Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-CISD–2009/007 Aug 2009

Ship Systems Integration & Design Department
Center for Innovation in Ship Design
Technical Report

SES T-Craft Model Testing

By:
Casey Hodges
Rebecca Silver
Jakob Wieser
Andrew Adelsen

NSWCCD-CISD-2009-007 SES T-Craft Model Testing

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
24-07-2008

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
18 May, 2009 – 24 Jul, 2009

4. TITLE AND SUBTITLE
SES Model Testing: Resistance and Seakeeping

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Casey Hodges, Rebecca Silver, Jakob Wieser, Andrew Adelsen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Naval Surface Warfare Center
Carderock Division
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-CISD-2009/007

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief of Naval Research
One Liberty Center
875 North Randolph Street
Suite 1425
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release, Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The aim of this project was to perform seakeeping and resistance tests using the NSWCCD Surface Effect Ship (SES) T-Craft model, DTMB number 5687, in Carderock's 140 foot tow basin. Seakeeping tests were previously performed on this model by the Seakeeping Division (Code 55) in the Maneuvering and Seakeeping Basin (MASK), but underway resistance tests were not performed. This project conducted resistance tests in calm water and various regular wave conditions, zero speed motion tests at headings of 180 and 90 degrees, as well as pitch, heave, and roll decay tests. It was of interest to understand the effect of the SES air cushion on ship motions and resistance, therefore RAO graphs were developed to describe ship motions, along with the resistance graphs at full, half, and zero cushion. Zero speed motions tests were conducted in the 140 ft basin for the same wave conditions used in the earlier MASK tests for comparison.

15. SUBJECT TERMS
T-Craft, SES, Model Testing, Seakeeping, Resistance

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL	46	Colen Kennell / 301-227-5468

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Abstract

The aim of this project was to perform seakeeping and resistance tests using the NSWCCD Surface Effect Ship (SES) T-Craft model, DTMB number 5687, in Carderock's 140 foot tow basin. Seakeeping tests were previously performed on this model by the Seakeeping Division (Code 55) in the Maneuvering and Seakeeping Basin (MASK), but underway resistance tests were not performed. This project conducted resistance tests in calm water and various regular wave conditions, zero speed motion tests at headings of 180 and 90 degrees, as well as pitch, heave, and roll decay tests. It was of interest to understand the effect of the SES air cushion on ship motions and resistance, therefore RAO graphs were developed to describe ship motions, along with the resistance graphs at full, half, and zero cushion. Zero speed motions tests were conducted in the 140 ft basin for the same wave conditions used in the earlier MASK tests for comparison.

Acknowledgements

This project would not have been possible without a great deal of help; we would like to thank the following people for their guidance, knowledge, and support throughout the experimentation process:

Steve Ouimette	CISD
Jack Offutt	CISD
Dr. Colen Kennell	CISD
Justin Ryan	CISD
Bob Lamb	CISD
Tony Blair	CISD
Tim Smith	Code 55
Andrew Silver	Code 55
Brian Chirozzi	Code 55
Jim Hickok	Code 55
Kathy Wilson	Code 55
Rich Bishop	Code 55
John Hamilton	Code 53
Charlie Krump	Code 51

The team would like to extend a special thanks to Mr. Tim Smith of Code 55. Without his hard work and assistance with model testing this project would not have been successful.

Table of Contents

List of Figures

List of Tables

List of Equations

Introduction

Background

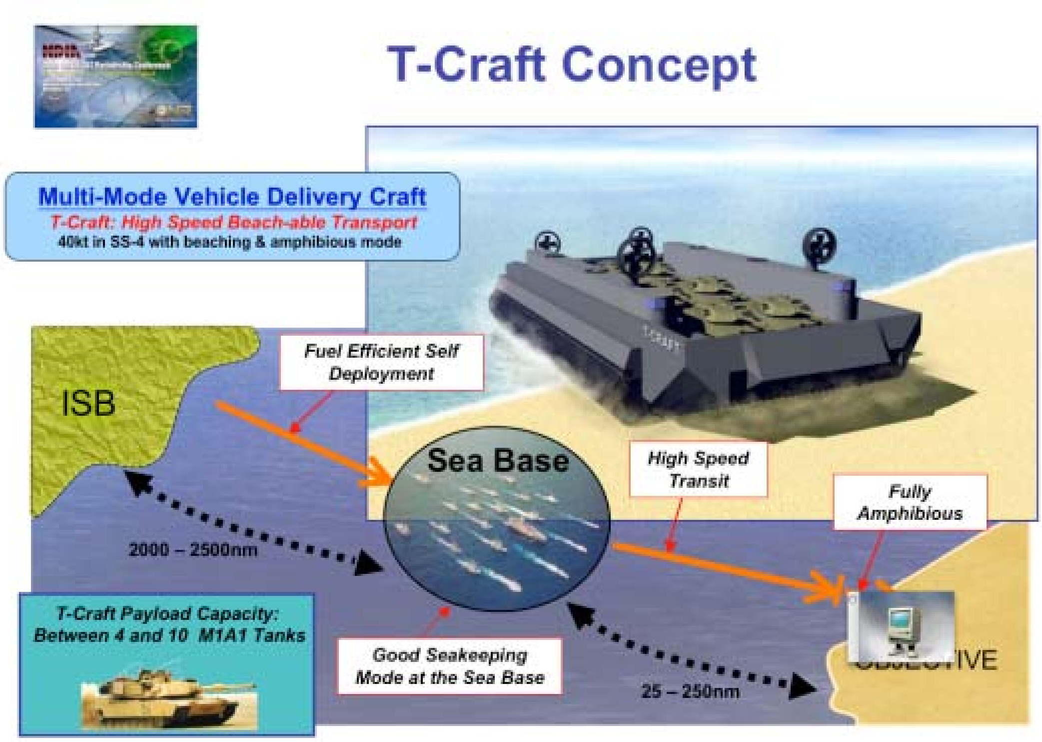

Figure 1: T-Craft Concept (Navy)

The Transformable Craft (T-Craft) is a highly capable surface connector being developed by the Office of Naval Research (ONR) under its Innovative Naval Prototype Program. It is intended to provide a dramatically improved operational capability over current Navy connectors, which are limited by their need to be carried into theater within the well decks of amphibious ships, by their relatively small payload capacity, and by their limited range and sea state capability. The objective of the T-Craft Program is to develop the enabling technologies to allow T-Craft self-deployment over a 2500 nm range in high sea states, to significantly increase payload capacity, to be able to travel fully loaded at 40 knots over a range of 500 nm, to be able to receive and discharge cargo at the Sea Base in high sea states, and to have a fully amphibious capability for traversing sand bars, mud flats, and landing on the beach. (See Figure 1: T-Craft Concept (Navy))

Currently three companies are under contract to ONR to develop competing T-Craft designs. Each of the contractors has chosen a variation of an air-cushion supported catamaran or Surface Effect Ship (SES) for high speed over-water transit and operations at the Sea Base, and with a deployable Air Cushion Vehicle (ACV) skirt system for providing the amphibious capability needed to carry cargo through the surf zone and onto the beach. Each of these designs include novel solutions for in water and out-of-water propulsion, SES and ACV variable/ retractable skirt geometry, high strength light weight materials, active ride control, high sea state vehicle transfer, and hybrid electric drives.

Objectives

The main objective of this project was to obtain an understanding of a generic Transformation Craft's resistance and seakeeping performance. The experiment took place in NSWCCD's 140 foot basin with NSWCCD's T Craft model 5687 representing a composite of designs being evaluated under ONR's T-Craft program. The model dimensions and instrumentation layout can be found in Appendix B. Zero speed seakeeping tests have already been completed on this model in the MASK at Carderock, but comprehensive resistance tests and motions tests at speed were not. The experiments outlined in this report focus on resistance tests in calm water and in waves. Some tests previously performed were repeated to establish a baseline comparison between MASK tests and the 140 ft basin tests. The ship was placed in different testing conditions while operating in full, half, and off cushion modes.

Figure 2: Generic T-Craft

Generic T-Craft Model

Description and Characteristics

The body plan of the model is shown in Figure 3. The figure shows that the cushion makes the entire ship rise up out of the water. The scale model was configured for off cushion (catamaran), full cushion and half cushion (SES) testing only. No ACV mode testing was conducted as the model did not include the deployable side seals. The principal characteristics can be found in Table 1.

