conventional bow; Figure 60 illustrates this comparison. The only exception is Bulb D which follows the same pattern as sea state 3 and the calm water resistance.

The head seas experiments were completed on a fix-in-surge tow post. It is a recommendation to tests these bulbs again using a free-to-surge tow post. This would more accurately quantify the motions.

11 References

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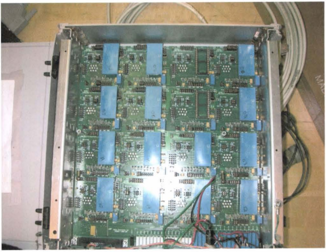
Appendices

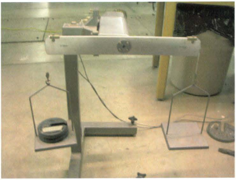
Appendix A – Calibration Pictures

Appendix A



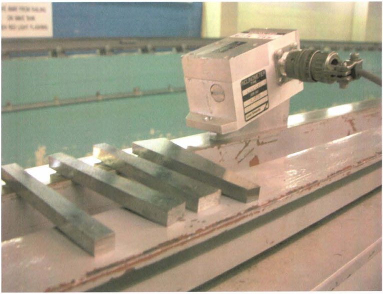
A-1: Signal Conditioner Box

A-2: Calibrating Thrust



A-3: Calibrating Torque

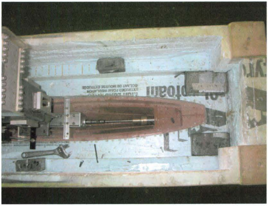
A-4: Calibrating Load Cell



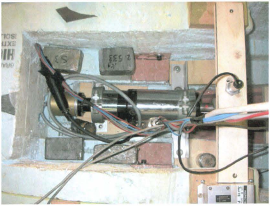
A-5: Calibrating Inclinometer

Appendix B – Select Experiment Set Up Pictures

Appendix B



B-1: Installed SP instrumentation, Shaft and Stuffing box; Aft.



B-2: Installed SP instrumentation, Motor, Tachometer and Inclinometer; Fwd.

B-3: Keel, Shaft and Fairing Hub

B-4: Bulb Variations

Appendix C – Matlab Routines

```
%Channel Assignments
Channel1='Resistance (N)';
Channel2='Speed (m/s)';
Channel3='Sinkage (mm)';
Channel4='Wave Height (cm)';
Channel5='inline (N)';
Channel6='Trim (N-m)';
Channel7='XAccel (g)';
Channel8='YAccel (g)';
Channel9='ZAccel (g)';
Channel10='Pitch (deg)';
channels = {'';''; Channel1; Channel2; Channel3; Channel4; Channel5; Channel6; Channel7;↙
Channel8; Channel9; Channel10};

%file management
existingfile = input('are you putting this data in an existing xls file? y/n:', 's');
if existingfile =='y'
    disp('here are the excel files in this directory: ');
    dir('*.xls');
    xlsfile = input('which excel file?: ', 's');
    tabref = 1;
else
    xlsfile = input('what are you calling the excel file?: ', 's');
    tabref = 2;
end
if tabref == 1;
    cellref = input('do you want to append this data to an existing tab? y/n:', 's');
    if cellref == 'y';
        [typ,desc] = xlsfinfo(xlsfile);
        disp('These are the availiable tabs: ');
        desc
        clear desc;
        clear typ;
        tabname = input('Which tab will you append to?  ', 's');
        [num, txt] = xlsread(xlsfile, tabname);
        [cell,col] = size(txt);
        clear col;
    else
        tabname = input('enter tab name:  ', 's');
        cell = 1;
    end
else
    tabname = input('enter tab name:  ', 's');
    cell = 1;
end



anotherfile = 'y';
sametab = 'y';
```

```
while anotherfile == 'y';
filename = input('what is the aquired data filename? ', 's');
B = load(filename, '-mat');
A = B.A;
if sametab == 'n';
    tabname = input('enter tab name:  ', 's');
    cell = 1;
end

% tare segments
plot(A(:,1)); % Change this to the channel you would like for the tare segment select
wh = axis;
[x1,y1] = ginput(1);
line([x1,x1], wh(3:4));
x1 = round(x1);
[x2,y2] = ginput(1);
line([x2,x2], wh(3:4));
x2 = round(x2);
tare = A(x1:x2,:);
tare = mean(tare);
[r,c] = size(A);
clear data
i=1;
%which channels to tare
zerotare = [tare(:,:)]; % to tare all channels
%zerotare = [tare(:,1),tare(:,2),tare(:,3),tare(:,4),0,tare(:,6),0,0]; % place a zero on
each channel that isn't tared
for i=1:r;
    data(i,:)=A(i,:) - zerotare(:,:);
end
plot(data)
d2 = ['Tare Mean',filename, num2cell(zerotare)];
tarelabel=[channels, d2'];
la = ['A' num2str(cell)];
xlswrite(xlsfile, tarelabel', tabname, la);
cell = cell+2;

chan = 1 ;%':' %0
another = 1;

while another == 1;if another >=2; break; end;
% data = input('enter which variable to take data from:');
    %if chan == 0
    %    chan = ':' % input('enter which channel to plot:');
    %end
plot(data(:,chan))
[x1,y1,another] = ginput(1);
x1 = round(x1);
[x2,y2,another] = ginput(1);
x2 = round(x2);
seg1 = data(x1:x2,:);
```

```
seglabel = filename; % input(' enter motor controller value:  ', 's');
%get stats
Me = mean(seg1);
Sd = std(seg1);
Mn = min(seg1);
Mx = max(seg1);
stats = [Me', Sd', Mn', Mx'];
stats2 = num2cell(stats);
label = {'Mean', 'Std', 'Min', 'Max'};
labelname = {seglabel, seglabel, seglabel, seglabel};
d = [label; labelname; stats2];
e = [channels, d];
li = ['A' num2str(cell)];
xlswrite(xlsfile, e', tabname, li)
%another = input('Is there another segment in this file? y/n: ', 's');
cell = cell + 5;
end
anotherfile = input('Is there another file to analyze? y/n: ', 's');

if anotherfile == 'Y';
    sametab = input('would you like to add the data to the same tab? y/n: ', 's');
    if sametab =='y'
        sametab ='y';
    end
elseif anotherfile == 'y'
    sametab = input('would you like to add the data to the same tab? y/n: ', 's');
     if sametab =='y'
        sametab ='y';
     end
     anotherfile = 'y';

end
end
```

```
%Channel Assignments
Channel1='Resistance (N)';
Channel2='Speed (m/s)';
Channel3='Sinkage (mm)';
Channel4='Thrust (N)';
Channel5='Torque (N-m)';
Channel6='Inline (N)';
Channel7='Shaft Speed (RPS)';
Channel8='Trim (deg)';
channels = {'';''; Channel1; Channel2; Channel3; Channel4; Channel5; Channel6; Channel7;↙
Channel8};

%file management
existingfile = input('are you putting this data in an existing xls file? y/n:', 's');
if existingfile =='y'
    disp('here are the excel files in this directory: ');
    dir('*.xls');
    xlsfile = input('which excel file?: ', 's');
    tabref = 1;
else
    xlsfile = input('what are you calling the excel file?: ', 's');
    tabref = 2;
end
if tabref == 1;
    cellref = input('do you want to append this data to an existing tab? y/n:', 's');
    if cellref == 'y';
        [typ,desc] = xlsfinfo(xlsfile);
        disp('These are the availiable tabs: ');
        desc
        clear desc;
        clear typ;
        tabname = input('Which tab will you append to?  ', 's');
        [num, txt] = xlsread(xlsfile, tabname);
        [cell,col] = size(txt);
        clear col;
    else
        tabname = input('enter tab name:  ', 's');
        cell = 1;
    end
else
    tabname = input('enter tab name:  ', 's');
    cell = 1;
end



anotherfile = 'y';
sametab = 'y';
while anotherfile == 'y';
filename = input('what is the aquired data filename? ', 's');
```

```
B = load(filename, '-mat');
A = B.A;
if sametab == 'n';
    tabname = input('enter tab name:  ', 's');
    cell = 1;
end

% tare segments
plot(A(:,4)); % Change this to the channel you would like for the tare segment select
wh = axis;
[x1,y1] = ginput(1);
line([x1,x1], wh(3:4));
x1 = round(x1);
[x2,y2] = ginput(1);
line([x2,x2], wh(3:4));
x2 = round(x2);
tare = A(x1:x2,:);
tare = mean(tare);
[r,c] = size(A);
clear data
i=1;
%which channels to tare
%zerotare = [tare(:,:)]; % to tare all channels
zerotare = [tare(:,1),tare(:,2),tare(:,3),tare(:,4),0,tare(:,6),0,0]; % place a zero on↙
each channel that isn't tared
for i=1:r;
    data(i,:)=A(i,:) - zerotare(:,:);
end
plot(data)
d2 = ['Tare Mean',filename, num2cell(zerotare)];
tarelabel=[channels, d2'];
la = ['A' num2str(cell)];
xlswrite(xlsfile, tarelabel', tabname, la);
cell = cell+2;

chan = ':'; %0
another = 1;

while another == 1;if another >=2; break; end;
% data = input('enter which variable to take data from:');
    %if chan == 0
    %     chan = ':' % input('enter which channel to plot:');
    %end
plot(data(:,chan))
[x1,y1,another] = ginput(1);
x1 = round(x1);
[x2,y2,another] = ginput(1);
x2 = round(x2);
seg1 = data(x1:x2,:);
seglabel = filename; % input(' enter motor controller value:  ', 's');
%get stats
```

```
Me = mean(seg1);
Sd = std(seg1);
Mn = min(seg1);
Mx = max(seg1);
stats = [Me', Sd', Mn', Mx'];
stats2 = num2cell(stats);
label = {'Mean', 'Std', 'Min', 'Max'};
labelname = {seglabel, seglabel, seglabel, seglabel};
d = [label; labelname; stats2];
e = [channels, d];
li = ['A' num2str(cell)];
xlswrite(xlsfile, e', tabname, li)
%another = input('Is there another segment in this file? y/n: ', 's');
cell = cell + 5;
end
close
anotherfile = input('Is there another file to analyze? y/n: ', 's');

if anotherfile == 'Y';
    sametab = input('would you like to add the data to the same tab? y/n: ', 's');
    if sametab =='y'
        sametab ='y';
    end
elseif anotherfile == 'y'
    sametab = input('would you like to add the data to the same tab? y/n: ', 's');
     if sametab =='y'
        sametab ='y';
     end
     anotherfile = 'y';

end
end
```

Appendix D – Maple Calm Water Resistance Routines

Open Water Resistance - ITTC '57 Method

Notes:
- Subscript M refers to model scale testing data and testing water properties.
- Subscript S refers to ship full scale data, corrected to target water properties.
- Nondimensional numbers do not have a scale subscript.

OCC Custom Setup

Clear Memory
> *restart*

Define Location of OCC Maple Standards,
> *libname* := *libname*, "."

libname := "C:\Program Files\Maple 12/lib", "." **(2.1)**

Load OCC Maple Standards,
> *with*(*occMapleStandards*)

["nEGADS.m", "nWater.m", "occArray.m", "occArrayCheck.m", "occArraySort.m", "occAssociate.m", "occCat.m", "occCurve.m", "occDataExport.m", "occDataImport.m", "occDataRead.m", "occEnumerate.m", "occEval.m", "occEvalDeep.m", "occFlatten.m", "occListLibrary.m", "occMap.m", "occMapleStandards.m", "occMax.m", "occMean.m", "occMin.m", "occModify.m", "occModifyRow.m", "occMultiPlot.m", "occPiecewiseDiff.m", "occPlot.m", "occSequence.m", "occSigDigits.m", "occSigDigitsDeep1.m", "occSigDigitsDeep2.m", "occSort.m", "occStringToSub.m", "occSubToString.m", "rEGADS.m", "rWater.m"]

[v_{EGADS}, v_{water}, ρ_{EGADS}, ρ_{water}, \`*\`, \`+\`, \`-\`, \`/\`, \`<\`, <=, <>, \`=\`, ℑ, *ModuleLoad*, ℜ, *Unit*, \`^\`, abs, *add*, *and*, arccos, arccosh, arccot, arccoth, arccsc, arccsch, arcsec, arcsech, arcsin, arcsinh, arctan, arctanh, argument, *cat*, ceil, *collect*, *cols*, *combine*, *conjugate*, *convert*, cos, cosh, cot, coth, csc, csch, csgn, *diff*, *eval*, *evalb*, *evalc*, *evalr*, exp, *expand*, *factor*, floor, frac, *fsolve*, *if*, *implies*, *int*, ln, log, log10, max, *mean*, min, *mul*, *normal*, *not*, *or*, *piecewise*, polar, *root*, round, *rows*, sec, sech, *seq*, *shake*, *sign*, signum, *simplify*, sin, sinh, *solve*, *sort*, sqrt, surd, tan, tanh, trunc, *type*, *verify*, *xor*] **(2.2)**

Display Full Tables,
> *interface*('*rtablesize*' = ∞)

10 **(2.3)**

Acquired Data

Project Name / Number and Tabs,
> *projectName* := "BULB"
> *projectTab* := "RES"
> *projectTabAdditional* := ["HYDRO"]

projectName := "BULB"

O

$projectTab := \text{"RES"}$

$projectTabAdditional := [\text{"HYDRO"}]$ **(3.1)**

Define Data Input/Ouput Files

> $sourceFile := cat(projectName, \text{" -Source Data.xls"})$
> $outputFile := cat(projectName, \text{" -Output.xls"})$
> $mapleOutputFile := cat(projectName, \text{" -RES -Output.m"})$

$sourceFile := \text{"BULB -Source Data.xls"}$

$outputFile := \text{"BULB -Output.xls"}$

$mapleOutputFile := \text{"BULB -RES -Output.m"}$ **(3.2)**

Import Test Data,

> $testData := occDataImport('filename' = sourceFile, 'tab' = projectTab, 'sortCol' = \text{"V,M"}) :$

$TEST_{DRAFT}, TEST_{DESCRIPTION}, TEST_{NAME}, V_M, R_{TM}, \theta, z_{VM}, TEMP_M, TANK, TEMP_S, SALINITY_S$ **(3.3)**

Import Additional Data (Hydrostatics, Full Scale Target, Frictions, etc...)

> $seq(occDataImport('filename' = sourceFile, 'tab' = projectTabAdditional[i]), i = 1 ..cols(projectTabAdditional)) :$

$TEST_{DRAFT\_HYDRO}, scale_{HYDRO}, T_{M\_HYDRO}, L_{M\_HYDRO}, B_{M\_HYDRO}, S_{M\_HYDRO}, vol_{M\_HYDRO}$ **(3.4)**

▼ Tank, Water, Model/Ship Properties and Test Condition

St. John's Gravity

> $g := 9.8082 \left[\!\left[\frac{m}{s^2}\right]\!\right] :$

Tank Width

> $b_T := \begin{cases} 4.5[\![m]\!] & TANK = \text{"OERC"} \\ 12[\![m]\!] & TANK = \text{"ICE"} \textbf{ or } TANK = \text{"TOW"} \end{cases} :$

Tank Water Depth

> $h_T := \begin{cases} 6[\![ft]\!] & TANK = \text{"OERC"} \\ 3[\![m]\!] & TANK = \text{"ICE"} \\ 7[\![m]\!] & TANK = \text{"TOW"} \end{cases} :$

Test Water Density

> $\rho_M := \begin{cases} \rho_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \rho_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases} :$

Test Water Viscosity

> $\nu_M := \begin{cases} \nu_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \nu_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases} :$

Target Freshwater Model Water Density (15° C, 0% Salinity)

> $\rho_{M15} := \rho_{water}(15, 0) :$

Target Freshwater Model Viscosity Density (15° C, 0% Salinity)

O

> $\nu_{M15} := \nu_{water}(15, 0)$:

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

> $\rho_S := \rho_{water}(TEMP_S, SALINITY_S)$:

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

> $\nu_S := \nu_{water}(TEMP_S, SALINITY_S)$:

Associate Hydrostatic Conditions with Tested Conditions; Model-Ship Scale Ratio

> $\lambda := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, scale_{HYDRO})$:

Associate Hydrostatic Conditions with Tested Conditions and Scale; Draft

> **if** $assigned(T_{M\_HYDRO})$ **then**
> $T_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, T_{M\_HYDRO})$;:
> $T_S := T_M \cdot \lambda$;
> **elif** $assigned(T_{S\_HYDRO})$ **then**
> $T_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, T_{S\_HYDRO})$;
> $T_M := \frac{T_S}{\lambda}$;
> **end if**;

$$T_M := \begin{bmatrix} [0.22409 \, [\![m]\!]] \\ [0.22409 \, [\![m]\!]] \\ [0.22409 \, [\![m]\!]] \\ [0.22409 \, [\![m]\!]] \\ [0.22409 \, [\![m]\!]] \end{bmatrix}$$

$$T_S := \begin{bmatrix} [4.10824197 \, [\![m]\!]] \\ [4.10824197 \, [\![m]\!]] \\ [4.10824197 \, [\![m]\!]] \\ [4.10824197 \, [\![m]\!]] \\ [4.10824197 \, [\![m]\!]] \end{bmatrix} \quad \textbf{(4.1)}$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Length on Waterline

> **if** $assigned(L_{M\_HYDRO})$ **then**
> $L_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{M\_HYDRO})$;
> $L_S := L_M \cdot \lambda$:;
> **elif** $assigned(L_{S\_HYDRO})$ **then**

O

$L_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{S\_HYDRO});$

$L_M := \frac{L_S}{\lambda};$

end if;

$$L_M := \begin{bmatrix} [\,1.829\ [\![m]\!]\,] \\ [\,1.833\ [\![m]\!]\,] \\ [\,1.833\ [\![m]\!]\,] \\ [\,1.833\ [\![m]\!]\,] \\ [\,1.833\ [\![m]\!]\,] \end{bmatrix}$$

$$L_S := \begin{bmatrix} [\,33.531057\ [\![m]\!]\,] \\ [\,33.604389\ [\![m]\!]\,] \\ [\,33.604389\ [\![m]\!]\,] \\ [\,33.604389\ [\![m]\!]\,] \\ [\,33.604389\ [\![m]\!]\,] \end{bmatrix} \quad (4.2)$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Beam on Waterline

> **if** $assigned(B_{M\_HYDRO})$ **then**

$B_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, B_{M\_HYDRO});$

$B_S := B_M \cdot \lambda;$

elif $assigned(B_{S\_HYDRO})$ **then**

$B_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, B_{S\_HYDRO});$

$B_M := \frac{B_S}{\lambda};$

end if;

$$B_M := \begin{bmatrix} [\,0.4988\ [\![m]\!]\,] \\ [\,0.4988\ [\![m]\!]\,] \\ [\,0.4988\ [\![m]\!]\,] \\ [\,0.4988\ [\![m]\!]\,] \\ [\,0.4988\ [\![m]\!]\,] \end{bmatrix}$$

O

$$B_S := \begin{bmatrix} [\ 9.1445004\ [\![m]\!]\ ] \\ [\ 9.1445004\ [\![m]\!]\ ] \\ [\ 9.1445004\ [\![m]\!]\ ] \\ [\ 9.1445004\ [\![m]\!]\ ] \\ [\ 9.1445004\ [\![m]\!]\ ] \end{bmatrix} \tag{4.3}$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(S_{M\_HYDRO})$ **then**
>
> $S_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{M\_HYDRO});$
>
> $S_S := S_M \cdot \lambda^2;$
>
> **elif** $assigned(S_{S\_HYDRO})$ **then**
>
> $S_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{S\_HYDRO});$
>
> $S_M := \frac{S_S}{\lambda^2};$
>
> **end if**;

$$S_M := \begin{bmatrix} [\ 0.9722\ [\![m^2]\!]\ ] \\ [\ 1.1225\ [\![m^2]\!]\ ] \\ [\ 1.0964\ [\![m^2]\!]\ ] \\ [\ 1.10625\ [\![m^2]\!]\ ] \\ [\ 1.109381\ [\![m^2]\!]\ ] \end{bmatrix}$$

$$S_S := \begin{bmatrix} [\ 326.7553399\ [\![m^2]\!]\ ] \\ [\ 377.2710029\ [\![m^2]\!]\ ] \\ [\ 368.4988219\ [\![m^2]\!]\ ] \\ [\ 371.8093960\ [\![m^2]\!]\ ] \\ [\ 372.8617216\ [\![m^2]\!]\ ] \end{bmatrix} \tag{4.4}$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(vol_{M\_HYDRO})$ **then**
>
> $vol_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, vol_{M\_HYDRO});$

$vol_S := vol_M \cdot \lambda^3;$

elif *assigned*(vol_{S_HYDRO}) **then**

$vol_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, vol_{S\_HYDRO});$

$vol_M := \frac{vol_S}{\lambda^3};$

end if;

$$vol_M := \begin{bmatrix} [0.0629 [[m^3]]] \\ [0.07262420284 [[m^3]]] \\ [0.07093556881 [[m^3]]] \\ [0.07157285024 [[m^3]]] \\ [0.07177542162 [[m^3]]] \end{bmatrix}$$

$$vol_S := \begin{bmatrix} [387.5709886 [[m^3]]] \\ [447.4886183 [[m^3]]] \\ [437.0837604 [[m^3]]] \\ [441.0104980 [[m^3]]] \\ [442.2586823 [[m^3]]] \end{bmatrix} \quad (4.5)$$

Define TEST,COND(ITION)

> $TEST_{COND} := occCat(TEST_{DRAFT}, TEST_{DESCRIPTION});$

$$TEST_{COND} := \begin{bmatrix} [\text{"Conv, Design Draft"}] \\ [\text{"Bulb C, Design Draft"}] \\ [\text{"Bulb D, Design Draft"}] \\ [\text{"Bulb G, Design Draft"}] \\ [\text{"Bulb H, Design Draft"}] \end{bmatrix} \quad (4.6)$$

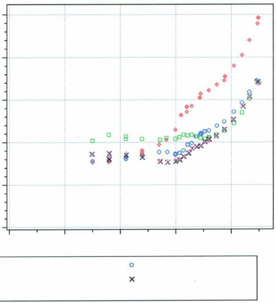
Model Resistance Coefficients and Non-Dimensional Numbers

Froude Number

r

Scott Method is Valid For:

BULB -RES -090121.mw



- Fr from 0.10 to 0.55.
- Tank Width/Height ratio should not substantially differ from 2.
- Tank Froude Depth Number < 1.

Residuary Resistance Coefficient in a Restricted Tank

$> C_{R\_TANK} := C_{TM} - C_{FM}:$

Tank Cross-Sectional Area

$> A_T := h_T \cdot b_T:$

Tank Froude Depth Number

$$> Fr_T := \frac{V_M}{\sqrt{g \cdot h_T}}:$$

Block Coefficient for Vesel

$$> C_B := \frac{vol_M}{L_M \cdot B_M \cdot T_M}:$$

Blockage Form Factor

$$> LVolC_B := \frac{L_M}{vol_M^{\frac{1}{3}} \cdot C_B}:$$

Model/Tank Function

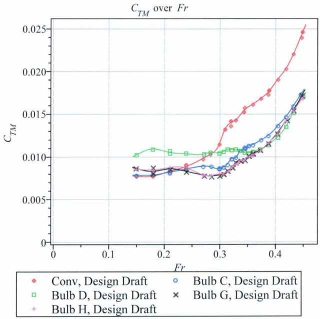
$$> f := \frac{L_M^4 \cdot (B_M \cdot T_M)^{\frac{1}{4}}}{A_T^{\frac{5}{4}} \cdot h_T^2}:$$

Power of Speed Proportional to Actual Resistance in Speed Vicinity

$> occPlot(Fr, C_{TM}, 'curve' = \text{"spline"}, 'assignCurve' = \text{"C,TM\_CURVE"})$

$$> n_t := 2 + \frac{Fr}{C_{TM}} \cdot \left(\frac{d}{dt} C_{TM\_CURVE} \Big|_{'t' = Fr} \right):$$

O



Function of Reynold's Number and Form, Evaluated at Zero

$$> b_0 := \begin{cases} 0.5 + 0.1 \cdot LVolC_B & LVolC_B > 11.6 \\ 0.143 \cdot LVolC_B & otherwise \end{cases} :$$

Function of Reynold's Number and Form

$$> b := \begin{cases} b_0 & Rn_M \cdot 10^{-6} < 4 \cdot b_0 \\ \frac{18\, b_0}{20 - 4\, b_0} - \frac{b_0 - 0.5}{20 - 4\, b_0} \cdot Rn_M \cdot 10^{-6} & 4 \cdot b_0 \le Rn_M \cdot 10^{-6} < 20 \\ 0.5 & otherwise \end{cases} :$$

Function of Froude Number, k

$$> k := \begin{cases} 0 & Fr \le 0.25 \\ 0.14 \cdot Fr - 0.035 & 0.25 < Fr \le 0.32 \\ -1.3393 \cdot Fr^2 + 1.3028 \cdot Fr - 0.2717 & 0.32 < Fr \le 0.42 \\ 0.18 \cdot Fr - 0.034 & otherwise \end{cases} :$$

O

Function of Froude Number, c

$$> c := \begin{cases} 0.6 & Fr \le 0.4 \\ 405092.59 \cdot Fr^6 - 1136618.59 \cdot Fr^5 + 1323361.83 \cdot Fr^4 - 818648.19 \cdot Fr^3 + 283862.03 \cdot Fr^2 - 52321 \cdot Fr + 4006.42 & 0.4 < Fr < 0.56 \\ 0 & otherwise \end{cases}$$

:

Change in Model Total Resistance Coefficient

$$> \Delta C_{TM} := \frac{n_t \cdot C_{TM} \cdot b \cdot vol_M \cdot A_T^{-\frac{3}{2}} + \frac{k \cdot f \cdot C_{R\_TANK}}{1 + k \cdot f}}{1 - c \cdot Fr_T^2} :$$

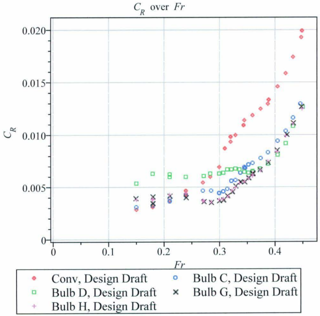
Corrected Model Total Resistance Coefficient

$> C_{TM\_CORR} := C_{TM} - \Delta C_{TM}:$

Residuary Resistance Coefficient (in Unrestricted Water)

$> C_R := C_{TM\_CORR} - C_{FM}:$

$> occPlot(Fr, C_R)$



O

Ship Behavior

Ship Sinkage due to Forward Velocity

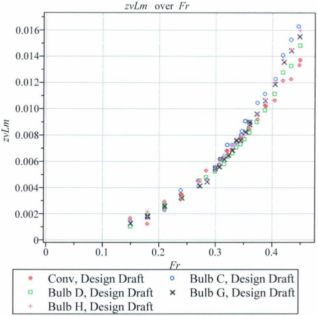
> $z_{VS} := z_{VM} \cdot \lambda$:

Ratio of Sinkage over Length

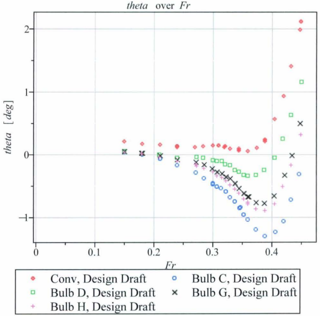
> $zvLm := \frac{z_{VM}}{L_M}$:

> $occPlot(Fr, zvLm)$

> $occPlot(Fr, [\theta, [[deg]]])$



O



Model Scale Transformation to Freshwater Target Conditon (for Different Test Temperature Comparisons)

Model Reynold's Number at Target Condition

$> Rn_{M15} := \frac{V_M \cdot L_M}{\nu_{M15}}$

Rn_{M15} := [[[1.011806886 10^6, 1.215526865 10^6, 1.420528 10^6, 1.618157497 10^6, 1.618157497 10^6, 1.618659033 10^6, 1.618659033 10^6, 1.621437870 10^6, 1.624285853 10^6, 1.624285853 10^6, 1.826605104 10^6, 1.923492655 10^6, 2.030304200 10^6, 2.100982372 10^6, 2.100982372 10^6, 2.166324840 10^6, 2.172521143 10^6, 2.172521143 10^6, 2.233028143 10^6, 2.330794399 10^6, 2.330794399 10^6, 2.336544131 10^6, 2.438926702 10^6, 2.535587084 10^6, 2.629611594 10^6, 2.634842911 10^6, 2.634842911 10^6, 2.743504416 10^6, 2.845846959 10^6, 2.937340660 10^6, 3.033815793 10^6, 3.047210469 10^6, **(8.1)**

O

$3.047210469\ 10^6]],$
$[[1.013813542\ 10^6, 1.219360352\ 10^6, 1.425023252\ 10^6, 1.425023252\ 10^6,$
$1.426084941\ 10^6, 1.623566991\ 10^6, 1.841744856\ 10^6, 1.933752143\ 10^6,$
$2.036367199\ 10^6, 2.036367199\ 10^6, 2.039183151\ 10^6, 2.091194761\ 10^6,$
$2.091194761\ 10^6, 2.134911333\ 10^6, 2.186085097\ 10^6, 2.186085097\ 10^6,$
$2.239812312\ 10^6, 2.292491233\ 10^6, 2.292491233\ 10^6, 2.348099163\ 10^6,$
$2.348099163\ 10^6, 2.355752177\ 10^6, 2.395226462\ 10^6, 2.395226462\ 10^6,$
$2.445229459\ 10^6, 2.542323643\ 10^6, 2.639001239\ 10^6, 2.759168933\ 10^6,$
$2.853770970\ 10^6, 2.945912533\ 10^6, 3.039154258\ 10^6]],$
$[[1.016614746\ 10^6, 1.221095594\ 10^6, 1.422928397\ 10^6, 1.422928397\ 10^6,$
$1.423619999\ 10^6, 1.628191079\ 10^6, 1.848893311\ 10^6, 1.923179945\ 10^6,$
$2.035774772\ 10^6, 2.088725820\ 10^6, 2.088725820\ 10^6, 2.139819466\ 10^6,$
$2.185389662\ 10^6, 2.185389662\ 10^6, 2.239629157\ 10^6, 2.291036494\ 10^6,$
$2.291036494\ 10^6, 2.344399703\ 10^6, 2.393946336\ 10^6, 2.393946336\ 10^6,$
$2.442666336\ 10^6, 2.442666336\ 10^6, 2.444454630\ 10^6, 2.537475296\ 10^6,$
$2.633953065\ 10^6, 2.751727211\ 10^6, 2.852655579\ 10^6, 2.945828406\ 10^6,$
$3.061939451\ 10^6]],$
$[[1.010590552\ 10^6, 1.217341970\ 10^6, 1.217341970\ 10^6, 1.218664863\ 10^6,$
$1.424408319\ 10^6, 1.629961778\ 10^6, 1.844705007\ 10^6, 1.932532139\ 10^6,$
$2.033758695\ 10^6, 2.088267792\ 10^6, 2.088267792\ 10^6, 2.139951969\ 10^6,$
$2.192427767\ 10^6, 2.192427767\ 10^6, 2.239428415\ 10^6, 2.292789167\ 10^6,$
$2.292789167\ 10^6, 2.341800126\ 10^6, 2.399598758\ 10^6, 2.399598758\ 10^6,$
$2.446348395\ 10^6, 2.446348395\ 10^6, 2.449167291\ 10^6, 2.538476697\ 10^6,$
$2.635538324\ 10^6, 2.749668564\ 10^6, 2.865586578\ 10^6, 2.948283972\ 10^6,$
$3.050154897\ 10^6]],$
$[[1.013940351\ 10^6, 1.217074022\ 10^6, 1.217541916\ 10^6, 1.217541916\ 10^6,$
$1.423642779\ 10^6, 1.624198553\ 10^6, 1.841827993\ 10^6, 1.849394671\ 10^6,$
$1.849394671\ 10^6, 1.935213916\ 10^6, 2.036673514\ 10^6, 2.085664133\ 10^6,$
$2.085664133\ 10^6, 2.144259905\ 10^6, 2.193950588\ 10^6, 2.193950588\ 10^6,$
$2.241102530\ 10^6, 2.289567460\ 10^6, 2.289567460\ 10^6, 2.342137849\ 10^6,$
$2.393768785\ 10^6, 2.393768785\ 10^6, 2.441356322\ 10^6, 2.441356322\ 10^6,$
$2.445512171\ 10^6, 2.541897489\ 10^6, 2.637408879\ 10^6, 2.750301850\ 10^6,$
$2.852625355\ 10^6, 2.946750143\ 10^6, 3.055903898\ 10^6]]]$

Model Frictional Resistance Coefficient at Target Condition

$$> C_{FM15} := \frac{0.075}{\left(\log10\left(Rn_{M15}\right) - 2\right)^2}$$

(8.2)

Oe

C_{FM15} := [[[0.004675575229, 0.004494974206, 0.004349631668, 0.004233495686, **(8.2)**
0.004233495686, 0.004233224964, 0.004233224964, 0.004231726967,
0.004230195181, 0.004230195181, 0.004129588634, 0.004086429244,
0.004042019163, 0.004014272510, 0.004014272510, 0.003989680249,
0.003987398366, 0.003987398366, 0.003965551364, 0.003931829234,
0.003931829234, 0.003929903374, 0.003896607346, 0.003866795054,
0.003839176034, 0.003837677033, 0.003837677033, 0.003807385452,
0.003780241850, 0.003757022668, 0.003733530044, 0.003730344590,
0.003730344590]],
[[0.004673566870, 0.004491966040, 0.004346758473, 0.004346758473,
0.004346081620, 0.004230581490, 0.004122649958, 0.004082025440,
0.004039589957, 0.004039589957, 0.004038464918, 0.004018041869,
0.004018041869, 0.004001380781, 0.003982432644, 0.003982432644,
0.003963149848, 0.003944818179, 0.003944818179, 0.003926051583,
0.003926051583, 0.003923514024, 0.003910593105, 0.003910593105,
0.003894617047, 0.003864772393, 0.003836488241, 0.003803146726,
0.003778192970, 0.003754895248, 0.003732258307]],
[[0.004670772082, 0.004490608480, 0.004348095941, 0.004348095941,
0.004347654101, 0.004228100466, 0.004119399591, 0.004086563954,
0.004039826904, 0.004018996325, 0.004018996325, 0.003999537948,
0.003982686266, 0.003982686266, 0.003963214561, 0.003945317043,
0.003945317043, 0.003927282091, 0.003911007778, 0.003911007778,
0.003895425633, 0.003895425633, 0.003894861364, 0.003866227414,
0.003837931743, 0.003805156522, 0.003778480929, 0.003754916086,
0.003726862616]],
[[0.004676795167, 0.004493548324, 0.004493548324, 0.004492510868,
0.004347150812, 0.004227152852, 0.004121301996, 0.004082547521,
0.004040633925, 0.004019173552, 0.004019173552, 0.003999488272,
0.003980124340, 0.003980124340, 0.003963285493, 0.003944716063,
0.003944716063, 0.003928148266, 0.003909178952, 0.003909178952,
0.003894264401, 0.003894264401, 0.003893376922, 0.003865926592,
0.003837478058, 0.003805713742, 0.003775151476, 0.003754308100,
0.003729646784]],
[[0.004673440130, 0.004493758637, 0.004493391422, 0.004493391422,
0.004347639549, 0.004230242084, 0.004122612063, 0.004119172240,
0.004119172240, 0.004081400468, 0.004039467478, 0.004020181967,
0.004020181967, 0.003997875448, 0.003979571429, 0.003979571429,
0.003962694197, 0.003945821225, 0.003945821225, 0.003928035668,
0.003911065314, 0.003911065314, 0.003895839327, 0.003895839327,
0.003894527925, 0.003864900140, 0.003836943182, 0.003805542272,
0.003778488732, 0.003754687793, 0.003728286819]]]

Uncorrected Model Total Resistance at Target Condition

O

> $C_{TM15\_UNCORR} := C_{FM15} + C_{R\_TANK}$

C_{TM15_UNCORR} := [[[0.007681437052, 0.007683764176, 0.008252134758, 0.009029057570, 0.009029057570, 0.008644249638, 0.008644249638, 0.008737930280, 0.008773026179, 0.008773026179, 0.009748889596, 0.01024835862, 0.01142103700, 0.01319827308, 0.01319827308, 0.01358686666, 0.01411356320, 0.01411356320, 0.01425351684, 0.01525944612, 0.01525944612, 0.01570292328, 0.01610076504, 0.01676924417, 0.01722775570, 0.01769711523, 0.01769711523, 0.01901002923, 0.02026738703, 0.02199909817, 0.02397362235, 0.02462617384, 0.02462617384]], [[0.007870028397, 0.007882576052, 0.008128092206, 0.008128092206, 0.008413611160, 0.008586742145, 0.008928233150, 0.008852703774, 0.008597276702, 0.008597276702, 0.008657496549, 0.008828490493, 0.008828490493, 0.009124680099, 0.009799142696, 0.009799142696, 0.009909791337, 0.01070120025, 0.01070120025, 0.01091247460, 0.01112279200, 0.01105060376, 0.01129299121, 0.01129299121, 0.01142886649, 0.01195824159, 0.01249352530, 0.01367537549, 0.01465784528, 0.01595629719, 0.01731475838]], [[0.01022243330, 0.01093910051, 0.01045400248, 0.01045400248, 0.01069564954, 0.01038804101, 0.01034037207, 0.01053322679, 0.01047764604, 0.01063480198, 0.01063480198, 0.01088943655, 0.01085943301, 0.01085943301, 0.01087926735, 0.01072996495, 0.01072996495, 0.01052563486, 0.01046275666, 0.01046275666, 0.01065060176, 0.01065060176, 0.01056948058, 0.01089651905, 0.01140294787, 0.01231262898, 0.01349063619, 0.01521067538, 0.01699830761]], [[0.008711589736, 0.008109618249, 0.008109618249, 0.008765441999, 0.008635055767, 0.008345551442, 0.007888351617, 0.007774248420, 0.007885750513, 0.008004026666, 0.008004026666, 0.008430400829, 0.008811945442, 0.008811945442, 0.009367877534, 0.009611895143, 0.009611895143, 0.009703975228, 0.01013754074, 0.01013754074, 0.01041599682, 0.01041599682, 0.01049056194, 0.01079418932, 0.01157461298, 0.01280532422, 0.01436472952, 0.01546769098, 0.01717480270]], [[0.008597787275, 0.008533846515, 0.008457453750, 0.008457453750, 0.008771644831, 0.008756648742, 0.007915181360, 0.007875776001, 0.007875776001, 0.007809657320, 0.008016091573, 0.008065720974, 0.008065720974, 0.008363486882, 0.008880083451, 0.008880083451, 0.009147224880, 0.009526834934, 0.009526834934, 0.009689331725, 0.01000878313, 0.01000878313, 0.01019470746, 0.01019470746, 0.01035630702, 0.01075407460, 0.01162682547, 0.01267497178, 0.01417608206, 0.01539716536, 0.01683275652]]] **(8.3)**

Corrected Model Total Resistance at Target Condition

> $C_{TM15\_CORR} := C_{FM15} + C_R$

C_{TM15_CORR} := [[[0.007602148696, 0.007589622984, 0.008139113822, 0.008898287649, 0.008898287649, 0.008517631414, 0.008517631414, 0.008609819382, 0.008644056490, 0.008644056490, 0.009586091123, 0.01007255652, 0.01103216920, 0.01280004225, 0.01280004225, 0.01335717119, 0.01388244128, 0.01388244128, **(8.4)**

0.01397267914, 0.01491525283, 0.01491525283, 0.01536096669, 0.01579020468, 0.01641782300, 0.01680015531, 0.01725288299, 0.01725288299, 0.01847725783, 0.01964859319, 0.02119491856, 0.02306546234, 0.02369994371, 0.02369994371]], [[0.007786556845, 0.007790512910, 0.008023767949, 0.008023767949, 0.008306153958, 0.008474129735, 0.008820891153, 0.008780083869, 0.008477848829, 0.008477848829, 0.008532708513, 0.008667982113, 0.008667982113, 0.008870709786, 0.009597458116, 0.009597458116, 0.009682434521, 0.01039720379, 0.01039720379, 0.01071054108, 0.01091786521, 0.01082993489, 0.01107436863, 0.01107436863, 0.01122795125, 0.01170020423, 0.01219054725, 0.01327558626, 0.01419074670, 0.01539155580, 0.01671079928]], [[0.01008350668, 0.01081765394, 0.01035421625, 0.01035421625, 0.01059308281, 0.01028034353, 0.01019602176, 0.01039841423, 0.01034352448, 0.01044378448, 0.01044378448, 0.01073318915, 0.01073512293, 0.01073512293, 0.01075267453, 0.01064536824, 0.01064536824, 0.01042893914, 0.01030271546, 0.01030271546, 0.01045168098, 0.01045168098, 0.01037276252, 0.01068741476, 0.01113103183, 0.01196003970, 0.01297791589, 0.01460126992, 0.01640362062]], [[0.008633387196, 0.008019227986, 0.008019227986, 0.008667618579, 0.008536069655, 0.008273900820, 0.007819312656, 0.007683669082, 0.007783675335, 0.007840498472, 0.007840498472, 0.008235484913, 0.008578418881, 0.008578418881, 0.009127917974, 0.009472422017, 0.009472422017, 0.009516264131, 0.009890058103, 0.009890058103, 0.01020452428, 0.01020452428, 0.01028038886, 0.01056109035, 0.01125155602, 0.01238524230, 0.01388192296, 0.01491615080, 0.01650606273]], [[0.008510674237, 0.008437368253, 0.008361756086, 0.008361756086, 0.008663513642, 0.008683025877, 0.007854211288, 0.007812650870, 0.007812650870, 0.007707022930, 0.007907519888, 0.007947947726, 0.007947947726, 0.008148408396, 0.008672889003, 0.008672889003, 0.008947704987, 0.009331278699, 0.009331278699, 0.009508472316, 0.009787855257, 0.009787855257, 0.009996198684, 0.009996198684, 0.01015542954, 0.01048924314, 0.01131294848, 0.01226071607, 0.01367656799, 0.01488588990, 0.01625455678]]]

▼ Full Scale Transformation to Saltwater Target Condition

Incremental Resistance Coefficient Correlation Allowance

O

$$> C_A := \begin{cases} 0.0004 & L_S < 150 \,[\![m]\!] \\ 0.0002 & 150 \,[\![m]\!] \le L_S < 210 \,[\![m]\!] \\ 0.0001 & 210 \,[\![m]\!] \le L_S < 260 \,[\![m]\!] \\ 0 & 260 \,[\![m]\!] \le L_S < 300 \,[\![m]\!] \\ -0.0001 & 300 \,[\![m]\!] \le L_S < 350 \,[\![m]\!] \\ -0.0002 & 350 \,[\![m]\!] \le L_S \end{cases}$$

$$C_A := \begin{bmatrix} [\,0.0004\,] \\ [\,0.0004\,] \\ [\,0.0004\,] \\ [\,0.0004\,] \\ [\,0.0004\,] \end{bmatrix} \qquad (9.1)$$

Ship Velocity

$$> V_S := V_M \cdot \sqrt{\lambda}$$

$$V_S := [[[2.697918719 \,[\![\tfrac{m}{s}]\!], 3.241125086 \,[\![\tfrac{m}{s}]\!], 3.787747579 \,[\![\tfrac{m}{s}]\!], \qquad (9.2)$$

$$4.314714064 \,[\![\tfrac{m}{s}]\!], 4.314714064 \,[\![\tfrac{m}{s}]\!], 4.316051378 \,[\![\tfrac{m}{s}]\!], 4.316051378 \,[\![\tfrac{m}{s}]\!],$$

$$4.323460972 \,[\![\tfrac{m}{s}]\!], 4.331054936 \,[\![\tfrac{m}{s}]\!], 4.331054936 \,[\![\tfrac{m}{s}]\!], 4.870526353 \,[\![\tfrac{m}{s}]\!],$$

$$5.128870846 \,[\![\tfrac{m}{s}]\!], 5.413677039 \,[\![\tfrac{m}{s}]\!], 5.602135890 \,[\![\tfrac{m}{s}]\!], 5.602135890 \,[\![\tfrac{m}{s}]\!],$$

$$5.776367426 \,[\![\tfrac{m}{s}]\!], 5.792889473 \,[\![\tfrac{m}{s}]\!], 5.792889473 \,[\![\tfrac{m}{s}]\!], 5.954227540 \,[\![\tfrac{m}{s}]\!],$$

$$6.214915046 \,[\![\tfrac{m}{s}]\!], 6.214915046 \,[\![\tfrac{m}{s}]\!], 6.230246339 \,[\![\tfrac{m}{s}]\!], 6.503242956 \,[\![\tfrac{m}{s}]\!],$$

$$6.760981716 \,[\![\tfrac{m}{s}]\!], 7.011692095 \,[\![\tfrac{m}{s}]\!], 7.025641069 \,[\![\tfrac{m}{s}]\!], 7.025641069 \,[\![\tfrac{m}{s}]\!],$$

$$7.315380061 \,[\![\tfrac{m}{s}]\!], 7.588269943 \,[\![\tfrac{m}{s}]\!], 7.832232077 \,[\![\tfrac{m}{s}]\!], 8.089476886 \,[\![\tfrac{m}{s}]\!],$$

$$8.125192936 \,[\![\tfrac{m}{s}]\!], 8.125192936 \,[\![\tfrac{m}{s}]\!]]],$$

$$[[2.697370225 \,[\![\tfrac{m}{s}]\!], 3.244251700 \,[\![\tfrac{m}{s}]\!], 3.791442044 \,[\![\tfrac{m}{s}]\!],$$

$$3.791442044 \,[\![\tfrac{m}{s}]\!], 3.794266796 \,[\![\tfrac{m}{s}]\!], 4.319691024 \,[\![\tfrac{m}{s}]\!], 4.900178909 \,[\![\tfrac{m}{s}]\!],$$