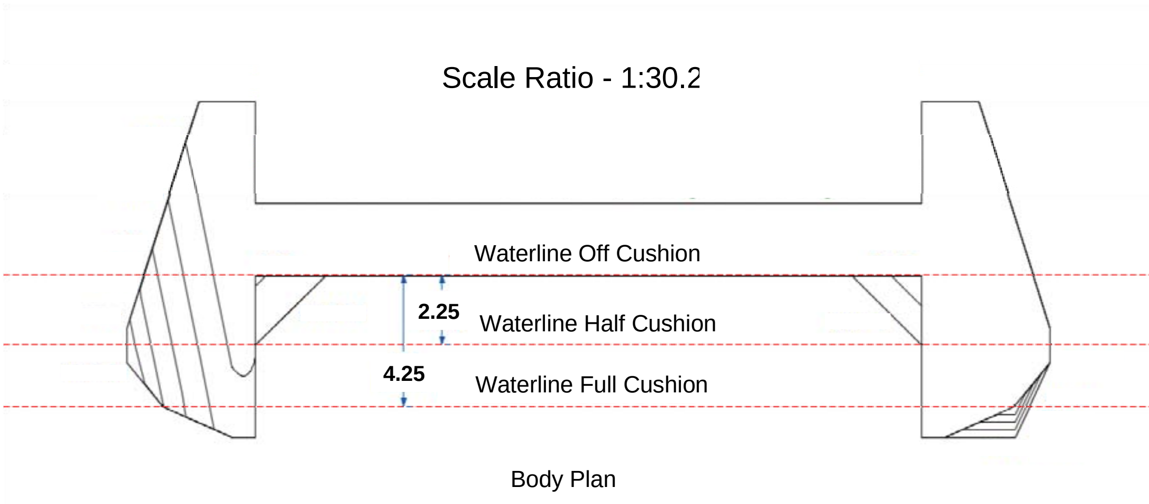

Figure 3: Hull Form

Table 1: Principal Characteristics

Parameter	LOA	Beam Max	Draft 100%	Draft 50%	Draft 0%
Model Scale (ft)	8.29	2.42	0.15	0.27	0.44
Prototype Scale (ft)	250.48	73.01	4.46	8.20	13.19

Test Equipment and Instrumentation

The towing carriage was equipped with a data collection computer (Figure 4) to gather eight channels of data. The channel list is shown below in Table 2. The model was attached to the carriage through a heave post, which allowed free movement in the vertical direction as shown in Figure 5. The heave post was attached to a block gauge which was attached to a one degree of freedom pitch gimbal and subsequently to the model. Roll was fixed for the majority of the experiments.

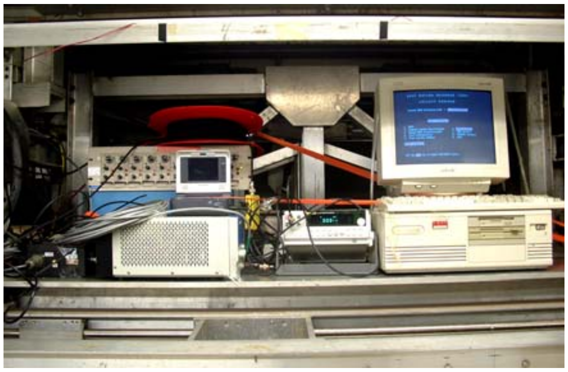

Figure 4: Data Collection Setup

Table 2: Channel List

Channel Number	Parameter Measured	Units
1	Carriage Speed	ft/sec
2	Forward String Pot	in
3	Aft String Pot	in
4	Longitudinal Acceleration	g’s
5	Transverse Acceleration	g’s
6	Vertical Acceleration	g’s
7	Wave Amplitude	in
8	Resistance	lb

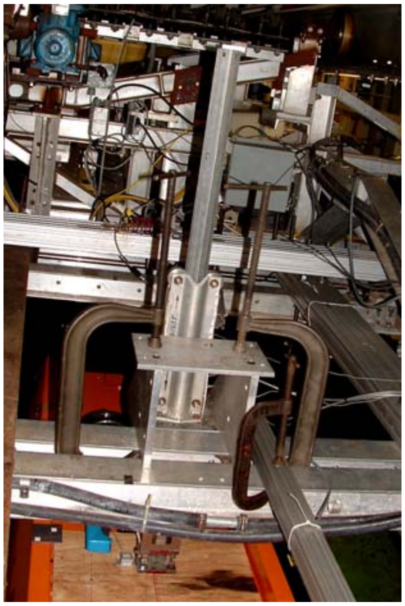

Figure 5: Heave Post

All sensors and measurement devices were calibrated prior to testing. These sensors can be seen in Figure 6. The string potentiometers were used to determine the heave and pitch of the model during testing. A 3-d accelerometer was installed on the starboard side of the heave post in order to measure accelerations in the longitudinal, transverse, and vertical directions. A block gauge was attached to the heave post and pitch gimbal in order to measure resistance. A sonic wave probe positioned ahead of the model was used to record wave amplitude and period. The placement, dimensions, and instrument specifications can be found in Appendix B. An underwater camera, above water camcorder, and a still camera were also used to record observations.

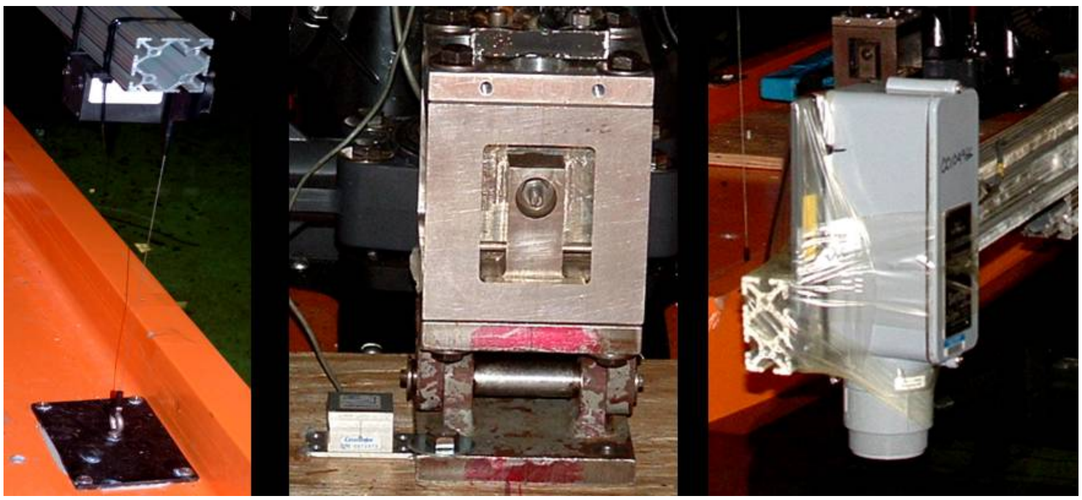

Figure 6: String Pot, Accelerometer and Block Gauge, Sonic Wave Probe

Testing

Preliminary Test Plan

A preliminary test matrix was provided by the CISD test directors. This matrix included both regular and irregular waves with 3 different wave lengths, 4 wave heights and 3 craft velocities. It also included calm water resistance tests for both half and full-cushion, under different speeds. “Full and half cushion” in the case of this testing actually means full or half fan power. Full power is 24V supplied to the fan and half power is 12V, this does not necessarily correspond to full or half cushion pressure or draft.

Calm water resistance tests with ten different speeds for full cushion were run first. Half cushion resistance tests were attempted at the same speeds, but were aborted for the higher speeds for fear that the model air cushion seals might be damaged. The next sets of tests planned were regular wave tests. The preliminary test matrix was altered to vary wave frequency, rather than test at constant wave lengths, because it was determined varying wave frequency was more practical for this type of testing. Planned irregular wave tests could not be run due to the unavailability of the software needed to produce irregular waves.

Testing in Calm Water

Calm water resistance tests were run at progressively higher speeds starting at 4.28 ft/sec and ending at 9.81 ft/sec at full cushion and up to 6.17 ft/sec at half cushion. Table 3 shows model and full scale speeds tested. Testing at half cushion was stopped prematurely at 6.14 ft/sec due to the high resistance experienced by the model which could possibly damage the skirt. Resistance, pitch, heave, and accelerations were measured in the calm water tests.

Table 3: Calm Water Tests

Model Speed (ft/sec)	Prototype Speed (knots)	Fr
3.69	12	0.134
4.30	14	0.156
4.61	15	0.167
4.91	16	0.178
5.53	18	0.200
6.14	20	0.223
6.76	22	0.245
7.37	24	0.267
7.99	26	0.289
8.60	28	0.312
9.21	30	0.334
9.83	32	0.356

Decay tests were also performed for pitch with the model oriented longitudinally as shown in Figure 7. The model was oriented transversely for roll and heave decay tests as shown in Figure 8. The heave decay tests created significant visible wave reflections from the side of the tank which influenced the behavior of the model. These decay tests were compared to decay tests carried out by Code 55 and were found to have reasonable correlation.

Figure 7: Model Longitudinal Orientation

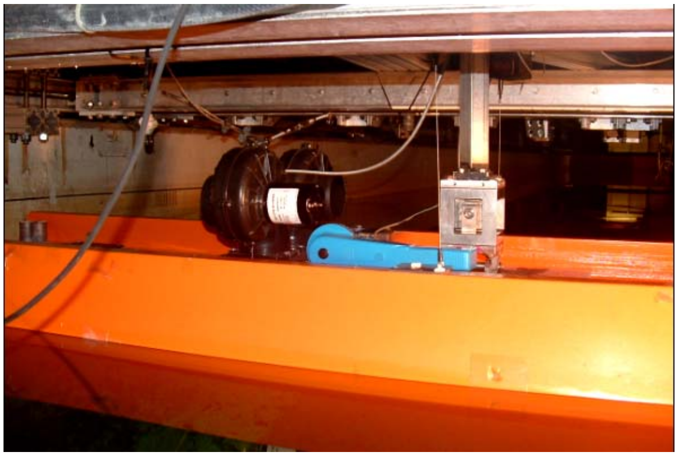

Figure 8: Model Transverse Orientation

Testing in Waves

Wave test conditions are summarized in Table 4.

Table 4: Wave Tests

Property	Model Scale	Prototype Scale
9 Wave Encounter Frequencies	2.7-5.5 rad/sec	0.5-1 rad/sec
3 wave heights	0.8 in	2 ft
	1 in	2.5 ft
	1.2 in	3 ft
3 speeds	4.607 ft/sec	15 knots
	6.142 ft/sec	20 knots
	7.678 ft/sec	25 knots

Testing in waves was conducted in groups of eight or nine in which the model velocity and wave heights were held constant while the wave frequency was varied during each test. Three wave heights were originally intended to be tested: 1.589 in, 1.986 in, and 2.383 in, corresponding to 4 ft, 5 ft, and 6 ft full scale significant wave heights. As tested, these waveheights turned out to be half of the intended height due to some user input errors discovered later in the testing, which is discussed later. Therefore, the waveheights tested were 2 ft, 2.5 ft, and 3 ft full scale. Wave frequencies from 0.5-0.8 rad/sec prototype scale were tested, corresponding to full scale periods from 18.2s to 12.9s.

The .5-.8 rad/sec range was selected because that is the range where the most response was expected based on previous testing. It was later found that the response expected was not being achieved. Consequently, extra tests were run at 0.4, 0.5, 0.9, and 1 rad/sec for the highest speed and two highest wave heights

Zero speed tests were also performed for frequency ranges of 0.4-1.1 rad/sec in order to get baseline transfer functions for comparison with the results from the MASK tests.

Wavemaker

The wavemaker, shown in Figure 9, was controlled by a function generator by specifying voltage amplitude and frequency.

Figure 9: Wavemaker

The maximum stroke of the wavemaker is 10 in and the safe maximum frequency is about 1.5 Hz which limits the wavemaking capabilities. The equation for wave generation by a flap wavemaker hinged at the bottom, Equation 1, was used to determine the required stroke and frequency to make the desired waves,

$$\left(\frac{H}{S}\right)_{flap} = \frac{kh}{2}$$

Equation 1: Wave Flap Equation

where H is wave height created, S is flap stroke, or total distance travelled by top of the flap, k is the wave number, and h is water depth (Dean and Dalrymple). The dispersion relation, Equation 2, was used to find the wave numbers of the desired waves,

$$\omega^2 = gk \tanh(kh)$$

Equation 2: Dispersion Relation

where ω is the desired wave frequency in rad/sec, g is 32.2 ft/sec^2, k is the wave number, and h is the water depth. This equation was used to back calculate the desired wave frequency through a Goal Seek macro in Excel. The wave number value was used as the input and then a Goal Seek was performed to determine the required wave number to change the wave frequency cell to the desired value. The wave frequency obtained was corrected to be the encounter frequency by using Equation 3:

$$\omega_e = \omega - \frac{\omega^2 V_s \cos \mu}{g}$$

Equation 3: Encounter Frequency Equation

where ω is the wave frequency, V_s is the ship speed, μ is the ship-to-wave angle with 180 degrees being head seas, and g is 32.2 ft/sec^2 (Zubaly). The wave number was then used in Equation 1, along with the desired wave height to find the stroke needed. The wavemaker is calibrated to 4 volts per inch of stroke; therefore each stroke is multiplied by 4 for input to the wavemaker. The frequency input to the wavemaker was found by dividing the wave frequency by 2π to convert the angular frequency from rad/sec to Hz.

Irregular wave testing was not undertaken because the available function generator was limited to producing only regular waves.

Results and Analysis

Calm Water Tests

Calm water tests were performed at 9 speeds and at two cushion configurations: full fan power, and half fan power.

Full Cushion

Figure 10 is the plot of average resistance, trim, and sinkage vs. velocity in calm water with the model at full cushion.

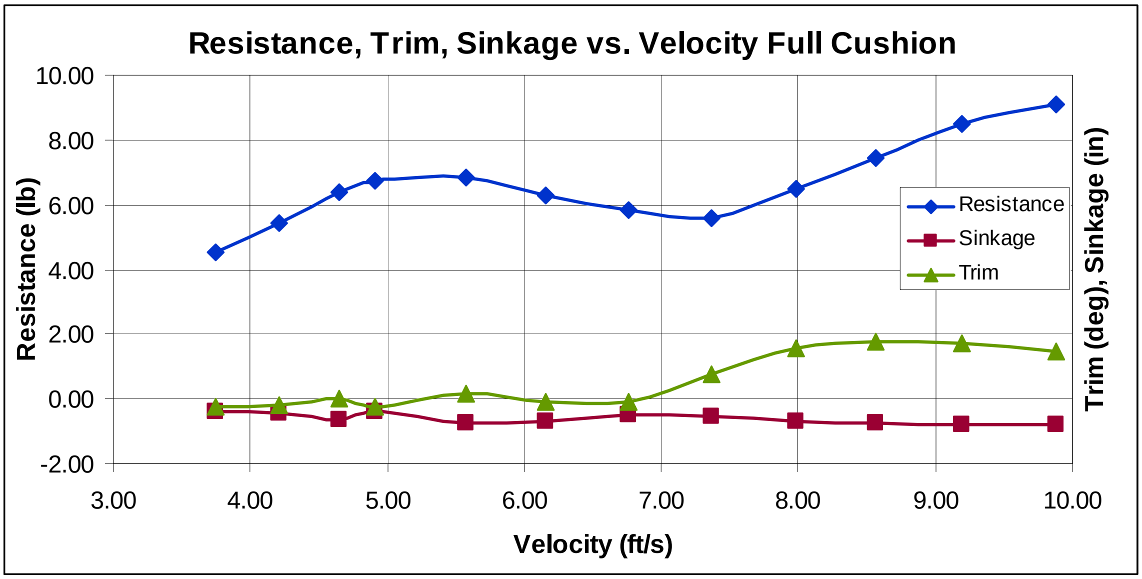

Figure 10: Resistance, Trim, and Sinkage vs. Velocity - Full Cushion

The operating speed for lowest resistance for the range of speeds tested for the full cushion case appears to be around 7.3 ft/sec (24 kts ship speed). This speed however is not the optimal operating speed for this craft as the primary hump on the resistance curve was not reached due to the limited range of speeds tested. The actual optimum operating speed of least resistance would be expected to be seen around the 40 knot full scale speed range. More testing at higher speeds with a model designed for resistance testing is needed in order observe the reduction in resistance with increasing speed beyond the primary hump.

Half Cushion

Figure 11 shows the plot of resistance, trim, and sinkage data in calm water with the model at half cushion.

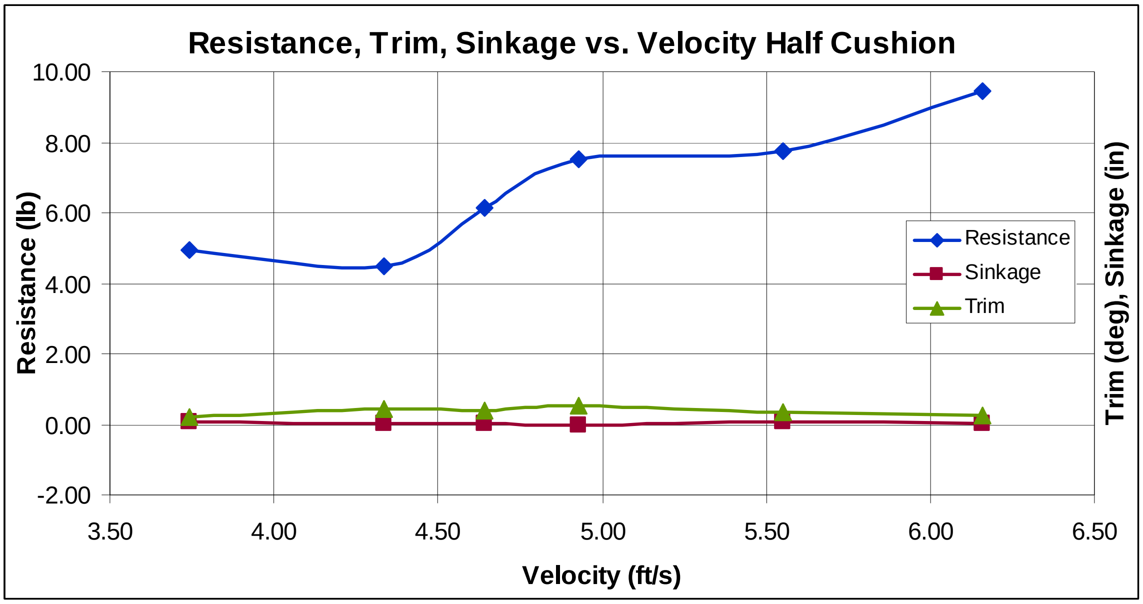

Figure 11: Resistance, Trim, and Sinkage vs. Velocity - Half Cushion

Half cushion testing was suspended for speeds beyond 6 ft/sec due to the high resistance values encountered and concern for damaging the skirt. It is likely that the partially inflated skirt added significant drag since more skirt was in the water with increasing model draft.