O

$5.144975123 \left[\left[\frac{m}{s}\right]\right], 5.417994552 \left[\left[\frac{m}{s}\right]\right], 5.417994552 \left[\left[\frac{m}{s}\right]\right], 5.425486727 \left[\left[\frac{m}{s}\right]\right],$

$5.563869733 \left[\left[\frac{m}{s}\right]\right], 5.563869733 \left[\left[\frac{m}{s}\right]\right], 5.680182818 \left[\left[\frac{m}{s}\right]\right], 5.816336639 \left[\left[\frac{m}{s}\right]\right],$

$5.816336639 \left[\left[\frac{m}{s}\right]\right], 5.959284217 \left[\left[\frac{m}{s}\right]\right], 6.099442683 \left[\left[\frac{m}{s}\right]\right], 6.099442683 \left[\left[\frac{m}{s}\right]\right],$

$6.247394127 \left[\left[\frac{m}{s}\right]\right], 6.247394127 \left[\left[\frac{m}{s}\right]\right], 6.267755871 \left[\left[\frac{m}{s}\right]\right], 6.372781849 \left[\left[\frac{m}{s}\right]\right],$

$6.372781849 \left[\left[\frac{m}{s}\right]\right], 6.505820709 \left[\left[\frac{m}{s}\right]\right], 6.764151209 \left[\left[\frac{m}{s}\right]\right], 7.021373330 \left[\left[\frac{m}{s}\right]\right],$

$7.341093619 \left[\left[\frac{m}{s}\right]\right], 7.592793471 \left[\left[\frac{m}{s}\right]\right], 7.837946942 \left[\left[\frac{m}{s}\right]\right], 8.086027523 \left[\left[\frac{m}{s}\right]\right]\Big]\Big],$

$\Big[\Big[2.704823156 \left[\left[\frac{m}{s}\right]\right], 3.248868515 \left[\left[\frac{m}{s}\right]\right], 3.785868436 \left[\left[\frac{m}{s}\right]\right],$

$3.785868436 \left[\left[\frac{m}{s}\right]\right], 3.787708526 \left[\left[\frac{m}{s}\right]\right], 4.331993956 \left[\left[\frac{m}{s}\right]\right], 4.919198213 \left[\left[\frac{m}{s}\right]\right],$

$5.116846546 \left[\left[\frac{m}{s}\right]\right], 5.416418332 \left[\left[\frac{m}{s}\right]\right], 5.557300827 \left[\left[\frac{m}{s}\right]\right], 5.557300827 \left[\left[\frac{m}{s}\right]\right],$

$5.693241484 \left[\left[\frac{m}{s}\right]\right], 5.814486352 \left[\left[\frac{m}{s}\right]\right], 5.814486352 \left[\left[\frac{m}{s}\right]\right], 5.958796912 \left[\left[\frac{m}{s}\right]\right],$

$6.095572180 \left[\left[\frac{m}{s}\right]\right], 6.095572180 \left[\left[\frac{m}{s}\right]\right], 6.237551279 \left[\left[\frac{m}{s}\right]\right], 6.369375924 \left[\left[\frac{m}{s}\right]\right],$

$6.369375924 \left[\left[\frac{m}{s}\right]\right], 6.499001216 \left[\left[\frac{m}{s}\right]\right], 6.499001216 \left[\left[\frac{m}{s}\right]\right], 6.503759184 \left[\left[\frac{m}{s}\right]\right],$

$6.751251613 \left[\left[\frac{m}{s}\right]\right], 7.007942070 \left[\left[\frac{m}{s}\right]\right], 7.321294042 \left[\left[\frac{m}{s}\right]\right], 7.589825842 \left[\left[\frac{m}{s}\right]\right],$

$7.837723111 \left[\left[\frac{m}{s}\right]\right], 8.146650210 \left[\left[\frac{m}{s}\right]\right]\Big]\Big],$

$\Big[\Big[2.688795080 \left[\left[\frac{m}{s}\right]\right], 3.238881556 \left[\left[\frac{m}{s}\right]\right], 3.238881556 \left[\left[\frac{m}{s}\right]\right],$

$3.242401271 \left[\left[\frac{m}{s}\right]\right], 3.789805943 \left[\left[\frac{m}{s}\right]\right], 4.336705108 \left[\left[\frac{m}{s}\right]\right], 4.908054737 \left[\left[\frac{m}{s}\right]\right],$

$5.141729158 \left[\left[\frac{m}{s}\right]\right], 5.411054323 \left[\left[\frac{m}{s}\right]\right], 5.556082189 \left[\left[\frac{m}{s}\right]\right], 5.556082189 \left[\left[\frac{m}{s}\right]\right],$

$5.693594022 \left[\left[\frac{m}{s}\right]\right], 5.833212060 \left[\left[\frac{m}{s}\right]\right], 5.833212060 \left[\left[\frac{m}{s}\right]\right], 5.958262812 \left[\left[\frac{m}{s}\right]\right],$

$6.100235373 \left[\left[\frac{m}{s}\right]\right], 6.100235373 \left[\left[\frac{m}{s}\right]\right], 6.230634796 \left[\left[\frac{m}{s}\right]\right], 6.384414857 \left[\left[\frac{m}{s}\right]\right],$

$6.384414857 \left[\left[\frac{m}{s}\right]\right], 6.508797770 \left[\left[\frac{m}{s}\right]\right], 6.508797770 \left[\left[\frac{m}{s}\right]\right], 6.516297772 \left[\left[\frac{m}{s}\right]\right],$

$6.753915956 \left[\left[\frac{m}{s}\right]\right], 7.012159837 \left[\left[\frac{m}{s}\right]\right], 7.315816769 \left[\left[\frac{m}{s}\right]\right], 7.624230286 \left[\left[\frac{m}{s}\right]\right],$

$7.844256432 \left[\left[\frac{m}{s}\right]\right], 8.115296019 \left[\left[\frac{m}{s}\right]\right]\Big]\Big],$

e

$$\left[\left[2.697707615\left[\!\left[\frac{m}{s}\right]\!\right], 3.238168649\left[\!\left[\frac{m}{s}\right]\!\right], 3.239413536\left[\!\left[\frac{m}{s}\right]\!\right],\right.\right.$$
$$3.239413536\left[\!\left[\frac{m}{s}\right]\!\right], 3.787769136\left[\!\left[\frac{m}{s}\right]\!\right], 4.321371371\left[\!\left[\frac{m}{s}\right]\!\right], 4.900400106\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$4.920532140\left[\!\left[\frac{m}{s}\right]\!\right], 4.920532140\left[\!\left[\frac{m}{s}\right]\!\right], 5.148864341\left[\!\left[\frac{m}{s}\right]\!\right], 5.418809541\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$5.549154848\left[\!\left[\frac{m}{s}\right]\!\right], 5.549154848\left[\!\left[\frac{m}{s}\right]\!\right], 5.705055796\left[\!\left[\frac{m}{s}\right]\!\right], 5.837263705\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$5.837263705\left[\!\left[\frac{m}{s}\right]\!\right], 5.962716993\left[\!\left[\frac{m}{s}\right]\!\right], 6.091663643\left[\!\left[\frac{m}{s}\right]\!\right], 6.091663643\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$6.231533347\left[\!\left[\frac{m}{s}\right]\!\right], 6.368903528\left[\!\left[\frac{m}{s}\right]\!\right], 6.368903528\left[\!\left[\frac{m}{s}\right]\!\right], 6.495515771\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$6.495515771\left[\!\left[\frac{m}{s}\right]\!\right], 6.506572898\left[\!\left[\frac{m}{s}\right]\!\right], 6.763017375\left[\!\left[\frac{m}{s}\right]\!\right], 7.017136669\left[\!\left[\frac{m}{s}\right]\!\right],$$
$$\left.\left.7.317501701\left[\!\left[\frac{m}{s}\right]\!\right], 7.589745427\left[\!\left[\frac{m}{s}\right]\!\right], 7.840175501\left[\!\left[\frac{m}{s}\right]\!\right], 8.130591910\left[\!\left[\frac{m}{s}\right]\!\right]\right]\right]$$

Ship Reynold's Number

$$> Rn_S := \frac{V_S \cdot L_S}{\nu_S}$$

$Rn_S := [[[7.620941048\ 10^7, 9.155362255\ 10^7, 1.069943316\ 10^8, 1.218798079\ 10^8,$ **(9.3)**
$1.218798079\ 10^8, 1.219175837\ 10^8, 1.219175837\ 10^8, 1.22126886\ 10^8,$
$1.223413964\ 10^8, 1.223413964\ 10^8, 1.375801056\ 10^8, 1.44877687\ 10^8,$
$1.529227448\ 10^8, 1.582462327\ 10^8, 1.582462327\ 10^8, 1.631678349\ 10^8,$
$1.636345412\ 10^8, 1.636345412\ 10^8, 1.681919353\ 10^8, 1.75555701\ 10^8, 1.75555701\ 10^8,$
$1.759887714\ 10^8, 1.837002384\ 10^8, 1.909807094\ 10^8, 1.980626463\ 10^8,$
$1.984566697\ 10^8, 1.984566697\ 10^8, 2.066410667\ 10^8, 2.143495187\ 10^8,$
$2.212408347\ 10^8, 2.285073528\ 10^8, 2.295162413\ 10^8, 2.295162413\ 10^8]],$
$[[7.636055204\ 10^7, 9.184236127\ 10^7, 1.073329144\ 10^8, 1.073329144\ 10^8,$
$1.074128811\ 10^8, 1.222872515\ 10^8, 1.387204334\ 10^8, 1.456504328\ 10^8,$
$1.533794105\ 10^8, 1.533794105\ 10^8, 1.535915084\ 10^8, 1.575090288\ 10^8,$
$1.575090288\ 10^8, 1.60801766\ 10^8, 1.646561798\ 10^8, 1.646561798\ 10^8,$
$1.687029198\ 10^8, 1.72670702\ 10^8, 1.72670702\ 10^8, 1.768590978\ 10^8, 1.768590978\ 10^8,$
$1.774355236\ 10^8, 1.804087313\ 10^8, 1.804087313\ 10^8, 1.841749628\ 10^8,$
$1.914881078\ 10^8, 1.987698754\ 10^8, 2.078209199\ 10^8, 2.149463561\ 10^8,$
$2.218864692\ 10^8, 2.289094466\ 10^8]],$
$[[7.657153899\ 10^7, 9.197305992\ 10^7, 1.071751297\ 10^8, 1.071751297\ 10^8,$
$1.072272213\ 10^8, 1.226355384\ 10^8, 1.392588558\ 10^8, 1.448541336\ 10^8,$
$1.533347888\ 10^8, 1.573230679\ 10^8, 1.573230679\ 10^8, 1.611714471\ 10^8,$
$1.646037995\ 10^8, 1.646037995\ 10^8, 1.686891245\ 10^8, 1.72561131\ 10^8, 1.72561131\ 10^8,$

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$1.765804541\ 10^8$, $1.80312312\ 10^8$, $1.80312312\ 10^8$, $1.83981908\ 10^8$, $1.83981908\ 10^8$,
$1.841166026\ 10^8$, $1.911229298\ 10^8$, $1.983896464\ 10^8$, $2.072604085\ 10^8$,
$2.148623447\ 10^8$, $2.218801327\ 10^8$, $2.306256299\ 10^8$]],
[[$7.611779604\ 10^7$, $9.169033648\ 10^7$, $9.169033648\ 10^7$, $9.178997703\ 10^7$,
$1.072865976\ 10^8$, $1.227689076\ 10^8$, $1.389433922\ 10^8$, $1.455585419\ 10^8$,
$1.531829378\ 10^8$, $1.572885691\ 10^8$, $1.572885691\ 10^8$, $1.611814272\ 10^8$,
$1.651339104\ 10^8$, $1.651339104\ 10^8$, $1.686740045\ 10^8$, $1.726931425\ 10^8$,
$1.726931425\ 10^8$, $1.763846535\ 10^8$, $1.807380531\ 10^8$, $1.807380531\ 10^8$,
$1.842592412\ 10^8$, $1.842592412\ 10^8$, $1.844715607\ 10^8$, $1.911983554\ 10^8$,
$1.985090483\ 10^8$, $2.07105351\ 10^8$, $2.158363091\ 10^8$, $2.220650862\ 10^8$,
$2.297380161\ 10^8$]],
[[$7.637010330\ 10^7$, $9.167015461\ 10^7$, $9.170539647\ 10^7$, $9.170539647\ 10^7$,
$1.072289371\ 10^8$, $1.22334821\ 10^8$, $1.387266953\ 10^8$, $1.392966182\ 10^8$,
$1.392966182\ 10^8$, $1.457605336\ 10^8$, $1.534024822\ 10^8$, $1.570924612\ 10^8$,
$1.570924612\ 10^8$, $1.615059015\ 10^8$, $1.652486094\ 10^8$, $1.652486094\ 10^8$,
$1.688000991\ 10^8$, $1.724504832\ 10^8$, $1.724504832\ 10^8$, $1.764100909\ 10^8$,
$1.802989389\ 10^8$, $1.802989389\ 10^8$, $1.838832376\ 10^8$, $1.838832376\ 10^8$,
$1.841962567\ 10^8$, $1.914560098\ 10^8$, $1.986499387\ 10^8$, $2.071530502\ 10^8$,
$2.148600682\ 10^8$, $2.219495581\ 10^8$, $2.301710313\ 10^8$]]]

Ship Frictional Resistance Coefficient

$$> C_{FS} := \frac{0.075}{\left(\log 10(Rn_S) - 2\right)^2}$$

C_{FS} := [[[0.002167753784, 0.002110204730, 0.002063092602, 0.002024916440, **(9.4)**
0.002024916440, 0.002024826884, 0.002024826884, 0.002024331296,
0.002023824446, 0.002023824446, 0.001990347329, 0.001975871212,
0.001960902482, 0.001951512240, 0.001951512240, 0.001943164860,
0.001942389137, 0.001942389137, 0.001934952072, 0.001923436067,
0.001923436067, 0.001922777050, 0.001911360256, 0.001901100729,
0.001891564301, 0.001891045843, 0.001891045843, 0.001880549447,
0.001871112190, 0.001863015430, 0.001854800688, 0.001853685059,
0.001853685059]],
[[0.002167119697, 0.002109236972, 0.002062153892, 0.002062153892,
0.002061932712, 0.002023952278, 0.001988024714, 0.001974390206,
0.001960081545, 0.001960081545, 0.001959701267, 0.001952789624,
0.001952789624, 0.001947139288, 0.001940700350, 0.001940700350,
0.001934133428, 0.001927877013, 0.001927877013, 0.001921458553,
0.001921458553, 0.001920589608, 0.001916161126, 0.001916161126,
0.001910676419, 0.001900403372, 0.001890634610, 0.001879077710,

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0.001870398617, 0.001862272468, 0.001854355342]],
[[0.002166237099, 0.002108800130, 0.002062590896, 0.002062590896,
0.002062446535, 0.002023131189, 0.001986936087, 0.001975916504,
0.001960161630, 0.001953112989, 0.001953112989, 0.001946513666,
0.001940786627, 0.001940786627, 0.001934155490, 0.001928047443,
0.001928047443, 0.001921879828, 0.001916303352, 0.001916303352,
0.001910954257, 0.001910954257, 0.001910760373, 0.001900905039,
0.001891133945, 0.001879775626, 0.001870498916, 0.001862279746,
0.001852465098]],
[[0.002168138882, 0.002109746046, 0.002109746046, 0.002109412271,
0.002062282090, 0.002022817520, 0.001987573298, 0.001974565820,
0.001960434376, 0.001953173030, 0.001953173030, 0.001946496800,
0.001939914996, 0.001939914996, 0.001934179672, 0.001927842125,
0.001927842125, 0.001922176335, 0.001915676043, 0.001915676043,
0.001910555240, 0.001910555240, 0.001910250253, 0.001900801328,
0.001890977016, 0.001879969097, 0.001869339022, 0.001862067384,
0.001853440613]],
[[0.002167079678, 0.002109813705, 0.002109695570, 0.002109695570,
0.002062441782, 0.002023839965, 0.001988012024, 0.001986859928,
0.001986859928, 0.001974179967, 0.001960040148, 0.001953514632,
0.001953514632, 0.001945949152, 0.001939726849, 0.001939726849,
0.001933978078, 0.001928219680, 0.001928219680, 0.001922137792,
0.001916323085, 0.001916323085, 0.001911096394, 0.001911096394,
0.001910645796, 0.001900447420, 0.001890791992, 0.001879909563,
0.001870501634, 0.001862200008, 0.001852964150]]]

Ship Total Resistance Coefficient

> $C_{TS} := C_{FS} + C_R + C_A$

C_{TS} := [[[0.005494327251, 0.005604853508, 0.006252574756, 0.007089708403, **(9.5)**
0.007089708403, 0.006709233334, 0.006709233334, 0.006802423711,
0.006837685755, 0.006837685755, 0.007846849818, 0.008361998487,
0.009351052524, 0.01113728198, 0.01113728198, 0.01171065580, 0.01223743205,
0.01223743205, 0.01234207985, 0.01330685967, 0.01330685967, 0.01375384037,
0.01420495759, 0.01485212868, 0.01525254358, 0.01570625180, 0.01570625180,
0.01695042183, 0.01813946353, 0.01970091132, 0.02158673299, 0.02222328418,
0.02222328418]],
[[0.005680109672, 0.005807783842, 0.006139163368, 0.006139163368,
0.006422005050, 0.006667500523, 0.007086265909, 0.007072448635,
0.006798340417, 0.006798340417, 0.006853944862, 0.007002729868,
0.007002729868, 0.007216468293, 0.007955725822, 0.007955725822,
0.008053418101, 0.008780262623, 0.008780262623, 0.009105948046,
0.009313272176, 0.009227010473, 0.009479936654, 0.009479936654,
0.009644010624, 0.01013583521, 0.01064469362, 0.01175151724, 0.01268295235,

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0.01389893302, 0.01523289631]],
[[0.007978971697, 0.008835845589, 0.008468711205, 0.008468711205,
0.008707875243, 0.008475374253, 0.008463558255, 0.008687766783,
0.008663859203, 0.008777901143, 0.008777901143, 0.009080164869,
0.009093223289, 0.009093223289, 0.009123615462, 0.009028098643,
0.009028098643, 0.008823536872, 0.008708011039, 0.008708011039,
0.008867209599, 0.008867209599, 0.008788661531, 0.009122092389,
0.009584234034, 0.01043465881, 0.01146993388, 0.01310863358, 0.01492922310]],
[[0.006524730911, 0.006035425708, 0.006035425708, 0.006684519982,
0.006651200933, 0.006469565488, 0.006085583958, 0.005975687381,
0.006103475786, 0.006174497950, 0.006174497950, 0.006582493441,
0.006938209537, 0.006938209537, 0.007498812153, 0.007855548079,
0.007855548079, 0.007910292200, 0.008296555194, 0.008296555194,
0.008620815114, 0.008620815114, 0.008697262191, 0.008995965085,
0.009705054974, 0.01085949766, 0.01237611050, 0.01342391008, 0.01502985656]],
[[0.006404313785, 0.006453423321, 0.006378060234, 0.006378060234,
0.006778315875, 0.006876623758, 0.006119611249, 0.006080338558,
0.006080338558, 0.005999802429, 0.006228092558, 0.006281280391,
0.006281280391, 0.006496482100, 0.007033044423, 0.007033044423,
0.007318988868, 0.007713677154, 0.007713677154, 0.007902574440,
0.008193113028, 0.008193113028, 0.008411455751, 0.008411455751,
0.008571547411, 0.008924790420, 0.009766797290, 0.01073508336, 0.01216858089,
0.01339340212, 0.01477923411]]]

Ship Total Resistance

> $R_{TS} := C_{TS} \cdot 0.5 \cdot \rho_S \cdot V_S^2 \cdot S_S$

> $occPlot([V_S, [\![knot]\!]], [R_{TS}, [\![kN]\!]], 'curve' = \text{"spline"})$

R_{TS} := [[[6709.499923 ⟦N⟧, 9878.107695 ⟦N⟧, 15050.08170 ⟦N⟧, 22143.70668 ⟦N⟧,
22143.70668 ⟦N⟧, 20968.33826 ⟦N⟧, 20968.33826 ⟦N⟧, 21332.64332 ⟦N⟧,
21518.62062 ⟦N⟧, 21518.62062 ⟦N⟧, 31229.50079 ⟦N⟧, 36903.83641 ⟦N⟧,
45979.37778 ⟦N⟧, 58641.40946 ⟦N⟧, 58641.40946 ⟦N⟧, 65555.44096 ⟦N⟧,
68896.74180 ⟦N⟧, 68896.74180 ⟦N⟧, 73410.31918 ⟦N⟧, 86231.09007 ⟦N⟧,
86231.09007 ⟦N⟧, 89567.88577 ⟦N⟧, 1.007900837 10^5 ⟦N⟧, 1.139006316 10^5 ⟦N⟧,
1.258073035 10^5 ⟦N⟧, 1.300655791 10^5 ⟦N⟧, 1.300655791 10^5 ⟦N⟧,
1.521851250 10^5 ⟦N⟧, 1.752378390 10^5 ⟦N⟧, 2.027567482 10^5 ⟦N⟧,
2.369985576 10^5 ⟦N⟧, 2.461464126 10^5 ⟦N⟧, 2.461464126 10^5 ⟦N⟧]],
[[8005.463444 ⟦N⟧, 11840.99410 ⟦N⟧, 17094.90426 ⟦N⟧, 17094.90426 ⟦N⟧,
17909.15159 ⟦N⟧, 24100.00127 ⟦N⟧, 32960.20905 ⟦N⟧, 36264.77603 ⟦N⟧,
38657.04694 ⟦N⟧, 38657.04694 ⟦N⟧, 39081.08895 ⟦N⟧, 41992.32486 ⟦N⟧,
41992.32486 ⟦N⟧, 45102.22576 ⟦N⟧, 52134.77653 ⟦N⟧, 52134.77653 ⟦N⟧,

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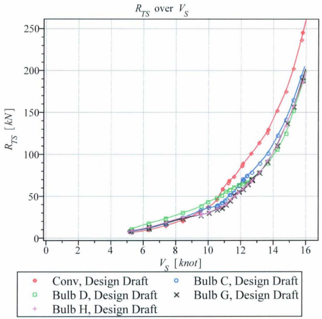
55400.93357 ⟦N⟧, 63275.62655 ⟦N⟧, 63275.62655 ⟦N⟧, 68844.87526 ⟦N⟧, 70412.33464 ⟦N⟧, 70215.63010 ⟦N⟧, 74578.24835 ⟦N⟧, 74578.24835 ⟦N⟧, 79069.77456 ⟦N⟧, 89832.77077 ⟦N⟧, 1.016543425 10^5 ⟦N⟧, 1.226772709 10^5 ⟦N⟧, 1.416355175 10^5 ⟦N⟧, 1.653997085 10^5 ⟦N⟧, 1.929307957 10^5 ⟦N⟧]],
[[11044.75260 ⟦N⟧, 17645.89557 ⟦N⟧, 22965.69931 ⟦N⟧, 22965.69931 ⟦N⟧, 23637.23200 ⟦N⟧, 30093.02770 ⟦N⟧, 38750.11082 ⟦N⟧, 43037.22453 ⟦N⟧, 48091.36466 ⟦N⟧, 51292.02143 ⟦N⟧, 51292.02143 ⟦N⟧, 55685.77406 ⟦N⟧, 58166.35944 ⟦N⟧, 58166.35944 ⟦N⟧, 61293.64617 ⟦N⟧, 63468.25655 ⟦N⟧, 63468.25655 ⟦N⟧, 64953.45833 ⟦N⟧, 66841.17122 ⟦N⟧, 66841.17122 ⟦N⟧, 70861.69350 ⟦N⟧, 70861.69350 ⟦N⟧, 70336.85732 ⟦N⟧, 78667.32285 ⟦N⟧, 89057.34276 ⟦N⟧, 1.058242669 10^5 ⟦N⟧, 1.250131942 10^5 ⟦N⟧, 1.523591615 10^5 ⟦N⟧, 1.874677917 10^5 ⟦N⟧]],
[[9005.204676 ⟦N⟧, 12086.86341 ⟦N⟧, 12086.86341 ⟦N⟧, 13415.88481 ⟦N⟧, 18236.83994 ⟦N⟧, 23227.92792 ⟦N⟧, 27985.72915 ⟦N⟧, 30159.34012 ⟦N⟧, 34115.88071 ⟦N⟧, 36387.69509 ⟦N⟧, 36387.69509 ⟦N⟧, 40736.05812 ⟦N⟧, 45069.06151 ⟦N⟧, 45069.06151 ⟦N⟧, 50821.48593 ⟦N⟧, 55806.55948 ⟦N⟧, 55806.55948 ⟦N⟧, 58623.62799 ⟦N⟧, 64558.81929 ⟦N⟧, 64558.81929 ⟦N⟧, 69721.29746 ⟦N⟧, 69721.29746 ⟦N⟧, 70501.76335 ⟦N⟧, 78338.38943 ⟦N⟧, 91099.75038 ⟦N⟧, 1.109560400 10^5 ⟦N⟧, 1.373383301 10^5 ⟦N⟧, 1.576878285 10^5 ⟦N⟧, 1.889640294 10^5 ⟦N⟧]],
[[8922.886547 ⟦N⟧, 12954.84123 ⟦N⟧, 12813.40091 ⟦N⟧, 12813.40091 ⟦N⟧, 18617.94824 ⟦N⟧, 24584.50438 ⟦N⟧, 28133.89929 ⟦N⟧, 28183.49969 ⟦N⟧, 28183.49969 ⟦N⟧, 30451.09129 ⟦N⟧, 35011.10717 ⟦N⟧, 37029.24706 ⟦N⟧, 37029.24706 ⟦N⟧, 40480.05108 ⟦N⟧, 45878.05531 ⟦N⟧, 45878.05531 ⟦N⟧, 49817.56472 ⟦N⟧, 54799.46288 ⟦N⟧, 54799.46288 ⟦N⟧, 58749.13213 ⟦N⟧, 63624.04847 ⟦N⟧, 63624.04847 ⟦N⟧, 67942.49027 ⟦N⟧, 67942.49027 ⟦N⟧, 69471.52695 ⟦N⟧, 78148.75181 ⟦N⟧, 92069.34583 ⟦N⟧, 1.100459587 10^5 ⟦N⟧, 1.341953183 10^5 ⟦N⟧, 1.576106246 10^5 ⟦N⟧, 1.870420565 10^5 ⟦N⟧]]]

Oc



Ship Effective Power

> $P_{ES} := R_{TS} \cdot V_S$

> $occPlot([V_S, [\![knot]\!]], [P_{ES}, [\![kW]\!]], 'curve' = "spline")$

P_{ES} := [[[18101.68544 [[W]], 32016.18265 [[W]], 57005.91052 [[W]], 95543.76264 [[W]], 95543.76264 [[W]], 90500.42524 [[W]], 90500.42524 [[W]], 92230.85082 [[W]], 93198.32805 [[W]], 93198.32805 [[W]], 1.521041066 10^5 [[W]], 1.892750107 10^5 [[W]], 2.489175018 10^5 [[W]], 3.285171446 10^5 [[W]], 3.285171446 10^5 [[W]], 3.786723138 10^5 [[W]], 3.991112103 10^5 [[W]], 3.991112103 10^5 [[W]], 4.371017442 10^5 [[W]], 5.359188991 10^5 [[W]], 5.359188991 10^5 [[W]], 5.580299924 10^5 [[W]], 6.554624019 10^5 [[W]], 7.700800877 10^5 [[W]], 8.821220754 10^5 [[W]], 9.137940742 10^5 [[W]], 9.137940742 10^5 [[W]], 1.113292029 10^6 [[W]], 1.329752027 10^6 [[W]], 1.588037907 10^6 [[W]], 1.917194354 10^6 [[W]], 1.999987093 10^6 [[W]], 1.999987093 10^6 [[W]]], [[21593.69873 [[W]], 38415.16524 [[W]], 64814.33875 [[W]], 64814.33875 [[W]], 67952.09922 [[W]], 1.041045592 10^5 [[W]], 1.615109212 10^5 [[W]],

O

$1.865813705\ 10^5$ ⟦W⟧, $2.094436697\ 10^5$ ⟦W⟧, $2.094436697\ 10^5$ ⟦W⟧,
$2.120339294\ 10^5$ ⟦W⟧, $2.336398253\ 10^5$ ⟦W⟧, $2.336398253\ 10^5$ ⟦W⟧,
$2.561888878\ 10^5$ ⟦W⟧, $3.032334109\ 10^5$ ⟦W⟧, $3.032334109\ 10^5$ ⟦W⟧,
$3.301499090\ 10^5$ ⟦W⟧, $3.859460574\ 10^5$ ⟦W⟧, $3.859460574\ 10^5$ ⟦W⟧,
$4.301010694\ 10^5$ ⟦W⟧, $4.398936059\ 10^5$ ⟦W⟧, $4.400944278\ 10^5$ ⟦W⟧,
$4.752709074\ 10^5$ ⟦W⟧, $4.752709074\ 10^5$ ⟦W⟧, $5.144137768\ 10^5$ ⟦W⟧,
$6.076424450\ 10^5$ ⟦W⟧, $7.137530893\ 10^5$ ⟦W⟧, $9.005853306\ 10^5$ ⟦W⟧,
$1.075409233\ 10^6$ ⟦W⟧, $1.296394139\ 10^6$ ⟦W⟧, $1.560043724\ 10^6$ ⟦W⟧]],
[[29874.10258 ⟦W⟧, 57329.19454 ⟦W⟧, 86945.11613 ⟦W⟧, 86945.11613 ⟦W⟧,
89530.94518 ⟦W⟧, $1.303628141\ 10^5$ ⟦W⟧, $1.906194759\ 10^5$ ⟦W⟧,
$2.202148737\ 10^5$ ⟦W⟧, $2.604829492\ 10^5$ ⟦W⟧, $2.850451931\ 10^5$ ⟦W⟧,
$2.850451931\ 10^5$ ⟦W⟧, $3.170325589\ 10^5$ ⟦W⟧, $3.382075031\ 10^5$ ⟦W⟧,
$3.382075031\ 10^5$ ⟦W⟧, $3.652363895\ 10^5$ ⟦W⟧, $3.868753389\ 10^5$ ⟦W⟧,
$3.868753389\ 10^5$ ⟦W⟧, $4.051505271\ 10^5$ ⟦W⟧, $4.257365467\ 10^5$ ⟦W⟧,
$4.257365467\ 10^5$ ⟦W⟧, $4.605302322\ 10^5$ ⟦W⟧, $4.605302322\ 10^5$ ⟦W⟧,
$4.574539818\ 10^5$ ⟦W⟧, $5.311028903\ 10^5$ ⟦W⟧, $6.241086990\ 10^5$ ⟦W⟧,
$7.747705748\ 10^5$ ⟦W⟧, $9.488283719\ 10^5$ ⟦W⟧, $1.194148921\ 10^6$ ⟦W⟧,
$1.527234525\ 10^6$ ⟦W⟧]],
[[24213.15003 ⟦W⟧, 39147.91897 ⟦W⟧, 39147.91897 ⟦W⟧, 43499.68196 ⟦W⟧,
69114.08439 ⟦W⟧, $1.007326737\ 10^5$ ⟦W⟧, $1.373554905\ 10^5$ ⟦W⟧,
$1.550711585\ 10^5$ ⟦W⟧, $1.846028838\ 10^5$ ⟦W⟧, $2.021730246\ 10^5$ ⟦W⟧,
$2.021730246\ 10^5$ ⟦W⟧, $2.319345770\ 10^5$ ⟦W⟧, $2.628973931\ 10^5$ ⟦W⟧,
$2.628973931\ 10^5$ ⟦W⟧, $3.028077697\ 10^5$ ⟦W⟧, $3.404331482\ 10^5$ ⟦W⟧,
$3.404331482\ 10^5$ ⟦W⟧, $3.652624164\ 10^5$ ⟦W⟧, $4.121702850\ 10^5$ ⟦W⟧,
$4.121702850\ 10^5$ ⟦W⟧, $4.538018254\ 10^5$ ⟦W⟧, $4.538018254\ 10^5$ ⟦W⟧,
$4.594104834\ 10^5$ ⟦W⟧, $5.290908983\ 10^5$ ⟦W⟧, $6.388060108\ 10^5$ ⟦W⟧,
$8.117340581\ 10^5$ ⟦W⟧, $1.047099056\ 10^6$ ⟦W⟧, $1.236943763\ 10^6$ ⟦W⟧,
$1.533499036\ 10^6$ ⟦W⟧]],
[[24071.33899 ⟦W⟧, 41949.96072 ⟦W⟧, 41507.90435 ⟦W⟧, 41507.90435 ⟦W⟧,
70520.48972 ⟦W⟧, $1.062387734\ 10^5$ ⟦W⟧, $1.378673631\ 10^5$ ⟦W⟧,
$1.386778160\ 10^5$ ⟦W⟧, $1.386778160\ 10^5$ ⟦W⟧, $1.567885381\ 10^5$ ⟦W⟧,
$1.897185216\ 10^5$ ⟦W⟧, $2.054810258\ 10^5$ ⟦W⟧, $2.054810258\ 10^5$ ⟦W⟧,
$2.309409500\ 10^5$ ⟦W⟧, $2.678023071\ 10^5$ ⟦W⟧, $2.678023071\ 10^5$ ⟦W⟧,
$2.970480397\ 10^5$ ⟦W⟧, $3.338198957\ 10^5$ ⟦W⟧, $3.338198957\ 10^5$ ⟦W⟧,
$3.660971760\ 10^5$ ⟦W⟧, $4.052154268\ 10^5$ ⟦W⟧, $4.052154268\ 10^5$ ⟦W⟧,
$4.413215171\ 10^5$ ⟦W⟧, $4.413215171\ 10^5$ ⟦W⟧, $4.520215544\ 10^5$ ⟦W⟧,

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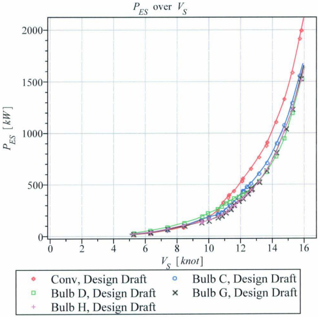
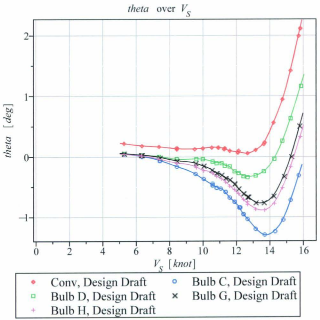
$5.285213663\ 10^5\ [\![W]\!],\ 6.460631827\ 10^5\ [\![W]\!],\ 8.052614900\ 10^5\ [\![W]\!],$
$1.018508303\ 10^6\ [\![W]\!],\ 1.235694958\ 10^6\ [\![W]\!],\ 1.520762631\ 10^6\ [\![W]\!]]]$

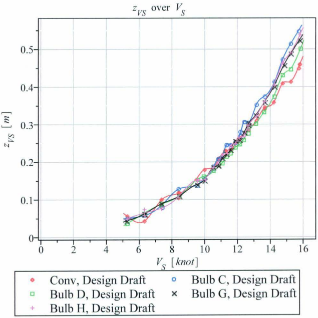


> $occPlot([V_S, [\![knot]\!]], [\theta, [\![deg]\!]], 'curve' = \text{"spline"})$



> $occPlot([V_S, [\![knot]\!]], [z_{VS}\ [\![m]\!]], 'curve' = \text{"spline"})$

O



Export Results

Export to Excel File

> $dataOut := occDataExport('filename' = outputFile, 'tab' = projectTab, 'outData'$
> $= [["TEST,COND"], ["V,S", "knot"], ["R,TS", "kN"], ["P,ES", "kW"], ["z,VS", "m"], ["theta", "deg"], ["Fr"], ["C,TS"], ["C,TM15\_CORR"], ["C,R"], ["C,A"], ["C,FS"], ["C,FM15"], ["zvLm"]], 'sigDigits' = 4)$

Export Curves for Resistance in Waves Analysis

Select Polynomial Curve Order and Check Fit

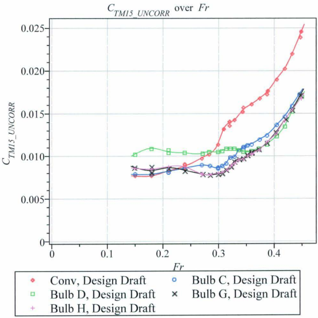
$polyOrder :=$ "spline" :

> $occPlot\ Fr, C_{TM15\_UNCORR}, 'curve' = polyOrder, 'assignCurve'$
> = "C,TM15_CALM_CURVE"

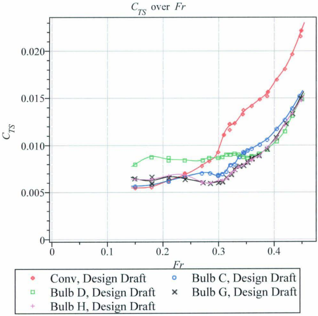
$occPlot\ Fr, C_{TS}, 'curve' = polyOrder, 'assignCurve' =$ "C,TS_CALM_CURVE"

> (   )

o


C_{TM15_UNCORR} over Fr
0.025
0.020
0.015
0.010
0.005
0
C_{TM15_UNCORR}
0
0.1
0.2
0.3
0.4
Fr
Conv, Design Draft
Bulb C, Design Draft
Bulb D, Design Draft
Bulb G, Design Draft
Bulb H, Design Draft

o



Rename TEST,DRAFT(_CALM) for Output

> $TEST_{COND\_CALM} := TEST_{DRAFT}$

$$TEST_{COND\_CALM} := \begin{bmatrix} [\text{"Conv"}] \\ [\text{"Bulb C"}] \\ [\text{"Bulb D"}] \\ [\text{"Bulb G"}] \\ [\text{"Bulb H"}] \end{bmatrix} \quad \textbf{(11.1)}$$

Save Polynomial Curves to Maple File

> **save** $TEST_{COND\_CALM}, C_{TM15\_CALM\_CURVE}, C_{TS\_CALM\_CURVE}, mapleOutputFile$:

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Appendix E – Maple Self-Propulsion Routines

Open Water Self Propulsion, for a 2-Prop Vessel

Notes:
• Subscript M refers to model scale testing data and testing water properties.
• Subscript S refers to ship full scale data, corrected to target water properties.
• Nondimensional numbers do not have a scale subscript.

OCC Custom Setup

Clear Memory
```
> restart
```
Define Location of OCC Maple Standards,
```
> libname := libname, "."
        libname := "C:\Program Files\Maple 12/lib", "."        (2.1)
```
Load OCC Maple Standards,
```
> with(occMapleStandards)
["nEGADS.m", "nWater.m", "occArray.m", "occArrayCheck.m", "occArraySort.m",
    "occAssociate.m", "occCat.m", "occCurve.m", "occDataExport.m", "occDataImport.m",
    "occDataRead.m", "occEnumerate.m", "occEval.m", "occEvalDeep.m", "occFlatten.m",
    "occListLibrary.m", "occMap.m", "occMapleStandards.m", "occMax.m", "occMean.m",
    "occMin.m", "occModify.m", "occModifyRow.m", "occMultiPlot.m",
    "occPiecewiseDiff.m", "occPlot.m", "occSequence.m", "occSigDigits.m",
    "occSigDigitsDeep1.m", "occSigDigitsDeep2.m", "occSort.m", "occStringToSub.m",
    "occSubToString.m", "rEGADS.m", "rWater.m"]
[ν_EGADS, ν_water, ρ_EGADS, ρ_water, `*`, `+`, `-`, `/`, `<`, <=, <>, `=`, ℑ, ModuleLoad, ℜ, Unit,        (2.2)
    `^`, abs, add, and, arccos, arccosh, arccot, arccoth, arccsc, arccsch, arcsec, arcsech, arcsin,
    arcsinh, arctan, arctanh, argument, cat, ceil, collect, cols, combine, conjugate, convert,
    cos, cosh, cot, coth, csc, csch, csgn, diff, eval, evalb, evalc, evalr, exp, expand, factor,
    floor, frac, fsolve, if, implies, int, ln, log, log10, max, mean, min, mul, normal, not, or,
    piecewise, polar, root, round, rows, sec, sech, seq, shake, sign, signum, simplify, sin, sinh,
    solve, sort, sqrt, surd, tan, tanh, trunc, type, verify, xor]
```
Display Full Tables,
```
> interface('rtablesize' = ∞)
        10        (2.3)
```

Acquired Data

Project Name / Number and Tabs,
```
> projectName := "BULB"
> projectTab := "SP_1P"
> projectTabAdditional := ["HYDRO", "FRICTIONS"]
        projectName := "BULB"
```

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$$projectTab := \text{"SP\_1P"}$$

$$projectTabAdditional := [\text{"HYDRO"}, \text{"FRICTIONS"}] \quad (3.1)$$

Define Data Input/Ouput Files

> $sourceFile := cat(projectName, \text{" -Source Data.xls"})$

> $outputFile := cat(projectName, \text{" -Output.xls"})$

> $mapleSourceFile := cat(projectName, \text{" -RES -Output.m"})$

$$sourceFile := \text{"BULB -Source Data.xls"}$$

$$outputFile := \text{"BULB -Output.xls"}$$

$$mapleSourceFile := \text{"BULB -RES -Output.m"} \quad (3.2)$$

Import Test Data

> $occDataImport('filename' = sourceFile, 'tab' = projectTab) :$

$$TEST_{DRAFT}, TEST_{DESCRIPTION}, TEST_{DATE}, TEST_{NAME}, V_M, F_{DM}, n_M, T_M, Q_M, trim, TEMP_M, TANK, DP_M \quad (3.3)$$

Import Additional Data (Hydrostatics, Full Scale Target, Frictions, etc...)