Half Cushion vs. Full Cushion

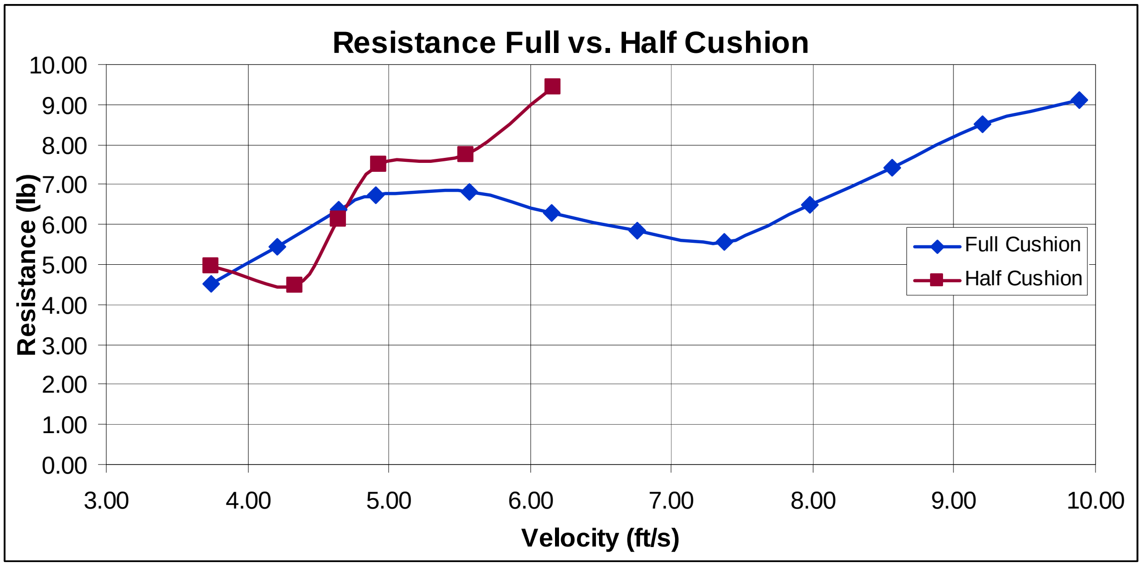

Figure 12: Resistance vs. Speed at Full & Half Cushion

When compared to the full cushion case, the half cushion case (Figure 12) seems to have lower resistance between 3.75 and 4.75 ft/sec (12-15.5 kts). At its lowest level (2.25 lb at 4.34 ft/sec) the half cushion model has 0.5 lbs less resistance than the (2.75 lbs at 4.28 ft/sec) full cushion model. Although the half cushion model has lower resistance at speeds between 3.75 ft/sec and 4.75, there is not enough data to assess half cushion performance throughout the speed range. A partially retractable bow seal could be expected to have lower resistance in the partial cushion mode. More research into this concept is needed for its application to this project.

Testing in Waves

Testing in waves covered the areas of added resistance, heave and pitch motions, sinkage and trim, zero speed motions, and decays tests.

Added Resistance

Added resistance in waves was an area of interest; however, it was somewhat difficult to draw conclusions from the data collected. Figure 13 shows the resistance, in waves and in calm water, in pounds versus the speed of the model for three different wave heights. Each of the data points on the graph is an average of resistance values obtained for 9 different wave frequencies.

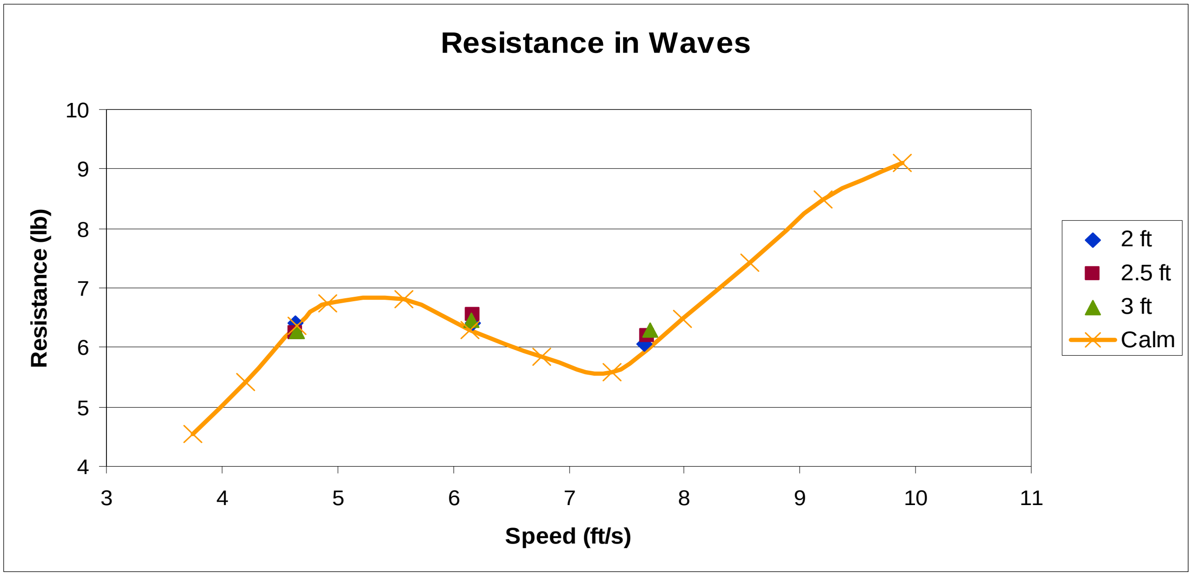

Figure 13: Resistance in Waves and Calm

First, it can be seen that the resistance in waves appears to follow the resistance in calm water curve with just a slight bit of added resistance. There are not enough data points to determine the shape of the added resistance curve but the data suggest that the resistance in waves will follow the general trend of the resistance in calm water. The very small amount of added resistance could be attributed to the fact that the wave heights and wave slopes tested were not high enough to have a significant impact on resistance. Added resistance RAOs can be found in Appendix 3.

Heave Motions

Heave RAOs were obtained for each of the combinations of speed and waveheight. Figure 14 shows the heave RAO holding waveheight constant at 2.5 ft full scale and varying the speed between 15, 20, and 25 knots full scale, each individual RAO plot can be found in Appendix C.

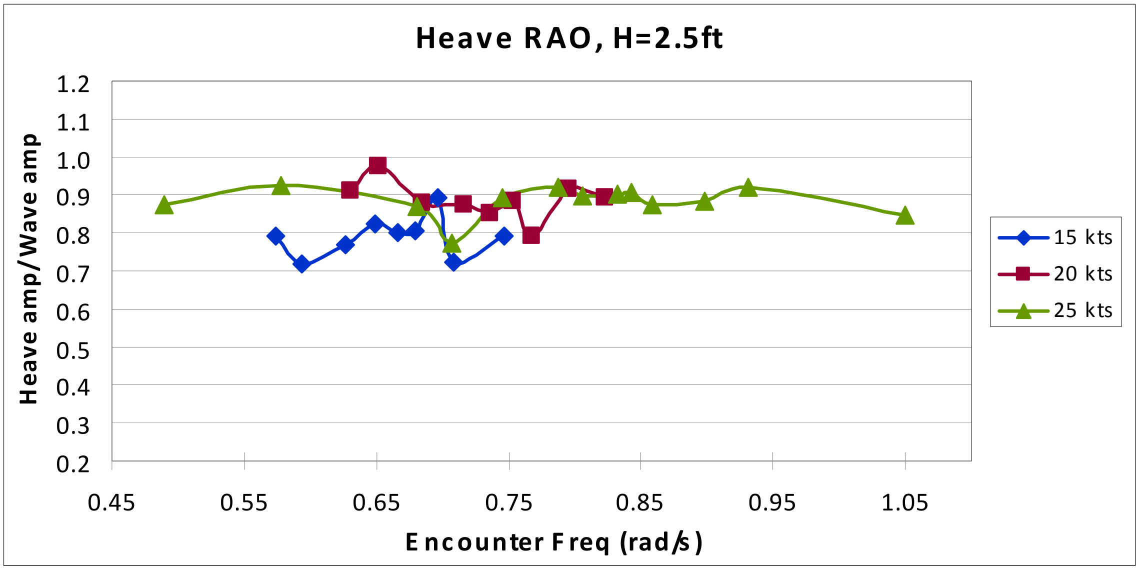

Figure 14: Heave RAO, H=2.5 ft

This plot indicates that there is not much correlation between speed and heave response at this waveheight and range of frequencies tested. These lines have not reached a peak yet and therefore more testing should be done over a wider range of frequencies to more completely define the RAO. Figure 15 shows the heave RAO variation with waveheight for a fixed speed of 20 knots full scale.