> $seq(occDataImport('filename' = sourceFile, 'tab' = projectTabAdditional[i]), i = 1 ..cols(projectTabAdditional)) :$

$$TEST_{DRAFT\_HYDRO}, scale_{HYDRO}, T_{M\_HYDRO}, L_{M\_HYDRO}, B_{M\_HYDRO}, S_{M\_HYDRO}, vol_{M\_HYDRO}, TEST_{DATE\_FR}, TEST_{NAME\_TC}, n_{M\_FR}, Q_{M\_FR} \quad (3.4)$$

Import Data from Calm Water Resistance Tests

> $occDataRead('filename' = mapleSourceFile);$

$$C_{TS\_CALM\_CURVE}, TEST_{COND\_CALM}, C_{TM15\_CALM\_CURVE} \quad (3.5)$$

From the Propellor Opens we Obtain the Propellor Opens Thrust Curve

> $K_{TO\_CURVE} := occArray([-0.0384 \cdot 't'^3 + 0.0167 \cdot 't'^2 - 0.4969 \cdot 't' + 0.6474])$

$$K_{TO\_CURVE} := \left[\left[-0.03840000000\, t^3 + 0.01670000000\, t^2 - 0.4969000000\, t + 0.6474000000\right]\right] \quad (3.6)$$

From the Propellor Opens we Obtain the Propellor Opens Torque Curve

> $K_{QO\_CURVE} := occArray([-0.02733 \cdot 't'^3 + 0.04555 \cdot 't'^2 - 0.09258 \cdot 't' + 0.11933])$

$$K_{QO\_CURVE} := \left[\left[-0.02733000000\, t^3 + 0.04555000000\, t^2 - 0.09258000000\, t + 0.1193300000\right]\right] \quad (3.7)$$

Calculate the Propellor Opens Efficiency

> $ETA_{O\_CURVE} := \frac{'t'}{2 \cdot \pi} \cdot \frac{K_{TO\_CURVE}(1)(1)}{K_{QO\_CURVE}(1)(1)}$

$$ETA_{O\_CURVE} := \frac{1.591549430\, t\, (384.\, t^3 - 167.\, t^2 + 4969.\, t - 6474.)}{2733.\, t^3 - 4555.\, t^2 + 9258.\, t - 11933.} \quad (3.8)$$

> $opensPlotLimits := rhs(solve([ETA_{O\_CURVE} = -0.1, t > 0])[1])$

> $PropOpens10KqCurvePlot := plot(10 \cdot K_{QO\_CURVE}(1)(1), 't' = 0 ..opensPlotLimits + 0.1, 'colour' = \text{"red"}, 'linestyle' = \text{"dash"}, 'legend' = [\text{"10·K.QO Opens Curve"}])$

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> $PropOpensKtCurvePlot := plot\left(K_{TO\_CURVE}(1)(1), 't' = 0..opensPlotLimits + 0.1, 'colour' = "blue", 'linestyle' = "solid", 'legend' = ["K.TO Opens Curve"], labels = ["c", "y"]\right)$

> $PropOpensEtaCurvePlot := plot\left(ETA_{O\_CURVE}, 't' = 0..opensPlotLimits, 'colour' = "green", 'linestyle' = "dashdot", 'legend' = ["ETA.O Opens Curve"]\right)$

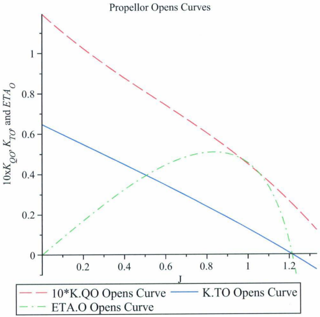
> $plots[display]\left(PropOpens10KqCurvePlot, PropOpensKtCurvePlot, PropOpensEtaCurvePlot, 'title' = "Propellor Opens Curves", 'labels' = \left["J", typeset\left("10x", 'K_{QO}', ", ", 'K_{TO}', ", and ", 'ETA_O'\right)\right], 'labeldirections' = ['Horizontal', 'Vertical']\right)$

$opensPlotLimits := 1.232929092$

$PropOpens10KqCurvePlot := PLOT(\ldots)$

$PropOpensKtCurvePlot := PLOT(\ldots)$

$PropOpensEtaCurvePlot := PLOT(\ldots)$



Tank, Water, and Vessel Properties

St. John's Gravity

O

> $g := 9.8082 \left[\!\left[\frac{m}{s^2} \right]\!\right]$

$$g := 9.8082 \left[\!\left[\frac{m}{s^2} \right]\!\right] \quad (4.1)$$

Test Water Density

> $\rho_M := \begin{cases} \rho_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \rho_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases}$:

Test Water Viscosity

> $\nu_M := \begin{cases} \nu_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \nu_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases}$:

Target Freshwater Model Water Density (15° C, 0% Salinity)

> $\rho_{M15} := \rho_{water}(15, 0)$:

Target Freshwater Model Viscosity Density (15° C, 0% Salinity)

> $\nu_{M15} := \nu_{water}(15, 0)$:

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

> $\rho_S := \rho_{water}(15, 3.5)$:

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

> $\nu_S := \nu_{water}(15, 3.5)$:

Associate Hydrostatic Conditions with Tested Conditions; Model-Ship Scale Ratio

> $\lambda := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, scale_{HYDRO})$:

Associate Hydrostatic Conditions with Tested Conditions and Scale; Length on Waterline

> **if** $assigned(L_{M\_HYDRO})$ **then**:

$L_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{M\_HYDRO})$:

$L_S := L_M \cdot \lambda$:

elif $assigned(L_{S\_HYDRO})$ **then**

$L_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{S\_HYDRO})$:

$L_M := \frac{L_S}{\lambda}$

end if:

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(S_{M\_HYDRO})$ **then**

$S_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{M\_HYDRO})$;

$S_S := S_M \cdot \lambda^2$;

elif $assigned(S_{S\_HYDRO})$ **then**

$S_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{S\_HYDRO})$;

$S_M := \frac{S_S}{\lambda^2}$;

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end if:

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(DP_M)$ **then**

$DP_S := DP_M \cdot \lambda;$

elif $assigned(DP_S)$ **then**

$DP_M := \frac{DP_S}{\lambda};$

end if:

Average Ship Velocity per Set

> $V_S := occArray\left(\left[seq\left(\left[\left(V_M \cdot \sqrt{\lambda}\right)(i)(1)\right], i=1..rows(V_M)\right)\right]\right):$

Define TEST,COND(ITION)

> $TEST_{COND} := occCat\left(TEST_{DRAFT}, occModify\left(x \rightarrow convert(x, string), \frac{V_S}{[\![knot]\!]}\right), \text{" Knots"}\right):$

Shaft Friction Correction

Shaft frictions are measured with bladeless props to measure system friction at various rps settings. These frictions are removed from the test data below.

Fit Curves to Frictions Data

> $frictionCurveType := 4:$

> $occPlot\left(\left[n_{M\_FR}, [\![rps]\!]\right], \left[Q_{M\_FR}, [\![N \cdot m]\!]\right], 'curve' = frictionCurveType, 'assignCurve' = \text{"Q,M\_FR\_CURVE"}, 'Legend' = \left[TEST_{DATE\_FR}\right]\right)$

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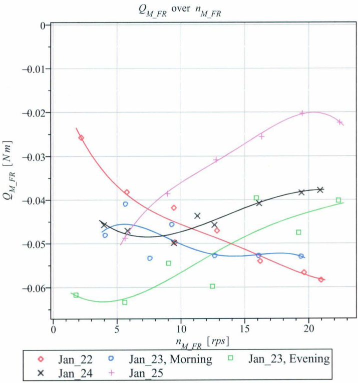
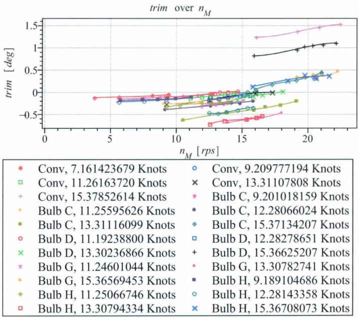


Fit Curves to Frictions Data

> *frictionCurveType* := 3 :

> *occPlot*([n_M, ⟦*rps*⟧], [*trim*, ⟦*deg*⟧], '*curve*' = *frictionCurveType*, '*assignCurve*' = "trim,CURVE")

O



> $joni := trim_{CURVE}$:

Associate Friction Test Sets with Tested Test Sets (by date)

> $Q_{M\_FR\_CURVE\_ASSOCIATED} := occAssociate(TEST_{DATE}, TEST_{DATE\_FR}, Q_{M\_FR\_CURVE})$

$$Q_{M\_FR\_CURVE\_ASSOCIATED} := [[[-0.0111635022715007911 - 0.00823225070923531630\, t + 0.000799080440394440614\, t^2 - 0.0000389262295261912320\, t^3 + 6.88475249710884426\ 10^{-7}\, t^4]], [[-0.0111635022715007911 - 0.00823225070923531630\, t + 0.000799080440394440614\, t^2 - 0.0000389262295261912320\, t^3 + 6.88475249710884426\ 10^{-7}\, t^4]], [[-0.0111635022715007911 - 0.00823225070923531630\, t + 0.000799080440394440614\, t^2 - 0.0000389262295261912320\, t^3 + 6.88475249710884426\ 10^{-7}\, t^4]], [[-0.0578728892972361770 - 0.00305785955266789974\, t + 0.000516868606062444994\, t^2 - 0.0000233532941214726044\, t^3 + 3.51471712144293148\ 10^{-7}\, t^4]], \tag{5.1}$$

O

$[[-0.0578728892972361770 - 0.00305785955266789974\, t + 0.000516868606062444994\, t^2 - 0.0000233532941214726044\, t^3 + 3.51471712144293148\, 10^{-7}\, t^4]]$,

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\, 10^{-7}\, t^4]]$,

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\, 10^{-7}\, t^4]]$,

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\, 10^{-7}\, t^4]]$,

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\, 10^{-7}\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]]$,

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$[[-0.102598824324606861 + 0.0168915118116515078\, t - 0.00172998802678490439\, t^2 + 0.0000867293738416355614\, t^3 - 0.00000160766081793043047\, t^4]],$

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\ 10^{-7}\, t^4]],$

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\ 10^{-7}\, t^4]],$

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\ 10^{-7}\, t^4]],$

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\ 10^{-7}\, t^4]],$

$[[-0.0304296482507338366 - 0.00584467295663113236\, t + 0.000603972258323771591\, t^2 - 0.0000211480903168765919\, t^3 + 2.31267980591385841\ 10^{-7}\, t^4]]]$

Correct Torque: Evalute Frictions Torque at Test RPM, and Remove from Total Torque

$$> Q_{M\_CORR} := Q_M - \left(Q_{M\_FR\_CURVE\_ASSOCIATED} \Big|_{'t' = \frac{n_M}{[[rps]]}} \right) \cdot [[N \cdot m]] :$$

▼ Non-Dimensionalize Velocity/Shaft Speed, Torque, Thrust and Drag

Hull Advance Coefficient

$$> J := \frac{V_M}{n_M \cdot DP_M} :$$

Drag Force Coefficient

$$> K_{FD} := \frac{F_{DM}}{\rho_M \cdot n_M^2 \cdot DP_M^4} :$$

Port Propellor Torque Coefficient

$$> K_Q := \frac{|Q_{M\_CORR}|}{\rho_M \cdot n_M^2 \cdot DP_M^5} :$$

Port Propellor Thrust Coefficient

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> $K_T := \frac{T_M}{\rho_M \cdot n_M^2 \cdot DP_M^4}$:

> *Alex* := *trim* :

> *trimncurve* := *occPlot*(n_M, *trim*, 'curve' = *kqktCurveType*, 'assignCurve' = "trim,n_CURVE", 'Legend' = ["trim Test"]) :

Plot Tested K.Q over K.T and Compare to Opens K.Q over K.T as a Data Quality Check

> *kqOverKtPlot* := *occPlot*(K_T, K_Q) :

> *kqOverKtOpensCurvePlot* := *plot*([$K_{TO\_CURVE}(1)(1)$, $K_{QO\_CURVE}(1)(1)$, $t = 0..\max(J)$], 'colour' = "blue", 'legend' = "K.Q over K.T Opens Curve") :

> *plots*[*display*](*kqOverKtPlot*, *kqOverKtOpensCurvePlot*, 'title' = *typeset*('K_Q', " over ", 'K_T', " Data Quality Check"), 'labels' = [*typeset*('K_T'), *typeset*('K_Q')]);

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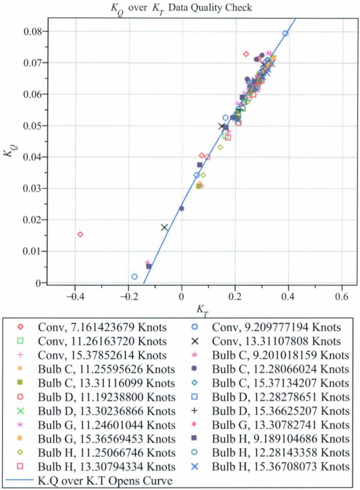

Fit Curves Througth K.T, K.Q over J

> *kqktCurveType* := 2 :

> *ktCurvePlot* := *occPlot*$(J, K_T$, '*curve*' = *kqktCurveType*, '*assignCurve*' = "K,T_CURVE")

> *tenKqCurvePlot* := *occPlot*$(J, 10 \cdot K_Q$, '*curve*' = *kqktCurveType*, '*assignCurve*'

= "TEN_K,Q_CURVE", 'colour' = "blue")

> $ktOpensCurvePlot := plot(K_{TO\_CURVE}(1)(1), 't' = 0..1.05 \cdot \max(J), 'colour' = "red",$ $'linestyle' = "dash", 'legend' = ["K.T Opens Curve"])$:

> $tenKqOpensCurvePlot := plot(10 \cdot K_{QO\_CURVE}(1)(1), 't' = 0..1.05 \cdot \max(J), 'colour'$ $= "blue", 'linestyle' = "dash", 'legend' = ["10·K.Q Opens Curve"])$:

> $K_{Q\_CURVE} := \frac{TEN\_K_{Q\_CURVE}}{10}$:

> plots[display](ktCurvePlot, tenKqCurvePlot, ktOpensCurvePlot, tenKqOpensCurvePlot, 'title' = typeset('K_T', " and 10x", 'K_Q', " over J"), 'labels' = ["J", typeset('K_T', " and 10x",'K_Q')])

$ktCurvePlot := PLOT(...)$

$tenKqCurvePlot := PLOT(...)$

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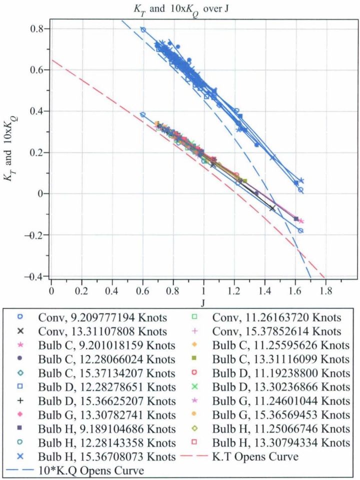

Fit Curves Throught K.FD over J

> $kfdCurveType := 2$:

> $kfdCurvePlot := occPlot(J, K_{FD}, 'curve' = kfdCurveType, 'assignCurve'$
= "K,FD_CURVE") :

> $plots[display](kfdCurvePlot, 'title' = typeset('K_{FD}', "$ over J"), 'labels' = ["J", typeset('K_{FD}

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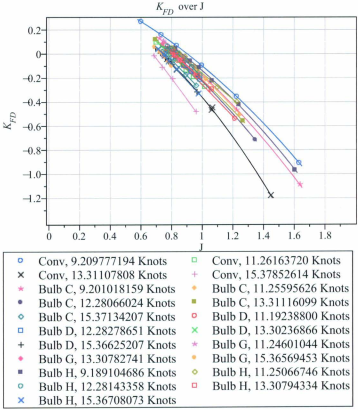
')])



Find Model-Ship Self-Propulsion Point

Model Velocity Average (per Set)

$> V_{M\_AVG} := \frac{V_S}{\sqrt{\lambda}}$:

Froude Number

$> Fr := \frac{V_S}{\sqrt{g \cdot L_S}}$:

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Associate the Calm Water Model Resistance Condition Sets with the Tested Condition Sets

$> C_{TM15\_CALM\_CURVE\_ASSOCIATED} := occAssociate\left(TEST_{DRAFT}, TEST_{COND\_CALM}, C_{TM15\_CALM\_CURVE}\right):$

Model Calm Water Resistance Coefficient at Tested Speed

$> C_{TM15} := C_{TM15\_CALM\_CURVE\_ASSOCIATED}\Big|_{t=Fr}:$

Associate the Calm Water Ship Resistance Condition Sets with the Tested Condition Sets

$> C_{TS\_CALM\_CURVE\_ASSOCIATED} := occAssociate\left(TEST_{DRAFT}, TEST_{COND\_CALM}, C_{TS\_CALM\_CURVE}\right):$

Ship Calm Water Resistance Coefficient at Tested Speed

$> C_{TS} := C_{TS\_CALM\_CURVE\_ASSOCIATED}\Big|_{t=Fr}:$

Model Reynold's Number

$> Rn_M := \frac{V_{M\_AVG} \cdot L_M}{\nu_M}:$

Model Reynold's Number at 15°C

$> Rn_{M15} := \frac{V_{M\_AVG} \cdot L_M}{\nu_{M15}}:$

Model Frictional Resistance Coefficient

$> C_{FM} := \frac{0.075}{\left(\log10(Rn_M) - 2\right)^2}:$

Model Frictional Resistance Coefficient at 15°C

$> C_{FM15} := \frac{0.075}{\left(\log10(Rn_{M15}) - 2\right)^2}:$

Correct Model Calm Water Resistance Coefficient to Tested Temperature

$> C_{TM} := C_{TM15} - C_{FM15} + C_{FM}:$

Model Drag Force Coefficient at Self-Propulsion Point

$> C_{FD\_SP} := C_{TM} - C_{TS}:$

Model Drag Force at Self-Propulsion Point (Skin Friction Correction)

$> F_{DM\_SP} := 0.5 \cdot \rho_M \cdot V_{M\_AVG}^2 \cdot S_M \cdot C_{FD\_SP}:$

Check Model Drag Force at SP Point vs Speed

$> occPlot\left(\left[V_S, [\![knot]\!]\right], \left[F_{DM\_SP}, [\![N]\!]\right]\right)$

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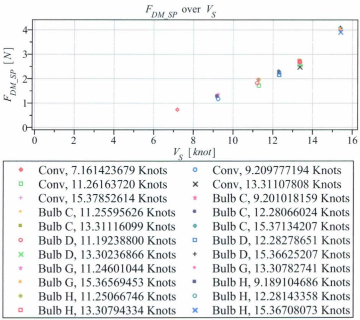

Interpolate to Self-Propulsion Point

Interpolate over K.FD to Find Values of J where Tested Tow Post Drag Force matches the Model-Ship Self-Propulsion Point, which Corresponds to the SP Point

$$> J_{SP} := fsolve\left(\frac{K_{FD\_CURVE}}{'t'^2} = \frac{C_{FD\_SP} \cdot S_S}{2 \cdot DP_S^2}, 't' = 0..1.25 \cdot \max(J) \right) :$$

Plot trim over n_msp

$$> nmsp := \frac{V_{M\_AVG}}{J_{SP} \cdot DP_M} :$$

$$> trimSP := joni \Big|_{t = \frac{nmsp}{[\![rps]\!]}} :$$

Plot K.FD over J, with SP Intersection Curve, and Interpolated SP Points

> *colourList* := ["red", "blue", "green", "black", "magenta", "DeepPink", "coral", "Indigo", "Olive", "DarkCyan"]

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> $kfdIntersectionCurvePlot := seq\left(\left[plot\left(\frac{C_{FD\_SP} \cdot S_S}{2 \cdot DP_S^2}(i)(1) \cdot t'^2, 't' = 0..1.05 \cdot \max(J), 'colour' = colourList\left[`if`\left(\text{frac}\left(\frac{i}{10}\right) \cdot 10 = 0, 10, \text{frac}\left(\frac{i}{10}\right) \cdot 10\right)\right], 'linestyle' = \text{"dash"}, 'legend' = cat\left(TEST_{COND}(i)(1), \text{" SP Intersection Curve"}\right)\right)\right], i = 1..rows(V_S)\right):$

> $kfdSPPointPlot := seq\left(\left[plots[pointplot]\left(\left[\left[J_{SP}(i)(1), \left(K_{FD\_CURVE}\Big|_{'t' = J_{SP}}\right)(i)(1)\right]\right], 'colour' = colourList\left[`if`\left(\text{frac}\left(\frac{i}{10}\right) \cdot 10 = 0, 10, \text{frac}\left(\frac{i}{10}\right) \cdot 10\right)\right], 'symbol' = \text{"solidcircle"}, 'symbolsize' = 15, 'legend' = cat\left(TEST_{COND}(i)(1), \text{" SP Point"}\right)\right)\right], i = 1..rows(V_S)\right):$

> $plots[display]\left(kfdCurvePlot, kfdIntersectionCurvePlot, kfdSPPointPlot, 'title' = typeset\left('K_{FD}', \text{" over J, with SP Intersection Curves, and Interpolated SP Points"}\right), 'labels' = [\text{"J"}, typeset('K_{FD}')]\right)$

$colourList :=$ ["red", "blue", "green", "black", "magenta", "DeepPink", "coral", "Indigo", "Olive", "DarkCyan"]

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K ...over L with SP Intersection Curves and Interpolated SP Points

- Conv, 13.31107808 Knots SP Point
- Conv, 15.37852614 Knots SP Point
- Bulb C, 9.201018159 Knots SP Point
- Bulb C, 11.25595626 Knots SP Point
- Bulb C, 12.28066024 Knots SP Point
- Bulb C, 13.31116099 Knots SP Point
- Bulb C, 15.37134207 Knots SP Point
- Bulb D, 11.19238800 Knots SP Point
- Bulb D, 12.28278651 Knots SP Point
- Bulb D, 13.30236866 Knots SP Point
- Bulb D, 15.36625207 Knots SP Point
- Bulb G, 11.24601044 Knots SP Point
- Bulb G, 13.30782741 Knots SP Point
- Bulb G, 15.36569453 Knots SP Point
- Bulb H, 9.189104686 Knots SP Point
- Bulb H, 11.25066746 Knots SP Point
- Bulb H, 12.28143358 Knots SP Point
- Bulb H, 13.30794334 Knots SP Point
- Bulb H, 15.36708073 Knots SP Point
- Conv, 7.161423679 Knots SP Intersection Curve
- Conv, 9.209777194 Knots SP Intersection Curve
- Conv, 11.26163720 Knots SP Intersection Curve
- Conv, 13.31107808 Knots SP Intersection Curve
- Conv, 15.37852614 Knots SP Intersection Curve
- Bulb C, 9.201018159 Knots SP Intersection Curve
- Bulb C, 11.25595626 Knots SP Intersection Curve
- Bulb C, 12.28066024 Knots SP Intersection Curve
- Bulb C, 13.31116099 Knots SP Intersection Curve
- Bulb C, 15.37134207 Knots SP Intersection Curve
- Bulb D, 11.19238800 Knots SP Intersection Curve
- Bulb D, 12.28278651 Knots SP Intersection Curve
- Bulb D, 13.30236866 Knots SP Intersection Curve
- Bulb D, 15.36625207 Knots SP Intersection Curve
- Bulb G, 11.24601044 Knots SP Intersection Curve
- Bulb G, 13.30782741 Knots SP Intersection Curve
- Bulb G, 15.36569453 Knots SP Intersection Curve
- Bulb H, 9.189104686 Knots SP Intersection Curve
- Bulb H, 11.25066746 Knots SP Intersection Curve
- Bulb H, 12.28143358 Knots SP Intersection Curve
- Bulb H, 13.30794334 Knots SP Intersection Curve
- Bulb H, 15.36708073 Knots SP Intersection Curve

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Evaluate Propellor Torque Coefficient at SP Point

> $K_{QSP} := K_{Q\_CURVE}\Big|_{t=J_{SP}}$:

Evaluate Propellor Thrust Coefficient at SP Point

> $K_{TSP} := K_{T\_CURVE}\Big|_{t=J_{SP}}$:

Show Translation from SP point at K,FD to K,T and 10*K,Q

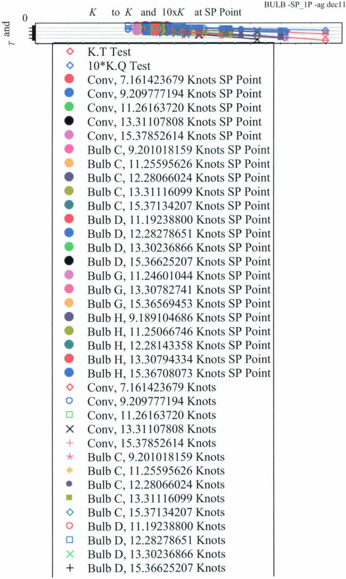
> $ktSPPointPlot := seq\Big(\Big[plots[pointplot]\big([J_{SP}(i)(1), K_{TSP}(i)(1)], 'colour' = colourList\Big[\,`if`\Big(\mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10 = 0, 10, \mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10\Big)\Big], 'symbol' = \text{"solidcircle"}, 'symbolsize' = 15, 'legend' = cat\big(TEST_{COND}(i)(1), \text{" SP Point"}\big)\big)\Big], i = 1..rows(V_S)\Big)$:

> $tenKqSPPointPlot := seq\Big(\Big[plots[pointplot]\big([J_{SP}(i)(1), 10\cdot K_{QSP}(i)(1)], 'colour' = colourList\Big[\,`if`\Big(\mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10 = 0, 10, \mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10\Big)\Big], 'symbol' = \text{"solidcircle"}, 'symbolsize' = 15\big)\Big], i = 1..rows(V_S)\Big)$:

> $kfdToKt10KqLinePlot := seq\Big(plot\Big(\Big[\Big[J_{SP}(i)(1), y, y = \min\Big(\Big(K_{FD\_CURVE}\Big|_{'t' = J_{SP}}\Big)(i)(1), 10\cdot K_{QSP}(i)(1), K_{TSP}(i)(1)\Big)..\max\Big(\Big(K_{FD\_CURVE}\Big|_{'t' = J_{SP}}\Big)(i)(1), 10\cdot K_{QSP}(i)(1), K_{TSP}(i)(1)\Big)\Big]\Big], 'colour' = colourList\Big[\,`if`\Big(\mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10 = 0, 10, \mathrm{frac}\Big(\frac{i}{10}\Big)\cdot 10\Big)\Big], 'linestyle' = \text{"dash"}\Big), i = 1..rows(V_S)\Big)$:

> $plots[display]\big(ktCurvePlot, tenKqCurvePlot, ktSPPointPlot, tenKqSPPointPlot, kfdCurvePlot, kfdSPPointPlot, kfdToKt10KqLinePlot, 'title' = typeset('K_{FD}', \text{" to "}, 'K_T', \text{" and 10x"}, 'K_Q', \text{" at SP Point"}), 'labels' = [\text{"J"}, typeset('K_{FD}', \text{" , "}, 'K_T', \text{" and 10x"}, 'K_Q')]\big)$

Oe


K to K and 10xK at SP Point
T and
0
K.T Test
10*K.Q Test
Conv, 7.161423679 Knots SP Point
Conv, 9.209777194 Knots SP Point
Conv, 11.26163720 Knots SP Point
Conv, 13.31107808 Knots SP Point
Conv, 15.37852614 Knots SP Point
Bulb C, 9.201018159 Knots SP Point
Bulb C, 11.25595626 Knots SP Point
Bulb C, 12.28066024 Knots SP Point
Bulb C, 13.31116099 Knots SP Point
Bulb C, 15.37134207 Knots SP Point
Bulb D, 11.19238800 Knots SP Point
Bulb D, 12.28278651 Knots SP Point
Bulb D, 13.30236866 Knots SP Point
Bulb D, 15.36625207 Knots SP Point
Bulb G, 11.24601044 Knots SP Point
Bulb G, 13.30782741 Knots SP Point
Bulb G, 15.36569453 Knots SP Point
Bulb H, 9.189104686 Knots SP Point
Bulb H, 11.25066746 Knots SP Point
Bulb H, 12.28143358 Knots SP Point
Bulb H, 13.30794334 Knots SP Point
Bulb H, 15.36708073 Knots SP Point
Conv, 7.161423679 Knots
Conv, 9.209777194 Knots
Conv, 11.26163720 Knots
Conv, 13.31107808 Knots
Conv, 15.37852614 Knots
Bulb C, 9.201018159 Knots
Bulb C, 11.25595626 Knots
Bulb C, 12.28066024 Knots
Bulb C, 13.31116099 Knots
Bulb C, 15.37134207 Knots
Bulb D, 11.19238800 Knots
Bulb D, 12.28278651 Knots
Bulb D, 13.30236866 Knots
Bulb D, 15.36625207 Knots

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Find Equivalent Propellor Opens Value at SP Point

Find J for Equivalent Opens Thrust.

$> J_{OPEN} := fsolve(K_{TSP} = K_{TO\_CURVE}, 't'=0..1.25 \cdot \max(J)) :$

Find Propellor Opens Thrust Coefficient at SP Point

$> K_{TO} := K_{TO\_CURVE} \Big|_{t = J_{OPEN}} :$

Find Propellor Opens Torque Coefficient at SP Point

$> K_{QO} := K_{QO\_CURVE} \Big|_{t = J_{OPEN}} :$

Show Translation from SP point at K,TSP to K,TO and then 10*K,QO

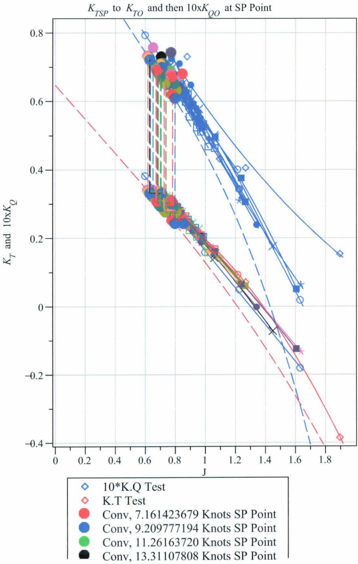
$> ktoSPPointPlot := seq\left(\left[plots[pointplot]\left([J_{OPEN}(i)(1), K_{TO}(i)(1)], 'colour' = colourList\left[`if`\left(\mathrm{frac}\left(\frac{i}{10}\right)\cdot 10 = 0, 10, \mathrm{frac}\left(\frac{i}{10}\right)\cdot 10\right)\right], 'symbol' = "solidcircle", 'symbolsize'= 15, 'legend' = cat(TEST_{COND}(i)(1), " SP Point")\right)\right], i = 1..rows(V_S)\right) :$

$> tenKqoSPPointPlot := seq\left(\left[plots[pointplot]\left([J_{OPEN}(i)(1), 10 \cdot K_{QO}(i)(1)], 'colour' = colourList\left[`if`\left(\mathrm{frac}\left(\frac{i}{10}\right)\cdot 10 = 0, 10, \mathrm{frac}\left(\frac{i}{10}\right)\cdot 10\right)\right], 'symbol' = "solidcircle", 'symbolsize'= 15, 'legend' = cat(TEST_{COND}(i)(1), " SP Point")\right)\right], i = 1..rows(V_S)\right) :$

$> ktToKtoLinePlot := seq\left(plot\left(K_{TO}(i)(1), x = \min(J_{SP}(i)(1), J_{OPEN}(i)(1))..\max(J_{SP}(i)(1), J_{OPEN}(i)(1)), 'colour' = colourList\left[`if`\left(\mathrm{frac}\left(\frac{i}{10}\right)\cdot 10 = 0, 10, \mathrm{frac}\left(\frac{i}{10}\right)\cdot 10\right)\right], 'linestyle' = "dash"\right), i = 1..rows(V_S)\right) :$

$> ktoTo10KqoLinePlot := seq\left(plot\left([J_{OPEN}(i)(1), y, y = \min(10 \cdot K_{QO}(i)(1), K_{TO}(i)(1))..\max(10 \cdot K_{QO}(i)(1), K_{TO}(i)(1))], 'colour' = colourList\left[`if`\left(\mathrm{frac}\left(\frac{i}{10}\right)\cdot 10 = 0, 10, \mathrm{frac}\left(\frac{i}{10}\right)\cdot 10\right)\right], 'linestyle' = "dash"\right), i = 1..rows(V_S)\right) :$

$> plots[display](tenKqCurvePlot, ktCurvePlot, tenKqSPPointPlot, ktSPPointPlot, ktOpensCurvePlot, ktoSPPointPlot, tenKqOpensCurvePlot, tenKqoSPPointPlot, ktToKtoLinePlot, ktoTo10KqoLinePlot, 'title' = typeset('K_{TSP}', " to ", 'K_{TO}', " and then 10x", 'K_{QO}', " at SP Point"), 'labels' = ["J", typeset('K_T', " and 10x",'K_Q')])$



K_{TSP} to K_{TO} and then $10xK_{QO}$ at SP Point
K_T and $10xK_Q$
J
0.8
0.6
0.4
0.2
0
−0.2
−0.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
10*K.Q Test
K.T Test
Conv, 7.161423679 Knots SP Point
Conv, 9.209777194 Knots SP Point
Conv, 11.26163720 Knots SP Point
Conv, 13.31107808 Knots SP Point

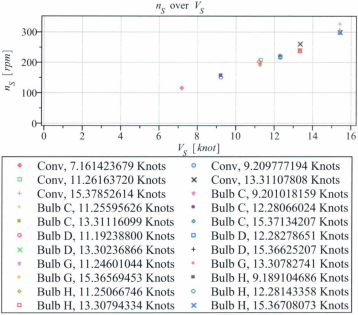
O

Ship Performance

Ship Shaft Speed

> $n_S := \dfrac{V_S}{J_{SP} \cdot DP_S}$:

> $occPlot([V_S, [\![knot]\!]], [n_S, [\![rpm]\!]])$

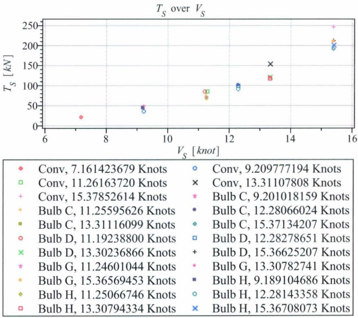


Ship Propellor Thurst

> $T_S := \rho_S \cdot n_S^2 \cdot DP_S^4 \cdot K_{TSP}$:

> $occPlot([V_S, [\![knot]\!]], [T_S, [\![kN]\!]])$

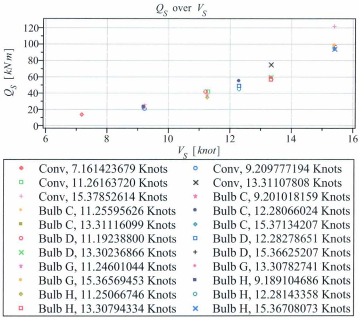
O



Ship Propellor Torque

> $Q_S := \rho_S \cdot n_S^2 \cdot DP_S^5 \cdot K_{QSP}$:

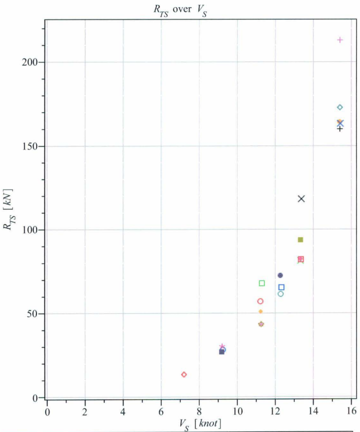
> $occPlot([V_S, [\![knot]\!]], [Q_S, [\![kN \cdot m]\!]])$



Ship Total Resistance

> $R_{TS} := C_{TS} \cdot 0.5 \cdot \rho_S \cdot V_S^2 \cdot S_S$:

> $occPlot([V_S, [\![knot]\!]], [R_{TS}, [\![kN]\!]])$



Conv, 7.161423679 Knots	Conv, 9.209777194 Knots
Conv, 11.26163720 Knots	Conv, 13.31107808 Knots
Conv, 15.37852614 Knots	Bulb C, 9.201018159 Knots
Bulb C, 11.25595626 Knots	Bulb C, 12.28066024 Knots
Bulb C, 13.31116099 Knots	Bulb C, 15.37134207 Knots
Bulb D, 11.19238800 Knots	Bulb D, 12.28278651 Knots
Bulb D, 13.30236866 Knots	Bulb D, 15.36625207 Knots
Bulb G, 11.24601044 Knots	Bulb G, 13.30782741 Knots
Bulb G, 15.36569453 Knots	Bulb H, 9.189104686 Knots

O

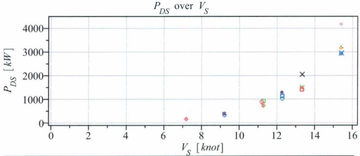
Ship Effective Power

> $P_{ES} := R_{TS} \cdot V_S$:

Ship Developed Power

> $P_{DS} := 2 \cdot \pi \cdot n_S \cdot Q_S$:

> $occPlot([V_S, [\![knot]\!]], [P_{DS}, [\![kW]\!]])$



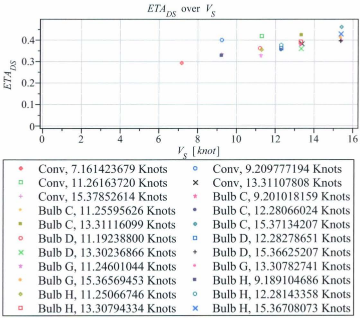
Conv, 7.161423679 Knots	Conv, 9.209777194 Knots
Conv, 11.26163720 Knots	Conv, 13.31107808 Knots
Conv, 15.37852614 Knots	Bulb C, 9.201018159 Knots
Bulb C, 11.25595626 Knots	Bulb C, 12.28066024 Knots
Bulb C, 13.31116099 Knots	Bulb C, 15.37134207 Knots
Bulb D, 11.19238800 Knots	Bulb D, 12.28278651 Knots
Bulb D, 13.30236866 Knots	Bulb D, 15.36625207 Knots
Bulb G, 11.24601044 Knots	Bulb G, 13.30782741 Knots
Bulb G, 15.36569453 Knots	Bulb H, 9.189104686 Knots
Bulb H, 11.25066746 Knots	Bulb H, 12.28143358 Knots
Bulb H, 13.30794334 Knots	Bulb H, 15.36708073 Knots

Ship Propulsive Efficiency

> $ETA_{DS} := \frac{P_{ES}}{P_{DS}}$:

> $occPlot([V_S, [\![knot]\!]], ETA_{DS})$

O



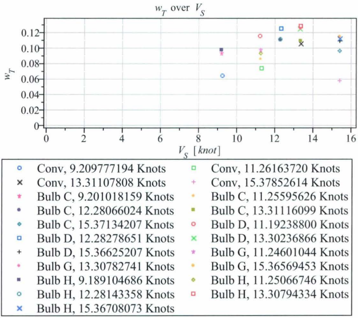
> $\eta_{DS} := \frac{P_{ES}}{P_{DS}}$:

Wake Fraction

> $w_T := 1 - \frac{J_{OPEN}}{J_{SP}}$:

> $occPlot([V_S, [[knot]]], w_T)$

O

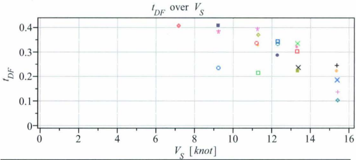


Thrust Deduction Factor

> $t_{DF} := 1 - \frac{R_{TS}}{T_S}$:

> $occPlot([V_S, [[knot]]], t_{DF})$

o



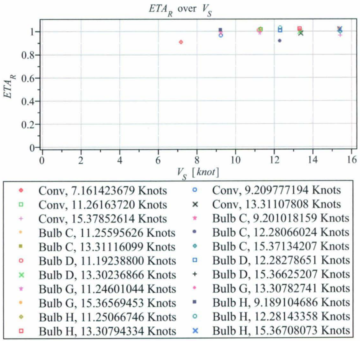
◆	Conv, 7.161423679 Knots	○	Conv, 9.209777194 Knots
□	Conv, 11.26163720 Knots	×	Conv, 13.31107808 Knots
+	Conv, 15.37852614 Knots	*	Bulb C, 9.201018159 Knots
•	Bulb C, 11.25595626 Knots	•	Bulb C, 12.28066024 Knots
■	Bulb C, 13.31116099 Knots	◆	Bulb C, 15.37134207 Knots
○	Bulb D, 11.19238800 Knots	□	Bulb D, 12.28278651 Knots
×	Bulb D, 13.30236866 Knots	+	Bulb D, 15.36625207 Knots
*	Bulb G, 11.24601044 Knots	•	Bulb G, 13.30782741 Knots
•	Bulb G, 15.36569453 Knots	■	Bulb H, 9.189104686 Knots
◆	Bulb H, 11.25066746 Knots	○	Bulb H, 12.28143358 Knots
□	Bulb H, 13.30794334 Knots	×	Bulb H, 15.36708073 Knots

Relative Rotative Efficiency

> $ETA_R := \frac{K_{QO}}{K_{QSP}}$:

> $occPlot([V_S, [\![knot]\!]], ETA_R)$

O



Opens Shaft Speed

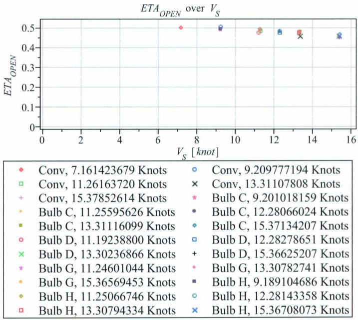
$$> n_{OPEN} := \frac{V_S}{J_{OPEN} \cdot DP_S} :$$

Propellor Open Efficiency

$$> ETA_{OPEN} := \frac{V_S}{2 \cdot \pi \cdot n_{OPEN} \cdot DP_S} \cdot \frac{K_{TO}}{K_{QO}} :$$

$$> occPlot([V_S, [\![knot]\!]], ETA_{OPEN})$$

O



Hull Efficiency

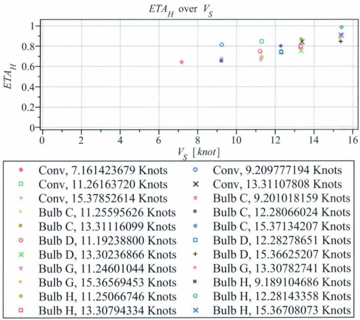
> $ETA_H := \dfrac{1 - t_{DF}}{1 - w_T}$

> $occPlot([V_S, [\![knot]\!]], ETA_H)$

O

$$ETA_H := \begin{bmatrix} [0.6450112205] \\ [0.8153757445] \\ [0.8478926343] \\ [0.8493819935] \\ [0.9152067609] \\ [0.6782376494] \\ [0.7346248825] \\ [0.8024401622] \\ [0.8713441503] \\ [0.9899623077] \\ [0.7498750589] \\ [0.7482227922] \\ [0.7577480411] \\ [0.8473863115] \\ [0.6716812199] \\ [0.7755607492] \\ [0.8781027331] \\ [0.6548296965] \\ [0.6930832258] \\ [0.7495701438] \\ [0.7990551527] \\ [0.9141023273] \end{bmatrix}$$

O



Export Results

Export to Excel File

> *dataOut* := *occDataExport*('*filename*' = *outputFile*, '*tab*' = *projectTab*, '*outData*'
= [["TEST,COND"], ["V,S", "knot"], ["n,S", "rpm"], ["T,S", "kN"], ["Q,S", "kN*m"], ["P,DS", "kW"], ["P,ES", "kW"], ["R,TS", "kN"], ["ETA,DS"], ["t,DF"], ["w,T"], ["ETA,R"], ["ETA,OPEN"], ["ETA,H"], ["J,SP"], ["J,OPEN"], ["trimSP"]]
, '*sigDigits*' = 3) :

Appendix F – Maple Head Seas Routines

Open Water Resistance - ITTC '57 Method

Notes:
- Subscript M refers to model scale testing data and testing water properties.
- Subscript S refers to ship full scale data, corrected to target water properties.
- Nondimensional numbers do not have a scale subscript.

OCC Custom Setup

Clear Memory

```
> restart
```

Define Location of OCC Maple Standards,

```
> libname := libname, "."
```

libname := "C:\Program Files\Maple 12/lib", "." (2.1)

Load OCC Maple Standards,

```
> with(occMapleStandards) :
```

Display Full Tables,

```
> interface('rtablesize' = ∞)
```

10 (2.2)

Acquired Data

Project Name / Number and Tabs,

```
> projectName := "HS"
> projectTab := "RES"
> projectTabAdditional := ["HYDRO"]
```

projectName := "HS"

projectTab := "RES"

projectTabAdditional := ["HYDRO"] (3.1)

Define Data Input/Ouput Files

```
> sourceFile := cat(projectName, " -Source Data.xls")
> outputFile := cat(projectName, " -Output.xls")
> mapleOutputFile := cat(projectName, " -RES -Output.m")
```

sourceFile := "HS -Source Data.xls"

outputFile := "HS -Output.xls"

mapleOutputFile := "HS -RES -Output.m" (3.2)

Import Test Data,

```
> testData := occDataImport('filename' = sourceFile, 'tab' = projectTab, 'sortCol' = "V,M") :
```

$TEST_{DRAFT}, TEST_{DESCRIPTION}, TEST_{NAME}, V_M, R_{TM}, \theta, z_{VM}, TEMP_M, TANK, TEMP_S,$ (3.3)
$SALINITY_S$

Import Additional Data (Hydrostatics, Full Scale Target, Frictions, etc...)

```
> seq(occDataImport('filename' = sourceFile, 'tab' = projectTabAdditional[i]), i = 1
  ..cols(projectTabAdditional)) :
```

$TEST_{DRAFT\_HYDRO}, scale_{HYDRO}, T_{M\_HYDRO}, L_{M\_HYDRO}, B_{M\_HYDRO}, S_{M\_HYDRO}, vol_{M\_HYDRO}$ (3.4)

Tank, Water, Model/Ship Properties and Test Condition

O

St. John's Gravity

$> g := 9.8082 \left[\left[\frac{m}{s^2} \right]\right]:$

Tank Width

$> b_T := \begin{cases} 4.5[[m]] & TANK = \text{"OERC"} \\ 12[[m]] & TANK = \text{"ICE"} \textbf{ or } TANK = \text{"TOW"} \end{cases}:$

Tank Water Depth

$> h_T := \begin{cases} 6[[ft]] & TANK = \text{"OERC"} \\ 3[[m]] & TANK = \text{"ICE"} \\ 7[[m]] & TANK = \text{"TOW"} \end{cases}:$

Test Water Density

$> \rho_M := \begin{cases} \rho_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \rho_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases}:$

Test Water Viscosity

$> \nu_M := \begin{cases} \nu_{EGADS}(TEMP_M) & TANK = \text{"ICE"} \\ \nu_{water}(TEMP_M, 0) & TANK = \text{"OERC"} \textbf{ or } TANK = \text{"TOW"} \textbf{ or } TANK = \text{"FLUME"} \end{cases}:$

Target Freshwater Model Water Density (15° C, 0% Salinity)

$> \rho_{M15} := \rho_{water}(15, 0):$

Target Freshwater Model Viscosity Density (15° C, 0% Salinity)

$> \nu_{M15} := \nu_{water}(15, 0):$

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

$> \rho_S := \rho_{water}(TEMP_S, SALINITY_S):$

Target Saltwater Ship Water Density (15° C, 3.5% Salinity)

$> \nu_S := \nu_{water}(TEMP_S, SALINITY_S):$

Associate Hydrostatic Conditions with Tested Conditions; Model-Ship Scale Ratio

$> \lambda := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, scale_{HYDRO}):$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Draft

$> \textbf{if } assigned(T_{M\_HYDRO}) \textbf{ then}$

$T_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, T_{M\_HYDRO});:$

$T_S := T_M \cdot \lambda;$

$\textbf{elif } assigned(T_{S\_HYDRO}) \textbf{ then}$

$T_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, T_{S\_HYDRO});$

$T_M := \frac{T_S}{\lambda};$

end if;

O

$$T_M := \begin{bmatrix} [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \\ [\ 0.22409\ [\![m]\!]\ ] \end{bmatrix}$$

$$T_S := \begin{bmatrix} [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \\ [\ 4.10824197\ [\![m]\!]\ ] \end{bmatrix} \quad (4.1)$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Length on Waterline

> **if** $assigned(L_{M\_HYDRO})$ **then**
$L_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{M\_HYDRO})$;
$L_S := L_M \cdot \lambda$:;
elif $assigned(L_{S\_HYDRO})$ **then**
$L_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, L_{S\_HYDRO})$;

O

$L_M := \frac{L_S}{\lambda};$

end if;

$$L_M := \begin{bmatrix} [\, 1.829 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.829 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \\ [\, 1.833 \, [\![m]\!] \,] \end{bmatrix}$$

$$L_S := \begin{bmatrix} [\, 33.531057 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.531057 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \\ [\, 33.604389 \, [\![m]\!] \,] \end{bmatrix} \quad \textbf{(4.2)}$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Beam on Waterline

> **if** $assigned(B_{M\_HYDRO})$ **then**

$B_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, B_{M\_HYDRO});$

O

$B_S := B_M \cdot \lambda;$

elif *assigned*(B_{S_HYDRO}) **then**

$B_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, B_{S\_HYDRO});$

$B_M := \frac{B_S}{\lambda};$

end if;

$$B_M := \begin{bmatrix} [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \\ [0.4988 [\![m]\!]] \end{bmatrix}$$

$$B_S := \begin{bmatrix} [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \\ [9.1445004 [\![m]\!]] \end{bmatrix} \quad (4.3)$$

O

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(S_{M\_HYDRO})$ **then**

$S_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{M\_HYDRO});$

$S_S := S_M \cdot \lambda^2;$

elif $assigned(S_{S\_HYDRO})$ **then**

$S_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, S_{S\_HYDRO});$

$S_M := \frac{S_S}{\lambda^2};$

end if;

$$S_M := \begin{bmatrix} [\, 0.9722 \, [\![m^2]\!] \,] \\ [\, 1.1225 \, [\![m^2]\!] \,] \\ [\, 1.0964 \, [\![m^2]\!] \,] \\ [\, 1.10625 \, [\![m^2]\!] \,] \\ [\, 1.109381 \, [\![m^2]\!] \,] \\ [\, 0.9722 \, [\![m^2]\!] \,] \\ [\, 1.1225 \, [\![m^2]\!] \,] \\ [\, 1.0964 \, [\![m^2]\!] \,] \\ [\, 1.10625 \, [\![m^2]\!] \,] \\ [\, 1.109381 \, [\![m^2]\!] \,] \end{bmatrix} \tag{4.4}$$

O

$$S_S := \begin{bmatrix} [\ 326.7553399\ [\![m^2]\!]\ ] \\ [\ 377.2710029\ [\![m^2]\!]\ ] \\ [\ 368.4988219\ [\![m^2]\!]\ ] \\ [\ 371.8093960\ [\![m^2]\!]\ ] \\ [\ 372.8617216\ [\![m^2]\!]\ ] \\ [\ 326.7553399\ [\![m^2]\!]\ ] \\ [\ 377.2710029\ [\![m^2]\!]\ ] \\ [\ 368.4988219\ [\![m^2]\!]\ ] \\ [\ 371.8093960\ [\![m^2]\!]\ ] \\ [\ 372.8617216\ [\![m^2]\!]\ ] \end{bmatrix} \quad \textbf{(4.4)}$$

Associate Hydrostatic Conditions with Tested Conditions and Scale; Wetted Surface Area

> **if** $assigned(vol_{M\_HYDRO})$ **then**

$vol_M := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, vol_{M\_HYDRO});$

$vol_S := vol_M \cdot \lambda^3;$

elif $assigned(vol_{S\_HYDRO})$ **then**

$vol_S := occAssociate(TEST_{DRAFT}, TEST_{DRAFT\_HYDRO}, vol_{S\_HYDRO});$

$vol_M := \frac{vol_S}{\lambda^3};$

end if;

O

$$vol_M := \begin{bmatrix} [0.0629 \, [[m^3]]] \\ [0.07262420284 \, [[m^3]]] \\ [0.07093556881 \, [[m^3]]] \\ [0.07157285024 \, [[m^3]]] \\ [0.07177542162 \, [[m^3]]] \\ [0.0629 \, [[m^3]]] \\ [0.07262420284 \, [[m^3]]] \\ [0.07093556881 \, [[m^3]]] \\ [0.07157285024 \, [[m^3]]] \\ [0.07177542162 \, [[m^3]]] \end{bmatrix}$$

$$vol_S := \begin{bmatrix} [387.5709886 \, [[m^3]]] \\ [447.4886183 \, [[m^3]]] \\ [437.0837604 \, [[m^3]]] \\ [441.0104980 \, [[m^3]]] \\ [442.2586823 \, [[m^3]]] \\ [387.5709886 \, [[m^3]]] \\ [447.4886183 \, [[m^3]]] \\ [437.0837604 \, [[m^3]]] \\ [441.0104980 \, [[m^3]]] \\ [442.2586823 \, [[m^3]]] \end{bmatrix} \qquad \textbf{(4.5)}$$

Define TEST,COND(ITION)

> $TEST_{COND} := occCat(TEST_{DRAFT}, TEST_{DESCRIPTION});$

O

$$TEST_{COND} := \begin{bmatrix} [\text{"Conv, SS3"}] \\ [\text{"Bulb C, SS3"}] \\ [\text{"Bulb D, SS3"}] \\ [\text{"Bulb G, SS3"}] \\ [\text{"Bulb H, SS3"}] \\ [\text{"Conv, SS5"}] \\ [\text{"Bulb C, SS5"}] \\ [\text{"Bulb D, SS5"}] \\ [\text{"Bulb G, SS5"}] \\ [\text{"Bulb H, SS5"}] \end{bmatrix} \quad (4.6)$$

Model Resistance Coefficients and Non-Dimensional Numbers

Froude Number

$$> Fr := \frac{V_M}{\sqrt{g \cdot L_M}} :$$

Model Reynold's Number

$$> Rn_M := \frac{V_M \cdot L_M}{\nu_M} :$$

Model Total Resistance Coefficient

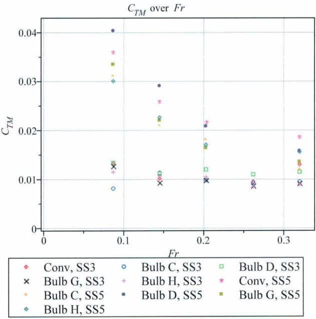
$$> C_{TM} := \frac{R_{TM}}{0.5 \cdot \rho_M \cdot V_M^2 \cdot S_M} :$$

Model Frictional Resistance Coefficient

$$> C_{FM} := \frac{0.075}{\left(\log 10(Rn_M) - 2\right)^2} :$$

$$> occPlot(Fr, C_{TM})$$

O



Blockage Correction using Scott's Method

Scott Method is Valid For:
- Fr from 0.10 to 0.55.
- Tank Width/Height ratio should not substantially differ from 2.
- Tank Froude Depth Number < 1.

Residuary Resistance Coefficient in a Restricted Tank

> $C_{R\_TANK} := C_{TM} - C_{FM}$:

Tank Cross-Sectional Area

> $A_T := h_T \cdot b_T$:

Tank Froude Depth Number

> $Fr_T := \dfrac{V_M}{\sqrt{g \cdot h_T}}$:

Block Coefficient for Vesel

> $C_B := \dfrac{vol_M}{L_M \cdot B_M \cdot T_M}$:

Blockage Form Factor

O

$$> LVolC_B := \frac{L_M}{vol_M^{\frac{1}{3}} \cdot C_B}:$$

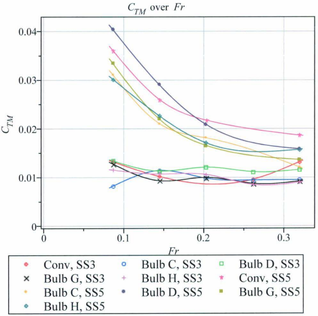
Model/Tank Function

$$> f := \frac{\left(L_M^4 \cdot (B_M \cdot T_M)\right)^{\frac{1}{4}}}{A_T^{\frac{5}{4}} \cdot h_T^2}:$$

Power of Speed Proportional to Actual Resistance in Speed Vicinity

> occPlot(Fr, C_{TM}, 'curve' = "spline", 'assignCurve' = "C,TM_CURVE")

$$> n_t := 2 + \frac{Fr}{C_{TM}} \cdot \left(\frac{d}{dt} C_{TM\_CURVE} \Big|_{'t' = Fr} \right):$$



Function of Reynold's Number and Form, Evaluated at Zero

$$> b_0 := \begin{cases} 0.5 + 0.1 \cdot LVolC_B & LVolC_B > 11.6 \\ 0.143 \cdot LVolC_B & otherwise \end{cases}:$$

O

Function of Reynold's Number and Form

$$> b := \begin{cases} b_0 & Rn_M \cdot 10^{-6} < 4 \cdot b_0 \\ \dfrac{18\, b_0}{20 - 4\, b_0} - \dfrac{b_0 - 0.5}{20 - 4\, b_0} \cdot Rn_M \cdot 10^{-6} & 4 \cdot b_0 \le Rn_M \cdot 10^{-6} < 20 \\ 0.5 & otherwise \end{cases} :$$

Function of Froude Number, k

$$> k := \begin{cases} 0 & Fr \le 0.25 \\ 0.14 \cdot Fr - 0.035 & 0.25 < Fr \le 0.32 \\ -1.3393 \cdot Fr^2 + 1.3028 \cdot Fr - 0.2717 & 0.32 < Fr \le 0.42 \\ 0.18 \cdot Fr - 0.034 & otherwise \end{cases} :$$

Function of Froude Number, c

$$> c := \begin{cases} 0.6 & Fr \le 0.4 \\ 405092.59 \cdot Fr^6 - 1136618.59 \cdot Fr^5 + 1323361.83 \cdot Fr^4 - 818648.19 \cdot Fr^3 + 283862.03 \cdot Fr^2 - 52321 \cdot Fr + 4006.42 & 0.4 < Fr < 0.56 \\ 0 & otherwise \end{cases}$$

:

Change in Model Total Resistance Coefficient

$$> \Delta C_{TM} := \frac{n_t \cdot C_{TM} \cdot b \cdot vol_M \cdot A_T^{-\frac{3}{2}} + \dfrac{k \cdot f \cdot C_{R\_TANK}}{1 + k \cdot f}}{1 - c \cdot Fr_T^2} :$$

Corrected Model Total Resistance Coefficient

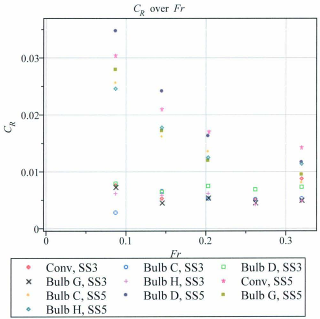
$> C_{TM\_CORR} := C_{TM} - \Delta C_{TM}:$

Residuary Resistance Coefficient (in Unrestricted Water)

$> C_R := C_{TM\_CORR} - C_{FM}:$

$> occPlot(Fr, C_R)$

O



Ship Behavior

Ship Sinkage due to Forward Velocity

> $z_{VS} := z_{VM} \cdot \lambda$:

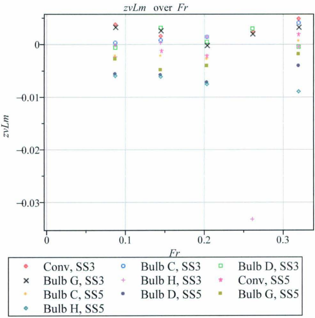
Ratio of Sinkage over Length

> $zvLm := \frac{z_{VM}}{L_M}$:

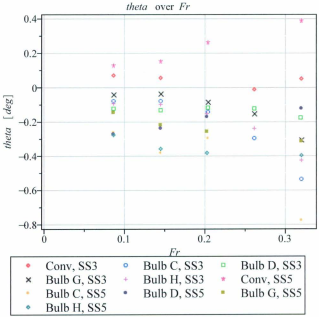
> $occPlot(Fr, zvLm)$

> $occPlot(Fr, [\theta, [\![deg]\!]])$

O


zvLm over Fr
zvLm
Fr
0
-0.01
-0.02
-0.03
0
0.1
0.2
0.3
Conv, SS3
Bulb C, SS3
Bulb D, SS3
Bulb G, SS3
Bulb H, SS3
Conv, SS5
Bulb C, SS5
Bulb D, SS5
Bulb G, SS5
Bulb H, SS5

O



Model Scale Transformation to Freshwater Target Conditon (for Different Test Temperature Comparisons)

Model Reynold's Number at Target Condition

$$> Rn_{M15} := \frac{V_M \cdot L_M}{\nu_{M15}}$$

$$Rn_{M15} := [[[\ 5.871863338\ 10^5\ \ 9.826901815\ 10^5\ \ 1.775795425\ 10^6\ \ 2.171023551\ 10^6\ ]], \quad \textbf{(8.1)}$$

$[[5.891408273\ 10^5, 9.852740682\ 10^5, 1.383249888\ 10^6, 1.779522530\ 10^6,$
$2.177428335\ 10^6]],$
$[[5.877551910\ 10^5, 9.847732866\ 10^5, 1.383769841\ 10^6, 1.779883886\ 10^6,$
$2.174938838\ 10^6]],$
$[[5.882852573\ 10^5, 9.856220672\ 10^5, 1.382996917\ 10^6, 1.779277634\ 10^6,$
$2.177524109\ 10^6]],$
$[[5.883761895\ 10^5, 9.849249014\ 10^5, 1.381728818\ 10^6, 1.779387730\ 10^6,$

$2.175895785\ 10^{6}$]],

$\left[\left[\ 5.873513356\ 10^{5}\ \ 9.836162177\ 10^{5}\ \ 1.381089904\ 10^{6}\ \ 2.172928219\ 10^{6}\ \right]\right],$

$\left[\left[\ 5.889135805\ 10^{5}\ \ 9.850888216\ 10^{5}\ \ 1.382519438\ 10^{6}\ \ 2.176057249\ 10^{6}\ \right]\right],$

$\left[\left[\ 5.874330687\ 10^{5}\ \ 9.844791966\ 10^{5}\ \ 1.381199645\ 10^{6}\ \ 2.175734979\ 10^{6}\ \right]\right],$

$\left[\left[\ 5.893458205\ 10^{5}\ \ 9.852640121\ 10^{5}\ \ 1.381244053\ 10^{6}\ \ 2.176021968\ 10^{6}\ \right]\right],$

$\left[\left[\ 5.875343396\ 10^{5}\ \ 9.860885260\ 10^{5}\ \ 1.381742948\ 10^{6}\ \ 2.175735097\ 10^{6}\ \right]\right]\right]$

Model Frictional Resistance Coefficient at Target Condition

$> C_{FM15} := \dfrac{0.075}{\left(\log 10\left(Rn_{M15}\right) - 2\right)^2}$

$C_{FM15} := \left[\left[\left[\ 0.005280324664\ \ 0.004705324227\ \ 0.004153435598\ \ 0.003987949100\ \right]\right],\right.$ **(8.2)**

[[0.005276282987, 0.004702637219, 0.004373928134, 0.004151656176, 0.003985597216]],

[[0.005279146466, 0.004703157257, 0.004373583349, 0.004151483915, 0.003986510308]],

[[0.005278049985, 0.004702276050, 0.004374095941, 0.004151772947, 0.003985562115]],

[[0.005277862022, 0.004702999776, 0.004374937741, 0.004151720448, 0.003986159160]],

$\left[\left[\ 0.005279982758\ \ 0.004704360156\ \ 0.004375362258\ \ 0.003987248751\ \right]\right],$

$\left[\left[\ 0.005276751982\ \ 0.004702829549\ \ 0.004374412786\ \ 0.003986099932\ \right]\right],$

$\left[\left[\ 0.005279813446\ \ 0.004703462818\ \ 0.004375289324\ \ 0.003986218154\ \right]\right],$

$\left[\left[\ 0.005275860126\ \ 0.004702647660\ \ 0.004375259813\ \ 0.003986112874\ \right]\right],$

$\left[\left[\ 0.005279603701\ \ 0.004701792196\ \ 0.004374928358\ \ 0.003986218112\ \right]\right]\right]$

Uncorrected Model Total Resistance at Target Condition

$> C_{TM15\_UNCORR} := C_{FM15} + C_{R\_TANK}$

$C_{TM15\_UNCORR} := \left[\left[\left[\ 0.01313965908\ \ 0.01014252288\ \ 0.009540193845\ \ 0.01309986101\ \right]\right],\right.$ **(8.3)**

[[0.008229931714, 0.01143650378, 0.009861723023, 0.009466658946, 0.009512835159]],

[[0.01343209151, 0.01131355677, 0.01209514057, 0.01117930661, 0.01160992695]],

[[0.01281091887, 0.009365787915, 0.01002775790, 0.008808791319, 0.009249569432]],

[[0.01155672053, 0.01071777161, 0.01064320108, 0.008563625259, 0.009032772768]],

O

$$[[\ 0.03603503807\ \ 0.02594365189\ \ 0.02170609259\ \ 0.01857979287\ ]],$$
$$[[\ 0.03111124615\ \ 0.02109142607\ \ 0.01811133242\ \ 0.01213336360\ ]],$$
$$[[\ 0.04041658209\ \ 0.02907090732\ \ 0.02090857984\ \ 0.01585074074\ ]],$$
$$[[\ 0.03345659105\ \ 0.02203121675\ \ 0.01659350727\ \ 0.01366190158\ ]],$$
$$[[\ 0.03023461668\ \ 0.02265783094\ \ 0.01710749406\ \ 0.01572030296\ ]]]$$

Corrected Model Total Resistance at Target Condition

> $C_{TM15\_CORR} := C_{FM15} + C_R$

$$C_{TM15\_CORR} := [[[\ 0.01302437751\ \ 0.01006572361\ \ 0.009371614510\ \ 0.01281004862\ ]], \quad \textbf{(8.4)}$$

[[0.008104919800, 0.01130570758, 0.009784707272, 0.009356083606, 0.009396511982]],

[[0.01331189278, 0.01119473761, 0.01196020627, 0.01106890425, 0.01143660359]],

[[0.01271089108, 0.009276770392, 0.009917447088, 0.008731334377, 0.009102552297]],

[[0.01144237405, 0.01060240160, 0.01055123604, 0.008497283529, 0.008881802349]],

$$[[\ 0.03574048742\ \ 0.02576079821\ \ 0.02151432529\ \ 0.01838362937\ ]],$$
$$[[\ 0.03087143556\ \ 0.02094827365\ \ 0.01794598503\ \ 0.01209607793\ ]],$$
$$[[\ 0.04007723383\ \ 0.02889270468\ \ 0.02079182867\ \ 0.01567937629\ ]],$$
$$[[\ 0.03319977999\ \ 0.02190924191\ \ 0.01647262552\ \ 0.01351116040\ ]],$$
$$[[\ 0.02997221443\ \ 0.02250571259\ \ 0.01699136269\ \ 0.01549838507\ ]]]$$

Full Scale Transformation to Saltwater Target Condition

Incremental Resistance Coefficient Correlation Allowance

$$> C_A := \begin{cases} 0.0004 & L_S < 150\ [\![m]\!] \\ 0.0002 & 150\ [\![m]\!] \le L_S < 210\ [\![m]\!] \\ 0.0001 & 210\ [\![m]\!] \le L_S < 260\ [\![m]\!] \\ 0 & 260\ [\![m]\!] \le L_S < 300\ [\![m]\!] \\ -0.0001 & 300\ [\![m]\!] \le L_S < 350\ [\![m]\!] \\ -0.0002 & 350\ [\![m]\!] \le L_S \end{cases}$$

O

$$C_A := \begin{bmatrix} [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \\ [0.0004] \end{bmatrix} \quad (9.1)$$

Ship Velocity

> $V_S := V_M \cdot \sqrt{\lambda}$

$V_S :=$ (9.2)

$[[1.565695019 [\frac{m}{s}], 2.620280877 [\frac{m}{s}], 4.735045572 [\frac{m}{s}], 5.788896239 [\frac{m}{s}]]],$

$[[1.567478496 [\frac{m}{s}], 2.621437597 [\frac{m}{s}], 3.680299095 [\frac{m}{s}], 4.734629087 [\frac{m}{s}], 5.793304306 [\frac{m}{s}]]],$

$[[1.563791847 [\frac{m}{s}], 2.620105208 [\frac{m}{s}], 3.681682489 [\frac{m}{s}], 4.735590518 [\frac{m}{s}], 5.786680705 [\frac{m}{s}]]],$

$[[1.565202151 [\frac{m}{s}], 2.622363488 [\frac{m}{s}], 3.679626036 [\frac{m}{s}], 4.733977514 [\frac{m}{s}], 5.793559123 [\frac{m}{s}]]],$

$[[1.565444087 [\frac{m}{s}], 2.620508596 [\frac{m}{s}], 3.676252109 [\frac{m}{s}], 4.734270438 [\frac{m}{s}], 5.789226774 [\frac{m}{s}]]],$

O

$$\left[\left[1.566134986 \left[\!\left[\frac{m}{s}\right]\!\right], 2.622750095 \left[\!\left[\frac{m}{s}\right]\!\right], 3.682588404 \left[\!\left[\frac{m}{s}\right]\!\right], 5.793974915 \left[\!\left[\frac{m}{s}\right]\!\right]\right]\right],$$
$$\left[\left[1.566873879 \left[\!\left[\frac{m}{s}\right]\!\right], 2.620944725 \left[\!\left[\frac{m}{s}\right]\!\right], 3.678355647 \left[\!\left[\frac{m}{s}\right]\!\right], 5.789656370 \left[\!\left[\frac{m}{s}\right]\!\right]\right]\right],$$
$$\left[\left[1.562934803 \left[\!\left[\frac{m}{s}\right]\!\right], 2.619322746 \left[\!\left[\frac{m}{s}\right]\!\right], 3.674844182 \left[\!\left[\frac{m}{s}\right]\!\right], 5.788798933 \left[\!\left[\frac{m}{s}\right]\!\right]\right]\right],$$
$$\left[\left[1.568023904 \left[\!\left[\frac{m}{s}\right]\!\right], 2.621410841 \left[\!\left[\frac{m}{s}\right]\!\right], 3.674962334 \left[\!\left[\frac{m}{s}\right]\!\right], 5.789562498 \left[\!\left[\frac{m}{s}\right]\!\right]\right]\right],$$
$$\left[\left[1.563204246 \left[\!\left[\frac{m}{s}\right]\!\right], 2.623604558 \left[\!\left[\frac{m}{s}\right]\!\right], 3.676289705 \left[\!\left[\frac{m}{s}\right]\!\right], 5.788799246 \left[\!\left[\frac{m}{s}\right]\!\right]\right]\right]\right]$$

Ship Reynold's Number

$$> Rn_S := \frac{V_S \cdot L_S}{\nu_S}$$

$$Rn_S := [[[\ 4.422694188\ 10^7\ \ 7.401633693\ 10^7\ \ 1.337531146\ 10^8\ \ 1.635217424\ 10^8\ ]], \tag{9.3}$$
$$[[4.437415456\ 10^7, 7.421095562\ 10^7, 1.041865399\ 10^8, 1.340338406\ 10^8, 1.640041515\ 10^8]],$$
$$[[4.426978826\ 10^7, 7.417323667\ 10^7, 1.042257027\ 10^8, 1.34061058\ 10^8, 1.638166422\ 10^8]],$$
$$[[4.430971292\ 10^7, 7.423716690\ 10^7, 1.041674861\ 10^8, 1.340153951\ 10^8, 1.640113652\ 10^8]],$$
$$[[4.431656195\ 10^7, 7.418465629\ 10^7, 1.040719727\ 10^8, 1.340236875\ 10^8, 1.638887195\ 10^8]],$$
$$[[\ 4.423936985\ 10^7\ \ 7.408608612\ 10^7\ \ 1.040238497\ 10^8\ \ 1.636652021\ 10^8\ ]],$$
$$[[\ 4.435703830\ 10^7\ \ 7.419700278\ 10^7\ \ 1.041315223\ 10^8\ \ 1.639008811\ 10^8\ ]],$$
$$[[\ 4.424552598\ 10^7\ \ 7.415108575\ 10^7\ \ 1.040321154\ 10^8\ \ 1.638766077\ 10^8\ ]],$$
$$[[\ 4.438959465\ 10^7\ \ 7.421019817\ 10^7\ \ 1.040354601\ 10^8\ \ 1.638982236\ 10^8\ ]],$$
$$[[\ 4.425315371\ 10^7\ \ 7.427230068\ 10^7\ \ 1.04073037\ 10^8\ \ 1.638766166\ 10^8\ ]]]$$

O

Ship Frictional Resistance Coefficient

> $C_{FS} := \dfrac{0.075}{\left(\log10\left(Rn_S\right) - 2\right)^2}$

C_{FS} := [[[0.002353031186 0.002177131011 0.001998316112 0.001942576377]], **(9.4)**
[[0.002351828658, 0.002176285206, 0.002071019018, 0.001997722220, 0.001941776696]],
[[0.002352680682, 0.002176448919, 0.002070906680, 0.001997664720, 0.001942087188]],
[[0.002352354454, 0.002176171499, 0.002071073692, 0.001997761196, 0.001941764758]],
[[0.002352298526, 0.002176399343, 0.002071347944, 0.001997743673, 0.001941967786]],
[[0.002352929476 0.002176827572 0.002071486239 0.001942338268]],
[[0.002351968222 0.002176345754 0.002071176920 0.001941947645]],
[[0.002352879109 0.002176545109 0.002071462479 0.001941987846]],
[[0.002351702818 0.002176288492 0.002071452866 0.001941952046]],
[[0.002352816712 0.002176019164 0.002071344886 0.001941987831]]]

Ship Total Resistance Coefficient

> $C_{TS} := C_{FS} + C_R + C_A$

C_{TS} := [[[0.01049708403 0.007937530392 0.007616495024 0.01116467589]], **(9.5)**
[[0.005580465471, 0.009179355564, 0.007881798156, 0.007602149650, 0.007752691462]],
[[0.01078542700, 0.009068029273, 0.01005752960, 0.009315085058, 0.009792180468]],
[[0.01018519555, 0.007150665841, 0.008014424839, 0.006977322626, 0.007458754940]],
[[0.008916810554, 0.008475801167, 0.008647646243, 0.006743306754, 0.007237610975]],
[[0.03321343414 0.02363326562 0.01961044927 0.01673871889]],
[[0.02834665180 0.01882178985 0.01604274916 0.01045192564]],
[[0.03755029949 0.02676578697 0.01888800183 0.01403514599]],
[[0.03067562268 0.01978288274 0.01456881858 0.01186699958]],
[[0.02744542744 0.02037993955 0.01508777922 0.01385415479]]]

Ship Total Resistance

> $R_{TS} := C_{TS} \cdot 0.5 \cdot \rho_S \cdot V_S^2 \cdot S_S$

> $occPlot\left(\left[V_S, [\![knot]\!]\right], \left[R_{TS}, [\![kN]\!]\right], 'curve' = \text{"spline"}\right)$

O

R_{TS} := [[[4317.187591 ⟦N⟧ 9143.216470 ⟦N⟧ 28649.78686 ⟦N⟧ 62770.49550 ⟦N⟧]

],

[[2655.964388 ⟦N⟧, 12219.11858 ⟦N⟧, 20679.50685 ⟦N⟧, 33010.87053 ⟦N⟧, 50402.70238 ⟦N⟧]],

[[4990.298786 ⟦N⟧, 11778.27501 ⟦N⟧, 25793.79831 ⟦N⟧, 39524.50372 ⟦N⟧, 62039.71077 ⟦N⟧]],

[[4763.496132 ⟦N⟧, 9387.454290 ⟦N⟧, 20715.49426 ⟦N⟧, 29850.85395 ⟦N⟧, 47793.93604 ⟦N⟧]],

[[4183.383451 ⟦N⟧, 11142.81578 ⟦N⟧, 22374.40535 ⟦N⟧, 28934.90459 ⟦N⟧, 46438.62722 ⟦N⟧]],

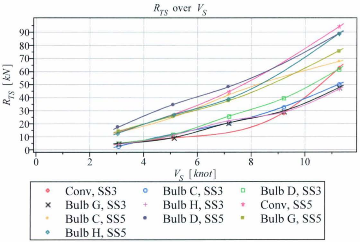
[[13667.53111 ⟦N⟧ 27274.41631 ⟦N⟧ 44618.17595 ⟦N⟧ 94274.30585 ⟦N⟧]],

[[13480.88765 ⟦N⟧ 25045.24492 ⟦N⟧ 42046.98566 ⟦N⟧ 67865.73024 ⟦N⟧]],

[[17355.07302 ⟦N⟧ 34744.76365 ⟦N⟧ 48260.87489 ⟦N⟧ 88986.71628 ⟦N⟧]],

[[14398.40279 ⟦N⟧ 25952.26889 ⟦N⟧ 37561.73920 ⟦N⟧ 75936.04839 ⟦N⟧]],

[[12839.39216 ⟦N⟧ 26856.08224 ⟦N⟧ 39038.02068 ⟦N⟧ 88879.17729 ⟦N⟧]]]



Ship Effective Power

> $P_{ES} := R_{TS} \cdot V_S$

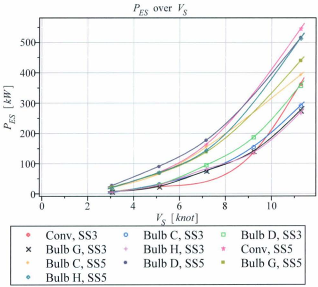
> $occPlot([V_S, ⟦knot⟧], [P_{ES}, ⟦kW⟧], 'curve' = "spline")$

P_{ES} := [

O

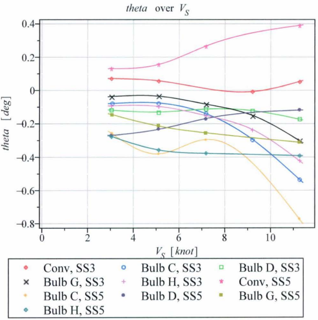
[[6759.399107 [[W]], 23957.79527 [[W]], 1.356580464 10^5 [[W]],
3.633718853 10^5 [[W]]],
[[4163.167064 [[W]], 32031.65685 [[W]], 76106.77035 [[W]],
1.562942278 10^5 [[W]], 2.919981927 10^5 [[W]]],
[[7803.788556 [[W]], 30860.31969 [[W]], 94964.57556 [[W]],
1.871718650 10^5 [[W]], 3.590039973 10^5 [[W]]],
[[7455.834392 [[W]], 24617.31738 [[W]], 76225.27203 [[W]],
1.413132714 10^5 [[W]], 2.768969942 10^5 [[W]]],
[[6548.852887 [[W]], 29199.84454 [[W]], 82253.95486 [[W]],
1.369856634 10^5 [[W]], 2.688437440 10^5 [[W]]],
[[21405.19864 [[W]], 71533.97797 [[W]], 1.643103774 10^5 [[W]],
5.462229632 10^5 [[W]]],
[[21122.85072 [[W]], 65642.20256 [[W]], 1.546637671 10^5 [[W]],
3.929192574 10^5 [[W]]],
[[27124.84763 [[W]], 91007.74973 [[W]], 1.773511953 10^5 [[W]],
5.151262083 10^5 [[W]]],
[[22577.03975 [[W]], 68031.55902 [[W]], 1.380379768 10^5 [[W]],
4.396364980 10^5 [[W]]],
[[20070.59234 [[W]], 70459.73977 [[W]], 1.435150735 10^5 [[W]],
5.145037145 10^5 [[W]]]]

O

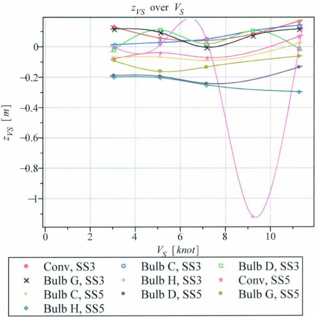


> $occPlot([V_S, [[knot]]], [\theta, [[deg]]], 'curve' = "spline")$

O



> $occPlot\left(\left[V_S \, [\![knot]\!] \right], \left[z_{VS} \, [\![m]\!] \right], 'curve' = \text{"spline"} \right)$



▶ Export Results

▶

o

Appendix G – Resistance Analysis Data

RESISTANCE SOURCE DATA

TEST,DRAFT_HYDRO	scale,HYDRO	T,M_HYDRO m	L,M_HYDRO m	B,M_HYDRO m	S,M_HYDRO m^2	vol,M_HYDRO m^3
Conv	18.333	0.2241	1.829	0.4988	0.9722	0.063
Bulb C	18.333	0.2241	1.833	0.4988	1.1225	0.073
Bulb D	18.333	0.2241	1.833	0.4988	1.0964	0.071
Bulb G	18.333	0.2241	1.833	0.4988	1.10625	0.072
Bulb H	18.333	0.2241	1.833	0.4988	1.109381	0.072

TEST,DRAFT	TEST,DESCRIPTION	TEST,NAME	V,M	R,TM	theta	z,VM	TEMP,M	TANK	TEMP,S	SALINITY,S
			m/s	N	deg	mm				
Conv	Design Draft	OERC_ConvBow	0.630103791	1.50	0.221313	3.121084	12.3	OERC	15	3.5
			0.756970619	2.16	0.185763	2.332854				
			0.884635289	3.16	0.166393	5.437574				
			1.007709264	4.49	0.137516	6.433277				
			1.007709264	4.49	0.137516	6.433277				
			1.008021596	4.30	0.137756	6.413839				
			1.008021596	4.30	0.137756	6.413839				
			1.00975212	4.36	0.131908	5.754878				
			1.011525704	4.39	0.139225	6.428325				
			1.011525704	4.39	0.139225	6.428325				
			1.137520228	6.17	0.131888	8.361946				
			1.197857051	7.19	0.141753	9.80467				
			1.264374052	8.92	0.158312	10.15972				
			1.308388957	11.03	0.155677	11.41709				
			1.308388957	11.03	0.155677	11.41709				
			1.349081047	12.06	0.133702	12.5204				
			1.352939801	12.60	0.138801	12.51173				
			1.352939801	12.60	0.138801	12.51173				
			1.390620598	13.45	0.100196	12.65567				
			1.451504636	15.68	0.073726	14.29568				
			1.451504636	15.68	0.073726	14.29568				
			1.455085287	16.21	0.10234	14.24485				
			1.51884414	18.11	0.0584	15.47012				
			1.579039493	20.38	0.111171	16.92963				
			1.637593355	22.52	0.218975	18.83233				
			1.640851163	23.22	0.245602	18.67696				
			1.640851163	23.22	0.245602	18.67696				
			1.708520228	27.03	0.570707	19.54908				
			1.772254153	31.01	0.945168	22.30706				
			1.82923195	35.85	1.421331	22.5429				
			1.88931194	41.66	1.995149	24.49683				
			1.897653488	43.17	2.122914	25.13507				
			1.897653488	43.17	2.122914	25.13507				
Bulb C	Design Draft	OERC_BulbC_DD	0.629975689	1.753306	0.049357	2.770479	14.67	OERC	15	3.5
			0.757700845	2.540205	0.011991	3.166926				
			0.885498138	3.577122	-0.05372	4.85354				
			0.885498138	3.577122	-0.05372	4.85354				
			0.886157864	3.708174	-0.05674	4.248224				
			1.008871642	4.904916	-0.15405	6.988917				
			1.144445636	6.562336	-0.28135	7.578909				
			1.201618234	7.173139	-0.36697	8.478303				
			1.265382415	7.725199	-0.46609	10.25865				
			1.265382415	7.725199	-0.46609	10.25865				
			1.267132226	7.800792	-0.44828	9.87831				
			1.299451827	8.365652	-0.5053	11.35935				
			1.299451827	8.365652	-0.5053	11.35935				
			1.326616958	9.01132	-0.52689	11.55844				
			1.358415929	10.14631	-0.57847	13.33597				
			1.358415929	10.14631	-0.57847	13.33597				
			1.391801594	10.7713	-0.67808	13.37656				
			1.424535857	12.18439	-0.73867	13.73398				
			1.424535857	12.18439	-0.73867	13.73398				
			1.459090184	13.03481	-0.84003	14.68261				
			1.459090184	13.28588	-0.84003	14.68261				
			1.463845706	13.28588	-0.83593	15.32625				
			1.488374713	14.0359	-0.94205	16.71062				
			1.488374713	14.0359	-0.94205	16.71062				
			1.519446179	14.80389	-1.02562	16.57252				
			1.579779734	16.74358	-1.18881	19.2071				
			1.639854425	18.84823	-1.29048	20.43042				
			1.714525676	22.55173	-1.22931	22.56665				
			1.773310631	25.85692	-1.04761	25.85713				
			1.830566667	29.99322	-0.71715	28.02842				
			1.888506335	34.63843	-0.30879	29.9184				

Bulb D	Design Draft	OERC_BulbD_DD	0.631716334	2.24	0.056734	1.991625	14.63 OERC	15	3.5
			0.758779111	3.45	0.030016	3.513064			
			0.884196412	4.48	0.007502	4.900276			
			0.884196412	4.48	0.007502	4.900276			
			0.884626169	4.59	0.010717	4.642492			
			1.011745014	5.83	-0.03712	5.940241			
			1.148887629	7.48	-0.03318	8.410991			
			1.195048754	8.25	-0.0371	8.825236			
			1.265014286	9.19	-0.07629	9.635724			
			1.297917647	9.82	-0.09974	10.56124			
			1.297917647	9.82	-0.09974	10.56124			
			1.329666833	10.55	-0.09842	10.71786			
			1.357983791	10.98	-0.14072	11.75195			
			1.357983791	10.98	-0.14072	11.75195			
			1.391687783	11.55	-0.16093	12.14651			
			1.423631894	11.92	-0.23888	12.9757			
			1.423631894	11.92	-0.23888	12.9757			
			1.456791369	12.24	-0.25921	13.4407			
			1.487579253	12.69	-0.31273	14.12166			
			1.487579253	12.69	-0.31273	14.12166			
			1.517853474	13.45	-0.32721	15.52133			
			1.517853474	13.45	-0.32721	15.52133			
			1.518964706	13.37	-0.33007	15.06243			
			1.57676701	14.85	-0.31195	16.51876			
			1.63671753	16.74	-0.24268	18.1804			
			1.709901449	19.73	-0.03852	20.47802			
			1.772617536	23.23	0.265194	23.48617			
			1.830514391	27.93	0.637333	24.39063			
			1.902664873	33.72	1.165053	27.30588			
Bulb G	Design Draft	OERC_BulbG_DD	0.627972948	1.90	0.059674	2.386553	15.47 OERC	15	3.5
			0.756446638	2.56	0.030991	3.405928			
			0.756446638	2.56	0.030991	3.405928			
			0.757268674	2.77	0.037846	3.338444			
			0.885116024	3.73	-0.00386	4.873832			
			1.012845313	4.72	-0.06194	5.939956			
			1.14628505	5.72	-0.10367	7.698396			
			1.200860133	6.19	-0.14841	8.292338			
			1.263761512	6.95	-0.21123	10.09546			
			1.297633032	7.44	-0.2644	10.39479			
			1.297633032	7.44	-0.2644	10.39479			
			1.329749169	8.23	-0.28941	11.42898			
			1.362357214	9.03	-0.34727	12.01827			
			1.362357214	9.03	-0.34727	12.01827			
			1.391563043	10.01	-0.37345	12.65109			
			1.424720991	10.77	-0.44632	13.98244			
			1.424720991	10.77	-0.44632	13.98244			
			1.455176012	11.34	-0.52525	14.05265			
			1.491091623	12.44	-0.607	15.22275			
			1.491091623	12.44	-0.607	15.22275			
			1.520141477	13.29	-0.66033	16.2649			
			1.520141477	13.29	-0.66033	16.2649			
			1.521893116	13.41	-0.65523	16.56251			
			1.577389272	14.83	-0.75189	17.72915			
			1.637702597	17.14	-0.76045	19.57507			
			1.708622222	20.64	-0.64066	21.87916			
			1.780652756	25.15	-0.31627	24.92283			
			1.83204026	28.67	0.003091	26.60904			
			1.895342045	34.07	0.505375	28.57108			

Bulb H	Design Draft	OERC_BulbH_DD	0.630054487	1.89	0.044449	2.726147	15.00	OERC	15	3.5
			0.756280137	2.70	0.021356	4.032235				
			0.756570883	2.68	0.018363	3.283409				
			0.756570883	2.68	0.018363	3.283409				
			0.884640324	3.80	-0.03249	4.236792				
			1.00926409	4.94	-0.09734	5.898538				
			1.144497297	5.75	-0.14599	8.211834				
			1.14919917	5.76	-0.16858	8.33484				
			1.14919917	5.76	-0.16858	8.33484				
			1.202526568	6.26	-0.21868	8.401216				
			1.265572757	7.11	-0.26567	10.15159				
			1.296015139	7.51	-0.32452	10.69337				
			1.296015139	7.51	-0.32452	10.69337				
			1.332426087	8.23	-0.3584	11.98016				
			1.363303483	9.15	-0.41516	12.14674				
			1.363303483	9.15	-0.41516	12.14674				
			1.392603325	9.83	-0.47678	13.30953				
			1.422719048	10.69	-0.54349	13.56632				
			1.422719048	10.69	-0.54349	13.56632				
			1.45538587	11.37	-0.61059	14.44244				
			1.487468924	12.27	-0.70018	14.68734				
			1.487468924	12.27	-0.70018	14.68734				
			1.517039442	13.00	-0.77612	16.23144				
			1.517039442	13.00	-0.77612	16.23144				
			1.519621854	13.25	-0.74758	15.64182				
			1.579514925	14.87	-0.85996	17.60275				
			1.638864945	17.30	-0.88262	19.69842				
			1.709015741	20.51	-0.77304	22.1435				
			1.772598755	24.68	-0.50475	25.27064				
			1.831087151	28.61	-0.15859	26.74321				
			1.898914428	33.63	0.331481	29.33327				

TEST,TIME	TEST,NAME	INLINE N	TOW_FORCE N
08.01.29.9.58	XPULL_001	10.3608628	10.81332973
		20.7379546	20.89134258
		25.6086539	26.30667621
		30.771128	30.97312365
		40.4087215	41.19293065
		42.2747871	42.49713193
		51.7994196	52.19456319
		55.5153597	55.85830141
08.01.29.16.22	XPULL_002	8.8223256	8.802837391
		17.9350318	17.84844532
		26.2735586	26.17201892
		35.1635037	35.06439089
		43.0878226	42.99827544
		50.7943303	50.52195661
		58.6641096	58.40116967
08.01.30.9.17	XPULL_003	8.98306384	8.931983485
		16.8510235	16.69130456
		23.0237909	22.80840427
		33.2954333	33.03966536
		42.2569229	41.7843607
		48.7830075	47.7918413
08.01.30.16.36	XPULL_004	9.66848401	9.693421854
		19.3765463	18.87673229
		28.7942333	28.59630233
		38.7457936	38.40632164
		49.0352841	48.53345854