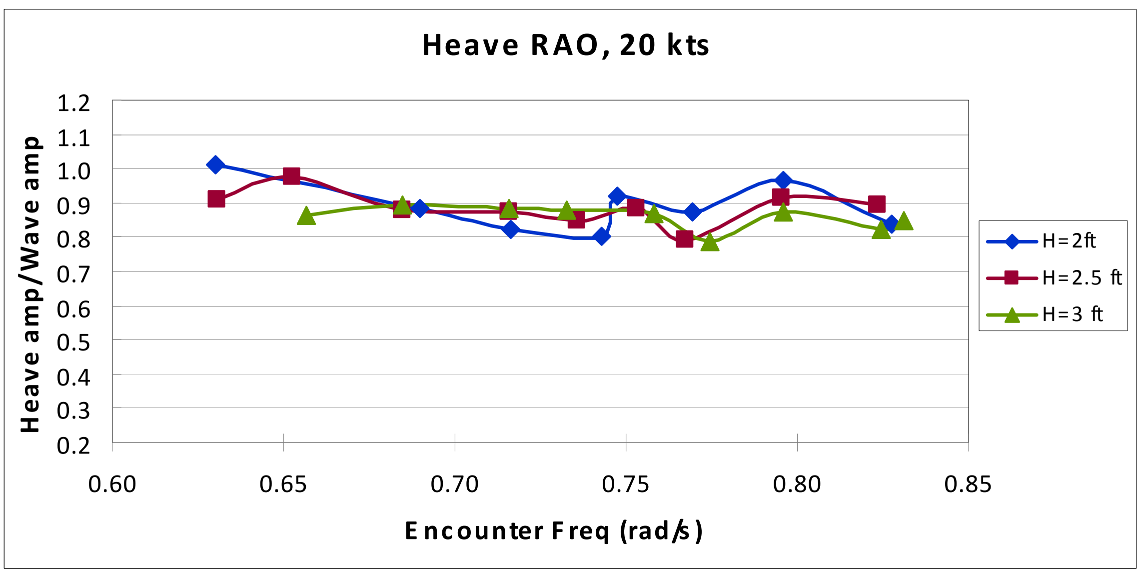

Figure 15: Heave RAO, 20 kts

The figure confirms the linearity of heave motion with waveheight since all three lines fall on top of each other and follow the same trend. This is to be expected since the heave amplitude is normalized by the wave amplitude. Similar results were seen for other speeds tested.

Pitch Motions

Pitch RAOs were obtained for each of the combinations of speed and waveheight. Each individual RAO plot can be found in Appendix C. Figure 16 shows the pitch RAO varying the speed for a fixed waveheight of 2.5 ft full scale.

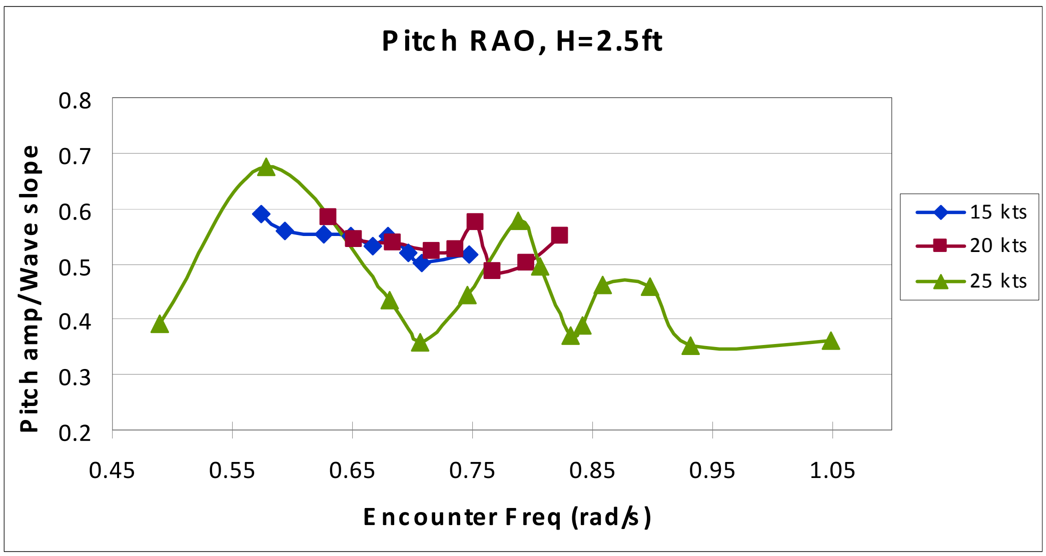

Figure 16: Pitch RAO, H=2.5 ft

The first thing to note is the oscillation of the 25 knot line which indicates an increased sensitivity at this particular speed. Three humps, however, would not be expected in an RAO curve, so this could be due to noise from the instruments during testing. The 15 and 20 knot lines are almost on top of each other and showing very little oscillatory behavior suggesting that speed does not have a significant impact on pitch. For these speeds, all three curves seem to follow the same downward trend showing less pitch motion as frequency increases. Figure 17 shows pitch RAO varying the waveheight at a constant speed of 20 knots full scale.

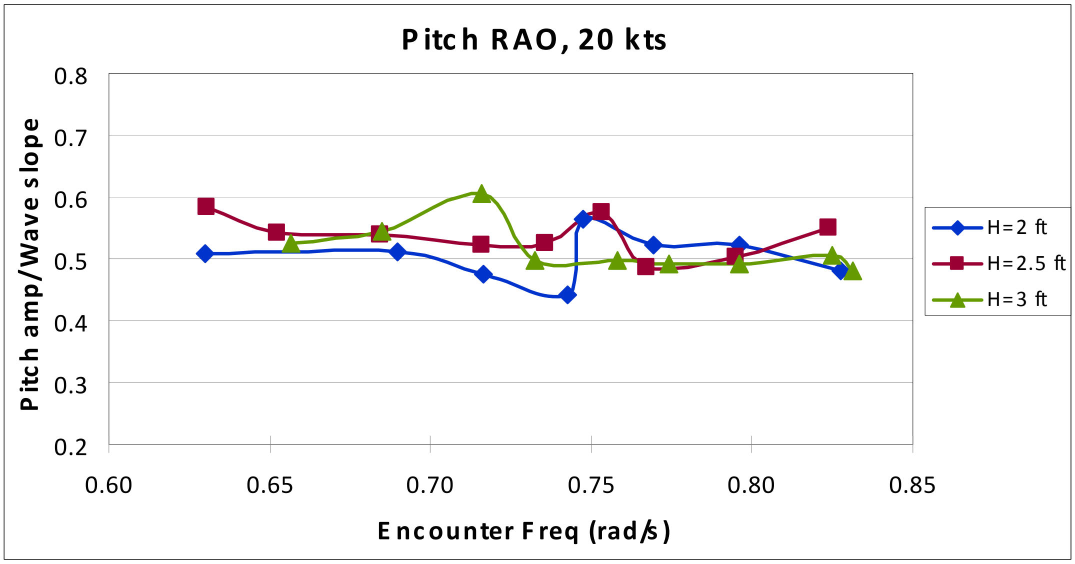

Figure 17: Pitch RAO, 20 kts

This figure shows that RAO pitch response is linear with waveheight since the pitch response is relatively unchanged with waveheight. This linearity is to be expected since the pitch amplitude is normalized by the wave slope. Similar results were seen for pitch response at the other speeds tested.

Sinkage and Trim

Sinkage and trim in waves were measured in addition to the pitch and heave. Figure 18 shows the variation in sinkage for 2, 2.5, and 3 ft wave heights.