RESISTANCE ANALYZED DATA

TEST,COND	V,S knot	R,TS kN	P,ES kW	z,VS m	theta deg	Fr	C,TS	C,TM15_C	C,R	C,A	C,FS	C,FM15	zvLm	
Conv, Design Draft	5.24	6.7	18	0.0572	0.05	0.1488	0.00549	0.0076	0.00293	0.0004	0.002168	0.004676	0%	18.333
Conv, Design Draft	6.3	9.9	32	0.0428	0.015	0.1787	0.0056	0.00759	0.00309	0.0004	0.00211	0.004495	0%	
Conv, Design Draft	7.36	15.1	57	0.0997	-0.005	0.2089	0.00625	0.00814	0.00379	0.0004	0.002063	0.00435	0%	
Conv, Design Draft	8.39	21	91	0.1176	-0.033	0.238	0.00671	0.00852	0.00428	0.0004	0.002025	0.004233	0%	
Conv, Design Draft	8.39	21	91	0.1176	-0.033	0.238	0.00671	0.00852	0.00428	0.0004	0.002025	0.004233	0%	
Conv, Design Draft	8.4	21.3	92	0.1055	-0.039	0.2384	0.0068	0.00861	0.00438	0.0004	0.002024	0.004232	0%	
Conv, Design Draft	8.42	21.5	93	0.1179	-0.032	0.2388	0.00684	0.00864	0.00441	0.0004	0.002024	0.00423	0%	
Conv, Design Draft	8.42	21.5	93	0.1179	-0.032	0.2388	0.00684	0.00864	0.00441	0.0004	0.002024	0.00423	0%	
Conv, Design Draft	9.47	31.2	152	0.1533	-0.039	0.2686	0.00785	0.00959	0.00546	0.0004	0.00199	0.00413	0%	
Conv, Design Draft	9.97	36.9	189	0.1797	-0.029	0.2828	0.00836	0.01007	0.00599	0.0004	0.001976	0.004086	1%	
Conv, Design Draft	10.52	46	249	0.1863	-0.013	0.2985	0.00935	0.01103	0.00699	0.0004	0.001961	0.004042	1%	
Conv, Design Draft	10.89	58.6	329	0.2093	-0.015	0.3089	0.01114	0.0128	0.00879	0.0004	0.001952	0.004014	1%	
Conv, Design Draft	10.89	58.6	329	0.2093	-0.015	0.3089	0.01114	0.0128	0.00879	0.0004	0.001952	0.004014	1%	
Conv, Design Draft	11.26	68.9	399	0.2294	-0.032	0.3194	0.01224	0.01388	0.0099	0.0004	0.001942	0.003987	1%	
Conv, Design Draft	11.26	68.9	399	0.2294	-0.032	0.3194	0.01224	0.01388	0.0099	0.0004	0.001942	0.003987	1%	
Conv, Design Draft	11.57	73.4	437	0.232	-0.071	0.3283	0.01234	0.01397	0.01001	0.0004	0.001935	0.003966	1%	
Conv, Design Draft	12.08	86.2	536	0.2621	-0.097	0.3427	0.01331	0.01492	0.01098	0.0004	0.001923	0.003932	1%	
Conv, Design Draft	12.08	86.2	536	0.2621	-0.097	0.3427	0.01331	0.01492	0.01098	0.0004	0.001923	0.003932	1%	
Conv, Design Draft	12.64	100.8	655	0.2836	-0.113	0.3586	0.0142	0.01579	0.01189	0.0004	0.001911	0.003897	1%	
Conv, Design Draft	13.14	113.9	770	0.3104	-0.06	0.3728	0.01485	0.01642	0.01255	0.0004	0.001901	0.003867	1%	
Conv, Design Draft	13.66	130.1	914	0.3424	0.075	0.3874	0.01571	0.01725	0.01342	0.0004	0.001891	0.003838	1%	
Conv, Design Draft	13.66	130.1	914	0.3424	0.075	0.3874	0.01571	0.01725	0.01342	0.0004	0.001891	0.003838	1%	
Conv, Design Draft	14.22	152.2	1113	0.3584	0.4	0.4034	0.01695	0.01848	0.01467	0.0004	0.001881	0.003807	1%	
Conv, Design Draft	14.75	175.2	1330	0.409	0.774	0.4184	0.01814	0.01965	0.01587	0.0004	0.001871	0.00378	1%	
Conv, Design Draft	15.22	202.8	1588	0.4133	1.25	0.4319	0.0197	0.02119	0.01744	0.0004	0.001863	0.003757	1%	
Conv, Design Draft	15.72	237	1917	0.4491	1.824	0.4461	0.02159	0.02307	0.01933	0.0004	0.001855	0.003734	1%	
Conv, Design Draft	15.79	246.1	2000	0.4608	1.952	0.448	0.02222	0.0237	0.01997	0.0004	0.001854	0.00373	1%	
Conv, Design Draft	15.79	246.1	2000	0.4608	1.952	0.448	0.02222	0.0237	0.01997	0.0004	0.001854	0.00373	1%	
Bulb C, Design Draft	5.24	8	22	0.0508	0.049	0.1486	0.00568	0.00779	0.00311	0.0004	0.002167	0.004674	0%	
Bulb C, Design Draft	6.31	11.8	38	0.0581	0.012	0.1787	0.00581	0.00779	0.0033	0.0004	0.002109	0.004492	0%	
Bulb C, Design Draft	7.37	17.1	65	0.089	-0.054	0.2088	0.00614	0.00802	0.00368	0.0004	0.002062	0.004347	0%	
Bulb C, Design Draft	7.37	17.1	65	0.089	-0.054	0.2088	0.00614	0.00802	0.00368	0.0004	0.002062	0.004347	0%	
Bulb C, Design Draft	7.38	17.9	68	0.0779	-0.057	0.209	0.00642	0.00831	0.00396	0.0004	0.002062	0.004346	0%	
Bulb C, Design Draft	8.4	24.1	104	0.1281	-0.154	0.2379	0.00667	0.00847	0.00424	0.0004	0.002024	0.004231	0%	
Bulb C, Design Draft	9.53	33	162	0.1389	-0.281	0.2699	0.00709	0.00882	0.0047	0.0004	0.001988	0.004123	0%	
Bulb C, Design Draft	10	36.3	187	0.1554	-0.367	0.2834	0.00707	0.00878	0.0047	0.0004	0.001974	0.004082	0%	
Bulb C, Design Draft	10.53	38.7	209	0.1881	-0.466	0.2984	0.0068	0.00848	0.00444	0.0004	0.00196	0.00404	1%	
Bulb C, Design Draft	10.53	38.7	209	0.1881	-0.466	0.2984	0.0068	0.00848	0.00444	0.0004	0.00196	0.00404	1%	
Bulb C, Design Draft	10.55	39.1	212	0.1811	-0.448	0.2988	0.00685	0.00853	0.00449	0.0004	0.00196	0.004038	1%	
Bulb C, Design Draft	10.82	42	234	0.2083	-0.505	0.3065	0.007	0.00867	0.00465	0.0004	0.001953	0.004018	1%	
Bulb C, Design Draft	10.82	42	234	0.2083	-0.505	0.3065	0.007	0.00867	0.00465	0.0004	0.001953	0.004018	1%	
Bulb C, Design Draft	11.04	45.1	256	0.2119	-0.527	0.3129	0.00722	0.00887	0.00487	0.0004	0.001947	0.004001	1%	
Bulb C, Design Draft	11.31	52.1	303	0.2445	-0.578	0.3204	0.00796	0.0096	0.00562	0.0004	0.001941	0.003982	1%	
Bulb C, Design Draft	11.31	52.1	303	0.2445	-0.578	0.3204	0.00796	0.0096	0.00562	0.0004	0.001941	0.003982	1%	
Bulb C, Design Draft	11.58	55.4	330	0.2452	-0.678	0.3282	0.00805	0.00968	0.00572	0.0004	0.001934	0.003963	1%	

Bulb C, Design Draft	11.86	63.3	386	0.2518	-0.739	0.336	0.00878	0.0104	0.00645	0.0004	0.001928	0.003945	1%
Bulb C, Design Draft	11.86	63.3	386	0.2518	-0.739	0.336	0.00878	0.0104	0.00645	0.0004	0.001928	0.003945	1%
Bulb C, Design Draft	12.14	68.8	430	0.2692	-0.84	0.3441	0.00911	0.01071	0.00678	0.0004	0.001921	0.003926	1%
Bulb C, Design Draft	12.14	70.4	440	0.2692	-0.84	0.3441	0.00931	0.01092	0.00699	0.0004	0.001921	0.003926	1%
Bulb C, Design Draft	12.18	70.2	440	0.281	-0.836	0.3452	0.00923	0.01083	0.00691	0.0004	0.001921	0.003924	1%
Bulb C, Design Draft	12.39	74.6	475	0.3064	-0.942	0.351	0.00948	0.01107	0.00716	0.0004	0.001916	0.003911	1%
Bulb C, Design Draft	12.39	74.6	475	0.3064	-0.942	0.351	0.00948	0.01107	0.00716	0.0004	0.001916	0.003911	1%
Bulb C, Design Draft	12.65	79.1	514	0.3038	-1.026	0.3584	0.00964	0.01123	0.00733	0.0004	0.001911	0.003895	1%
Bulb C, Design Draft	13.15	89.8	608	0.3521	-1.189	0.3726	0.01014	0.0117	0.00784	0.0004	0.0019	0.003865	1%
Bulb C, Design Draft	13.65	101.7	714	0.3746	-1.29	0.3867	0.01064	0.01219	0.00835	0.0004	0.001891	0.003836	1%
Bulb C, Design Draft	14.27	122.7	901	0.4137	-1.229	0.4044	0.01175	0.01328	0.00947	0.0004	0.001879	0.003803	1%
Bulb C, Design Draft	14.76	141.6	1075	0.474	-1.048	0.4182	0.01268	0.01419	0.01041	0.0004	0.00187	0.003778	1%
Bulb C, Design Draft	15.24	165.4	1296	0.5138	-0.717	0.4317	0.0139	0.01539	0.01164	0.0004	0.001862	0.003755	2%
Bulb C, Design Draft	15.72	192.9	1560	0.5485	-0.309	0.4454	0.01523	0.01671	0.01298	0.0004	0.001854	0.003732	2%
Bulb D, Design Draft	5.26	11	30	0.0365	0.057	0.149	0.00798	0.01008	0.00541	0.0004	0.002166	0.004671	0%
Bulb D, Design Draft	6.32	17.6	57	0.0644	0.03	0.179	0.00884	0.01082	0.00633	0.0004	0.002109	0.004491	0%
Bulb D, Design Draft	7.36	23	87	0.0898	0.008	0.2085	0.00847	0.01035	0.00601	0.0004	0.002063	0.004348	0%
Bulb D, Design Draft	7.36	23	87	0.0898	0.008	0.2085	0.00847	0.01035	0.00601	0.0004	0.002063	0.004348	0%
Bulb D, Design Draft	8.42	30.1	130	0.1089	-0.037	0.2386	0.00848	0.01028	0.00605	0.0004	0.002023	0.004228	0%
Bulb D, Design Draft	9.56	38.8	191	0.1542	-0.033	0.271	0.00846	0.0102	0.00608	0.0004	0.001987	0.004119	0%
Bulb D, Design Draft	9.95	43	220	0.1618	-0.037	0.2818	0.00869	0.0104	0.00631	0.0004	0.001976	0.004087	0%
Bulb D, Design Draft	10.53	48.1	260	0.1767	-0.076	0.2983	0.00866	0.01034	0.0063	0.0004	0.00196	0.00404	1%
Bulb D, Design Draft	10.8	51.3	285	0.1936	-0.1	0.3061	0.00878	0.01044	0.00642	0.0004	0.001953	0.004019	1%
Bulb D, Design Draft	10.8	51.3	285	0.1936	-0.1	0.3061	0.00878	0.01044	0.00642	0.0004	0.001953	0.004019	1%
Bulb D, Design Draft	11.07	55.7	317	0.1965	-0.098	0.3136	0.00908	0.01073	0.00673	0.0004	0.001947	0.004	1%
Bulb D, Design Draft	11.3	58.2	338	0.2154	-0.141	0.3203	0.00909	0.01074	0.00675	0.0004	0.001941	0.003983	1%
Bulb D, Design Draft	11.3	58.2	338	0.2154	-0.141	0.3203	0.00909	0.01074	0.00675	0.0004	0.001941	0.003983	1%
Bulb D, Design Draft	11.58	61.3	365	0.2227	-0.161	0.3282	0.00912	0.01075	0.00679	0.0004	0.001934	0.003963	1%
Bulb D, Design Draft	11.85	63.5	387	0.2379	-0.239	0.3358	0.00903	0.01065	0.0067	0.0004	0.001928	0.003945	1%
Bulb D, Design Draft	11.85	63.5	387	0.2379	-0.239	0.3358	0.00903	0.01065	0.0067	0.0004	0.001928	0.003945	1%
Bulb D, Design Draft	12.12	65	405	0.2464	-0.259	0.3436	0.00882	0.01043	0.0065	0.0004	0.001922	0.003927	1%
Bulb D, Design Draft	12.38	66.8	426	0.2589	-0.313	0.3508	0.00871	0.0103	0.00639	0.0004	0.001916	0.003911	1%
Bulb D, Design Draft	12.38	66.8	426	0.2589	-0.313	0.3508	0.00871	0.0103	0.00639	0.0004	0.001916	0.003911	1%
Bulb D, Design Draft	12.63	70.9	461	0.2846	-0.327	0.358	0.00887	0.01045	0.00656	0.0004	0.001911	0.003895	1%
Bulb D, Design Draft	12.63	70.9	461	0.2846	-0.327	0.358	0.00887	0.01045	0.00656	0.0004	0.001911	0.003895	1%
Bulb D, Design Draft	12.64	70.3	457	0.2761	-0.33	0.3582	0.00879	0.01037	0.00648	0.0004	0.001911	0.003895	1%
Bulb D, Design Draft	13.12	78.7	531	0.3028	-0.312	0.3719	0.00912	0.01069	0.00682	0.0004	0.001901	0.003866	1%
Bulb D, Design Draft	13.62	89.1	624	0.3333	-0.243	0.386	0.00958	0.01113	0.00729	0.0004	0.001891	0.003838	1%
Bulb D, Design Draft	14.23	105.8	775	0.3754	-0.039	0.4033	0.01043	0.01196	0.00815	0.0004	0.00188	0.003805	1%
Bulb D, Design Draft	14.75	125	949	0.4306	0.265	0.4181	0.01147	0.01298	0.0092	0.0004	0.00187	0.003778	1%
Bulb D, Design Draft	15.24	152.4	1194	0.4472	0.637	0.4317	0.01311	0.0146	0.01085	0.0004	0.001862	0.003755	1%
Bulb D, Design Draft	15.84	187.5	1527	0.5006	1.165	0.4487	0.01493	0.0164	0.01268	0.0004	0.001852	0.003727	1%
Bulb G, Design Draft	5.23	9	24	0.0438	0.06	0.1481	0.00652	0.00863	0.00396	0.0004	0.002168	0.004677	0%
Bulb G, Design Draft	6.3	13.4	43	0.0612	0.038	0.1786	0.00668	0.00867	0.00418	0.0004	0.002109	0.004493	0%
Bulb G, Design Draft	7.37	18.2	69	0.0894	-0.004	0.2087	0.00665	0.00854	0.00419	0.0004	0.002062	0.004347	0%
Bulb G, Design Draft	8.43	23.2	101	0.1089	-0.062	0.2389	0.00647	0.00827	0.00405	0.0004	0.002023	0.004227	0%
Bulb G, Design Draft	9.54	28	137	0.1411	-0.104	0.2703	0.00609	0.00782	0.0037	0.0004	0.001988	0.004121	0%

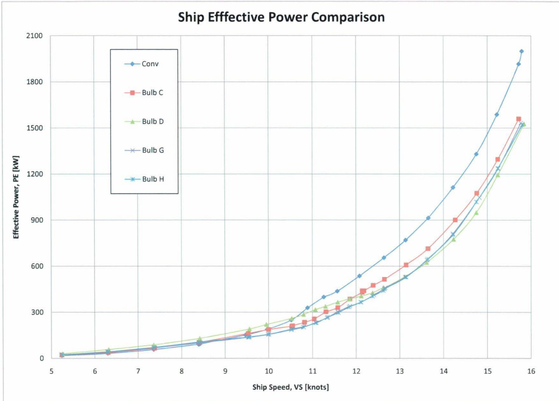
Bulb G, Design Draft	9.99	30.2	155	0.152	-0.148	0.2832	0.00598	0.00768	0.0036	0.0004	0.001975	0.004083	0%
Bulb G, Design Draft	10.52	34.1	185	0.1851	-0.211	0.2981	0.0061	0.00778	0.00374	0.0004	0.00196	0.004041	1%
Bulb G, Design Draft	10.8	36.4	202	0.1906	-0.264	0.306	0.00617	0.00784	0.00382	0.0004	0.001953	0.004019	1%
Bulb G, Design Draft	10.8	36.4	202	0.1906	-0.264	0.306	0.00617	0.00784	0.00382	0.0004	0.001953	0.004019	1%
Bulb G, Design Draft	11.07	40.7	232	0.2095	-0.289	0.3136	0.00658	0.00824	0.00424	0.0004	0.001946	0.003999	1%
Bulb G, Design Draft	11.34	45.1	263	0.2203	-0.347	0.3213	0.00694	0.00858	0.0046	0.0004	0.00194	0.00398	1%
Bulb G, Design Draft	11.34	45.1	263	0.2203	-0.347	0.3213	0.00694	0.00858	0.0046	0.0004	0.00194	0.00398	1%
Bulb G, Design Draft	11.58	50.8	303	0.2319	-0.373	0.3282	0.0075	0.00913	0.00516	0.0004	0.001934	0.003963	1%
Bulb G, Design Draft	11.86	55.8	340	0.2563	-0.446	0.336	0.00786	0.00947	0.00553	0.0004	0.001928	0.003945	1%
Bulb G, Design Draft	11.86	55.8	340	0.2563	-0.446	0.336	0.00786	0.00947	0.00553	0.0004	0.001928	0.003945	1%
Bulb G, Design Draft	12.11	58.6	365	0.2576	-0.525	0.3432	0.00791	0.00952	0.00559	0.0004	0.001922	0.003928	1%
Bulb G, Design Draft	12.41	64.6	412	0.2791	-0.607	0.3517	0.0083	0.00989	0.00598	0.0004	0.001916	0.003909	1%
Bulb G, Design Draft	12.41	64.6	412	0.2791	-0.607	0.3517	0.0083	0.00989	0.00598	0.0004	0.001916	0.003909	1%
Bulb G, Design Draft	12.65	69.7	454	0.2982	-0.66	0.3585	0.00862	0.0102	0.00631	0.0004	0.001911	0.003894	1%
Bulb G, Design Draft	12.65	69.7	454	0.2982	-0.66	0.3585	0.00862	0.0102	0.00631	0.0004	0.001911	0.003894	1%
Bulb G, Design Draft	12.67	70.5	459	0.3036	-0.655	0.3589	0.0087	0.01028	0.00639	0.0004	0.00191	0.003893	1%
Bulb G, Design Draft	13.13	78.3	529	0.325	-0.752	0.372	0.009	0.01056	0.0067	0.0004	0.001901	0.003866	1%
Bulb G, Design Draft	13.63	91.1	639	0.3589	-0.76	0.3862	0.00971	0.01125	0.00741	0.0004	0.001891	0.003837	1%
Bulb G, Design Draft	14.22	111	812	0.4011	-0.641	0.403	0.01086	0.01239	0.00858	0.0004	0.00188	0.003806	1%
Bulb G, Design Draft	14.82	137.3	1047	0.4569	-0.316	0.42	0.01238	0.01388	0.01011	0.0004	0.001869	0.003775	1%
Bulb G, Design Draft	15.25	157.7	1237	0.4878	0.003	0.4321	0.01342	0.01492	0.01116	0.0004	0.001862	0.003754	1%
Bulb G, Design Draft	15.77	189	1533	0.5238	0.505	0.447	0.01503	0.01651	0.01278	0.0004	0.001853	0.00373	2%
Bulb H, Design Draft	5.24	8.9	24	0.05	0.044	0.1486	0.0064	0.00851	0.00384	0.0004	0.002167	0.004673	0%
Bulb H, Design Draft	6.29	13	42	0.0739	0.021	0.1784	0.00645	0.00844	0.00394	0.0004	0.00211	0.004494	0%
Bulb H, Design Draft	6.3	12.8	42	0.0602	0.018	0.1784	0.00638	0.00836	0.00387	0.0004	0.00211	0.004493	0%
Bulb H, Design Draft	6.3	12.8	42	0.0602	0.018	0.1784	0.00638	0.00836	0.00387	0.0004	0.00211	0.004493	0%
Bulb H, Design Draft	7.36	18.6	71	0.0777	-0.032	0.2086	0.00678	0.00866	0.00432	0.0004	0.002062	0.004348	0%
Bulb H, Design Draft	8.4	24.6	106	0.1081	-0.097	0.238	0.00688	0.00868	0.00445	0.0004	0.002024	0.00423	0%
Bulb H, Design Draft	9.53	28.1	138	0.1505	-0.146	0.2699	0.00612	0.00785	0.00373	0.0004	0.001988	0.004123	0%
Bulb H, Design Draft	9.56	28.2	139	0.1528	-0.169	0.271	0.00608	0.00781	0.00369	0.0004	0.001987	0.004119	0%
Bulb H, Design Draft	9.56	28.2	139	0.1528	-0.169	0.271	0.00608	0.00781	0.00369	0.0004	0.001987	0.004119	0%
Bulb H, Design Draft	10.01	30.5	157	0.154	-0.219	0.2836	0.006	0.00771	0.00363	0.0004	0.001974	0.004081	0%
Bulb H, Design Draft	10.53	35	190	0.1861	-0.266	0.2985	0.00623	0.00791	0.00387	0.0004	0.00196	0.004039	1%
Bulb H, Design Draft	10.79	37	205	0.196	-0.325	0.3057	0.00628	0.00795	0.00393	0.0004	0.001954	0.00402	1%
Bulb H, Design Draft	10.79	37	205	0.196	-0.325	0.3057	0.00628	0.00795	0.00393	0.0004	0.001954	0.00402	1%
Bulb H, Design Draft	11.09	40.5	231	0.2196	-0.358	0.3142	0.0065	0.00815	0.00415	0.0004	0.001946	0.003998	1%
Bulb H, Design Draft	11.35	45.9	268	0.2227	-0.415	0.3215	0.00703	0.00867	0.00469	0.0004	0.00194	0.00398	1%
Bulb H, Design Draft	11.35	45.9	268	0.2227	-0.415	0.3215	0.00703	0.00867	0.00469	0.0004	0.00194	0.00398	1%
Bulb H, Design Draft	11.59	49.8	297	0.244	-0.477	0.3284	0.00732	0.00895	0.00499	0.0004	0.001934	0.003963	1%
Bulb H, Design Draft	11.84	54.8	334	0.2487	-0.543	0.3355	0.00771	0.00933	0.00539	0.0004	0.001928	0.003946	1%
Bulb H, Design Draft	11.84	54.8	334	0.2487	-0.543	0.3355	0.00771	0.00933	0.00539	0.0004	0.001928	0.003946	1%
Bulb H, Design Draft	12.11	58.7	366	0.2648	-0.611	0.3432	0.0079	0.00951	0.00558	0.0004	0.001922	0.003928	1%
Bulb H, Design Draft	12.38	63.6	405	0.2693	-0.7	0.3508	0.00819	0.00979	0.00588	0.0004	0.001916	0.003911	1%
Bulb H, Design Draft	12.38	63.6	405	0.2693	-0.7	0.3508	0.00819	0.00979	0.00588	0.0004	0.001916	0.003911	1%
Bulb H, Design Draft	12.63	67.9	441	0.2976	-0.776	0.3578	0.00841	0.01	0.0061	0.0004	0.001911	0.003896	1%
Bulb H, Design Draft	12.63	67.9	441	0.2976	-0.776	0.3578	0.00841	0.01	0.0061	0.0004	0.001911	0.003896	1%
Bulb H, Design Draft	12.65	69.5	452	0.2868	-0.748	0.3584	0.00857	0.01016	0.00626	0.0004	0.001911	0.003895	1%
Bulb H, Design Draft	13.15	78.1	529	0.3227	-0.86	0.3725	0.00892	0.01049	0.00662	0.0004	0.0019	0.003865	1%

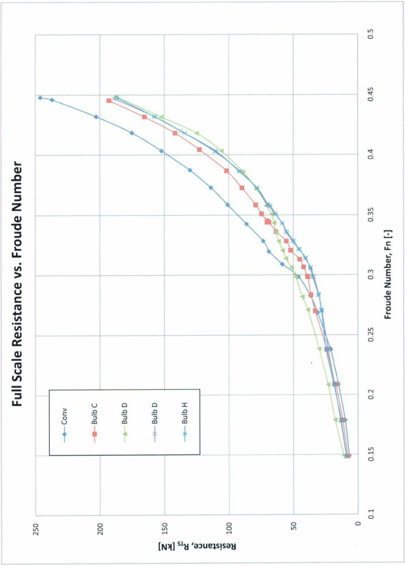
Bulb H, Design Draft	13.64	92.1	646	0.3611	-0.883	0.3865	0.00977	0.01131	0.00748	0.0004	0.001891	0.003837	1%
Bulb H, Design Draft	14.22	110	805	0.406	-0.773	0.4031	0.01074	0.01226	0.00846	0.0004	0.00188	0.003806	1%
Bulb H, Design Draft	14.75	134.2	1019	0.4633	-0.505	0.4181	0.01217	0.01368	0.0099	0.0004	0.001871	0.003778	1%
Bulb H, Design Draft	15.24	157.6	1236	0.4903	-0.159	0.4319	0.01339	0.01489	0.01113	0.0004	0.001862	0.003755	1%
Bulb H, Design Draft	15.8	187	1521	0.5378	0.331	0.4478	0.01478	0.01625	0.01253	0.0004	0.001853	0.003728	2%

V kts	Values Conv	Bulb C	Bulb D	Bulb G	Bulb H
8	79.8599	99.83871	111.5765	95.32102	94.8223461
9	114.8796	138.6741	157.1886	120.6306	121.6981173
10	197.857	173.0458	222.4911	148.3848	155.691472
11	343.558	260.1542	306.7381	228.0458	229.3665509
12	524.3018	406.4658	397.0588	353.9714	349.5391568
13	735.0849	582.7262	507.9117	510.4654	508.2537868
14	1027.718	811.9045	706.3457	742.8736	739.114456
15	1459.536	1181.146	1070.257	1121.147	1124.363483

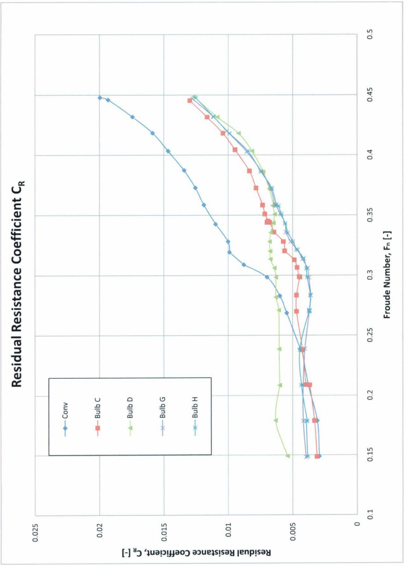
% of Conv Bulb C	Bulb D	Bulb G	Bulb H
125.02%	139.72%	119.36%	118.74%
120.71%	136.83%	105.01%	105.94%
87.46%	112.45%	75.00%	78.69%
75.72%	89.28%	66.38%	66.76%
77.53%	75.73%	67.51%	66.67%
79.27%	69.10%	69.44%	69.14%
79.00%	68.73%	72.28%	71.92%
80.93%	73.33%	76.82%	77.04%

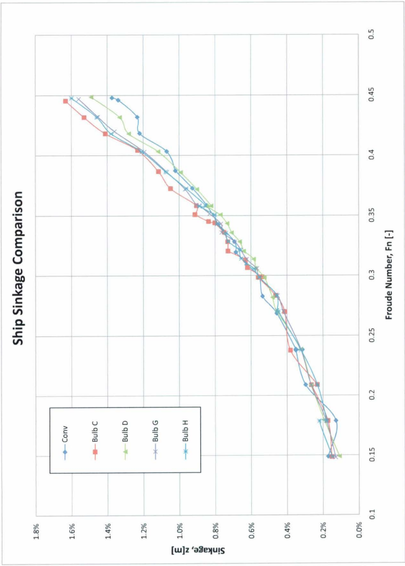
	dud	% of Conv Bulb C	Bulb D	Bulb G	Bulb H
8	0%	25%	40%	19%	19%
9	10%	21%	37%	5%	6%
10	4%	-13%	12%	-25%	-21%
11	5%	-24%	-11%	-34%	-33%
12	-8%	-22%	-24%	-32%	-33%
13	5%	-21%	-31%	-31%	-31%
14	-6%	-21%	-31%	-28%	-28%
15	-7%	-19%	-27%	-23%	-23%


Ship Efffective Power Comparison
Conv
Bulb C
Bulb D
Bulb G
Bulb H
Effective Power, PE [kW]
2100
1800
1500
1200
900
600
300
0
5
6
7
8
9
10
11
12
13
14
15
16
Ship Speed, VS [knots]

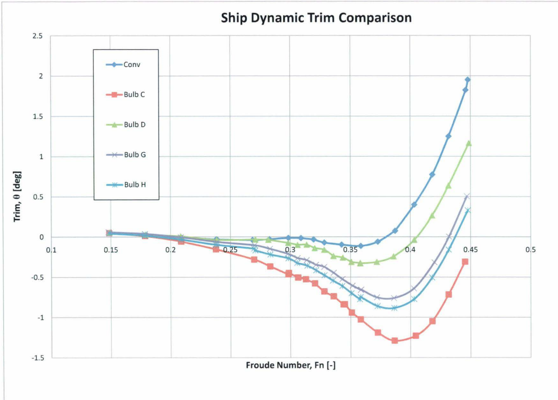


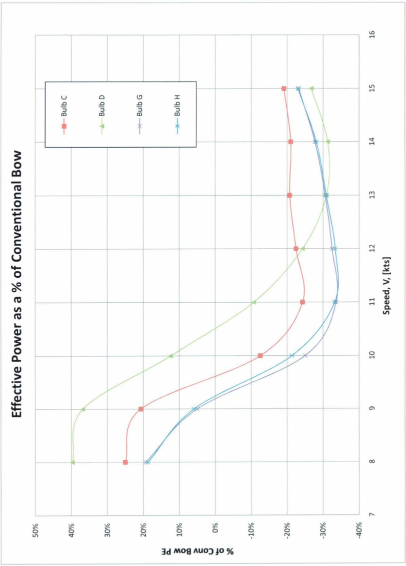
Full Scale Resistance vs. Froude Number
Resistance, R_{TS} [kN]
Froude Number, Fn [-]
Conv
Bulb C
Bulb D
Bulb D
Bulb H
0
50
100
150
200
250
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Residual Resistance Coefficient C_R
Conv
Bulb C
Bulb D
Bulb G
Bulb H
Residual Resistance Coefficient, C_R [-]
Froude Number, F_n [-]
0.025
0.02
0.015
0.01
0.005
0
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5



Ship Sinkage Comparison
Sinkage, z[m]
1.8%
1.6%
1.4%
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Froude Number, Fn [-]
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Conv
Bulb C
Bulb D
Bulb G
Bulb H


Ship Dynamic Trim Comparison
Conv
Bulb C
Bulb D
Bulb G
Bulb H
Trim, θ [deg]
Froude Number, Fn [-]
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Effective Power as a % of Conventional Bow
% of Conv Bow PE
50%
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
Speed, V, [kts]
7
8
9
10
11
12
13
14
15
16
Bulb C
Bulb D
Bulb G
Bulb H

Appendix H – Self-Propulsion Analysis Data

SELF-PROPULSION SOURCE DATA

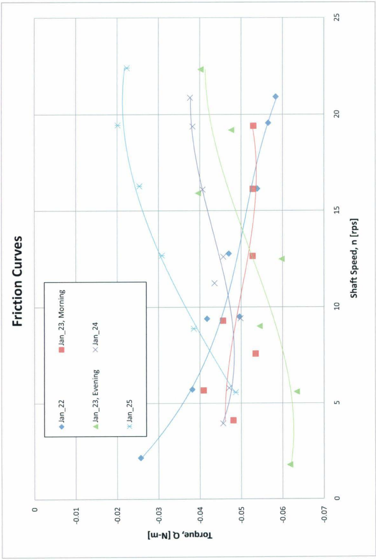
TEST,DRAFT	TEST,DESCRIP	TEST,DATE	TEST,NAME	V,M	F,DM	n,M	T,M	Q,M	trim	TEMP,M	TANK	DP,M
				m/s	N	rps	N	N*m	deg			m
Conv	9 knots	Jan_22	INT097_C_9k_003	1.106549	-6.05262	5.633004	-1.20355	-0.03685	-0.20917	11.2	OERC	0.1205
			INT097_C_9k_001	1.10691	13.46754	15.38935	19.12964	-0.53016	0.001521			
			INT097_C_9k_002	1.107001	1.769901	11.02752	6.301353	-0.24508	-0.12521			
			INT097_C_9k_003	1.107076	-4.2106	7.519038	0.617705	-0.09178	-0.19744			
			INT097_C_9k_002	1.107529	-1.69663	9.222188	2.868064	-0.15877	-0.15757			
			INT097_C_9k_001	1.108087	5.367847	12.56819	10.31861	-0.33089	-0.09052			
Conv	11 knots	Jan_22	INT097_C_11k_002	1.353079	0.76074	14.33795	12.29546	-0.38492	-0.0392	11.2	OERC	0.1205
			INT097_C_11k_001	1.353191	5.242778	16.05148	17.40189	-0.50943	0.013881			
			INT097_C_11k_003	1.353314	-1.54933	13.6304	10.2186	-0.34163	-0.05662			
			INT097_C_11k_003	1.354049	-5.63672	11.94735	6.12782	-0.23836	-0.10609			
			INT097_C_11k_001	1.354059	-4.4027	12.58704	7.455911	-0.2724	-0.08265			
			INT097_C_11k_002	1.354219	-7.02357	11.07358	4.129159	-0.19309	-0.12002			
Conv	13 knots	Jan_23, Evening	INT097_C_13k_002	1.599318	-6.78307	15.94861	14.39585	-0.46413	-0.01483	11.2	OERC	0.1205
			INT097_C_13k_001	1.599865	-15.3117	12.56297	4.785094	-0.25343	-0.15316			
			INT097_C_13k_002	1.600017	-14.6247	12.50108	5.161015	-0.2498	-0.18536			
			INT097_C_13k_003	1.600341	-2.41815	17.24456	18.78595	-0.57217	0.001007			
			INT097_C_13k_001	1.600448	-20.8575	9.192995	-1.22895	-0.09608	-0.25511			
Bulb C	9 knots	Jan_24	int097_bulbC_9k_001	1.105497	4.526475	12.76236	10.93245	-0.34805	-0.03568	11.2	OERC	0.1205
			int097_bulbC_9k_004	1.105819	-0.58505	10.52587	5.807639	-0.22496	-0.08273			
			int097_bulbC_9k_001	1.105908	-7.2155	5.61781	-0.87222	-0.05303	-0.14815			
			int097_bulbC_9k_002	1.10596	1.522622	11.61973	8.040219	-0.26482	-0.06391			
			int097_bulbC_9k_004	1.106138	-3.69982	8.748978	2.79411	-0.1422	-0.1116			
			int097_bulbC_9k_002	1.106468	-5.46781	7.501067	0.851762	-0.09278	-0.12882			
Bulb C	11 knots	Jan_24	int097_bulbC_11k_002	1.352397	2.12799	14.24073	12.08502	-0.38552	-0.12605	11.2	OERC	0.1205
			int097_bulbC_11k_003	1.352797	-0.53615	13.22597	9.324597	-0.31564	-0.15334			
			int097_bulbC_11k_001	1.35295	-1.91168	12.63541	7.828185	-0.28243	-0.17316			
			int097_bulbC_11k_002	1.35323	-5.39719	10.98529	4.138366	-0.19726	-0.22329			
			int097_bulbC_11k_001	1.353376	-8.60066	9.026457	1.130896	-0.11368	-0.26244			
			int097_bulbC_11k_003	1.353381	-3.83603	11.7388	5.861168	-0.23187	-0.21469			
Bulb C	12 knots	Jan_24	int097_bulbC_12k_002	1.475514	2.192983	15.81791	15.6794	-0.5019	-0.19417	11.2	OERC	0.1205
			int097_bulbC_12k_001	1.476287	-6.26035	12.58039	6.284231	-0.25685	-0.3019			
			int097_bulbC_12k_003	1.476334	-0.77212	14.81281	12.71646	-0.43798	-0.2456			
			int097_bulbC_12k_003	1.476574	-4.40138	13.59706	9.436124	-0.34754	-0.26326			
			int097_bulbC_12k_002	1.476667	-2.50217	14.18459	10.64851	-0.36261	-0.24011			
			int097_bulbC_12k_001	1.477143	-12.5059	9.128064	-0.02424	-0.09819	-0.38887			

Bulb C	13 knots	Jan_24	int097_bulbC_13k_003	1.599328	4.906939	17.94229	21.38534	-0.60677	-0.28451	11.2 OERC	0.1205
			int097_bulbC_13k_002	1.59999	-1.23057	15.85672	14.42228	-0.44441	-0.39957		
			int097_bulbC_13k_002	1.600013	9.363771	19.11581	26.15513	-0.70429	-0.2022		
			int097_bulbC_13k_003	1.600158	0.643511	16.75225	17.20183	-0.51251	-0.33682		
			int097_bulbC_13k_001	1.600561	-6.84372	13.80811	8.338952	-0.30771	-0.46887		
			int097_bulbC_13k_001	1.601455	-13.003	10.48707	1.410395	-0.13258	-0.63356		
Bulb C	15 knots	Jan_25	int097_bulbC_15k_002	1.846858	-10.4682	17.21685	15.49446	-0.50285	0.170565	11.2 OERC	0.1205
			int097_bulbC_15k_001	1.846885	0.755913	20.4089	27.11657	-0.75303	0.338902		
			int097_bulbC_15k_001	1.847916	-13.7829	16.02353	11.25312	-0.38811	0.070909		
			int097_bulbC_15k_002	1.848361	-4.53132	19.09097	22.02424	-0.64335	0.27615		
			int097_bulbC_15k_003	1.858229	2.276101	20.9913	29.3355	-0.81663	0.454286		
			int097_bulbC_15k_003	1.858322	2.44032	20.99102	29.34387	-0.81777	0.437008		
			int097_bulbC_15k_003	1.858979	-1.89803	19.7889	24.41322	-0.69441	0.33935		
Bulb D	9 knots	Jan_25	int097_bulbD_9k_003	1.104544	2.446558	12.05796	5.910176	-0.29219	-0.00221	11.2 OERC	0.1205
			int097_bulbD_9k_001	1.105339	-2.5419	9.333893	4.042098	-0.16676	-0.05806		
			int097_bulbD_9k_003	1.1055	-0.59973	10.71614	2.862514	-0.22288	-0.03576		
			int097_bulbD_9k_001	1.10565	-7.07374	5.584734	-0.63631	-0.05567	-0.11072		
			int097_bulbD_9k_002	1.106417	0.225666	11.14281	7.35171	-0.24338	-0.01891		
			int097_bulbD_9k_002	1.106864	-1.95534	9.937191	5.068477	-0.18859	-0.04647		
Bulb D	11 knots	Jan_25	int097_bulbD_11k_001	1.344759	-3.38189	12.61849	8.206444	-0.27397	-0.02495	11.2 OERC	0.1205
			int097_bulbD_11k_001	1.345846	-9.62007	9.223887	1.680343	-0.12432	-0.09442		
			int097_bulbD_11k_003	1.351825	-0.26485	13.87827	11.54821	-0.35339	0.003241		
			int097_bulbD_11k_002	1.351827	1.982988	14.65979	13.88341	-0.39904	0.017977		
			int097_bulbD_11k_003	1.352231	-3.27395	12.88535	8.90739	-0.29029	-0.02556		
			int097_bulbD_11k_002	1.352871	-1.99716	13.30014	10.03032	-0.31408	0.010656		
Bulb D	12 knots	Jan_25	int097_bulbD_12k_002	1.47577	1.296173	15.54497	15.28822	-0.44085	-0.06484	11.2 OERC	0.1205
			int097_bulbD_12k_003	1.475914	-1.00148	14.80535	13.03562	-0.3907	-0.09389		
			int097_bulbD_12k_001	1.476031	0.273457	15.12439	14.00555	-0.4103	-0.0735		
			int097_bulbD_12k_001	1.476044	-6.92921	12.46644	6.684987	-0.24272	-0.17502		
			int097_bulbD_12k_003	1.476489	-3.84706	13.9128	10.46621	-0.33322	-0.11083		
			int097_bulbD_12k_002	1.47705	-5.29976	13.19705	8.461271	-0.28604	-0.15096		
Bulb D	13 knots	Jan_25	int097_bulbD_13k_003	1.598272	-1.51027	15.83005	14.72131	-0.44052	-0.08205	11.2 OERC	0.1205
			int097_bulbD_13k_001	1.598885	4.966561	18.02159	22.23856	-0.60576	0.023338		
			int097_bulbD_13k_003	1.59906	-4.72227	14.57833	11.04692	-0.35662	-0.16301		
			int097_bulbD_13k_002	1.599575	0.378396	16.50951	16.75247	-0.48439	-0.05466		
			int097_bulbD_13k_001	1.599982	-3.98781	15.34046	13.11175	-0.40007	-0.07482		
			int097_bulbD_13k_002	1.600091	-6.34218	13.96913	9.369485	-0.31646	-0.216		

Bulb D	15 knots	Jan_25	int097_bulbD_15k_003	1.846246	1.095873	21.14073	30.41661	-0.80444	1.0745	11.2 OERC	0.1205
			int097_bulbD_15k_002	1.846781	5.273815	22.08317	34.69485	-0.90304	1.115113		
			int097_bulbD_15k_001	1.846967	-6.39869	19.17873	22.24919	-0.63226	0.965109		
			int097_bulbD_15k_003	1.847108	-4.99226	19.67706	24.15967	-0.67249	1.025344		
			int097_bulbD_15k_001	1.847496	-16.6465	15.88249	11.40254	-0.38098	0.819992		
			int097_bulbD_15k_002	1.847865	-2.42411	20.32644	26.87557	-0.73577	1.056451		
Bulb G	11 knots	Jan_25	int097_bulbG_11k_003	1.351202	1.473256	13.60773	10.65476	-0.33319	-0.2477	11.2 OERC	0.1205
			int097_bulbG_11k_001	1.351898	5.512975	15.04973	14.86537	-0.43344	-0.18851		
			int097_bulbG_11k_002	1.351931	2.069797	13.84889	11.18309	-0.35045	-0.22491		
			int097_bulbG_11k_003	1.352054	-0.66367	12.9559	8.825453	-0.29339	-0.26765		
			int097_bulbG_11k_001	1.352493	-2.04567	12.51774	7.539678	-0.27277	-0.26016		
			int097_bulbG_11k_002	1.352883	-2.87615	11.89038	6.114265	-0.23835	-0.30446		
Bulb G	13 knots	Jan_25	int097_bulbG_13k_002	1.598928	0.022122	16.43188	16.43617	-0.47586	-0.57533	11.2 OERC	0.1205
			int097_bulbG_13k_003	1.59995	-2.47125	15.67667	14.14714	-0.42359	-0.59442		
			int097_bulbG_13k_003	1.599958	-0.54277	16.26352	15.92371	-0.46392	-0.58193		
			int097_bulbG_13k_001	1.600005	5.562832	17.95754	22.03727	-0.59157	-0.45997		
			int097_bulbG_13k_002	1.600117	-6.72824	13.90152	9.072652	-0.30766	-0.6896		
			int097_bulbG_13k_001	1.60032	-2.53548	15.40849	13.39737	-0.40625	-0.62209		
Bulb G	15 knots	Jan_25	int097_bulbG_15k_003	1.846179	0.163514	20.68825	28.98998	-0.77463	0.303174	11.2 OERC	0.1205
			int097_bulbG_15k_001	1.84628	5.763183	22.22383	35.35672	-0.91801	0.466422		
			int097_bulbG_15k_002	1.846893	1.633395	21.14297	30.8115	-0.81147	0.380802		
			int097_bulbG_15k_001	1.847064	-7.60985	19.13197	22.04006	-0.62647	0.333151		
			int097_bulbG_15k_003	1.847148	-5.50281	19.68599	24.48859	-0.68113	0.337917		
			int097_bulbG_15k_002	1.847319	-2.06978	20.41086	27.47894	-0.73992	0.40403		
Bulb H	9 knots	Jan_24	int097_bulbH_9k_002	1.104066	1.098508	11.1035	7.021143	-0.24682	-0.10694	11.2 OERC	0.1205
			int097_bulbH_9k_001	1.105602	-2.04408	9.355977	3.73699	-0.16455	-0.14341		
			int097_bulbH_9k_003	1.105782	-1.16104	9.968584	4.661945	-0.19615	-0.1394		
			int097_bulbH_9k_003	1.105895	-3.42911	8.608841	2.536272	-0.14142	-0.16042		
			int097_bulbH_9k_001	1.105993	-6.65907	5.71844	-0.85946	-0.05209	-0.18375		
			int097_bulbH_9k_002	1.106429	-4.90389	7.411601	0.758257	-0.10098	-0.16348		
Bulb H	11 knots	Jan_24	int097_bulbH_11k_003	1.351761	0.416802	13.25003	9.423218	-0.31427	-0.22666	11.2 OERC	0.1205
			int097_bulbH_11k_002	1.351871	2.209539	13.96489	11.62397	-0.3589	-0.21203		
			int097_bulbH_11k_001	1.352331	-0.6643	12.67812	8.193266	-0.28042	-0.26269		
			int097_bulbH_11k_003	1.352663	-2.94304	11.91443	6.259501	-0.23894	-0.24158		
			int097_bulbH_11k_002	1.352703	-5.98741	10.25053	3.153162	-0.16274	-0.28734		
			int097_bulbH_11k_001	1.353023	-7.06471	9.197234	1.356446	-0.12191	-0.33996		

Bulb H	12 knots	Jan_24	int097_bulbH_12k_003	1.475607	0.324566	14.65662	12.292	-0.38033	-0.40951	11.2 OERC	0.1205
			int097_bulbH_12k_001	1.475637	3.407172	15.8255	15.90201	-0.46398	-0.34589		
			int097_bulbH_12k_002	1.475845	2.042254	15.39748	14.53892	-0.43136	-0.34313		
			int097_bulbH_12k_003	1.475983	-3.85693	13.18528	8.21939	-0.29093	-0.48503		
			int097_bulbH_12k_002	1.476447	-2.11894	13.77602	9.895068	-0.32848	-0.4327		
			int097_bulbH_12k_001	1.476909	-5.77401	12.45617	6.454984	-0.25322	-0.4672		
Bulb H	13 knots	Jan_24	int097_bulbH_13k_001	1.598942	-0.46135	16.07047	15.21339	-0.45098	-0.572	11.2 OERC	0.1205
			int097_bulbH_13k_003	1.599237	0.807222	16.47597	16.75245	-0.4852	-0.53525		
			int097_bulbH_13k_003	1.599246	0.887362	16.47628	16.75464	-0.48525	-0.53686		
			int097_bulbH_13k_002	1.599386	-7.17492	13.67356	8.244267	-0.287	-0.64222		
			int097_bulbH_13k_003	1.59966	-2.54239	15.30291	13.02627	-0.39842	-0.60773		
			int097_bulbH_13k_001	1.600151	-9.64452	12.5128	5.530907	-0.22998	-0.722		
Bulb H	15 knots	Jan_24	int097_bulbH_15k_002	1.846346	0.014951	20.53965	28.08225	-0.76855	0.325722	11.2 OERC	0.1205
			int097_bulbH_15k_003	1.847228	4.499891	21.57702	32.41508	-0.86673	0.386855		
			int097_bulbH_15k_002	1.84723	-8.81491	18.42416	19.42156	-0.57362	0.261087		
			int097_bulbH_15k_001	1.847641	-0.96746	20.43543	27.41709	-0.7498	0.341834		
			int097_bulbH_15k_003	1.847678	-4.76599	19.68551	24.1215	-0.68613	0.39569		
			int097_bulbH_15k_001	1.847991	-17.0182	15.75253	10.71536	-0.36823	0.132518		

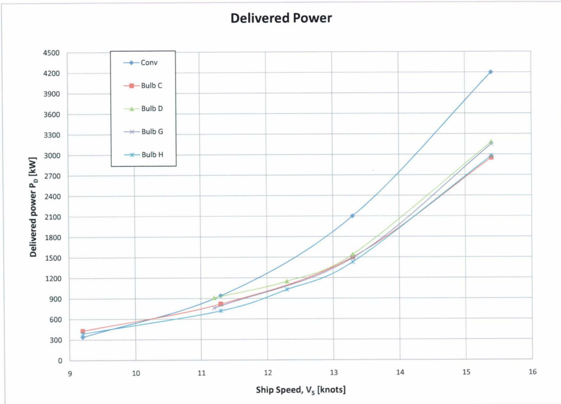
TEST,DATE_FR	TEST,NAME_TC	n,M_FR rps	Q,M_FR N*m
Jan_22	Friction_C_SP_001	2.155506	-0.02567
	Friction_C_SP_001	5.72721	-0.03815
	Friction_C_SP_001	9.396281	-0.04174
	Friction_C_SP_001	9.502341	-0.04959
	Friction_C_SP_001	12.78701	-0.047
	Friction_C_SP_001	16.14057	-0.05388
	Friction_C_SP_001	19.56354	-0.05653
	Friction_C_SP_001	20.9158	-0.05835
Jan_23, Morning	Friction_C_SP_005	5.674921	-0.04089
	Friction_C_SP_005	9.292045	-0.04561
	Friction_C_SP_005	12.6539	-0.05277
	Friction_C_SP_005	16.12295	-0.05279
	Friction_C_SP_005	19.4064	-0.05295
	Friction_C_SP_005	7.578063	-0.05347
	Friction_C_SP_005	4.099436	-0.04807
Jan_23, Evening	Friction_C_SP_006	5.595233	-0.06342
	Friction_C_SP_006	12.49746	-0.05978
	Friction_C_SP_006	19.19261	-0.04761
	Friction_C_SP_006	22.33098	-0.0402
	Friction_C_SP_006	15.9125	-0.03958
	Friction_C_SP_006	9.005455	-0.05445
	Friction_C_SP_006	1.776533	-0.06177
Jan_24	Friction_C_SP_007	5.801325	-0.04705
	Friction_C_SP_007	9.413855	-0.04984
	Friction_C_SP_007	12.6217	-0.04567
	Friction_C_SP_007	16.09702	-0.04068
	Friction_C_SP_007	19.38065	-0.03825
	Friction_C_SP_007	20.87328	-0.03765
	Friction_C_SP_007	11.24291	-0.04355
	Friction_C_SP_007	3.942354	-0.04562
Jan_25	Friction_001	5.574452	-0.04867
	Friction_001	12.69431	-0.03081
	Friction_001	19.44776	-0.02012
	Friction_001	22.4125	-0.02233
	Friction_001	16.27965	-0.02537
	Friction_001	8.881871	-0.03851

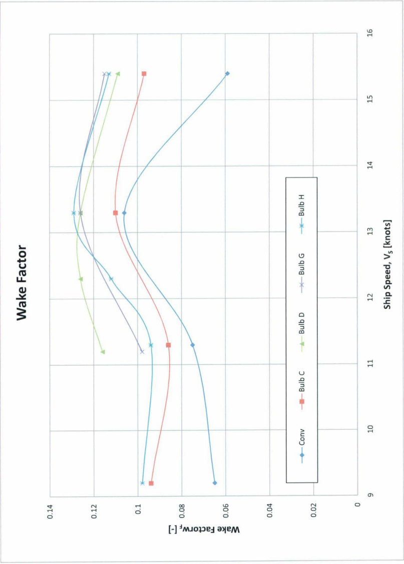


Friction Curves
Torque, Q [N-m]
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
Shaft Speed, n [rps]
0
5
10
15
20
25
Jan_22
Jan_23, Morning
Jan_23, Evening
Jan_24
Jan_25

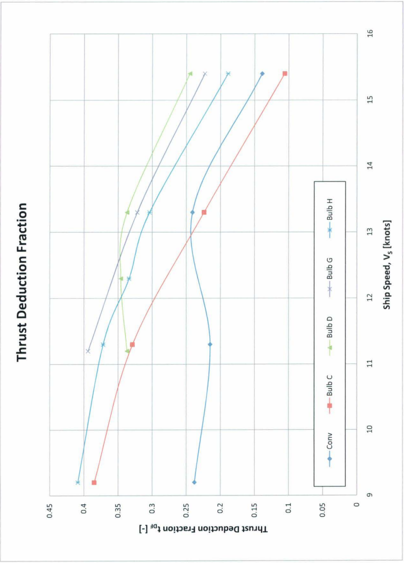
SELF-PROPULSION ANALYZED DATA

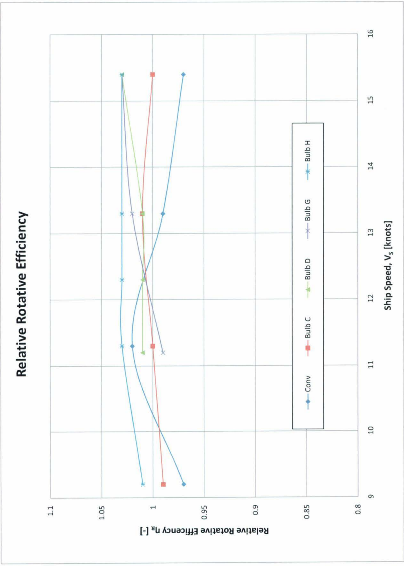
TEST,COND	V,S	n,S	T,S	Q,S	P,DS	P,ES	R,TS	ETA,DS	t,DF	w,T	ETA,R	ETA,OPEN	ETA,H	J,SP	J,OPEN	trimSP	
Conv, 9.209777194 Knots	9.2	151	37	21	340	140	29	0.402	0.238	0.065	0.97	0.507	0.815	0.853	0.798	-0.13	-0.1%
Conv, 11.26163720 Knots	11.3	208	87	43	940	390	68	0.421	0.215	0.075	1.02	0.486	0.848	0.756	0.7	-0.02	-0.1%
Conv, 13.31107808 Knots	13.3	263	156	76	2100	810	118	0.387	0.241	0.106	0.99	0.46	0.849	0.706	0.631	-0.05	0.0%
Conv, 15.37852614 Knots	15.4	328	248	122	4200	1690	213	0.402	0.139	0.059	0.97	0.454	0.915	0.655	0.616	1.54	0.1%
Bulb C, 9.201018159 Knots	9.2	161	49	26	430	140	30	0.332	0.385	0.094	0.99	0.494	0.678	0.8	0.725	-0.07	0.0%
Bulb C, 11.25595626 Knots	11.3	199	76	39	820	300	51	0.362	0.329	0.086	1	0.493	0.735	0.791	0.723	-0.13	0.0%
Bulb C, 13.31116099 Knots	13.3	242	120	59	1500	640	93	0.425	0.224	0.11	1.01	0.481	0.871	0.769	0.684	-0.32	-0.2%
Bulb C, 15.37134207 Knots	15.4	298	193	95	2950	1370	173	0.463	0.106	0.097	1	0.469	0.99	0.721	0.651	0.48	0.1%
Bulb D, 11.19238800 Knots	11.2	204	86	43	910	330	57	0.363	0.337	0.116	1.01	0.479	0.75	0.768	0.679	0.02	0.0%
Bulb D, 12.28278651 Knots	12.3	221	101	50	1150	420	66	0.363	0.346	0.126	1.01	0.48	0.748	0.778	0.68	-0.06	0.0%
Bulb D, 13.30236866 Knots	13.3	242	124	61	1540	560	82	0.364	0.337	0.126	1.01	0.476	0.758	0.767	0.67	-0.02	0.0%
Bulb D, 15.36625207 Knots	15.4	306	212	99	3180	1270	160	0.399	0.245	0.109	1.03	0.458	0.847	0.702	0.625	1.11	0.1%
Bulb G, 11.24601044 Knots	11.2	194	72	37	760	250	43	0.33	0.394	0.098	0.99	0.495	0.672	0.808	0.729	-0.23	-0.1%
Bulb G, 13.30782741 Knots	13.3	241	121	59	1490	560	82	0.378	0.322	0.126	1.02	0.478	0.776	0.772	0.675	-0.53	0.0%
Bulb G, 15.36569453 Knots	15.4	305	211	99	3150	1300	164	0.412	0.223	0.115	1.03	0.457	0.878	0.705	0.623	0.4	0.1%
Bulb H, 9.189104686 Knots	9.2	157	46	24	390	130	27	0.33	0.409	0.098	1.01	0.497	0.655	0.818	0.738	-0.1	-0.1%
Bulb H, 11.25066746 Knots	11.3	193	70	35	720	250	44	0.355	0.372	0.094	1.03	0.497	0.693	0.813	0.737	-0.22	0.0%
Bulb H, 12.28143358 Knots	12.3	216	93	46	1030	390	62	0.378	0.334	0.112	1.03	0.488	0.75	0.794	0.705	-0.35	-0.1%
Bulb H, 13.30794334 Knots	13.3	239	118	57	1430	560	82	0.394	0.304	0.129	1.03	0.479	0.799	0.779	0.679	-0.46	0.0%
Bulb H, 15.36708073 Knots	15.4	301	202	95	2980	1300	164	0.435	0.189	0.113	1.03	0.462	0.914	0.714	0.634	0.37	0.0%


Delivered Power
Conv
Bulb C
Bulb D
Bulb G
Bulb H
Delivered power P_D [kW]
4500
4200
3900
3600
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
9
10
11
12
13
14
15
16
Ship Speed, V_S [knots]

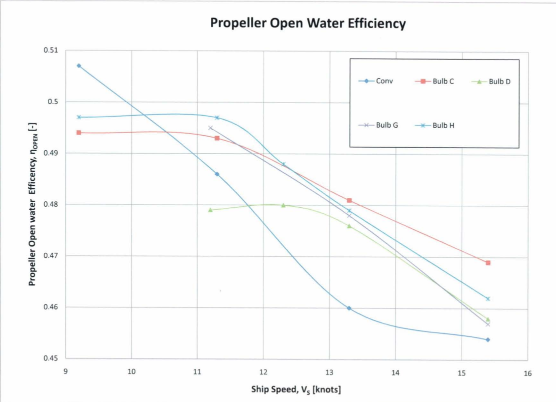


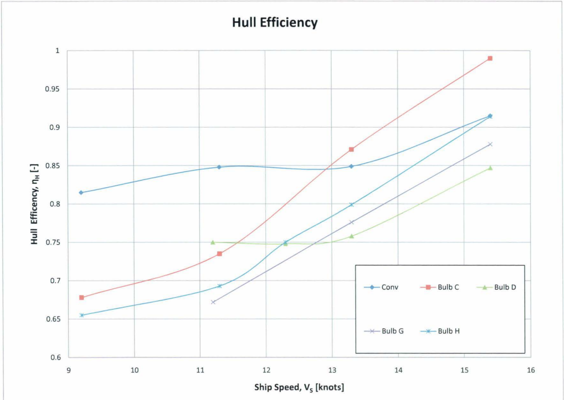
Wake Factor
Wake Factor$_F$ [-]
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
9
10
11
12
13
14
15
16
Ship Speed, V_S [knots]
Conv
Bulb C
Bulb D
Bulb G
Bulb H

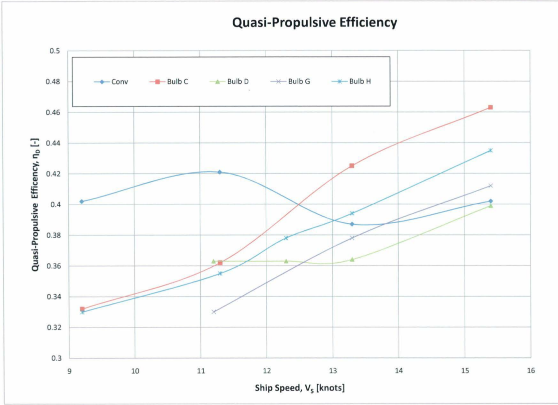

Thrust Deduction Fraction
Thrust Deduction Fraction t_{DF} [-]
Ship Speed, V_S [knots]
Conv
Bulb C
Bulb D
Bulb G
Bulb H
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
9
10
11
12
13
14
15
16



Relative Rotative Efficiency
Relative Rotative Efficency η_R [-]
Ship Speed, V_S [knots]
1.1
1.05
1
0.95
0.9
0.85
0.8
9
10
11
12
13
14
15
16
Conv
Bulb C
Bulb D
Bulb G
Bulb H


Propeller Open Water Efficiency
Conv
Bulb C
Bulb D
Bulb G
Bulb H
0.51
0.5
0.49
0.48
0.47
0.46
0.45
Propeller Open water Efficency, η_{OPEN} [-]
9
10
11
12
13
14
15
16
Ship Speed, V_S [knots]


Hull Efficiency
Hull Efficency, ηH [-]
Ship Speed, VS [knots]
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
9
10
11
12
13
14
15
16
Conv
Bulb C
Bulb D
Bulb G
Bulb H


Quasi-Propulsive Efficiency
Conv
Bulb C
Bulb D
Bulb G
Bulb H
Quasi-Propulsive Efficency, η_D [-]
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
0.3
9
10
11
12
13
14
15
16
Ship Speed, V_S [knots]

Appendix I – Head Seas Analysis Data

HEAD SEAS SEA STATE 3 SOURCE DATA

Bulb C		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	0.619258	0.366087	0.770946	0.605419	0.33805	0.001644	0.001403	-0.00104	0.000368	-0.07834
Std	Bulb C	18.53372	0.001977	13.00222	1.451888	0.566138	0.012254	0.051996	0.007589	0.033173	1.560464
Min	Bulb C	-60.6341	0.351488	-41.2762	-4.19708	-5.61825	-0.08197	-0.16986	-0.03958	-0.08008	-3.98377
Max	Bulb C	60.26001	0.376484	39.65628	5.084373	3.740618	0.081295	0.156498	0.033558	0.117246	4.176716
Bulb D		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	0.982165	0.365226	-1.00578	0.522678	0.092673	-0.00079	0.001654	0.002629	0.001829	-0.11806
Std	Bulb D	18.91362	0.001774	10.2384	1.414789	0.488407	0.010948	0.05884	0.00764	0.038341	1.772152
Min	Bulb D	-58.4027	0.352949	-36.1565	-4.68802	-2.40847	-0.04613	-0.19833	-0.03729	-0.09747	-5.25515
Max	Bulb D	69.46885	0.378406	31.06271	5.076582	4.223798	0.131129	0.182876	0.038887	0.126774	5.294488
Bulb G		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	0.944802	0.365556	6.334048	0.219739	0.072123	0.000587	-0.00191	-9.4E-05	0.001089	-0.03626
Std	Bulb G	18.50782	0.002112	8.808774	1.676553	0.533461	0.01123	0.054816	0.007825	0.035272	1.648302
Min	Bulb G	-62.1992	0.356129	-22.7716	-4.72102	-3.43216	-0.08557	-0.18661	-0.03071	-0.08764	-5.0295
Max	Bulb G	68.86877	0.376448	35.76581	5.314888	5.152946	0.058098	0.189108	0.033286	0.12773	4.559603
Bulb H		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	0.856043	0.365612	-0.23947	0.433695	0.005998	-0.00122	0.000332	0.002227	0.001036	-0.09196
Std	Bulb H	18.21801	0.001667	10.53871	1.46335	0.482503	0.01012	0.055144	0.007543	0.034079	1.696085
Min	Bulb H	-58.9242	0.352023	-37.7018	-4.14876	-3.60835	-0.08116	-0.21088	-0.02928	-0.08583	-4.34653
Max	Bulb H	63.13872	0.374566	27.32309	5.695832	2.839691	0.127818	0.152956	0.030448	0.138111	4.666253
Conventional Bow		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventional Bow	0.859346	0.365671	7.134848	0.323433	-0.00089	-0.00038	0.001654	-0.00031	0.001236	0.071902
Std	Conventional Bow	17.50129	0.001791	9.257117	1.612248	0.54686	0.011537	0.060842	0.008765	0.03925	1.777052
Min	Conventional Bow	-49.8578	0.347633	-19.5774	-4.97249	-4.2395	-0.07525	-0.20341	-0.03905	-0.11832	-4.53299
Max	Conventional Bow	55.68601	0.376156	35.61712	5.795168	2.613841	0.12066	0.181763	0.036517	0.125814	4.836955

		Resistance	Speed (m/s)	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)
Mean	Bulb C	2.405603	0.612241486	1.54043	0.747234	0.492582	-0.00048	0.002974	0.000938
Mean	Bulb D	2.322303	0.611930304	5.997706	0.620502	0.208232	0.000189	0.000325	0.001556
Mean	Bulb G	1.938534	0.61245773	5.080211	0.358601	0.168907	0.002044	0.001851	0.000221
Mean	Bulb H	2.224649	0.612024516	0.640508	0.655343	0.280021	0.002814	0.002039	3.7E-05
Mean	Conventional Bow	1.858971	0.611971332	3.118843	0.501888	0	0.000437	0.00098	-0.00076

ZAccel (g)	Pitch (deg)
0.001149	-0.07544
0.001992	-0.12931
-0.00011	-0.03422
0.001313	-0.09562
0.001606	0.058028

		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	4.088691	0.859541	2.729803	0.855018	0.538086	0.000399	0.003762	0.001208	6.75E-05	-0.13832
Std	Bulb C	15.71182	0.002105	12.49553	1.125164	0.536996	0.011327	0.050159	0.007223	0.047783	1.352734
Min	Bulb C	-54.46	0.850327	-34.3095	-2.74377	-1.46153	-0.06175	-0.14626	-0.02824	-0.12453	-3.91876
Max	Bulb C	53.58846	0.869879	37.25069	4.272176	3.917977	0.064198	0.155111	0.025693	0.147441	3.256832
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	4.901444	0.859864	1.017662	0.851777	0.30011	0.00091	0.004999	0.002152	0.000709	-0.11225
Std	Bulb D	15.30369	0.002122	9.535185	1.190855	0.459946	0.010421	0.054909	0.006922	0.051632	1.479825
Min	Bulb D	-53.9652	0.849905	-27.3435	-3.00602	-2.63333	-0.04804	-0.15185	-0.02716	-0.12477	-4.44805
Max	Bulb D	60.03494	0.882262	28.36383	4.263931	4.883244	0.056452	0.155918	0.027085	0.137413	3.891013
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	4.087417	0.859383	-0.1995	0.655081	0.278048	0.001351	0.005496	0.003414	-0.00011	-0.08198
Std	Bulb G	15.37969	0.001886	8.092998	1.374395	0.499223	0.011168	0.05435	0.006956	0.052118	1.438086
Min	Bulb G	-47.7051	0.852636	-21.6456	-3.1133	-1.5972	-0.05248	-0.1354	-0.0217	-0.11469	-4.06608
Max	Bulb G	52.92468	0.868202	26.84273	5.049446	2.9717	0.063197	0.180599	0.025223	0.153914	3.342209
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	4.347792	0.858595	2.723165	0.764502	0.275364	0.000688	0.004884	0.002041	8.88E-05	-0.14954
Std	Bulb H	15.49193	0.001872	9.695338	1.151874	0.477222	0.010683	0.053929	0.007084	0.048315	1.49342
Min	Bulb H	-49.8304	0.844672	-29.6888	-3.08459	-2.40794	-0.03946	-0.13676	-0.02202	-0.1074	-4.08693
Max	Bulb H	61.56962	0.868748	26.23722	4.75606	2.308335	0.060366	0.153949	0.038924	0.151111	3.821915
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventional Bow !	5.705005	1.105878	4.543488	0.839027	0	-0.0003	0.001139	0.001462	0.001059	-0.00702
Std	Conventional Bow !	13.98255	0.00191	8.30753	1.428324	0	0.012156	0.065598	0.007858	0.068051	1.598209
Min	Conventional Bow !	-43.8404	1.100053	-25.2671	-3.55457	0	-0.04428	-0.16001	-0.02895	-0.15619	-4.34923
Max	Conventional Bow !	45.56589	1.113471	23.13922	4.991896	0	0.070473	0.170009	0.028334	0.162283	3.383746

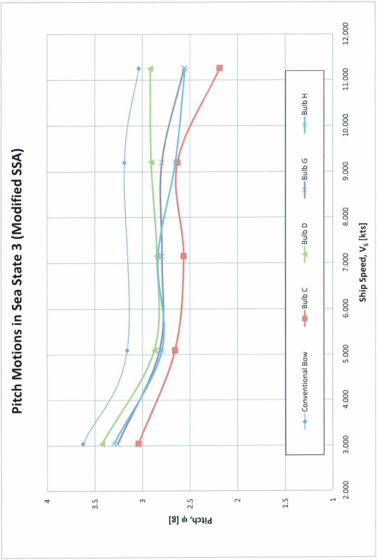
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	6.495626	1.105781	5.719523	0.891416	0.578034	-0.00016	0.00851	0.001266	0.000934	-0.29339
Std	Bulb C	16.17765	0.002166	14.0886	1.289281	0.544639	0.01125	0.053767	0.00707	0.059908	1.462986
Min	Bulb C	-50.2677	1.082941	-35.1712	-3.12484	-4.39974	-0.04766	-0.11998	-0.02855	-0.121	-4.10827
Max	Bulb C	54.78711	1.113382	40.50434	4.030534	3.448441	0.063353	0.161277	0.023866	0.165651	3.351423
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	7.49521	1.106006	5.716213	1.123111	0.446217	0.000593	0.003404	0.001602	0.00187	-0.12147
Std	Bulb D	14.78579	0.001843	11.1788	1.305835	0.438193	0.010215	0.057608	0.007131	0.062261	1.514842
Min	Bulb D	-51.2666	1.100402	-27.8677	-2.83006	-1.00697	-0.08648	-0.13791	-0.02597	-0.1461	-4.53892
Max	Bulb D	54.99281	1.117808	31.03207	5.411593	2.530235	0.049724	0.182044	0.041072	0.172374	3.57827
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	5.942657	1.105629	4.051162	0.912961	0.322743	0.00137	0.004332	-0.00271	0.001177	-0.14957
Std	Bulb G	15.20262	0.001921	9.012863	1.371314	0.518455	0.01092	0.055278	0.007588	0.060151	1.472575
Min	Bulb G	-45.9559	1.09808	-22.3309	-2.66905	-2.6106	-0.04898	-0.12385	-0.04588	-0.14068	-4.14694
Max	Bulb G	53.24257	1.113645	31.85195	5.369397	3.874283	0.053638	0.175083	0.043399	0.151788	3.68885
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	5.801625	1.105697	-60.8234	1.041666	0.215757	0.000614	0.005403	0.0004	0.000573	-0.23453
Std	Bulb H	14.13043	0.001948	10.0874	1.156994	0.497817	0.010408	0.053376	0.007263	0.055696	1.444428
Min	Bulb H	-44.0505	1.100474	-91.4053	-1.82715	-1.91326	-0.09317	-0.13548	-0.03594	-0.13636	-4.37551
Max	Bulb H	56.80587	1.118953	-32.5603	4.594315	3.134633	0.056102	0.154925	0.025614	0.164677	3.324997

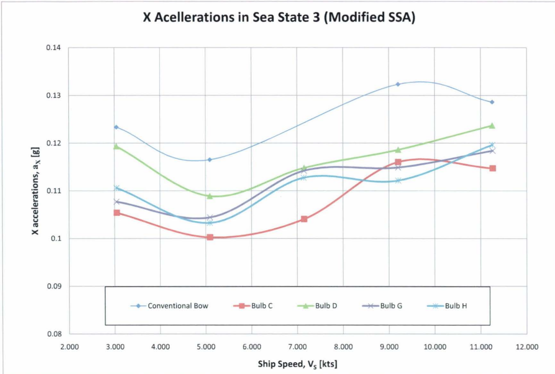
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	9.772222	1.353037	7.64336	1.160725	0.46866	0.000617	0.012029	-0.00073	0.002067	-0.53387
Std	Bulb C	14.86837	0.002028	16.12293	1.486424	0.528234	0.010666	0.051351	0.00702	0.069648	1.360581
Min	Bulb C	-50.3318	1.346434	-38.9978	-2.16653	-6.04205	-0.03494	-0.11643	-0.0246	-0.17365	-4.34362
Max	Bulb C	57.38277	1.361922	45.13392	5.697901	2.874669	0.063017	0.176714	0.022022	0.180923	3.018675
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	11.62195	1.35149	-0.69717	1.150125	0.44131	-0.00012	0.004821	-0.00082	0.00241	-0.17275
Std	Bulb D	13.70063	0.002214	2.803856	1.522092	0.496646	0.010735	0.059435	0.007202	0.073385	1.544882
Min	Bulb D	-42.3618	1.342285	-17.5619	-2.66232	-1.70589	-0.06481	-0.1687	-0.03034	-0.16054	-4.18084
Max	Bulb D	55.2743	1.367588	0	5.249666	2.678772	0.050876	0.154308	0.022377	0.1977	3.636015
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	9.347125	1.353096	6.353043	0.988135	0.260062	0.000927	0.006436	0.002276	0.001141	-0.30152
Std	Bulb G	14.58402	0.002003	9.641283	1.489055	0.54752	0.010777	0.055979	0.007297	0.0704	1.431578
Min	Bulb G	-41.8427	1.346329	-25.9379	-2.58713	-3.97032	-0.03825	-0.13351	-0.02239	-0.16853	-4.22339
Max	Bulb G	61.54229	1.362738	31.64931	4.869813	4.062089	0.048513	0.165426	0.03094	0.19063	3.471703
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	9.150569	1.352084	-0.6666	1.121684	0.468589	0.001304	0.008058	0.000694	0.000486	-0.42129
Std	Bulb H	14.77103	0.002283	3.075861	1.465684	0.511689	0.010704	0.055788	0.007207	0.068698	1.486493
Min	Bulb H	-50.2862	1.342751	-25.5191	-2.20251	-1.74427	-0.04315	-0.13689	-0.02402	-0.14838	-4.62712
Max	Bulb H	62.53321	1.363147	0	4.948547	3.082549	0.060408	0.178499	0.026868	0.197933	3.527954
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventional Bow	11.68476	1.352007	9.181948	0.980233	0	0.000349	0.002734	0.001212	0.001598	0.053049
Std	Conventional Bow	12.09075	0.001978	8.6588	1.535417	0	0.011343	0.062945	0.0082	0.074548	1.492803
Min	Conventional Bow	-30.3423	1.341477	-17.7579	-3.1972	0	-0.04417	-0.15524	-0.02746	-0.18527	-3.84542
Max	Conventional Bow	56.49963	1.359113	29.91011	5.336286	0	0.053782	0.183913	0.02678	0.191935	3.465464

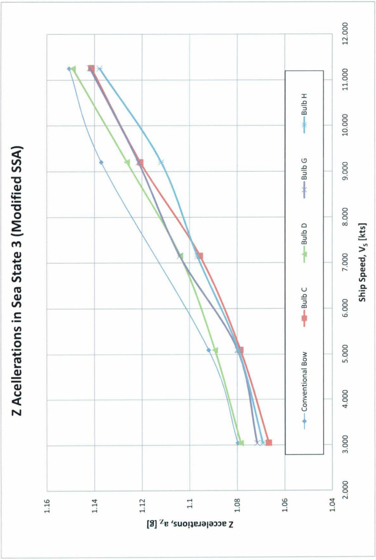
HEAD SEAS SEA STATE 3 ANALYSED DATA

		Speed (m/s	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	0.001652	0.001851	0.00022138	-0.000110167	-0.034223
Mean	Conventional Bow	0.001667	0.001654	-0.000305253	0.001236198	0.071902
Mean	Bulb C	0.001768	0.003762	0.001208263	6.75027E-05	-0.138315
Mean	Bulb G	0.001774	-0.001908	-9.43912E-05	0.001088759	-0.036258
Mean	Bulb C	0.001791	0.002974	0.00093779	0.001148586	-0.075437
Mean	Bulb G	0.001843	0.004332	-0.002708703	0.001176578	-0.149568
Mean	Bulb H	0.001868	0.002039	3.69782E-05	0.001313482	-0.095619
Mean	Conventional Bow 9KNOTS	0.001872	0.001139	0.001461528	0.001058508	-0.007016
Mean	Bulb H	0.001886	0.004884	0.002041493	8.87659E-05	-0.149535
Mean	Bulb C	0.00191	0.00851	0.00126578	0.000933854	-0.293392
Mean	Bulb H	0.001921	0.005403	0.000400115	0.000573234	-0.234535
Mean	Bulb D	0.001977	0.001654	0.002629323	0.001828581	-0.11806
Mean	Bulb C	0.001978	0.001403	-0.001043938	0.000368329	-0.078338
Mean	Bulb D	0.001982	0.000325	0.001555734	0.001992001	-0.12931
Mean	Bulb H	0.002003	0.008058	0.000693784	0.00048595	-0.421288
Mean	Bulb D	0.002028	0.004821	-0.000820317	0.002410135	-0.172747
Mean	Bulb D	0.002105	0.004999	0.002151634	0.000708675	-0.112251
Mean	Bulb H	0.002112	0.000332	0.002227469	0.001035918	-0.091962
Mean	Bulb G	0.002122	0.005496	0.003413665	-0.000109045	-0.081981
Mean	Bulb D	0.002166	0.003404	0.001602405	0.001869733	-0.121472
Mean	Conventional Bow	0.002173	0.00098	-0.00075579	0.001605601	0.058028
Mean	Bulb G	0.002214	0.006436	0.0022763	0.001141136	-0.301522
Mean	Conventional Bow	0.002283	0.002734	0.001212423	0.001597975	0.053049

		Speed (m/s	V_S [knots]	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Std	Conventional Bow	0.365671	3.044	0.060841542	0.008765211	0.03925	1.777052	0.123338	0.017225	1.079737	3.626006
Std	Conventional Bow	0.611971	5.094	0.057771358	0.007569739	0.045186	1.551628	0.116522	0.014384	1.091979	3.161284
Std	Conventional Bow	1.105878	9.205	0.065597799	0.007858423	0.068051	1.598209	0.132335	0.017178	1.13716	3.189402
Std	Conventional Bow	1.352007	11.254	0.062945257	0.008200283	0.074548	1.492803	0.128625	0.017613	1.150694	3.038656
Std	Bulb C	0.366087	3.047	0.05199621	0.007589463	0.033173	1.560464	0.105396	0.014135	1.066714	3.04259
Std	Bulb C	0.612241	5.096	0.04864126	0.007743569	0.038736	1.366875	0.100257	0.016425	1.078621	2.658314
Std	Bulb C	0.859541	7.155	0.050158606	0.007222883	0.047783	1.352734	0.10408	0.015654	1.095634	2.567152
Std	Bulb C	1.105781	9.204	0.053767049	0.007069923	0.059908	1.462986	0.116044	0.015406	1.120751	2.632579
Std	Bulb C	1.353037	11.262	0.051350981	0.007020442	0.069648	1.360581	0.114731	0.01331	1.141363	2.187286
Std	Bulb D	0.365226	3.040	0.058839665	0.007639798	0.038341	1.772152	0.119333	0.017909	1.078511	3.426244
Std	Bulb D	0.61193	5.094	0.054289926	0.006955817	0.043671	1.503122	0.108905	0.015467	1.089334	2.876934
Std	Bulb D	0.859864	7.157	0.054909393	0.006922346	0.051632	1.479825	0.114818	0.015996	1.103973	2.847398
Std	Bulb D	1.106006	9.206	0.057607655	0.007131141	0.062261	1.514842	0.11862	0.015865	1.126392	2.908212
Std	Bulb D	1.35149	11.249	0.059435419	0.007201641	0.073385	1.544882	0.123692	0.013583	1.14918	2.917018
Std	Bulb G	0.365556	3.043	0.054815822	0.007825428	0.035272	1.648302	0.107724	0.015556	1.071633	3.260347
Std	Bulb G	0.612458	5.098	0.051293929	0.007575613	0.039986	1.427061	0.104438	0.015373	1.079862	2.819899
Std	Bulb G	0.859383	7.153	0.054350449	0.006956367	0.052118	1.438086	0.114197	0.017326	1.104127	2.794191
Std	Bulb G	1.105629	9.203	0.055277983	0.007587559	0.060151	1.472575	0.114888	0.012466	1.121479	2.795582
Std	Bulb G	1.353096	11.263	0.055979243	0.007297259	0.0704	1.431578	0.118394	0.016871	1.141941	2.561634
Std	Bulb H	0.365612	3.043	0.055144458	0.007542867	0.034079	1.696085	0.110621	0.017313	1.069195	3.300208
Std	Bulb H	0.612025	5.094	0.050619578	0.007153373	0.039073	1.445705	0.103278	0.014344	1.079459	2.795791
Std	Bulb H	0.858595	7.147	0.053928874	0.00708401	0.048315	1.49342	0.112742	0.01621	1.09672	2.837306
Std	Bulb H	1.105697	9.203	0.053375992	0.00726287	0.055696	1.444428	0.112155	0.014926	1.111965	2.654321
Std	Bulb H	1.352084	11.254	0.055787607	0.007207308	0.068698	1.486493	0.119633	0.015108	1.137882	2.551697


Pitch Motions in Sea State 3 (Modified SSA)
Pitch, φ [g]
4
3.5
3
2.5
2
1.5
1
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V_s [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H


X Acellerations in Sea State 3 (Modified SSA)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
X accelerations, a_X [g]
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V_S [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H


Z Acellerations in Sea State 3 (Modified SSA)
Z accelerations, a_Z [g]
1.16
1.14
1.12
1.1
1.08
1.06
1.04
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V_S [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H

HEAD SEAS SEA STATE 5 SOURCE DATA

		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	2.336935	0.365946	-3.779925	0.717761	0.145881	-5.8919E-05	0.008509	0.001492	0.004348	-0.257407
Std	Bulb C	40.56669	0.002529	40.21382	5.017223	0.794377	0.010918194	0.112912	0.011788	0.081455	3.686308
Min	Bulb C	-117.5974	0.354041	-142.3436	-13.22575	-3.86964	-0.085075685	-0.341607	-0.049741	-0.191881	-10.62088
Max	Bulb C	153.472	0.375664	66.53308	16.59229	3.499546	0.110837803	0.316289	0.054779	0.320855	8.224525
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	2.95031	0.365026	-10.24322	0.667917	0.009674	-0.001479471	0.007523	0.002094	0.007022	-0.269364
Std	Bulb D	41.7604	0.002503	20.84118	4.903809	0.74525	0.010213746	0.127885	0.013694	0.089439	4.141407
Min	Bulb D	-127.2337	0.35199	-108.9877	-14.1932	-2.75176	-0.055999571	-0.290528	-0.055569	-0.190314	-13.16686
Max	Bulb D	118.0611	0.385267	0	14.92228	4.248966	0.057816836	0.394488	0.054131	0.294276	9.471981
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	2.478104	0.366215	-5.01488	0.31076	-0.018927	-0.000241027	0.00875	0.000206	0.005157	-0.144371
Std	Bulb G	40.33512	0.002412	33.81533	5.135832	0.802104	0.01117538	0.119776	0.01259	0.087431	3.880674
Min	Bulb G	-115.2999	0.357039	-130.4009	-12.89894	-4.198228	-0.093705918	-0.321875	-0.057674	-0.205069	-11.40778
Max	Bulb G	122.9101	0.376515	76.34293	16.10845	3.871031	0.070488242	0.338459	0.057511	0.330611	8.950127
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	2.23317	0.365089	-10.78088	0.734436	0.175044	7.17799E-05	0.008481	-0.000743	0.001799	-0.27494
Std	Bulb H	41.00985	0.002455	21.10992	5.071643	0.773103	0.010847075	0.121167	0.012145	0.083839	4.011108
Min	Bulb H	-149.9192	0.342514	-123.4666	-13.22542	-3.313643	-0.068925842	-0.370338	-0.057126	-0.193901	-10.79022
Max	Bulb H	151.3261	0.377786	0	19.90117	3.281778	0.057018543	0.361606	0.048917	0.31394	9.540634
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventional Bow	2.347914	0.365774	-4.353765	0.390005	0	0.000650152	0.003267	0.000135	0.007377	0.131051
Std	Conventional Bow	37.05471	0.002269	30.77193	4.893378	0	0.011631309	0.133726	0.012009	0.095874	4.106181
Min	Conventional Bow	-122.4611	0.34633	-121.5094	-16.12055	0	-0.104038382	-0.386216	-0.072752	-0.280491	-11.80046
Max	Conventional Bow	114.9021	0.378534	74.76154	15.74466	0	0.098405554	0.434098	0.051574	0.365935	12.79463

		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	4.433212	0.612126	-3.718555	0.90129	0.204771	-0.000837	0.010085	0.000233011	0.006201	-0.379957
Std	Bulb C	41.97343	0.002427	40.53164	5.039195	0.79655	0.0104	0.127097	0.01170416	0.108168	3.857316
Min	Bulb C	-118.4295	0.60174	-123.525	-11.7185	-2.610258	-0.047583	-0.388421	-0.073050357	-0.257643	-10.90586
Max	Bulb C	161.3587	0.623976	66.88742	16.31286	3.358783	0.069965	0.398678	0.042439533	0.374404	9.181476
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	5.960526	0.611748	-10.56225	0.931336	0.075365	-0.00079	0.006559	0.00185268	0.009691	-0.233171
Std	Bulb D	42.28776	0.002506	22.06928	5.1151	0.758714	0.010537	0.141139	0.013669195	0.114978	4.294705
Min	Bulb D	-121.581	0.591858	-125.0662	-12.55519	-6.064629	-0.100403	-0.431976	-0.089028314	-0.25031	-11.30196
Max	Bulb D	162.3341	0.620305	0	17.25529	2.925778	0.073121	0.390775	0.063333018	0.34472	12.08366
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	4.560236	0.612235	-8.846671	0.57138	0.084865	0.001439	0.01132	9.51399E-06	0.004275	-0.213298
Std	Bulb G	41.87135	0.002498	33.51534	5.274679	0.816645	0.011759	0.136207	0.011851876	0.114202	4.079267
Min	Bulb G	-120.8684	0.602517	-115.145	-12.39078	-6.54504	-0.054737	-0.367195	-0.073214062	-0.287049	-11.5339
Max	Bulb G	141.2915	0.6223	55.76407	16.48041	3.034902	0.064677	0.424779	0.043494718	0.370697	9.592435
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	4.714124	0.612748	-11.08494	0.964506	0.281661	0.000954	0.012433	0.001161357	0.006095	-0.356472
Std	Bulb H	41.15644	0.00272	21.34412	4.997396	0.792833	0.01145	0.135526	0.013172205	0.112264	4.117697
Min	Bulb H	-124.8776	0.60133	-114.8258	-13.5148	-4.190889	-0.064946	-0.404446	-0.054293528	-0.280456	-11.35467
Max	Bulb H	185.3727	0.623566	0	17.82078	3.215143	0.12537	0.449386	0.049921623	0.351592	9.833896
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventional Bow	4.742679	0.612548	-2.119931	0.756906	0	-0.000385	0.002141	-7.66649E-05	0.00762	0.156257
Std	Conventional Bow	35.40459	0.002162	29.27316	4.845076	0	0.011697	0.136244	0.012480081	0.114124	3.940818
Min	Conventional Bow	-119.4404	0.605278	-108.3185	-11.42202	0	-0.049555	-0.281917	-0.044700676	-0.308208	-11.62438
Max	Conventional Bow	112.8657	0.624907	63.92355	18.85323	0	0.123968	0.41346	0.043668896	0.32537	9.041987

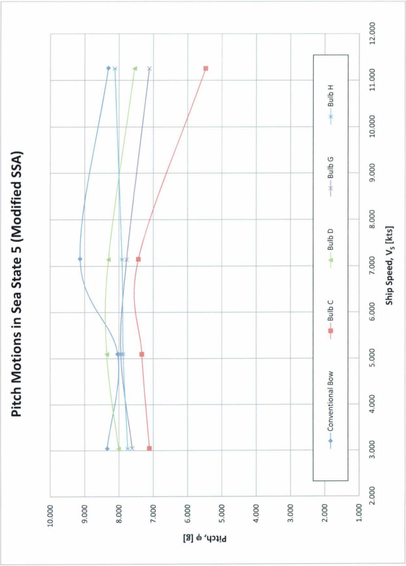
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	7.4983	0.859087	-4.90613	1.020401	0.195187	0.001106	0.007257	-3.5E-06	0.006292	-0.29373
Std	Bulb C	41.95933	0.002569	47.02965	5.656751	0.843762	0.010749	0.1264	0.012185	0.129226	3.864527
Min	Bulb C	-115.151	0.827556	-127.954	-12.6252	-2.87259	-0.05967	-0.29888	-0.06258	-0.31177	-10.4678
Max	Bulb C	115.7597	0.868271	66.35473	16.58323	2.838533	0.058809	0.342561	0.044989	0.453972	7.481984
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	8.438928	0.858266	-13.1337	0.899362	0.226608	0.001828	0.007354	-9.7E-06	0.008106	-0.16936
Std	Bulb D	41.10097	0.002335	22.5956	5.418355	0.797033	0.010143	0.143575	0.011972	0.140018	4.239047
Min	Bulb D	-110.087	0.8465	-96.4367	-11.3241	-2.98617	-0.10178	-0.36987	-0.06146	-0.32051	-10.9218
Max	Bulb D	121.6105	0.868737	0	14.83518	3.167099	0.064277	0.405648	0.05525	0.45991	9.22502
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	6.749554	0.858294	-7.26982	0.634419	0.10691	0.001917	0.011458	0.000471	0.008571	-0.2537
Std	Bulb G	41.43128	0.002635	36.90167	5.413425	0.823489	0.012558	0.136271	0.012305	0.132339	4.015216
Min	Bulb G	-99.5567	0.849553	-109.723	-14.2634	-4.02034	-0.12877	-0.36214	-0.06127	-0.29327	-9.10148
Max	Bulb G	131.8548	0.873169	66.38846	14.85424	3.054079	0.069013	0.35914	0.052088	0.403634	9.806161
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	6.988625	0.858604	-13.6266	0.865812	0.122886	0.000227	0.010743	-6.4E-05	0.007407	-0.37684
Std	Bulb H	40.7269	0.002804	23.21894	5.377979	0.80262	0.011777	0.13869	0.013952	0.133475	4.145277
Min	Bulb H	-139.674	0.84827	-97.8381	-11.7066	-2.27238	-0.04876	-0.36219	-0.07297	-0.3183	-10.4685
Max	Bulb H	166.7475	0.875107	0	15.44491	3.143976	0.053863	0.387425	0.054097	0.499441	8.872042
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventior	7.824501	0.860075	-3.86969	0.765621	0	-0.00135	0.004302	0.003294	0.00857	0.266562
Std	Conventior	38.70126	0.002314	35.26503	5.347452	0	0.012083	0.157815	0.014854	0.15591	4.434332
Min	Conventior	-102.553	0.852415	-99.1849	-10.5352	0	-0.04724	-0.4036	-0.06291	-0.38996	-10.7866
Max	Conventior	115.3332	0.870971	69.74162	15.69431	0	0.055379	0.452063	0.057457	0.444609	10.6617

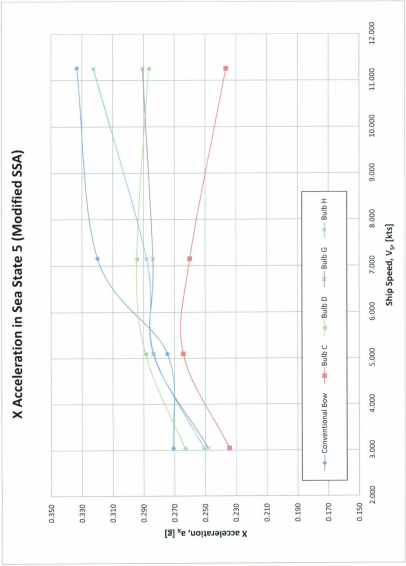
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	9.937065	1.106094	-4.87654	1.313637	0.465923	-0.0008	0.013334	0.002895	0.008004	-0.46853
Std	Bulb C	36.87265	0.00256	42.81653	5.40139	0.801102	0.010819	0.122897	0.012283	0.142107	3.497964
Min	Bulb C	-114.65	1.09763	-135.094	-10.7053	-2.70012	-0.04384	-0.28909	-0.0712	-0.37612	-9.83819
Max	Bulb C	113.8389	1.115725	66.59116	17.89031	3.711071	0.055983	0.423047	0.060136	0.575927	8.246908
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	10.63603	1.105518	-14.4362	0.869961	0.257616	-6.5E-05	0.011056	-0.00014	0.006581	-0.25232
Std	Bulb D	38.21437	0.002458	24.00905	5.516967	0.796284	0.009668	0.143051	0.011406	0.165371	4.084542
Min	Bulb D	-87.3155	1.096758	-96.7922	-13.0261	-2.43439	-0.04164	-0.34607	-0.04715	-0.3916	-9.47429
Max	Bulb D	125.5612	1.11401	0	13.13965	2.687193	0.051655	0.403855	0.056149	0.469897	9.311596
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	9.845472	1.106164	-2.41467	1.094954	0.231563	0.001424	0.008319	-0.00011	0.009052	-0.17711
Std	Bulb G	39.675	0.002381	38.57625	5.510726	0.819013	0.011086	0.14321	0.024627	0.161746	3.945861
Min	Bulb G	-121.731	1.097232	-86.0078	-13.8603	-2.76761	-0.04271	-0.38515	-0.25653	-0.36164	-8.43419
Max	Bulb G	107.0689	1.115558	85.16105	13.39386	3.643577	0.058044	0.43364	0.332195	0.478744	8.446857
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	10.43725	1.105422	-13.018	1.485565	0.392231	0.001542	0.017091	-0.00282	0.006397	-0.45263
Std	Bulb H	37.99112	0.002622	23.82641	5.3585	0.786031	0.011528	0.145871	0.015419	0.166349	4.0249
Min	Bulb H	-119.275	1.095222	-110.205	-8.56564	-1.95441	-0.04872	-0.33033	-0.07315	-0.39091	-12.1065
Max	Bulb H	93.1959	1.120218	0	19.0993	3.31456	0.123869	0.444887	0.06337	0.45529	7.54796
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventior	10.42209	1.105322	-0.05819	0.91439	0	0.000366	0.003119	-0.00091	0.007269	0.326795
Std	Conventior	34.42848	0.002349	35.70868	5.354119	0	0.011851	0.158657	0.016147	0.177037	4.093992
Min	Conventior	-71.0497	1.094358	-96.1495	-12.604	0	-0.07618	-0.38001	-0.07253	-0.39463	-9.75067
Max	Conventior	123.1371	1.114447	71.00653	15.18634	0	0.054431	0.387896	0.054539	0.493785	9.795518