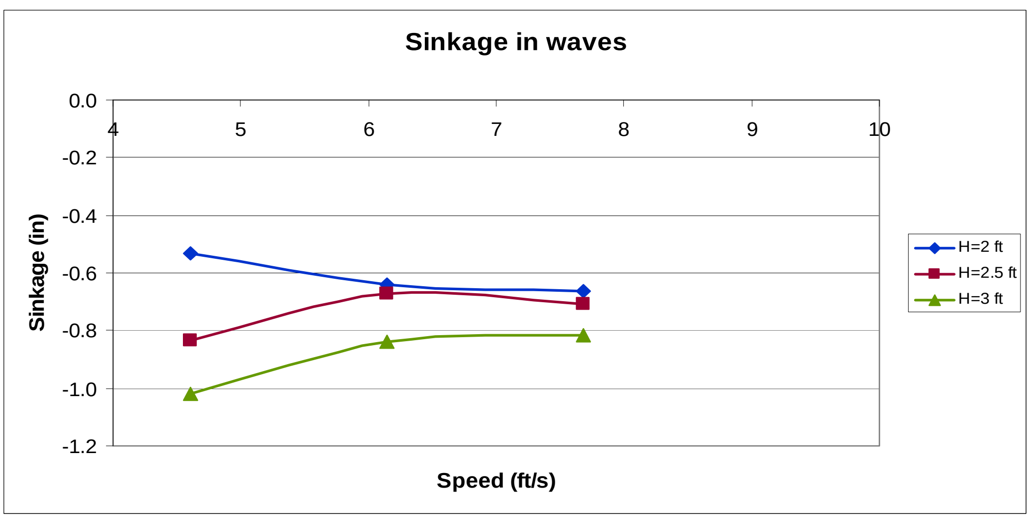

Figure 18: Sinkage in Waves

Sinkage seems to increase, that is, grows more negative, with increasing wave height. For wave heights of 2.5 ft and 3 ft, the sinkage tends to have a positive slope with increased speed. At a wave height of 2 ft, the sinkage tends to do the opposite with increased velocity. This is somewhat abnormal as the sinkage should follow the same general trend. It is unclear why the results indicate this. The sinkage for each wave condition is compared with the sinkage in calm water in Figure 19.

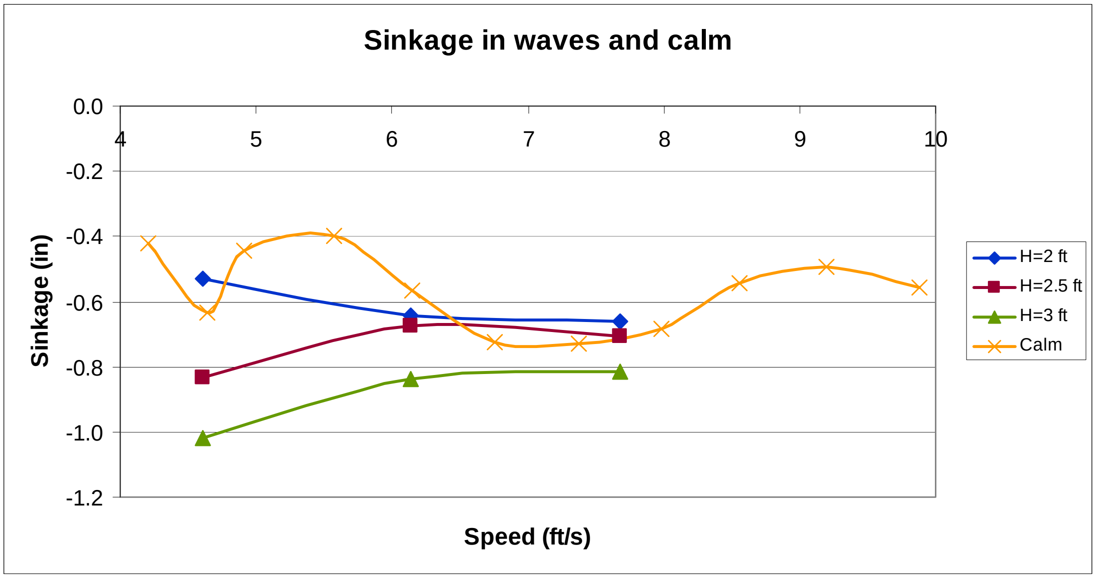

Figure 19: Sinkage in Waves and Calm

The shape of the calm water sinkage curve is quite different from that of the sinkage curves for waves. It is possible that with more data points, the shape of the wave curves might better resemble the calm water curve. Trim versus speed for each wave height is shown below in Figure 20.

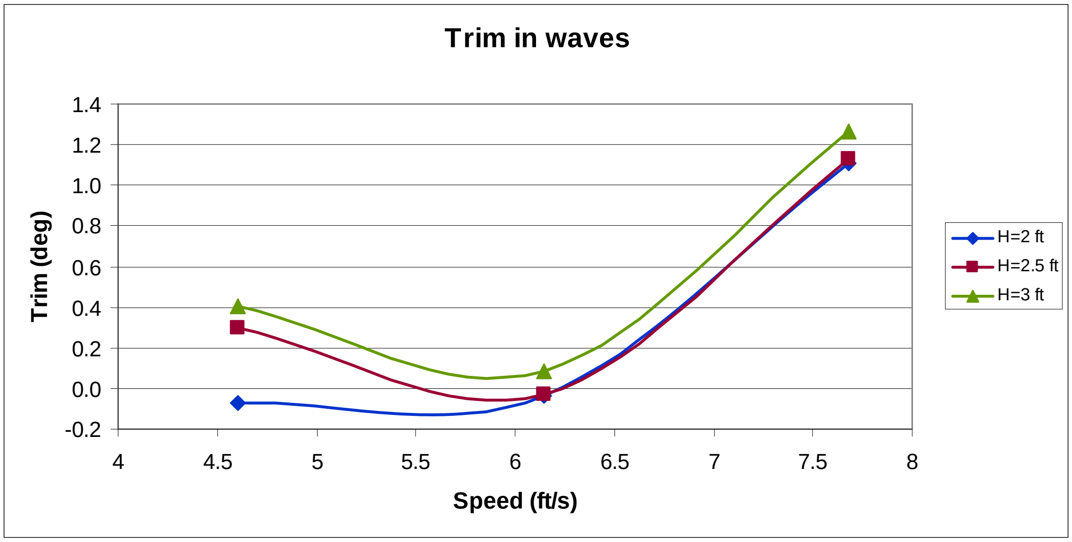

Figure 20: Trim in Waves

Trim tends to decrease at low speed, then increase for each wave height with increasing speed. Trim values also seem to be similar regardless of wave height. Trim in waves is compared with trim in calm water in Figure 21.

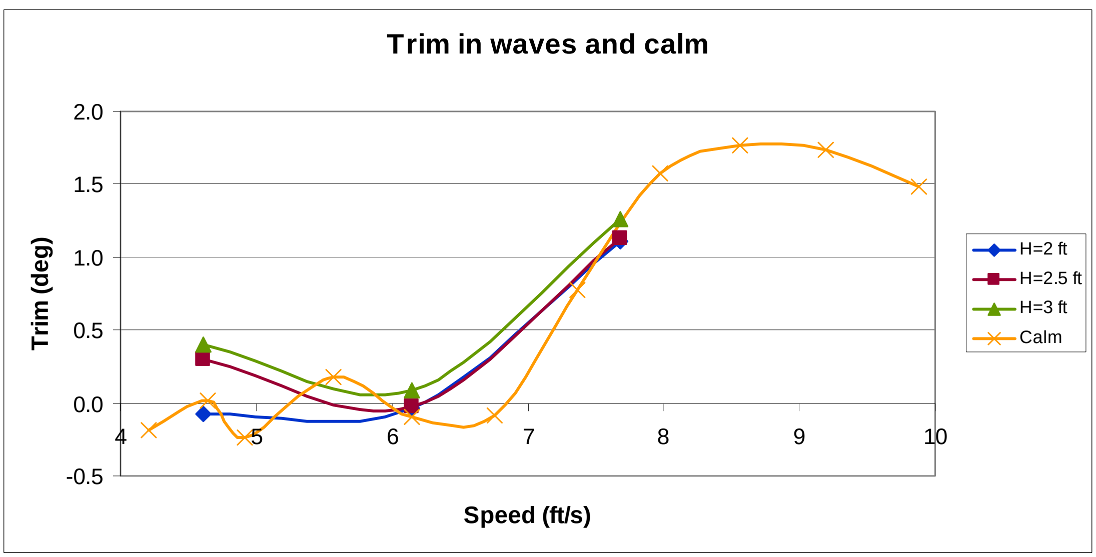

Figure 21: Trim in Waves and Calm

The greater number of data points in the calm water tests indicates humps and hollows in the curve not evident in the wave curves. This curve also seems to generally increase with increasing speed, and seems to follow generally the same trend as the wave tests.

Zero Speed

Zero speed tests were performed in order to get a baseline for other motion data, and to correlate with similar tests run by Code 55 in the MASK. This correlation also helps see any differences in results obtained between the 140 ft basin and the MASK. Figure 22 shows the non-dimensional transfer function (NDTF) for heave at zero speed in head seas, at a waveheight of 1 inch model scale or 2.5 ft full scale.

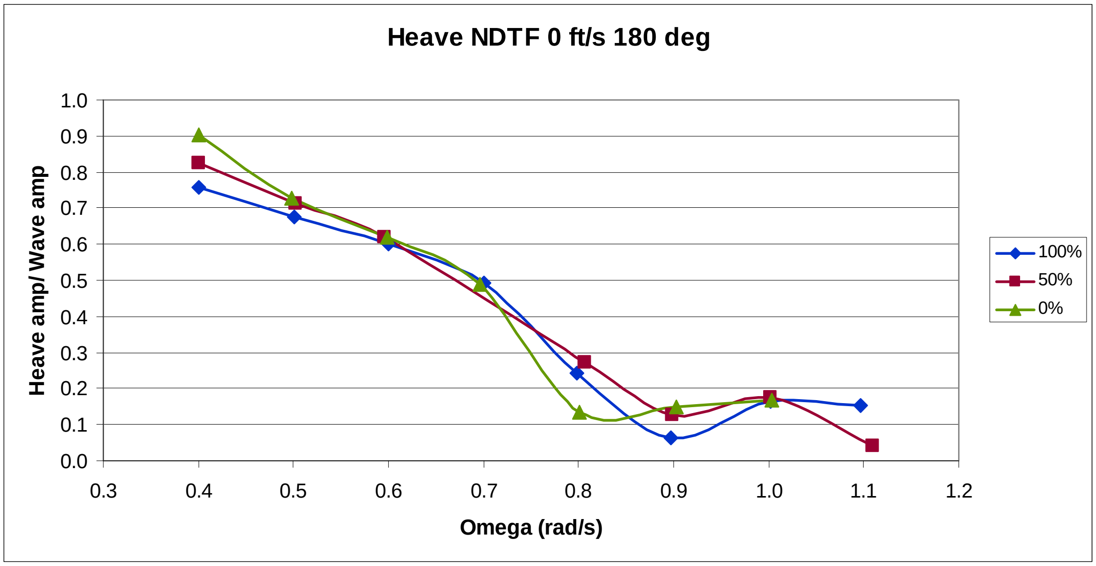

Figure 22: Heave Non-Dimensional Transfer Function, Zero Speed, Head Seas

The heave amplitude is non-dimensionalized by the wave amplitude and then plotted against the wave frequency at prototype scale. The figure shows that cushion pressure has very little effect on heave at zero speed. Figure 23 compares the CISD heave transfer function for 100% cushion pressure with the Code 55 heave transfer function at 100%.

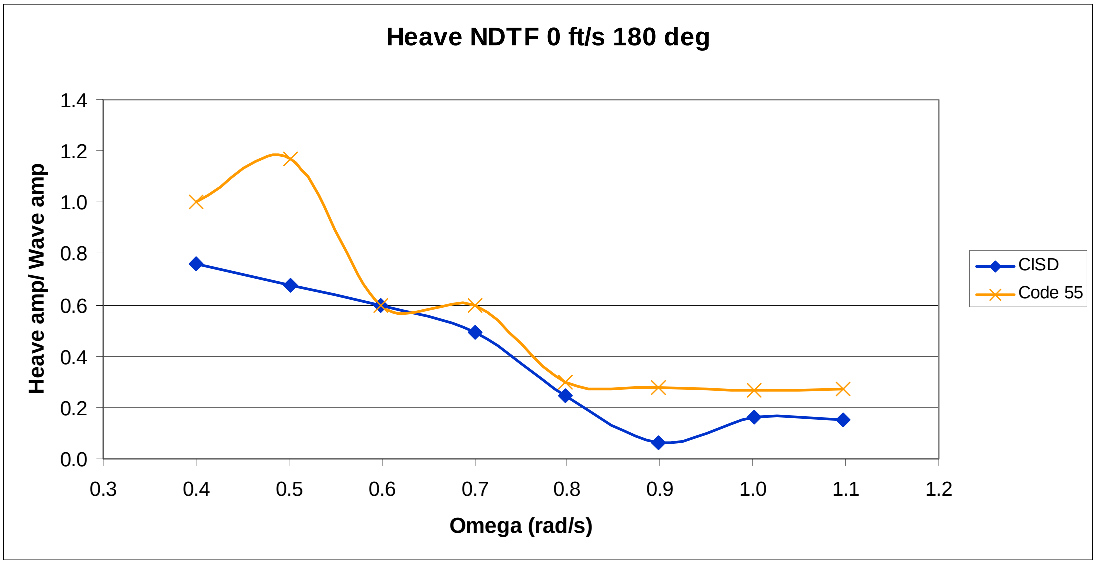

Figure 23: Heave Non-Dimensional Transfer Function at Zero Speed, Head Seas, 100% Cushion

The figure shows good agreement between the CISD and MASK data. The major difference in the shape of the curve is in the 0.4-0.6 rad/sec range where a significant hump in the MASK curve is not evident in the CISD data. This could be due to the characteristics of the 140 ft basin versus the MASK basin since hydrodynamic blockage due to model size could have a significant effect on results in the 140 ft basin. The waves were also in the intermediate depth range in the 140 ft basin since it is only 4.6 ft deep rather than the deepwater waves in the MASK. Figure 24 shows the CISD heave transfer function in beam seas compared to MASK test result.

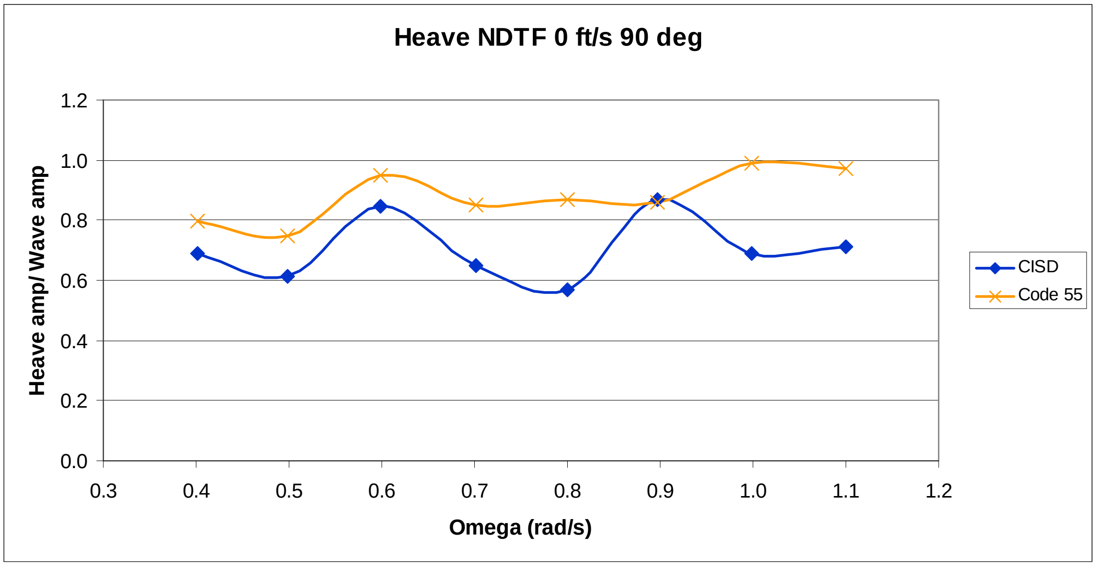

Figure 24: Heave NDTF at Zero Speed, Beam Seas, 100% Cushion

This figure shows that the 140 ft basin test results achieved a similar shape to the MASK results in beam seas. This could be showing the affect of blockage on the results at 180 degrees since the data were more closely matched at the 90 degree heading. The effect of variation in cushion pressures on the beam sea transfer function is shown in Figure 25.