		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb C	12.44655	1.352185	1.237372	1.370105	0.346832	-0.0004	0.016821	8.74E-05	0.002502	-0.77318
Std	Bulb C	34.21179	0.002575	41.32102	5.125216	0.724906	0.009682	0.109852	0.010304	0.150316	3.125115
Min	Bulb C	-78.2267	1.344868	-97.1222	-9.44235	-1.97352	-0.03115	-0.25499	-0.03225	-0.30423	-7.92048
Max	Bulb C	84.5438	1.365034	66.34238	13.31759	3.40599	0.056546	0.278886	0.041494	0.485672	4.923622
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb D	15.87592	1.351984	-7.32828	1.430126	0.327548	0.001865	0.00785	1.91E-05	0.012336	-0.11852
Std	Bulb D	35.13067	0.002394	44.79886	5.430284	0.804433	0.009664	0.139494	0.019028	0.181378	3.834666
Min	Bulb D	-85.5219	1.343624	-108.524	-13.7795	-3.94606	-0.08718	-0.37674	-0.1341	-0.81619	-9.68899
Max	Bulb D	151.1256	1.360186	56.98461	12.81753	2.354593	0.041562	0.411879	0.242838	0.592911	9.256528
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb G	13.79168	1.352163	-3.38638	2.018726	0.288267	0.000578	0.01189	0.001373	0.007243	-0.31118
Std	Bulb G	36.13092	0.002591	37.63982	5.541187	0.828726	0.011573	0.139408	0.074975	0.185426	3.716456
Min	Bulb G	-113.887	1.345112	-107.206	-8.47454	-3.62525	-0.04351	-0.357	-0.66077	-0.94606	-9.70431
Max	Bulb G	111.1197	1.361828	68.29045	16.85679	5.438845	0.073108	0.38744	1.038364	0.627332	8.215743
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Bulb H	15.92296	1.351985	-16.1206	2.162009	0.570757	2.22E-05	0.014165	-0.00085	0.008341	-0.39114
Std	Bulb H	43.98307	0.002918	32.09635	6.435367	0.841358	0.011478	0.154205	0.026687	0.21139	4.258837
Min	Bulb H	-147.97	1.343416	-190.221	-13.8934	-3.11046	-0.05502	-0.42934	-0.21129	-1.2972	-10.9213
Max	Bulb H	137.6149	1.366573	0	20.17143	3.853421	0.055061	0.484524	0.205263	0.743642	11.82846
		Resistance	Speed (m/s	Sinkage (m	Wave Heig	inline (N)	Trim (N-m)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Mean	Conventior	16.57998	1.353193	3.707656	1.600889	0	0.000614	0.003643	0.003215	0.007532	0.390997
Std	Conventior	31.733	0.002173	36.00589	5.604169	0	0.012553	0.164831	0.019762	0.209641	3.961505
Min	Conventior	-69.8015	1.346555	-103.634	-7.92309	0	-0.09071	-0.42018	-0.11143	-0.53812	-10.8096
Max	Conventior	103.7989	1.361507	63.22811	19.55918	0	0.053893	0.471137	0.129297	0.54395	9.802639

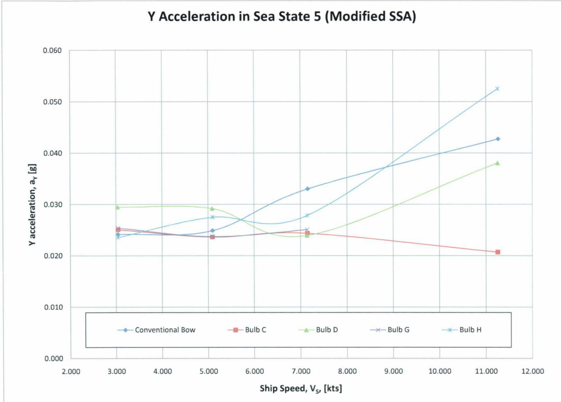
HEAD SEAS SEA STATE 5 ANALYSED DATA

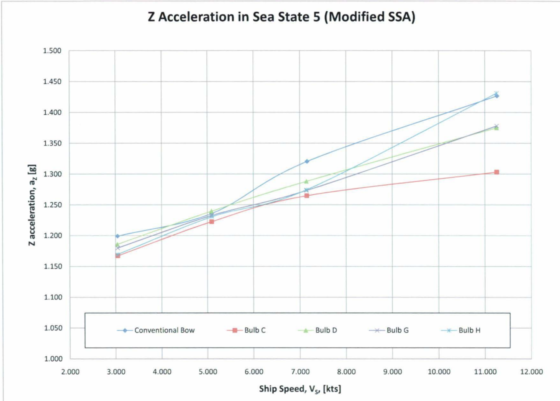
							modified SSA			
	Speed (m/s)	V_S [knots]	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)	XAccel (g)	YAccel (g)	ZAccel (g)	Pitch (deg)
Conventional Bow	0.366	3.045	0.134	0.012	0.096	4.106	0.271	0.024	1.199	8.343
Conventional Bow	0.613	5.099	0.136	0.012	0.114	3.941	0.275	0.025	1.236	8.038
Conventional Bow	0.860	7.159	0.158	0.015	0.156	4.434	0.320	0.033	1.320	9.135
Conventional Bow	1.353	11.264	0.165	0.020	0.210	3.962	0.333	0.043	1.427	8.314
Bulb C	0.366	3.046	0.113	0.012	0.081	3.686	0.234	0.025	1.167	7.115
Bulb C	0.612	5.095	0.127	0.012	0.108	3.857	0.264	0.024	1.223	7.335
Bulb C	0.859	7.151	0.126	0.012	0.129	3.865	0.260	0.024	1.265	7.435
Bulb C	1.352	11.255	0.110	0.010	0.150	3.125	0.237	0.021	1.303	5.477
Bulb D	0.365	3.038	0.128	0.014	0.089	4.141	0.263	0.029	1.186	8.013
Bulb D	0.612	5.092	0.141	0.014	0.115	4.295	0.289	0.029	1.240	8.356
Bulb D	0.858	7.144	0.144	0.012	0.140	4.239	0.295	0.024	1.288	8.309
Bulb D	1.352	11.253	0.139	0.019	0.181	3.835	0.287	0.038	1.375	7.551
Bulb G	0.366	3.048	0.120	0.013	0.087	3.881	0.248	0.025	1.180	7.617
Bulb G	0.612	5.096	0.136	0.012	0.114	4.079	0.284	0.024	1.233	7.945
Bulb G	0.858	7.144	0.136	0.012	0.132	4.015	0.284	0.025	1.273	7.777
Bulb G	1.352	11.255	0.139	0.075	0.185	3.716	0.291		1.378	7.122
Bulb H	0.365	3.039	0.121	0.012	0.084	4.011	0.251	0.024	1.169	7.747
Bulb H	0.613	5.100	0.136	0.013	0.112	4.118	0.283	0.028	1.231	7.879
Bulb H	0.859	7.147	0.139	0.014	0.133	4.145	0.288	0.028	1.274	7.914
Bulb H	1.352	11.253	0.154	0.027	0.211	4.259	0.323	0.053	1.431	8.127


Pitch Motions in Sea State 5 (Modified SSA)
Pitch, φ [g]
10.000
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V$_s$ [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H



X Acceleration in Sea State 5 (Modified SSA)
X acceleration, a_x [g]
0.150
0.170
0.190
0.210
0.230
0.250
0.270
0.290
0.310
0.330
0.350
Ship Speed, V_s, [kts]
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H


Y Acceleration in Sea State 5 (Modified SSA)
Y acceleration, a_Y [g]
0.060
0.050
0.040
0.030
0.020
0.010
0.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V_S, [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H


Z Acceleration in Sea State 5 (Modified SSA)
1.500
1.450
1.400
1.350
1.300
1.250
1.200
1.150
1.100
1.050
1.000
Z acceleration, a_Z [g]
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
Ship Speed, V_S, [kts]
Conventional Bow
Bulb C
Bulb D
Bulb G
Bulb H

HEAD SEAS RESISTANCE SOURCE DATA

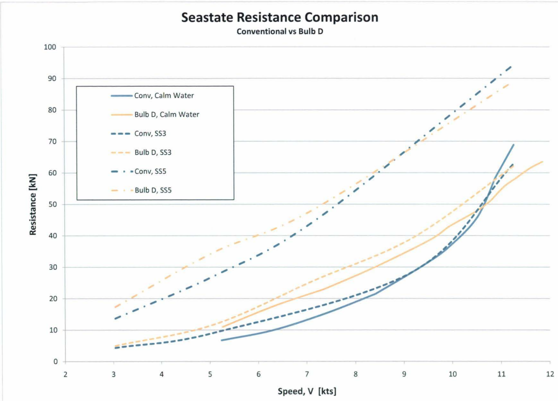
TEST,DRAFT_HYDRO	scale,HYDRO	T,M_HYDRO m	L,M_HYDRO m	B,M_HYDRO m	S,M_HYDRO m^2	vol,M_HYDRO m^3
Conv	18.333	0.2241	1.829	0.4988	0.9722	0.063
Bulb C	18.333	0.2241	1.833	0.4988	1.1225	0.073
Bulb D	18.333	0.2241	1.833	0.4988	1.0964	0.071
Bulb G	18.333	0.2241	1.833	0.4988	1.10625	0.072
Bulb H	18.333	0.2241	1.833	0.4988	1.109381	0.072

TEST,DRAFT	TEST,DESCRIPTION	TEST,NAME	V,M m/s	R,TM N	theta deg	z,VM mm	TEMP,M	TANK	TEMP,S	SALINITY,S
Conv	SS3	OERC_ConvBow	0.3656709	0.859346	0.071902	7.134848	12.3	OERC	15	3.5
			0.611971332	1.858971	0.058028	3.118843				
			1.105878447	5.705005	-0.00702	4.543488				
			1.352007174	11.68476	0.053049	9.181948				
Bulb C	SS3	OERC_BulbC_DD	0.366087434	0.619258	-0.07834	0.770946	14.67	OERC	15	3.5
			0.612241486	2.405603	-0.07544	1.54043				
			0.859540502	4.088691	-0.13832	2.729803				
			1.105781176	6.495626	-0.29339	5.719523				
			1.353036686	9.772222	-0.53387	7.64336				
Bulb D	SS3	OERC_BulbD_DD	0.365226411	0.982165	-0.11806	-1.00578	14.63	OERC	15	3.5
			0.611930304	2.322303	-0.12931	5.997706				
			0.859863596	4.901444	-0.11225	1.017662				
			1.10600572	7.49521	-0.12147	5.716213				
			1.351489732	11.62195	-0.17275	-0.69717				
Bulb G	SS3	OERC_BulbG_DD	0.36555579	0.944802	-0.03626	6.334048	15.47	OERC	15	3.5
			0.61245773	1.938534	-0.03422	5.080211				
			0.859383308	4.087417	-0.08198	-0.1995				
			1.105629	5.942657	-0.14957	4.051162				
			1.353096199	9.347125	-0.30152	6.353043				
Bulb H	SS3	OERC_BulbH_DD	0.365612294	0.856043	-0.09196	-0.23947	15.00	OERC	15	3.5
			0.612024516	2.224649	-0.09562	0.640508				
			0.858595321	4.347792	-0.14954	2.723165				
			1.105697413	5.801625	-0.23453	-60.8234				
			1.352084371	9.150569	-0.42129	-0.6666				
Conv	SS5	OERC_ConvBow	0.365773655	2.347914	0.131051	-4.35377	12.3	OERC	15	3.5
			0.612548023	4.742679	0.156257	-2.11993				
			0.860075174	7.824501	0.266562	-3.86969				
			1.353193308	16.57998	0.390997	3.707656				
Bulb C	SS5	OERC_BulbC_DD	0.365946225	2.336935	-0.25741	-3.77992	14.67	OERC	15	3.5
			0.612126375	4.433212	-0.37996	-3.71856				
			0.859086606	7.4983	-0.29373	-4.90613				
			1.352184704	12.44655	-0.77318	1.237372				
Bulb D	SS5	OERC_BulbD_DD	0.365026247	2.95031	-0.26936	-10.2432	14.63	OERC	15	3.5
			0.611747559	5.960526	-0.23317	-10.5622				
			0.858266497	8.438928	-0.16936	-13.1337				
			1.351984448	15.87592	-0.11852	-7.32828				
Bulb G	SS5	OERC_BulbG_DD	0.366214815	2.478104	-0.14437	-5.01488	15.47	OERC	15	3.5
			0.612235237	4.560236	-0.2133	-8.84667				
			0.858294092	6.749554	-0.2537	-7.26982				
			1.35216278	13.79168	-0.31118	-3.38638				
Bulb H	SS5	OERC_BulbH_DD	0.365089176	2.23317	-0.27494	-10.7809	15.00	OERC	15	3.5
			0.612747584	4.714124	-0.35647	-11.0849				
			0.858604102	6.988625	-0.37684	-13.6266				
			1.351984521	15.92296	-0.39114	-16.1206				

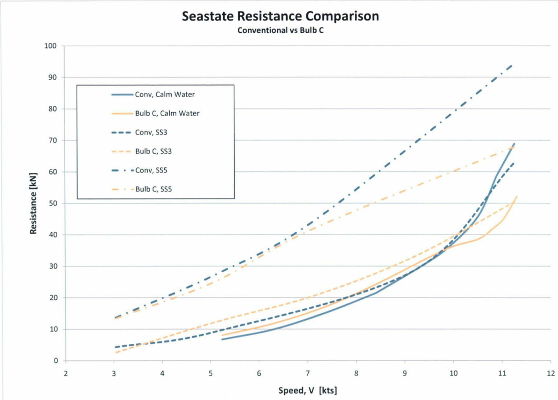
HEAD SEAS RESISTANCE ANALYZED DATA

TEST,COND	V,S knot	R,TS kN	P,ES kW	z,VS m	theta deg	Fr	C,TS	C,TM15_C	C,R	C,A	C,FS	C,FM15	zvLm
Conv, SS3	3.04	4.32	6.8	0.131	0.0719	0.0863	0.0105	0.01302	0.00774	0.0004	0.002353	0.00528	0.0039
Conv, SS3	5.09	9.14	24	0.057	0.058	0.1445	0.00794	0.01007	0.00536	0.0004	0.002177	0.004705	0.00171
Conv, SS3	9.2	28.65	135.7	0.083	-0.007	0.2611	0.00762	0.00937	0.00522	0.0004	0.001998	0.004153	0.00248
Conv, SS3	11.25	62.77	363.4	0.168	0.053	0.3192	0.01116	0.01281	0.00882	0.0004	0.001943	0.003988	0.00502
Bulb C, SS3	3.05	2.66	4.2	0.014	-0.0783	0.0863	0.00558	0.0081	0.00283	0.0004	0.002352	0.005276	0.00042
Bulb C, SS3	5.1	12.22	32	0.028	-0.0754	0.1444	0.00918	0.01131	0.0066	0.0004	0.002176	0.004703	0.00084
Bulb C, SS3	7.15	20.68	76.1	0.05	-0.1383	0.2027	0.00788	0.00978	0.00541	0.0004	0.002071	0.004374	0.00149
Bulb C, SS3	9.2	33.01	156.3	0.105	-0.2934	0.2608	0.0076	0.00936	0.0052	0.0004	0.001998	0.004152	0.00312
Bulb C, SS3	11.26	50.4	292	0.14	-0.5339	0.3191	0.00775	0.0094	0.00541	0.0004	0.001942	0.003986	0.00417
Bulb D, SS3	3.04	4.99	7.8	-0.018	-0.1181	0.0861	0.01079	0.01331	0.00803	0.0004	0.002353	0.005279	-0.00055
Bulb D, SS3	5.09	11.78	30.9	0.11	-0.1293	0.1443	0.00907	0.01119	0.00649	0.0004	0.002176	0.004703	0.00327
Bulb D, SS3	7.16	25.79	95	0.019	-0.1123	0.2028	0.01006	0.01196	0.00759	0.0004	0.002071	0.004374	0.00056
Bulb D, SS3	9.21	39.52	187.2	0.105	-0.1215	0.2608	0.00932	0.01107	0.00692	0.0004	0.001998	0.004151	0.00312
Bulb D, SS3	11.25	62.04	359	-0.013	-0.1727	0.3187	0.00979	0.01144	0.00745	0.0004	0.001942	0.003987	-0.00038
Bulb G, SS3	3.04	4.76	7.5	0.116	-0.0363	0.0862	0.01019	0.01271	0.00743	0.0004	0.002352	0.005278	0.00346
Bulb G, SS3	5.1	9.39	24.6	0.093	-0.0342	0.1444	0.00715	0.00928	0.00457	0.0004	0.002176	0.004702	0.00277
Bulb G, SS3	7.15	20.72	76.2	-0.004	-0.082	0.2027	0.00801	0.00992	0.00554	0.0004	0.002071	0.004374	-0.00011
Bulb G, SS3	9.2	29.85	141.3	0.074	-0.1496	0.2608	0.00698	0.00873	0.00458	0.0004	0.001998	0.004152	0.00221
Bulb G, SS3	11.26	47.79	276.9	0.116	-0.3015	0.3191	0.00746	0.0091	0.00512	0.0004	0.001942	0.003986	0.00347
Bulb H, SS3	3.04	4.18	6.5	-0.004	-0.092	0.0862	0.00892	0.01144	0.00616	0.0004	0.002352	0.005278	-0.00013
Bulb H, SS3	5.09	11.14	29.2	0.012	-0.0956	0.1443	0.00848	0.0106	0.0059	0.0004	0.002176	0.004703	0.00035
Bulb H, SS3	7.15	22.37	82.3	0.05	-0.1495	0.2025	0.00865	0.01055	0.00618	0.0004	0.002071	0.004375	0.00149
Bulb H, SS3	9.2	28.93	137	-1.115	-0.2345	0.2608	0.00674	0.0085	0.00435	0.0004	0.001998	0.004152	-0.03318
Bulb H, SS3	11.25	46.44	268.8	-0.012	-0.4213	0.3189	0.00724	0.00888	0.0049	0.0004	0.001942	0.003986	-0.00036
Conv, SS5	3.04	13.67	21.4	-0.08	0.1311	0.0864	0.03321	0.03574	0.03046	0.0004	0.002353	0.00528	-0.00238
Conv, SS5	5.1	27.27	71.5	-0.039	0.1563	0.1446	0.02363	0.02576	0.02106	0.0004	0.002177	0.004704	-0.00116
Conv, SS5	7.16	44.62	164.3	-0.071	0.2666	0.2031	0.01961	0.02151	0.01714	0.0004	0.002071	0.004375	-0.00212
Conv, SS5	11.26	94.27	546.2	0.068	0.391	0.3195	0.01674	0.01838	0.0144	0.0004	0.001942	0.003987	0.00203
Bulb C, SS5	3.05	13.48	21.1	-0.069	-0.2574	0.0863	0.02835	0.03087	0.02559	0.0004	0.002352	0.005277	-0.00206
Bulb C, SS5	5.09	25.05	65.6	-0.068	-0.38	0.1444	0.01882	0.02095	0.01625	0.0004	0.002176	0.004703	-0.00203
Bulb C, SS5	7.15	42.05	154.7	-0.09	-0.2937	0.2026	0.01604	0.01795	0.01357	0.0004	0.002071	0.004374	-0.00268
Bulb C, SS5	11.25	67.87	392.9	0.023	-0.7732	0.3189	0.01045	0.0121	0.00811	0.0004	0.001942	0.003986	0.00068

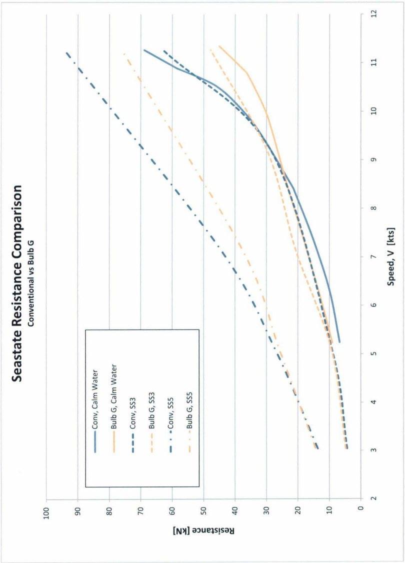
Bulb D, SS5	3.04	17.36	27.1	-0.188	-0.2694	0.0861	0.03755	0.04008	0.0348	0.0004	0.002353	0.00528	-0.00559
Bulb D, SS5	5.09	34.74	91	-0.194	-0.2332	0.1443	0.02677	0.02889	0.02419	0.0004	0.002177	0.004703	-0.00576
Bulb D, SS5	7.14	48.26	177.4	-0.241	-0.1694	0.2024	0.01889	0.02079	0.01642	0.0004	0.002071	0.004375	-0.00717
Bulb D, SS5	11.25	88.99	515.1	-0.134	-0.1185	0.3189	0.01404	0.01568	0.01169	0.0004	0.001942	0.003986	-0.004
Bulb G, SS5	3.05	14.4	22.6	-0.092	-0.1444	0.0864	0.03068	0.0332	0.02792	0.0004	0.002352	0.005276	-0.00274
Bulb G, SS5	5.1	25.95	68	-0.162	-0.2133	0.1444	0.01978	0.02191	0.01721	0.0004	0.002176	0.004703	-0.00483
Bulb G, SS5	7.14	37.56	138	-0.133	-0.2537	0.2024	0.01457	0.01647	0.0121	0.0004	0.002071	0.004375	-0.00397
Bulb G, SS5	11.25	75.94	439.6	-0.062	-0.3112	0.3189	0.01187	0.01351	0.00953	0.0004	0.001942	0.003986	-0.00185
Bulb H, SS5	3.04	12.84	20.1	-0.198	-0.2749	0.0861	0.02745	0.02997	0.02469	0.0004	0.002353	0.00528	-0.00588
Bulb H, SS5	5.1	26.86	70.5	-0.203	-0.3565	0.1445	0.02038	0.02251	0.0178	0.0004	0.002176	0.004702	-0.00605
Bulb H, SS5	7.15	39.04	143.5	-0.25	-0.3768	0.2025	0.01509	0.01699	0.01262	0.0004	0.002071	0.004375	-0.00743
Bulb H, SS5	11.25	88.88	514.5	-0.296	-0.3911	0.3189	0.01385	0.0155	0.01151	0.0004	0.001942	0.003986	-0.00879



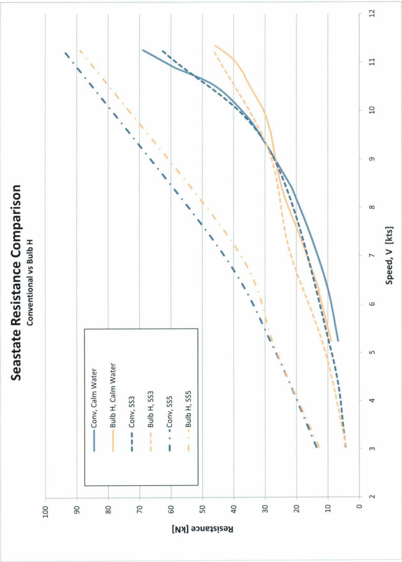
Seastate Resistance Comparison
Conventional vs Bulb D
Resistance [kN]
Speed, V [kts]
Conv, Calm Water
Bulb D, Calm Water
Conv, SS3
Bulb D, SS3
Conv, SS5
Bulb D, SS5
100
90
80
70
60
50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11
12

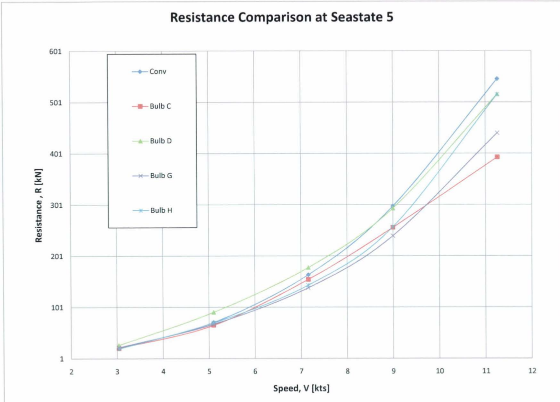


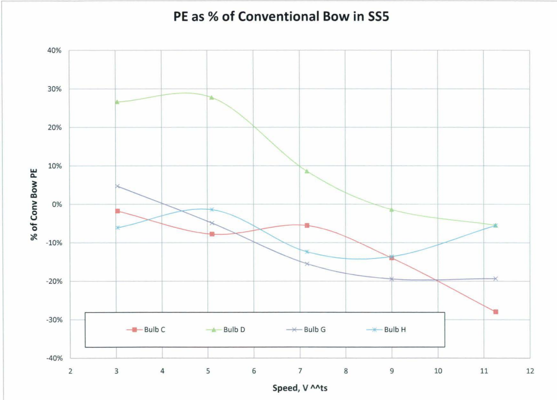
Seastate Resistance Comparison
Conventional vs Bulb C
Conv, Calm Water
Bulb C, Calm Water
Conv, SS3
Bulb C, SS3
Conv, SS5
Bulb C, SS5
Resistance [kN]
Speed, V [kts]
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
12



Seastate Resistance Comparison
Conventional vs Bulb G
Resistance [kN]
Speed, V [kts]
Conv, Calm Water
Bulb G, Calm Water
Conv, SS3
Bulb G, SS3
Conv, SS5
Bulb G, SS5
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
12


Seastate Resistance Comparison
Conventional vs Bulb H
Resistance [kN]
Speed, V [kts]
Conv, Calm Water
Bulb H, Calm Water
Conv, SS3
Bulb H, SS3
Conv, SS5
Bulb H, SS5
0
10
20
30
40
50
60
70
80
90
100
2
3
4
5
6
7
8
9
10
11
12


Resistance Comparison at Seastate 5
601
501
401
301
201
101
1
2
3
4
5
6
7
8
9
10
11
12
Resistance , R [kN]
Speed, V [kts]
Conv
Bulb C
Bulb D
Bulb G
Bulb H



PE as % of Conventional Bow in SS5
% of Conv Bow PE
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
2
3
4
5
6
7
8
9
10
11
12
Speed, V ^^ts
Bulb C
Bulb D
Bulb G
Bulb H

Appendix J – Uncertainty Analysis Data

Bias Limit

From ITTC procedure 7.5-01-01-01

B_L	Length bias	**0.002**	**m**

Wetted surface area From ITTC procedure 7.5-02-02-02

Data Aquisition Bias

∇	Displacement	72.62	kg	model and equipment weighted together
S	Wetted Surface	1.123	m^2	
L	Length	1.833	m	
B	Beam	0.499	m	
T	Draft	0.224	m	
Cs	Wetted Surface coefficient	0.09734	-	
C_B	Block Coefficient	0.35444	-	
A_{WP}	Waterplane area	0.7004	m^2	
L'	Length w/bias	1.835	m	
B'	Beam w/bias	0.501	m	
T'	Draft w/bias	0.225	m	
∇'	Displacement w/bias	73.32	kg	
	$\nabla' - \nabla$	0.70	kg	
S'	wetted surface area w/bias	1.128988	m^2	
	S'-S	0.005988	m^2	

using water density 1000 kg/m3 and an increase in mass by 0.70kg the draft changes by:

T''	T''	0.000994	m
L''	total WL length = 2*L	3.666	m

the draft change decreases the wetted surface By:

S''	T''*L''	0.003645	m^2
B_{S1}	**S'-S-S''**	**0.002342**	m^2

Calibration Bias

The model was weighed together on a scale with a calibtration of +-0.2kg

using water density 1000 kg/m3 and an increase in mass by 0.20kg the draft changes by:

T'''	T'''	0.000286	m

the draft change increase the wetted surface By:

S'''	T''' * L''	0.001047	m^2
B_{S2}	**0.2kg*S'''**	**0.000209**	m^2

Total wetted surface bias using RSS

B_S	**RSS of BS1 and BS2**	**0.002352**	m^2

Temperature

B_{to} **0.5** °C from ITTC procedure 7.5-02-03-01.2

taken from the manufacturers calibration

there was no change in temperature during the self-proplsion and seakeeping experiments

for full scale:

ts	**15** oC	from ITTC procedure 7.5-02-03-01.2
B_{tso}	**15** °C	

Density

Calibration

from ITTC procedure 7.5-02-03-01.2 the density equation is

$\rho = 1000.1 + 0.0552(t) - 0.0077(t^2) + 0.00001(t^3)$

$$D_{\rho 1} - \left|\frac{\partial \rho}{\partial t}\right| \times D_{t^v}$$

t	11.2 °C	test temperature
ρ	999.754 kg/m3	
$B_{\rho 1}$	0.0511136 kg/m^3	

data reduction

$B_{\rho 2}$	0.07 kg/m^3	from ITTC procedure 7.5-02-02-02

using HSS to get

B_ρ **0.086675257** kg/m^3

Viscosity

Freshwater

from ITTC 7.5-02-01-03

v=	1.26226E-06
$\frac{\partial v}{\partial t}$	3.4546E-08
Bv1=	**1.7273E-08**

from the tables v @ 11.2degrees = 1.26277x10-6

Bv2=	**-5.076E-10**
Bv	**1.72805E-08 m2/s**

Viscosity

saltwater

from ITTC 7.5-02-01-03

v=	1.18738E-06
$\frac{\partial v}{\partial t}$	3.2304E-08
Bv1=	**4.8456E-07**

from the tables v @ 11.2degrees = 1.18831x10-6

Bv2=	**-9.3E-10**
Bv	**4.84561E-07 m2/s**

Propeller diameter
the CNC machine has a calibrated accuracy of 0.1mm
the polishing process is accurate within 0.1mm

D	0.1205 m	Propeller diameter
B_D	**0.000141 m**	

Shaft Speed

Bn	**0.00167 rps**	from manufacturer

			B_{Rx1}	measured x weight accuracy
Res. Load cell				
mass	weight	volts	weight	
actual	actual		calculated	
1.002	9.830221	-0.1814	9.828013	4.87677E-06
2.508	24.60498	-0.3705	24.609	1.60853E-05
3.51	34.43521	-0.4962	34.43432	7.79018E-07
4.51	44.24581	-0.6217	44.24402	3.19576E-06
6.522	63.98473	-0.8742	63.98066	1.6627E-05
				4.15638E-05
			SEE=	0.003722179 N
			B_{Rx2}	**0.007444358**

AD converter	
AD card resolution	16 bits
AD card volt range	10 volts
AD card error	1 bit

B_{Rx4} **-0.024159241** **0.000305176**

conv

V,M	R,TM	B_{Rx}		
m/s	N	N		
0.756971	2.158	0.0253	1.17%	2.184
1.008022	4.299	0.0254	0.59%	4.324
1.011526	4.393	0.0254	0.58%	4.418
1.197857	7.186	0.0255	0.36%	7.212
1.35294	12.602	0.0261	0.21%	12.628
1.451505	15.677	0.0265	0.17%	15.703
1.579039	20.380	0.0273	0.13%	20.407
1.640851	23.219	0.0278	0.12%	23.247
1.772254	31.007	0.0297	0.10%	31.037
1.889312	41.664	0.0328	0.08%	41.696

bulb C

V,M	R,TM	B_{Rx}		
m/s	N	N		
0.757701	2.540205	0.0253	1.00%	
1.008872	4.904916	0.0254	0.52%	
1.144446	6.562336	0.0255	0.39%	9.526008764
1.265382	7.725199	0.0256	0.33%	10.53264882
1.358416	10.14631	0.0258	0.25%	11.30703079
1.424536	12.18439	0.0260	0.21%	11.85739246
1.488375	14.0359	0.0262	0.19%	12.3887672
1.57978	16.74358	0.0266	0.16%	13.14959411
1.714526	22.55173	0.0277	0.12%	14.27117733
1.888506	34.63843	0.0306	0.09%	

Bulb D

V,M	R,TM	B_{Rx}	
m/s	N	N	
0.758779	3.45	0.0253	0.73%
1.011745	5.83	0.0254	0.44%
1.148888	7.48	0.0256	0.34%
1.265014	9.19	0.0257	0.28%
1.357984	10.98	0.0259	0.24%
1.456791	12.24	0.0260	0.21%
1.487579	12.69	0.0261	0.21%
1.576767	14.85	0.0263	0.18%
1.772618	23.23	0.0278	0.12%
1.902665	33.72	0.0304	0.09%

Bulb G

V,M	R,TM	B_{Rx}	
m/s	N	N	
0.756447	2.56	0.0253	0.99%
1.012845	4.72	0.0254	0.54%
1.146285	5.72	0.0254	0.44%
1.263762	6.95	0.0255	0.37%
1.362357	9.03	0.0257	0.28%
1.424721	10.77	0.0258	0.24%
1.491092	12.44	0.0260	0.21%
1.577389	14.83	0.0263	0.18%
1.780653	25.15	0.0282	0.11%
1.895342	34.07	0.0305	0.09%

Bulb H

V,M	R,TM	B_{Rx}	
m/s	N	N	
0.758779	3.45	0.0253	0.73%
1.011745	5.83	0.0254	0.44%
1.148888	7.48	0.0256	0.34%
1.265014	9.19	0.0257	0.28%
1.357984	10.98	0.0259	0.24%
1.423632	11.92	0.0260	0.22%
1.487579	12.69	0.0261	0.21%
1.576767	14.85	0.0263	0.18%
1.772618	23.23	0.0278	0.12%
1.902665	33.72	0.0304	0.09%

Speed Bias
based on carriage calibration manuals and work completed by BOSE and Luznik (1996)

resolution	10000	pulses/m
Diameter of Wheel	0.5	m
Max pulse duration	2.00E-07	s
min Pulse duration	1.20E-07	s
moax output signal	5	volts
circuit speed	100	ms
AD/DA card	12	bits

from ittc 7.502-02-02

max number of pulses	4096	pulses
number of windows	6366	pulses/revolution

speed $$V = \frac{c \times \pi \times D}{6366 \times \Delta t}$$

calibration error	0.001220703	Volts
Bc1	1	pulse
AD/DAconversion Error	0.001831055	Volts
Bc2 and Bc3 =	1.5	pulses
Curve fit error	0.000305	volts
Bc4	0.25	pulses
Bc	**2.358495283**	**pulses**

the wheel bias from manufacturer

B_{DW} **0.0001 m**

$B_{\Delta t}$ **1.03E-05 s** From ITTC 7.5-02-02-02

using nominal values of:

V=	1.358	m/s	11.30357
c=	550.36		

∂V/∂c	0.001963495
∂V/∂D	2.7160
∂V/∂t	-13.5800001

Bv= **0.00464094** m/s

Precision

Std.dev CT repeats	0.000160
P_{CT}	**0.000185**

Total Resistance Coefficient Bias

conv

V,M	Rx	∂CT/∂S	∂CT/∂V	∂CT/∂R	∂CT/∂ρ	B_{CTM}	**U_{CT}**	C_{Tm}		CTS	B_{CTS}	CFD			
m/s	N												CTS	CFS	CR
0.756971	2.158	-0.00598	-0.00886	0.00671	-6.71189E-06	0.000175	0.000255	0.006710231	3.7938%	0.004627	0.000216	0.00208304	0.00463	0.00211	0.00212
1.008022	4.299	-0.00671	-0.00748	0.007536	-7.53804E-06	0.000195	0.000269	0.007536178	3.5630%	0.005638	0.000228	0.00189818	0.00564	0.00202	0.00321
1.011526	4.393	-0.00681	-0.00756	0.007648	-7.64944E-06	0.000198	0.000271	0.00764756	3.5387%	0.005752	0.000231	0.00189606	0.00575	0.00202	0.00333
1.197857	7.186	-0.00794	-0.00745	0.008921	-8.92368E-06	0.000231	0.000296	0.008921486	3.3162%	0.007126	0.000258	0.0017957	0.00713	0.00198	0.00475
1.35294	12.602	-0.01092	-0.00907	0.012264	-1.22675E-05	0.000323	0.000372	0.012264491	3.0357%	0.010537	0.000342	0.00172706	0.01054	0.00194	0.00820
1.451505	15.677	-0.0118	-0.00913	0.013255	-1.32583E-05	0.000354	0.000400	0.013255067	3.0152%	0.011566	0.000371	0.00168873	0.01157	0.00192	0.00924
1.579039	20.380	-0.01297	-0.00922	0.01456	-1.4564E-05	0.0004	0.000441	0.014560401	3.0278%	0.012916	0.000415	0.00164404	0.01292	0.00190	0.01062
1.640851	23.219	-0.01368	-0.00936	0.015363	-1.53666E-05	0.000431	0.000469	0.015362824	3.0507%	0.013739	0.000444	0.00162409	0.01374	0.00189	0.01145
1.772254	31.007	-0.01566	-0.00992	0.017586	-1.75904E-05	0.000525	0.000556	0.01758604	3.1637%	0.016001	0.000535	0.00158485	0.01600	0.00187	0.01373
1.889312	41.664	-0.01852	-0.01101	0.020793	-2.07976E-05	0.000684	0.000709	0.020792515	3.4093%	0.019239	0.000692	0.00155305	0.01924	0.00185	0.01699

bulb C

V,M	R,TM	∂CT/∂S	∂CT/∂V	∂CT/∂R	∂CT/∂ρ	B_{CTM}	**U_{CT}**	C_T		CTS	B_{CTS}		Bulb C		
m/s	N											Vs	CTS	CFS	CR
0.757701	2.540205	-0.00702	-0.0104	0.007882	-7.88384E-06	0.000206	0.000277	0.007881893	3.5090%	0.0058	0.000242	6.3	0.00580	0.00211	0.00329
1.008872	4.904916	-0.00764	-0.00851	0.008585	-8.58666E-06	0.000222	0.000289	0.00858454	3.3663%	0.006687	0.000252	8.4	0.00669	0.00202	0.00426
1.144446	6.562336	-0.00795	-0.0078	0.008925	-8.92755E-06	0.000231	0.000296	0.008925352	3.3145%	0.007103	0.000258	9.5	0.00710	0.00199	0.00472
1.265382	7.725199	-0.00765	-0.00679	0.008595	-8.59667E-06	0.000223	0.000289	0.008594554	3.3665%	0.00683	0.000250	10.5	0.00683	0.00196	0.00447
1.358416	10.14631	-0.00872	-0.00721	0.009795	-9.79731E-06	0.000256	0.000315	0.009794898	3.2190%	0.00807	0.000279	11.3	0.00807	0.00194	0.00573
1.424536	12.18439	-0.00952	-0.00751	0.010696	-1.06985E-05	0.000281	0.000336	0.010695828	3.1451%	0.008997	0.000302	11.9	0.00900	0.00193	0.00667
1.488375	14.0359	-0.01005	-0.00758	0.011287	-1.12896E-05	0.000299	0.000352	0.011286855	3.1145%	0.009612	0.000318	12.4	0.00961	0.00192	0.00730
1.57978	16.74358	-0.01064	-0.00757	0.011951	-1.19542E-05	0.000321	0.000370	0.011951227	3.0998%	0.010307	0.000339	13.1	0.01031	0.00190	0.00801
1.714526	22.55173	-0.01217	-0.00797	0.013666	-1.36696E-05	0.000381	0.000424	0.013666243	3.0991%	0.012065	0.000396	14.3	0.01206	0.00188	0.00979
1.888506	34.63843	-0.01541	-0.00916	0.017301	-1.73056E-05	0.000533	0.000564	0.017301292	3.2609%	0.015748	0.000543	15.7	0.01575	0.00185	0.01349

Bulb D

V,M	R,TM	∂CT/∂S	∂CT/∂V	∂CT/∂R	∂CT/∂ρ	B_{CT}	U_{CF}	C_T		CTS	B_{CTS}		CTS	CFS	CR
m/s	N														
0.758779	3.45	-0.00951	-0.01408	0.010682	-1.06844E-05	0.000279	0.000335	0.010681722	3.1347%	0.0086	0.000307	6.3	0.00860	0.00211	0.00609
1.011745	5.83	-0.00903	-0.01003	0.010143	-1.01458E-05	0.000263	0.000321	0.0101433	3.1691%	0.008247	0.000289	8.4	0.00825	0.00202	0.00582
1.148888	7.48	-0.00899	-0.00879	0.010096	-1.0099E-05	0.000262	0.000321	0.010096473	3.1752%	0.008277	0.000286	9.6	0.00828	0.00199	0.00589
1.265014	9.19	-0.00911	-0.00809	0.01023	-1.02327E-05	0.000266	0.000324	0.010230172	3.1682%	0.008466	0.000289	10.5	0.00847	0.00196	0.00611
1.357984	10.98	-0.00944	-0.00781	0.010602	-1.06051E-05	0.000278	0.000333	0.010602494	3.1441%	0.008877	0.000299	11.3	0.00888	0.00194	0.00654
1.456791	12.24	-0.00915	-0.00705	0.010277	-1.02792E-05	0.00027	0.000327	0.01027667	3.1841%	0.00859	0.000292	12.1	0.00859	0.00192	0.00627
1.487579	12.69	-0.0091	-0.00687	0.010215	-1.02178E-05	0.000269	0.000326	0.010215277	3.1940%	0.00854	0.000290	12.4	0.00854	0.00192	0.00622
1.576767	14.85	-0.00947	-0.00675	0.010638	-1.0641E-05	0.000283	0.000338	0.010638346	3.1756%	0.008994	0.000303	13.1	0.00899	0.00190	0.00669
1.772618	23.23	-0.01173	-0.00743	0.013169	-1.31723E-05	0.000369	0.000413	0.013169022	3.1333%	0.011584	0.000384	14.8	0.01158	0.00187	0.00931
1.902665	33.72	-0.01477	-0.00872	0.016591	-1.65952E-05	0.000507	0.000540	0.016591101	3.2519%	0.015042	0.000517	15.8	0.01504	0.00185	0.01279

Bulb G

V,M	R,TM	∂CT/∂S	∂CT/∂V	∂CT/∂R	∂CT/∂ρ	B_{CT}	U_{CF}	C_T		CTS	B_{CTS}		CTS	CFS	CR
m/s	N														
0.756447	2.56	-0.0071	-0.01054	0.007971	-7.97252E-06	0.000208	0.000278	0.007970551	3.4919%	0.005887	0.000244	6.29642604	0.00589	0.00211	0.00338
1.012845	4.72	-0.00731	-0.0081	0.008204	-8.20581E-06	0.000212	0.000281	0.008203787	3.4301%	0.006309	0.000243	8.43060869	0.00631	0.00202	0.00389
1.146285	5.72	-0.0069	-0.00676	0.007754	-7.75608E-06	0.0002	0.000273	0.007754169	3.5143%	0.005933	0.000231	9.54131947	0.00593	0.00199	0.00355
1.263762	6.95	-0.0069	-0.00613	0.007752	-7.75382E-06	0.000201	0.000273	0.007751905	3.5161%	0.005987	0.000230	10.5191569	0.00599	0.00196	0.00363
1.362357	9.03	-0.00771	-0.00636	0.008664	-8.66589E-06	0.000225	0.000291	0.008663758	3.3610%	0.006941	0.000251	11.3398368	0.00694	0.00194	0.00460
1.424721	10.77	-0.00842	-0.00663	0.009451	-9.45359E-06	0.000247	0.000308	0.009451258	3.2630%	0.007752	0.000270	11.8589335	0.00775	0.00193	0.00542
1.491092	12.44	-0.00888	-0.00669	0.009969	-9.97122E-06	0.000262	0.000321	0.009968767	3.2170%	0.008294	0.000284	12.4113819	0.00829	0.00192	0.00598
1.577389	14.83	-0.00945	-0.00673	0.010615	-1.06179E-05	0.000282	0.000337	0.010615247	3.1774%	0.008971	0.000302	13.1296966	0.00897	0.00190	0.00667
1.780653	25.15	-0.01258	-0.00794	0.01413	-1.41335E-05	0.000402	0.000442	0.01412997	3.1291%	0.012547	0.000415	14.8215985	0.01255	0.00187	0.01028
1.895342	34.07	-0.01505	-0.00891	0.016896	-1.69002E-05	0.000518	0.000550	0.01689602	3.2544%	0.015345	0.000528	15.7762364	0.01534	0.00185	0.01309

Bulb H

V,M	R,TM	∂CT/∂S	∂CT/∂V	∂CT/∂R	∂CT/∂ρ	B_{CT}	U_{CF}	C_T					CTS	CFS	CR
m/s	N														
0.758779	3.45	-0.00951	-0.01408	0.010682	-1.06844E-05	0.000279	0.000335	0.010681722	3.1347%	0.0086	0.000307	6.31584081	0.00860	0.00211	0.00609
1.011745	5.83	-0.00903	-0.01003	0.010143	-1.01458E-05	0.000263	0.000321	0.0101433	3.1691%	0.008247	0.000289	8.42145015	0.00825	0.00202	0.00582
1.148888	7.48	-0.00899	-0.00879	0.010096	-1.0099E-05	0.000262	0.000321	0.010096473	3.1752%	0.008277	0.000286	9.56298253	0.00828	0.00199	0.00589
1.265014	9.19	-0.00911	-0.00809	0.01023	-1.02327E-05	0.000266	0.000324	0.010230172	3.1682%	0.008466	0.000289	10.5295846	0.00847	0.00196	0.00611
1.357984	10.98	-0.00944	-0.00781	0.010602	-1.06051E-05	0.000278	0.000333	0.010602494	3.1441%	0.008877	0.000299	11.3034338	0.00888	0.00194	0.00654
1.423632	11.92	-0.00933	-0.00736	0.010476	-1.04787E-05	0.000275	0.000331	0.010476073	3.1626%	0.008777	0.000296	11.8498682	0.00878	0.00193	0.00645
1.487579	12.69	-0.0091	-0.00687	0.010215	-1.02178E-05	0.000269	0.000326	0.010215277	3.1940%	0.00854	0.000290	12.382146	0.00854	0.00192	0.00622
1.576767	14.85	-0.00947	-0.00675	0.010638	-1.0641E-05	0.000283	0.000338	0.010638346	3.1756%	0.008994	0.000303	13.1245171	0.00899	0.00190	0.00669
1.772618	23.23	-0.01173	-0.00743	0.013169	-1.31723E-05	0.000369	0.000413	0.013169022	3.1333%	0.011584	0.000384	14.7547159	0.01158	0.00187	0.00931
1.902665	33.72	-0.01477	-0.00872	0.016591	-1.65952E-05	0.000507	0.000540	0.016591101	3.2519%	0.015042	0.000517	15.8371894	0.01504	0.00185	0.01279

Precision

Std.dev CF repeats	8.550E-08
P_{CF}	**9.873E-08**

Frictional Resistance Coefficient Bias

conv

V,M	R,TM	∂CF/∂V	∂CF/∂L	∂CF/∂ν	B_{CF}	U_{CF}	C_F	$C_F + U_{CF}$	$C_F - U_{CF}$	
m/s	N									
0.756971	2.158	-0.001304068	-0.000539	782.0414	1.48465E-05	1.4847E-05	0.004593	4.6075E-03	4.5778E-03	0.3233%
1.008022	4.299	-0.000894149	-0.000492	714.0522	1.30553E-05	1.3056E-05	0.004322	4.3355E-03	4.3094E-03	0.3020%
1.011526	4.393	-0.000890085	-0.000491	713.2777	1.30366E-05	1.3037E-05	0.004319	4.3324E-03	4.3063E-03	0.3018%
1.197857	7.186	-0.000713255	-0.000466	676.8618	1.21916E-05	1.2192E-05	0.004171	4.1832E-03	4.1588E-03	0.2923%
1.35294	12.602	-0.000608452	-0.000449	652.1611	1.16527E-05	1.1653E-05	0.004069	4.0806E-03	4.0573E-03	0.2864%
1.451505	15.677	-0.000555202	-0.00044	638.4395	1.13635E-05	1.1364E-05	0.004012	4.0230E-03	4.0003E-03	0.2833%
1.579039	20.380	-0.000497625	-0.000429	622.5084	1.10357E-05	1.1036E-05	0.003945	3.9557E-03	3.9336E-03	0.2798%
1.640851	23.219	-0.000473426	-0.000424	615.4204	1.08924E-05	1.0893E-05	0.003915	3.9255E-03	3.9037E-03	0.2783%
1.772254	31.007	-0.000428425	-0.000414	601.5213	1.06154E-05	1.0616E-05	0.003855	3.8661E-03	3.8449E-03	0.2753%
1.889312	41.664	-0.000394382	-0.000406	590.2977	1.03954E-05	1.0396E-05	0.003807	3.8178E-03	3.7970E-03	0.2730%
				mean	1.19085E-05					
				std.dev	1.39116E-06					

bulb C

V,M	R,TM	∂CF/∂V	∂CF/∂L	∂CF/∂ν	B_{CF}	U_{CF}	C_F	$C_F + U_{CF}$	$C_F - U_{CF}$	
m/s	N									
0.757701	2.540205	-0.001302407	-0.000538	781.7984	1.48395E-05	1.4840E-05	0.004592	4.6065E-03	4.5769E-03	0.3232%
1.008872	4.904916	-0.00089316	-0.000492	713.8639	1.30508E-05	1.3051E-05	0.004322	4.3347E-03	4.3086E-03	0.3020%
1.144446	6.562336	-0.000757104	-0.000473	686.4373	1.24075E-05	1.2408E-05	0.00421	4.2227E-03	4.1979E-03	0.2947%
1.265382	7.725199	-0.000663943	-0.000458	665.5837	1.19424E-05	1.1943E-05	0.004125	4.1365E-03	4.1126E-03	0.2896%
1.358416	10.14631	-0.000605257	-0.000449	651.3623	1.16357E-05	1.1636E-05	0.004066	4.0772E-03	4.0540E-03	0.2862%
1.424536	12.18439	-0.000568922	-0.000442	642.0611	1.14392E-05	1.1440E-05	0.004027	4.0383E-03	4.0154E-03	0.2841%
1.488375	14.0359	-0.000537376	-0.000436	633.638	1.12638E-05	1.1264E-05	0.003992	4.0028E-03	3.9803E-03	0.2822%
1.57978	16.74358	-0.000497322	-0.000429	622.4212	1.10339E-05	1.1034E-05	0.003944	3.9553E-03	3.9332E-03	0.2798%
1.714526	22.55173	-0.000447211	-0.000418	607.4442	1.07328E-05	1.0733E-05	0.003881	3.8915E-03	3.8700E-03	0.2766%
1.888506	34.63843	-0.0003946	-0.000407	590.3717	1.03968E-05	1.0397E-05	0.003808	3.8181E-03	3.7973E-03	0.2731%
				mean	1.18742E-05					
				std.dev	1.30284E-06					

Bulb D

V,M	R,TM	∂CF/∂V	∂CF/∂L	∂CF/∂ν	B_{CF}	U_{CF}	C_F	$C_F + U_{CF}$	$C_F - U_{CF}$	
m/s	N									
0.758779	3.45	-0.00129996	-0.000538	781.4401	1.48292E-05	1.4829E-05	0.00459	4.6051E-03	4.5755E-03	0.3231%
1.011745	5.83	-0.000889831	-0.000491	713.2293	1.30354E-05	1.3036E-05	0.004319	4.3322E-03	4.3061E-03	0.3018%
1.148888	7.48	-0.000753275	-0.000472	685.6171	1.23888E-05	1.2389E-05	0.004207	4.2193E-03	4.1945E-03	0.2945%
1.265014	9.19	-0.000664195	-0.000458	665.6428	1.19437E-05	1.1944E-05	0.004125	4.1368E-03	4.1129E-03	0.2896%
1.357984	10.98	-0.000605508	-0.000449	651.4251	1.1637E-05	1.1637E-05	0.004066	4.0775E-03	4.0542E-03	0.2862%
1.456791	12.24	-0.000552581	-0.000439	637.7405	1.13489E-05	1.1349E-05	0.004009	4.0201E-03	3.9974E-03	0.2831%
1.487579	12.69	-0.00053775	-0.000436	633.7399	1.12659E-05	1.1266E-05	0.003992	4.0032E-03	3.9807E-03	0.2822%
1.576767	14.85	-0.000498556	-0.000429	622.7763	1.10411E-05	1.1042E-05	0.003946	3.9568E-03	3.9347E-03	0.2798%
1.772618	23.23	-0.000428311	-0.000414	601.4848	1.06147E-05	1.0615E-05	0.003855	3.8659E-03	3.8447E-03	0.2753%
1.902665	33.72	-0.000390806	-0.000406	589.079	1.03716E-05	1.0372E-05	0.003802	3.8125E-03	3.7918E-03	0.2728%
				mean	1.18477E-05					
				std.dev	1.31585E-06					

Bulb G

V,M	R,TM	∂CF/∂V	∂CF/∂L	∂CF/∂v	B_{CF}	U_{CF}	C_F	$C_F + U_{CF}$	$C_F - U_{CF}$	
m/s	N									
0.756447	2.56	-0.001305263	-0.000539	782.216	1.48515E-05	1.4852E-05	0.004593	4.6082E-03	4.5785E-03	0.3233%
1.012845	4.72	-0.000888563	-0.000491	712.987	1.30296E-05	1.3030E-05	0.004318	4.3312E-03	4.3051E-03	0.3017%
1.146285	5.72	-0.000755514	-0.000472	686.0971	1.23997E-05	1.2400E-05	0.004209	4.2213E-03	4.1965E-03	0.2946%
1.263762	6.95	-0.000665055	-0.000459	665.8444	1.19481E-05	1.1949E-05	0.004126	4.1376E-03	4.1137E-03	0.2896%
1.362357	9.03	-0.000602975	-0.000448	650.7901	1.16235E-05	1.1624E-05	0.004063	4.0749E-03	4.0516E-03	0.2861%
1.424721	10.77	-0.000568826	-0.000442	642.0359	1.14386E-05	1.1439E-05	0.004027	4.0381E-03	4.0153E-03	0.2841%
1.491092	12.44	-0.000536103	-0.000436	633.2908	1.12567E-05	1.1257E-05	0.00399	4.0013E-03	3.9788E-03	0.2821%
1.577389	14.83	-0.000498301	-0.000429	622.7029	1.10397E-05	1.1040E-05	0.003945	3.9565E-03	3.9344E-03	0.2798%
1.780653	25.15	-0.000425809	-0.000414	600.682	1.05988E-05	1.0599E-05	0.003852	3.8625E-03	3.8413E-03	0.2752%
1.895342	34.07	-0.00039276	-0.000406	589.7459	1.03846E-05	1.0385E-05	0.003805	3.8154E-03	3.7946E-03	0.2729%
				mean	1.18571E-05					
				std.dev	1.31882E-06					

Bulb H

V,M	R,TM	∂CF/∂V	∂CF/∂L	∂CF/∂v	B_{CF}	U_{CF}	C_F	$C_F + U_{CF}$	$C_F - U_{CF}$	
m/s	N									
0.758779	3.45	-0.00129996	-0.000538	781.4401	1.48292E-05	1.4829E-05	0.00459	4.6051E-03	4.5755E-03	0.3231%
1.011745	5.83	-0.000889831	-0.000491	713.2293	1.30354E-05	1.3036E-05	0.004319	4.3322E-03	4.3061E-03	0.3018%
1.148888	7.48	-0.000753275	-0.000472	685.6171	1.23888E-05	1.2389E-05	0.004207	4.2193E-03	4.1945E-03	0.2945%
1.265014	9.19	-0.000664195	-0.000458	665.6428	1.19437E-05	1.1944E-05	0.004125	4.1368E-03	4.1129E-03	0.2896%
1.357984	10.98	-0.000605508	-0.000449	651.4251	1.1637E-05	1.1637E-05	0.004066	4.0775E-03	4.0542E-03	0.2862%
1.423632	11.92	-0.000569392	-0.000442	642.1841	1.14418E-05	1.1442E-05	0.004027	4.0388E-03	4.0159E-03	0.2841%
1.487579	12.69	-0.00053775	-0.000436	633.7399	1.12659E-05	1.1266E-05	0.003992	4.0032E-03	3.9807E-03	0.2822%
1.576767	14.85	-0.000498556	-0.000429	622.7763	1.10411E-05	1.1042E-05	0.003946	3.9568E-03	3.9347E-03	0.2798%
1.772618	23.23	-0.000428311	-0.000414	601.4848	1.06147E-05	1.0615E-05	0.003855	3.8659E-03	3.8447E-03	0.2753%
1.902665	33.72	-0.000390806	-0.000406	589.079	1.03716E-05	1.0372E-05	0.003802	3.8125E-03	3.7918E-03	0.2728%
				mean	1.18569E-05					
				std.dev	1.31226E-06					

Precision

Std.dev CR repeats	0.0001599
P_{CR}	**0.0001846**

Residuary Resistance Coefficient Bias **Residuary Resistance Coefficient Uncertainty**

Conv

V,M m/s	B_{CR}	U_{CR}	C_R	$C_R + U_{CR}$	$C_{R-} U_{CR}$	
0.756971	0.000176	0.000238	0.002118	2.3553E-03	1.8799E-03	11.2256%
1.008022	0.000195	0.000252	0.003214	3.4662E-03	2.9612E-03	7.8565%
1.011526	0.000198	0.000255	0.003328	3.5830E-03	3.0735E-03	7.6534%
1.197857	0.000231	0.000281	0.00475	5.0318E-03	4.4691E-03	5.9224%
1.35294	0.000324	0.000361	0.008196	8.5564E-03	7.8347E-03	4.4034%
1.451505	0.000355	0.000389	0.009243	9.6324E-03	8.8544E-03	4.2087%
1.579039	0.0004	0.000431	0.010616	1.1047E-02	1.0185E-02	4.0621%
1.640851	0.000431	0.000460	0.011448	1.1908E-02	1.0989E-02	4.0148%
1.772254	0.000525	0.000549	0.013731	1.4279E-02	1.3182E-02	3.9967%
1.889312	0.000684	0.000703	0.016985	1.7688E-02	1.6282E-02	4.1384%

bulb C

V,M m/s	B_{CR}	U_{CR}	C_R	$C_R + U_{CR}$	$C_{R-} U_{CR}$	
0.757701	0.000206	0.000261	0.00329	3.5513E-03	3.0291E-03	7.9369%
1.008872	0.000223	0.000274	0.004263	4.5370E-03	3.9887E-03	6.4312%
1.144446	0.000231	0.000281	0.004715	4.9964E-03	4.4337E-03	5.9667%
1.265382	0.000223	0.000274	0.00447	4.7445E-03	4.1955E-03	6.1404%
1.358416	0.000256	0.000302	0.005729	6.0310E-03	5.4276E-03	5.2660%
1.424536	0.000281	0.000324	0.006669	6.9927E-03	6.3453E-03	4.8536%
1.488375	0.000299	0.000339	0.007295	7.6347E-03	6.9560E-03	4.6521%
1.57978	0.000321	0.000359	0.008007	8.3659E-03	7.6480E-03	4.4829%
1.714526	0.000381	0.000413	0.009786	1.0199E-02	9.3720E-03	4.2256%
1.888506	0.000533	0.000557	0.013494	1.4050E-02	1.2937E-02	4.1254%

Bulb D

V,M m/s	B_{CR}	U_{CR}	C_R	$C_R + U_{CR}$	$C_{R-} U_{CR}$	
0.758779	0.00028	0.000322	0.006091	6.4136E-03	5.7692E-03	5.2895%
1.011745	0.000263	0.000308	0.005824	6.1324E-03	5.5160E-03	5.2915%
1.148888	0.000262	0.000307	0.00589	6.1968E-03	5.5823E-03	5.2169%
1.265014	0.000267	0.000311	0.006105	6.4163E-03	5.7944E-03	5.0926%
1.357984	0.000278	0.000321	0.006537	6.8571E-03	6.2161E-03	4.9035%
1.456791	0.00027	0.000314	0.006268	6.5821E-03	5.9538E-03	5.0118%
1.487579	0.000269	0.000313	0.006223	6.5365E-03	5.9102E-03	5.0317%
1.576767	0.000283	0.000325	0.006693	7.0177E-03	6.3674E-03	4.8586%
1.772618	0.000369	0.000402	0.009314	9.7160E-03	8.9114E-03	4.3196%
1.902665	0.000507	0.000532	0.012789	1.3321E-02	1.2257E-02	4.1572%

Bulb G

V,M m/s	B_{CR}	U_{CR}	C_R	$C_R + U_{CR}$	$C_{R-} U_{CR}$	
0.756447	0.000209	0.000263	0.003377	3.6402E-03	3.1142E-03	7.7871%
1.012845	0.000213	0.000266	0.003886	4.1518E-03	3.6195E-03	6.8494%
1.146285	0.000201	0.000257	0.003545	3.8020E-03	3.2886E-03	7.2402%
1.263762	0.000201	0.000257	0.003626	3.8830E-03	3.3695E-03	7.0799%
1.362357	0.000225	0.000276	0.004601	4.8769E-03	4.3241E-03	6.0082%
1.424721	0.000247	0.000294	0.005425	5.7190E-03	5.1301E-03	5.4285%
1.491092	0.000262	0.000307	0.005979	6.2860E-03	5.6714E-03	5.1403%
1.577389	0.000282	0.000325	0.00667	6.9944E-03	6.3452E-03	4.8667%
1.780653	0.000402	0.000433	0.010278	1.0711E-02	9.8456E-03	4.2083%
1.895342	0.000518	0.000542	0.013091	1.3633E-02	1.2549E-02	4.1415%

Bulb H

V,M m/s	B_{CR}	U_{CR}	C_R	$C_R + U_{CR}$	$C_{R-} U_{CR}$	
0.758779	0.00028	0.000322	0.006091	6.4136E-03	5.7692E-03	5.2895%
1.011745	0.000263	0.000308	0.005824	6.1324E-03	5.5160E-03	5.2915%
1.148888	0.000262	0.000307	0.00589	6.1968E-03	5.5823E-03	5.2169%
1.265014	0.000267	0.000311	0.006105	6.4163E-03	5.7944E-03	5.0926%
1.357984	0.000278	0.000321	0.006537	6.8571E-03	6.2161E-03	4.9035%
1.423632	0.000275	0.000318	0.006449	6.7672E-03	6.1303E-03	4.9375%
1.487579	0.000269	0.000313	0.006223	6.5365E-03	5.9102E-03	5.0317%
1.576767	0.000283	0.000325	0.006693	7.0177E-03	6.3674E-03	4.8586%
1.772618	0.000369	0.000402	0.009314	9.7160E-03	8.9114E-03	4.3196%
1.902665	0.000507	0.000532	0.012789	1.3321E-02	1.2257E-02	4.1572%

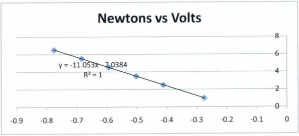
acc= accuracy of measured weights is 0.005%

B_{T1} =acc x measured thrust

	Mass	T (actual)	T Predicted	
volt	kg	N	N	
-0.2754	1.002	9.830021	9.867376	0.001395411
-0.4116	2.509	24.61429	24.636904	0.00051123
-0.5017	3.511	34.44431	34.407348	0.001366515
-0.5922	4.514	44.28415	44.221168	0.003966178
-0.6836	5.521	54.16322	54.132584	0.000938466
-0.7753	6.523	63.99324	64.076532	0.006937691
	y = -108.44x - 19.997		SEE	0.007557745

B_{T2} **0.01512 N**

B_{T3} **-0.0271 N**

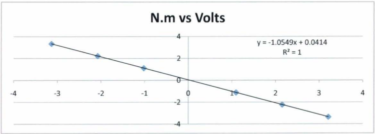


acc= accuracy of measured weights is 0.005%

ma	0.25	m	moment arm
Bma	0.0002	m	
F =Q measured/0.25		N	

$$B_{q1}^2 = \left(\frac{\partial Q}{\partial F} \times B_F\right)^2 + \left(\frac{\partial Q}{\partial ma} \times B_{ma}\right)^2$$

	Q	Q Pred	
volt	N.m	N.m	
-1.0203	1.1154	1.11771447	5.35677E-06
-2.0753	2.2309	2.23063397	7.0772E-08
-3.1317	3.3463	3.34503033	1.61206E-06
1.0972	-1.1154	-1.11603628	4.04852E-07
2.1539	-2.2309	-2.23074911	2.27678E-08
3.2119	-3.3463	-3.34683331	2.8442E-07
y = -108.44x - 19.997		SEE	3.87582E-06
	B_{q2}	**7.75164E-06 N.m**	
	B_{q3}	**-0.0005 N.m**	



J	Kto	Kqo	10Kqo	η
0.1	0.5978386	0.11050017	1.1050017	0.086108
0.2	0.5483808	0.10241736	1.0241736	0.170435
0.3	0.4987962	0.09491759	0.9491759	0.25091
0.4	0.4488544	0.08783688	0.8783688	0.325318
0.5	0.398325	0.08101125	0.8101125	0.391275
0.6	0.3469776	0.07427672	0.7427672	0.446088
0.7	0.2945818	0.06746931	0.6746931	0.486427
0.8	0.2409072	0.06042504	0.6042504	0.507625
0.9	0.1857234	0.05297993	0.5297993	0.502132
1	0.1288	0.04497	0.4497	0.455841
1.2	0.0088128	0.02659976	0.2659976	0.063276

	slope	-1.84124194	
	intercept	1.241648637	
Kto	J	J	
	polynomial	linear	
0.3469776	0.6	0.602778927	7.7224E-06
0.327464409	0.6375	0.638707432	1.4579E-06
0.307791638	0.675	0.674929765	4.933E-09
0.287947134	0.7125	0.711468296	1.0644E-06
0.26791875	0.75	0.748345397	2.7377E-06
0.247694334	0.7875	0.78558344	3.6732E-06
0.227261738	0.825	0.823204794	3.2228E-06
0.206608809	0.8625	0.861231832	1.6083E-06
0.1857234	0.9	0.899686923	9.8017E-08
0.164593359	0.9375	0.93859244	1.1934E-06
0.143206538	0.975	0.977970754	8.8254E-06
		SEE	1.0536E-05
		B_{JT1}	0.002032
		B_{JT2}	0.00002107
		B_{JT3}	-0.00297094
Open water advance coeff.		**B_{JT}**	**0.00359944**

	J = a*Kto+b	Kto= a*J+b	
slope	-13.817215	-0.07230114	
intercept	1.62126244	0.117293004	
Kqo	J	J	
	polynomial	linear	
0.11050017	0.1	0.094457799	3.0716E-05
0.10241736	0.2	0.206139725	3.7696E-05
0.09491759	0.3	0.309765662	9.5368E-05
0.08783688	0.4	0.407601356	5.7781E-05
0.08101125	0.5	0.501912556	3.6579E-06
0.07427672	0.6	0.594965007	2.5351E-05
0.06746931	0.7	0.689024456	0.00012046
0.06042504	0.8	0.786356652	0.00018614
0.05297993	0.9	0.88922734	0.00011605
0.04497	1	0.999902267	9.5517E-09
0.03623127	1.1	1.120647181	0.00042631
		SEE	0.00036651
		B_{JQ1}	0.0002628
		B_{JQ2}	0.00073303
		B_{JQ3}	-3.1111E-05
Open water torque coeff.		$\mathbf{B_{KQT}}$	**0.00077933**

TEST,COND	VM	Vs	n_M	η_O	η_H	J	J_o	K_{QO}	F_D	B_{FD}	
	m/s	knots	rps	[-]	[-]	[-]	[-]	[-]	N	**N**	**%**
Conventional Bow	0.860367	7.161	8.38587277	*0.5054292*	*0.645011*	*0.851502*	0.781472	0.061756	0.759091	**0.025283**	**3.3307%**
Conventional Bow	1.106454	9.210	10.7630485	*0.507403*	*0.815376*	*0.853195*	0.797729	0.060589	1.195825	**0.025287**	**2.1146%**
Conventional Bow	1.352962	11.262	14.8478411	*0.4863974*	*0.847893*	*0.756263*	0.699906	0.067476	1.740965	**0.025295**	**1.4529%**
Conventional Bow	1.59918	13.311	18.8000902	*0.460255*	*0.849382*	*0.705973*	0.630844	0.072192	2.506726	**0.025311**	**1.0097%**
Conventional Bow	1.847562	15.379	23.4186185	*0.4536402*	*0.915207*	*0.654769*	0.616056	0.073193	4.00613	**0.025359**	**0.6330%**
Bulb C	1.105402	9.201	11.4680199	*0.493737*	*0.678238*	*0.799985*	0.724953	0.06574	1.348729	**0.030515**	**2.2625%**
Bulb C	1.35228	11.256	14.195395	*0.4930827*	*0.734625*	*0.790623*	0.722535	0.065908	1.992611	**0.030524**	**1.5318%**
Bulb C	1.475387	12.281	15.8704765	*0.4818466*	*0.80244*	*0.771554*	0.686124	0.068424	2.307029	**0.030529**	**1.3233%**
Bulb C	1.59919	13.311	17.2669287	*0.4811864*	*0.871344*	*0.768662*	0.684208	0.068556	2.745259	**0.030538**	**1.1124%**
Bulb C	1.846698	15.371	21.2671322	*0.4687557*	*0.989962*	*0.720672*	0.651091	0.070818	4.107949	**0.030576**	**0.7443%**
Bulb D	1.344643	11.192	14.5337828	*0.4793903*	*0.749875*	*0.767854*	0.67909	0.068907	1.847831	**0.025297**	**1.3690%**
Bulb D	1.475642	12.283	15.7374077	*0.4797217*	*0.748223*	*0.778213*	0.680024	0.068843	2.166216	**0.025303**	**1.1681%**
Bulb D	1.598134	13.302	17.2976725	*0.4762513*	*0.757748*	*0.766789*	0.670447	0.069498	2.61043	**0.025314**	**0.9697%**
Bulb D	1.846087	15.366	21.8256861	*0.4577606*	*0.847386*	*0.701996*	0.625179	0.072576	4.073435	**0.025362**	**0.6226%**
Bulb G	1.351085	11.246	13.8740804	*0.4947773*	*0.671681*	*0.808219*	0.728893	0.065466	1.96531	**0.025299**	**1.2873%**
Bulb G	1.59879	13.308	17.191171	*0.4778746*	*0.775561*	*0.771856*	0.674871	0.069196	2.687095	**0.025316**	**0.9421%**
Bulb G	1.84602	15.366	21.7429494	*0.4569862*	*0.878103*	*0.704642*	0.623443	0.072693	4.033193	**0.025360**	**0.6288%**
Bulb H	1.10397	9.189	11.1995232	*0.497133*	*0.65483*	*0.818104*	0.738307	0.064808	1.279112	**0.025288**	**1.9770%**
Bulb H	1.351644	11.251	13.7971834	*0.4967774*	*0.693083*	*0.81306*	0.736837	0.064911	1.970181	**0.025299**	**1.2841%**
Bulb H	1.47548	12.281	15.4263241	*0.4880184*	*0.74957*	*0.793819*	0.705095	0.067118	2.280549	**0.025306**	**1.1096%**
Bulb H	1.598804	13.308	17.0270629	*0.4793202*	*0.799055*	*0.779302*	0.678893	0.06892	2.725209	**0.025317**	**0.9290%**
Bulb H	1.846186	15.367	21.4482184	*0.4615576*	*0.914102*	*0.714389*	0.633848	0.071989	3.940278	**0.025357**	**0.6435%**

T	B_T		R	B_{RX}		Q	B_Q	
N	**N**	**%**	N	**N**	**%**	N.m	**N.m**	**%**
3.719982	**0.031013**	**0.8337%**	1.944	**0.0253**	**1.3005%**	0.12447	**5.4821E-04**	**0.4404%**
5.912649	**0.031014**	**0.5245%**	5.822	**0.0254**	**0.4368%**	0.188667	**5.5987E-04**	**0.2967%**
13.69137	**0.03102**	**0.2266%**	12.603	**0.0261**	**0.2067%**	0.379751	**6.1906E-04**	**0.1630%**
24.65524	**0.031037**	**0.1259%**	21.259	**0.0274**	**0.1290%**	0.672201	**7.6217E-04**	**0.1134%**
39.14751	**0.031075**	**0.0794%**	37.461	**0.0315**	**0.0841%**	1.081328	**1.0207E-03**	**0.0944%**
7.798552	**0.031015**	**0.3977%**	6.104	**0.0255**	**0.4171%**	0.227265	**5.6900E-04**	**0.2504%**
12.00376	**0.031019**	**0.2584%**	9.969	**0.0258**	**0.2585%**	0.346922	**6.0655E-04**	**0.1748%**
16.02944	**0.031023**	**0.1935%**	13.659	**0.0262**	**0.1917%**	0.487379	**6.6573E-04**	**0.1366%**
19.038	**0.031027**	**0.1630%**	17.438	**0.0267**	**0.1534%**	0.525566	**6.8414E-04**	**0.1302%**
30.54138	**0.03105**	**0.1017%**	31.262	**0.0298**	**0.0952%**	0.83687	**8.6056E-04**	**0.1028%**
13.60826	**0.03102**	**0.2280%**	10.747	**0.0257**	**0.2396%**	0.376405	**6.1775E-04**	**0.1641%**
15.92983	**0.031023**	**0.1947%**	12.504	**0.0260**	**0.2083%**	0.439311	**6.4388E-04**	**0.1466%**
19.56336	**0.031028**	**0.1586%**	15.498	**0.0264**	**0.1706%**	0.537908	**6.9028E-04**	**0.1283%**
33.52617	**0.031058**	**0.0926%**	28.671	**0.0291**	**0.1015%**	0.877833	**8.8639E-04**	**0.1010%**
11.32893	**0.031018**	**0.2738%**	8.747	**0.0257**	**0.2933%**	0.330837	**6.0075E-04**	**0.1816%**
19.17806	**0.031028**	**0.1618%**	15.601	**0.0265**	**0.1696%**	0.523202	**6.8298E-04**	**0.1305%**
33.3626	**0.031058**	**0.0931%**	29.962	**0.0294**	**0.0982%**	0.873091	**8.8337E-04**	**0.1012%**
7.249078	**0.031015**	**0.4278%**	6.901	**0.0255**	**0.3697%**	0.209248	**5.6455E-04**	**0.2698%**
11.03338	**0.031018**	**0.2811%**	10.869	**0.0259**	**0.2379%**	0.312951	**5.9456E-04**	**0.1900%**
14.64098	**0.031021**	**0.2119%**	12.506	**0.0260**	**0.2082%**	0.403577	**6.2867E-04**	**0.1558%**
18.68412	**0.031027**	**0.1661%**	15.519	**0.0264**	**0.1704%**	0.506748	**6.7496E-04**	**0.1332%**
31.93814	**0.031054**	**0.0972%**	28.679	**0.0291**	**0.1015%**	0.838823	**8.6178E-04**	**0.1027%**

KT					B_{KT}	
K,TSP	∂KT/∂T	∂KT/∂rho	∂KT/∂n	∂KT/∂D	[-]	%
0.250959204	0.067462479	-0.000251	-0.0598529	-8.330596	**0.0024033**	**0.9577%**
0.242142118	0.040953237	-0.000242	-0.0449951	-8.0379126	**0.0017063**	**0.7047%**
0.29463152	0.021519502	-0.000295	-0.0396868	-9.7802994	**0.0015374**	**0.5218%**
0.330939194	0.013422672	-0.000331	-0.0352061	-10.985533	**0.0016098**	**0.4864%**
0.338641657	0.008650402	-0.000339	-0.0289207	-11.241217	**0.0016133**	**0.4764%**
0.281316982	0.036072975	-0.000281	-0.0490611	-9.3383231	**0.001733**	**0.6160%**
0.282605849	0.023543112	-0.000283	-0.0398166	-9.381107	**0.0015161**	**0.5365%**
0.301923665	0.018835576	-0.000302	-0.0380485	-10.022362	**0.0015346**	**0.5083%**
0.302935356	0.015912142	-0.000303	-0.0350885	-10.055945	**0.0015068**	**0.4974%**
0.320353634	0.010489166	-0.00032	-0.0301266	-10.634146	**0.0015398**	**0.4807%**
0.305635817	0.022459573	-0.000306	-0.0420587	-10.145587	**0.0015968**	**0.5224%**
0.305143136	0.019155454	-0.000305	-0.0387793	-10.129233	**0.0015524**	**0.5088%**
0.310189336	0.01585563	-0.00031	-0.0358649	-10.296741	**0.0015384**	**0.4960%**
0.333892722	0.009959167	-0.000334	-0.0305963	-11.083576	**0.0015988**	**0.4788%**
0.279215374	0.024646225	-0.000279	-0.0402499	-9.2685601	**0.0015191**	**0.5441%**
0.307859574	0.016052694	-0.000308	-0.035816	-10.219405	**0.0015301**	**0.4970%**
0.334797182	0.010035105	-0.000335	-0.0307959	-11.113599	**0.0016034**	**0.4789%**
0.274184279	0.037823331	-0.000274	-0.0489636	-9.1015528	**0.0017436**	**0.6359%**
0.274970848	0.024921717	-0.000275	-0.039859	-9.127663	**0.0015063**	**0.5478%**
0.291879798	0.019935812	-0.000292	-0.0378418	-9.688956	**0.0015049**	**0.5156%**
0.305739814	0.016363619	-0.000306	-0.0359122	-10.149039	**0.0015239**	**0.4984%**
0.329371483	0.010312795	-0.000329	-0.0307132	-10.933493	**0.0015801**	**0.4797%**
					0.0016136	

K_Q					B_{KQ}	
[-]	∂KQ/∂Q	∂KQ/∂rho	∂KQ/∂n	∂KQ/∂D	[-]	
0.067843375	0.5598546	-6.97E-05	-0.0166196	-2.8914962	**0.0005121**	**0.7548%**
0.062425827	0.3398609	-6.414E-05	-0.0119149	-2.6605994	**0.0004221**	**0.6762%**
0.06602554	0.1785851	-6.783E-05	-0.009135	-2.8140198	**0.0004134**	**0.6261%**
0.072898546	0.1113915	-7.49E-05	-0.0079656	-3.1069485	**0.0004478**	**0.6142%**
0.075574358	0.0717876	-7.765E-05	-0.0066294	-3.220992	**0.0004616**	**0.6107%**
0.066236136	0.2993608	-6.805E-05	-0.011865	-2.8229955	**0.0004345**	**0.6561%**
0.06598967	0.1953785	-6.78E-05	-0.0095497	-2.812491	**0.0004154**	**0.6295%**
0.074169733	0.1563118	-7.62E-05	-0.0096006	-3.1611267	**0.0004593**	**0.6193%**
0.067567303	0.132051	-6.942E-05	-0.0080387	-2.87973	**0.0004174**	**0.6178%**
0.070921784	0.087047	-7.286E-05	-0.0068507	-3.0226985	**0.0004342**	**0.6122%**
0.068302587	0.1863865	-7.017E-05	-0.0096543	-2.911068	**0.0004278**	**0.6264%**
0.067990047	0.1589664	-6.985E-05	-0.0088751	-2.8977474	**0.0004227**	**0.6217%**
0.068908387	0.131582	-7.08E-05	-0.0081836	-2.9368872	**0.0004254**	**0.6174%**
0.070634299	0.0826487	-7.257E-05	-0.0066483	-3.0104459	**0.0004322**	**0.6119%**
0.065878783	0.204533	-6.768E-05	-0.0097545	-2.807765	**0.000416**	**0.6315%**
0.067857497	0.1332174	-6.972E-05	-0.0081088	-2.8920981	**0.0004193**	**0.6179%**
0.070788404	0.0832789	-7.273E-05	-0.0066881	-3.0170139	**0.0004332**	**0.6119%**
0.063944401	0.3138866	-6.57E-05	-0.0117291	-2.7253212	**0.0004247**	**0.6642%**
0.063013803	0.2068192	-6.474E-05	-0.0093823	-2.685659	**0.0003996**	**0.6341%**
0.0650041	0.1654424	-6.679E-05	-0.0086565	-2.7704859	**0.0004057**	**0.6241%**
0.066996519	0.1357977	-6.883E-05	-0.008083	-2.8554031	**0.0004143**	**0.6185%**
0.069891998	0.0855834	-7.181E-05	-0.0066942	-2.9788089	**0.0004279**	**0.6122%**
					0.0004303	

w					B_w		t				B_t	
[-]	∂w/∂JT	∂w/∂D	∂w/∂Jn	∂w/∂JV	[-]	%	[-]	∂t/∂T	∂t/∂Fd	∂t/∂Rc	[-]	%
0.0822434	-0.60416	-7.6169	-0.10945	1.066796	**0.005517**	**6.7078%**	0.408037	0.085611	0.268819	0.268819	**0.009971**	**2.4436%**
0.06501036	-0.60296	-7.75992	-0.08688	0.845106	**0.004617**	**7.1022%**	0.237632	0.132342	0.169129	0.169129	**0.007324**	**3.0820%**
0.0745202	-0.68025	-7.68099	-0.06234	0.684099	**0.004155**	**5.5759%**	0.215292	0.057945	0.073039	0.073039	**0.003204**	**1.4882%**
0.10641888	-0.7287	-7.41625	-0.04753	0.558823	**0.003836**	**3.6043%**	0.241008	0.030849	0.040559	0.040559	**0.001791**	**0.7432%**
0.05912487	-0.78569	-7.80877	-0.04018	0.509296	**0.003848**	**6.5086%**	0.138905	0.02183	0.025544	0.025544	**0.001236**	**0.8896%**
0.09379205	-0.64307	-7.52105	-0.07903	0.819871	**0.004581**	**4.8841%**	0.385376	0.078196	0.128229	0.128229	**0.005644**	**1.4645%**
0.08611921	-0.65068	-7.58473	-0.06438	0.675866	**0.00406**	**4.7148%**	0.32864	0.055356	0.083307	0.083307	**0.003745**	**1.1394%**
0.11072535	-0.66676	-7.38051	-0.05604	0.602792	**0.003832**	**3.4608%**	0.28641	0.044181	0.062385	0.062385	**0.002859**	**0.9983%**
0.10987187	-0.66927	-7.38759	-0.05156	0.55666	**0.003685**	**3.3535%**	0.224392	0.040539	0.052527	0.052527	**0.002476**	**1.1032%**
0.09655013	-0.71384	-7.49816	-0.04248	0.489267	**0.00359**	**3.7182%**	0.105619	0.029111	0.032742	0.032742	**0.001664**	**1.5756%**
0.11560029	-0.66998	-7.34005	-0.06086	0.657778	**0.004028**	**3.4842%**	0.336811	0.048054	0.073485	0.073485	**0.003043**	**0.9033%**
0.12617195	-0.66106	-7.25231	-0.05553	0.592219	**0.003778**	**2.9946%**	0.346182	0.04074	0.062775	0.062775	**0.002606**	**0.7529%**
0.12564424	-0.67091	-7.25669	-0.05055	0.547158	**0.003652**	**2.9070%**	0.337459	0.033673	0.051116	0.051116	**0.002143**	**0.6351%**
0.10942684	-0.73283	-7.39129	-0.04081	0.482453	**0.003615**	**3.3036%**	0.24534	0.021884	0.029827	0.029827	**0.001337**	**0.5451%**
0.09814946	-0.63652	-7.48488	-0.06501	0.667559	**0.003997**	**4.0728%**	0.394244	0.052836	0.08827	0.08827	**0.003578**	**0.9075%**
0.12565178	-0.6665	-7.25663	-0.05086	0.546929	**0.003641**	**2.8979%**	0.32189	0.03511	0.052143	0.052143	**0.002198**	**0.6830%**
0.11523454	-0.73008	-7.34309	-0.0407	0.479324	**0.003597**	**3.1213%**	0.223085	0.023295	0.029974	0.029974	**0.001371**	**0.6144%**
0.09753845	-0.62883	-7.48995	-0.08059	0.81754	**0.004545**	**4.6599%**	0.409041	0.10699	0.137949	0.137949	**0.005964**	**1.4580%**
0.09374851	-0.63273	-7.52141	-0.06569	0.670539	**0.004002**	**4.2687%**	0.371892	0.073099	0.090634	0.090634	**0.003986**	**1.0719%**
0.11176776	-0.64806	-7.37186	-0.05758	0.602048	**0.003787**	**3.3886%**	0.334208	0.047701	0.068301	0.068301	**0.002888**	**0.8641%**
0.1288452	-0.66013	-7.23013	-0.05117	0.544926	**0.003619**	**2.8085%**	0.303899	0.036647	0.053521	0.053521	**0.002265**	**0.7455%**
0.11274103	-0.72012	-7.36378	-0.04137	0.480632	**0.003575**	**3.1713%**	0.188955	0.024253	0.031311	0.031311	**0.001424**	**0.7538%**

η_R			$B_{\eta R}$									
[-]	$\partial\eta_R/\partial K_{QO}$	$\partial\eta_R/\partial K_Q$	[-]	%	PD	∂PD/∂Jn	∂PD/∂JQ	BPD		PPD	u	
0.910267	14.73983	13.41718	**0.013385**	**1.470%**	6.558319	0.782068	52.68999	0.028915	0.441%	0.002755	0.029045663	0.443%
0.970574	16.01901	15.54763	**0.014104**	**1.453%**	12.75882	1.185428	67.62623	0.037913	0.297%	0.002755	0.038013351	0.298%
1.021965	15.14565	15.47833	**0.013426**	**1.314%**	35.42764	2.386046	93.29174	0.057891	0.163%	0.002755	0.057956083	0.164%
0.990314	13.71769	13.58482	**0.0123**	**1.242%**	79.40338	4.223564	118.1245	0.090306	0.114%	0.002755	0.090348348	0.114%
0.968489	13.232	12.81504	**0.011888**	**1.227%**	159.1104	6.794184	147.1435	0.150618	0.095%	0.002755	0.150643185	0.095%
0.992511	15.0975	14.98444	**0.013448**	**1.355%**	16.37573	1.427947	72.05569	0.041069	0.251%	0.002755	0.041161565	0.251%
0.998768	15.15389	15.13522	**0.013379**	**1.340%**	30.94274	2.179773	89.1923	0.054222	0.175%	0.002755	0.054292291	0.175%
0.922538	13.48259	12.4382	**0.01196**	**1.296%**	48.60007	3.062295	99.71715	0.066582	0.137%	0.002755	0.066638587	0.137%
1.014631	14.80006	15.0166	**0.013127**	**1.294%**	57.01934	3.302228	108.4913	0.074428	0.131%	0.002755	0.074479159	0.131%
0.998539	14.10004	14.07944	**0.012575**	**1.259%**	111.827	5.258209	133.6253	0.115327	0.103%	0.002755	0.115359782	0.103%
1.008847	14.64073	14.77026	**0.013043**	**1.293%**	34.37269	2.36502	91.31845	0.05655	0.165%	0.002755	0.056616803	0.165%
1.012543	14.70804	14.89252	**0.013077**	**1.292%**	43.43954	2.760273	98.88105	0.063834	0.147%	0.002755	0.063893476	0.147%
1.008563	14.51202	14.63628	**0.01291**	**1.280%**	58.46223	3.379775	108.6845	0.075235	0.129%	0.002755	0.075285052	0.129%
1.027489	14.15743	14.54661	**0.012699**	**1.236%**	120.3815	5.515587	137.1348	0.121903	0.101%	0.002755	0.12193443	0.101%
0.993728	15.17939	15.08419	**0.013391**	**1.348%**	28.84022	2.078712	87.17342	0.052485	0.182%	0.002755	0.052556913	0.182%
1.019722	14.73677	15.02741	**0.0131**	**1.285%**	56.5138	3.287374	108.0153	0.073976	0.131%	0.002755	0.074027355	0.131%
1.026912	14.12661	14.50678	**0.012676**	**1.234%**	119.2773	5.485792	136.615	0.121029	0.101%	0.002755	0.121060799	0.101%
1.013502	15.63859	15.84974	**0.013923**	**1.374%**	14.72453	1.314746	70.36868	0.039787	0.270%	0.002755	0.039882275	0.271%
1.030103	15.86954	16.34726	**0.013987**	**1.358%**	27.12985	1.966332	86.69026	0.051647	0.190%	0.002755	0.051720839	0.191%
1.032512	15.38364	15.88379	**0.013611**	**1.318%**	39.11726	2.535747	96.92645	0.061082	0.156%	0.002755	0.061143943	0.156%
1.028716	14.92615	15.35476	**0.013259**	**1.289%**	54.21404	3.183992	106.9842	0.072406	0.134%	0.002755	0.072457941	0.134%
1.030002	14.30779	14.73705	**0.01281**	**1.244%**	113.0424	5.270481	134.7631	0.116469	0.103%	0.002755	0.11650139	0.103%

Input Repeats

	Speed (m/s)	Shaft Speed (RPS)	Resistance (N)	Thrust (N)	Torque (N-m)	Trim (deg)
int097_C_13k_002	1.600341136	17.24560923	-2.418152394	18.78594854	-0.572165173	0.001007004
int097_C_13k_001	1.600141567	17.2419591	-2.483980209	18.75523834	-0.57038615	0.069215991
int097_C_13k_005	1.600276326	17.24429758	-2.61512492	18.75755232	-0.571334903	0.068347805

	t	w	ETA,R	K,QSP	K,TSP	J,SP
	0.241008288	0.106418881	0.99031394	0.072898546	0.330939194	0.70597279
	0.247401837	0.105357488	0.99117532	0.072933636	0.331690616	0.703524954
	0.240488344	0.106419641	0.99031543	0.072899476	0.330947125	0.705956377
std dev	0.003850199	0.000613015	0.000496888	1.99962E-05	0.000431562	0.001408545
	P_t					

Precision

P_{KQ}	**2.30896E-05**
P_{KT}	**0.000498325**
P_t	**0.004445827**
P_w	**0.000707849**
$P\eta_R$	**0.000573757**
P_J	0.001626447