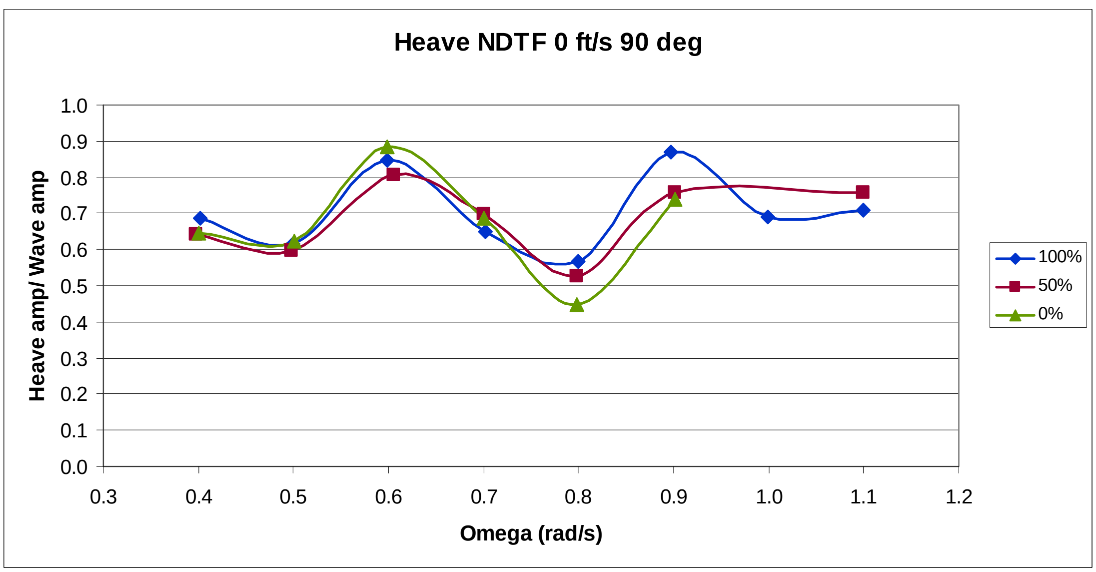

Figure 25: Heave Non-Dimensional Transfer Function at Zero Speed, Beam Seas

The three transfer functions are very similar as in the head sea case. This shows that cushion pressure has almost no affect on the heave motions at zero speed over the frequency range tested. Figure 26 shows the pitch transfer function at zero speed in head seas. Pitch is non-dimensionalized by the wave slope which is the product the wave number and the wave amplitude (kA).

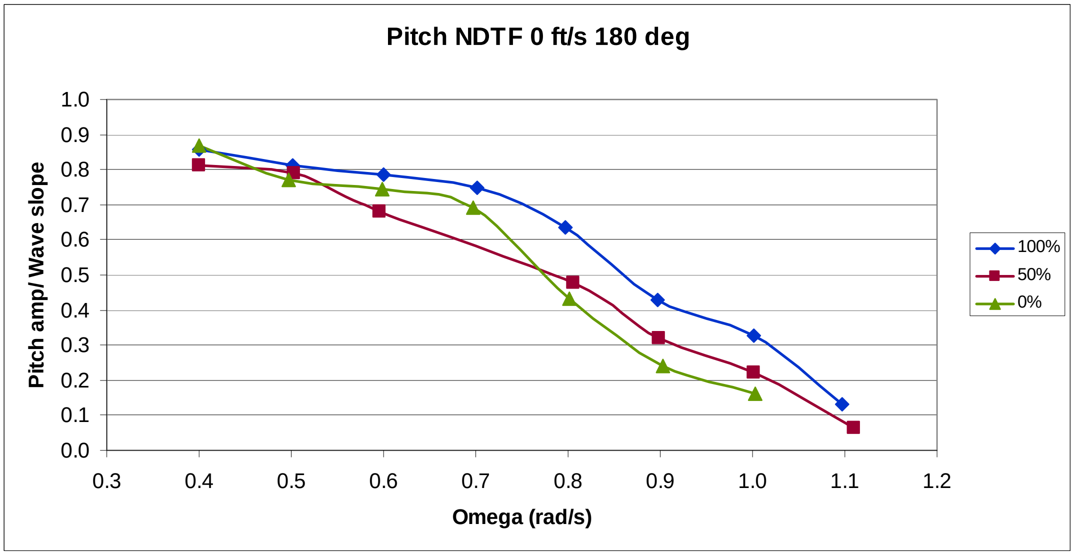

Figure 26: Pitch Non-Dimensional Transfer Function at Zero Speed, Head Seas

Once again, cushion pressure seems to have little influence on the pitch motion. Figure 27 compares the CISD pitch transfer function with the MASK results.

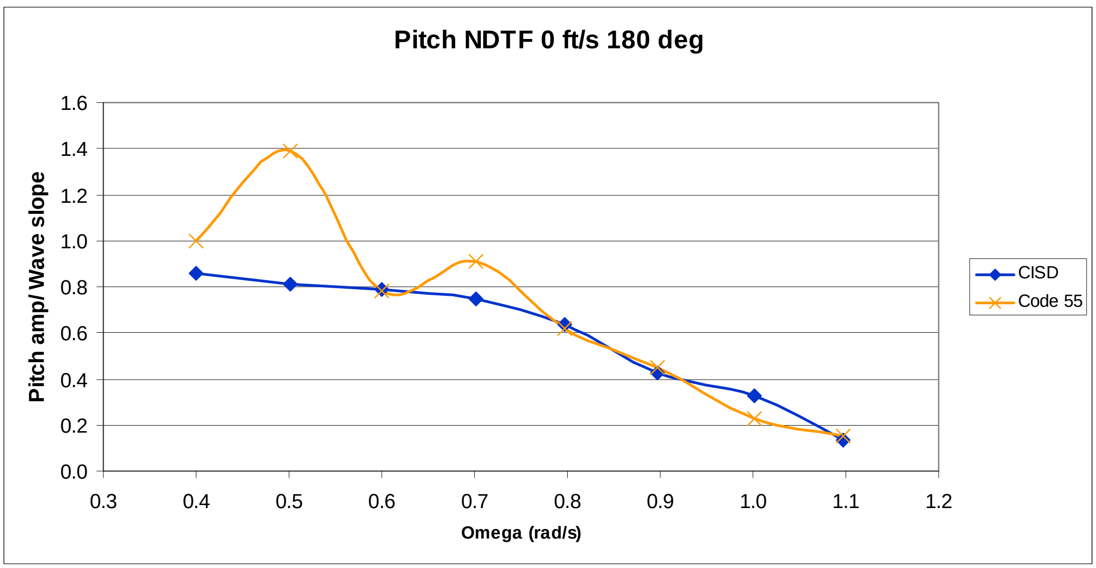

Figure 27: Pitch Non-Dimensional Transfer Function at Zero Speed, 100% Cushion Pressure

Both follow the same downward trend and agree closely for higher frequencies, however, the CISD data does not show the peaks at 0.5 rad/sec and 0.7 rad/sec evident in the Code 55 tests. This could be due to many different factors that need to be investigated. Figure 28 compares the CISD roll transfer function results at zero speed in beam seas with the MASK test data.

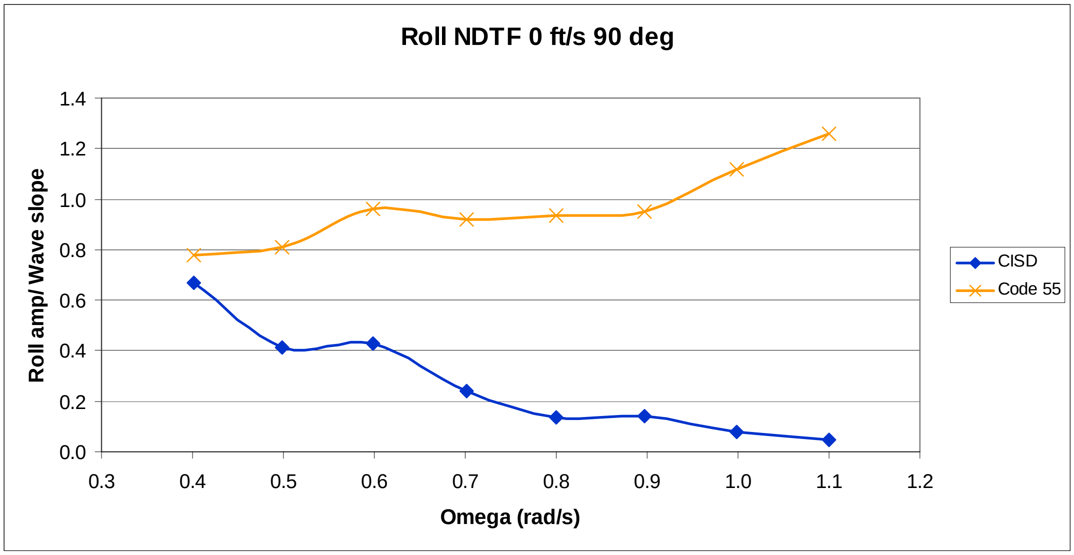

Figure 28: Roll Non-Dimensional Transfer Function at Zero Speed, Beam Seas, 100 % cushion

Very large discrepancies are evident between the 140 foot basin results and the MASK results particularly at higher frequencies. For this case, the model was oriented transversely across the 140 foot basin which could be the basis for the problem. There was only about a foot of clearance on either end of the model in this orientation so there could have been significant blockage effects for this orientation. The model was acting as a breakwater and the waves were observed to be significantly altered as they encountered the model. Figure 29 shows the roll transfer function at zero speed in beam seas for each cushion configuration.

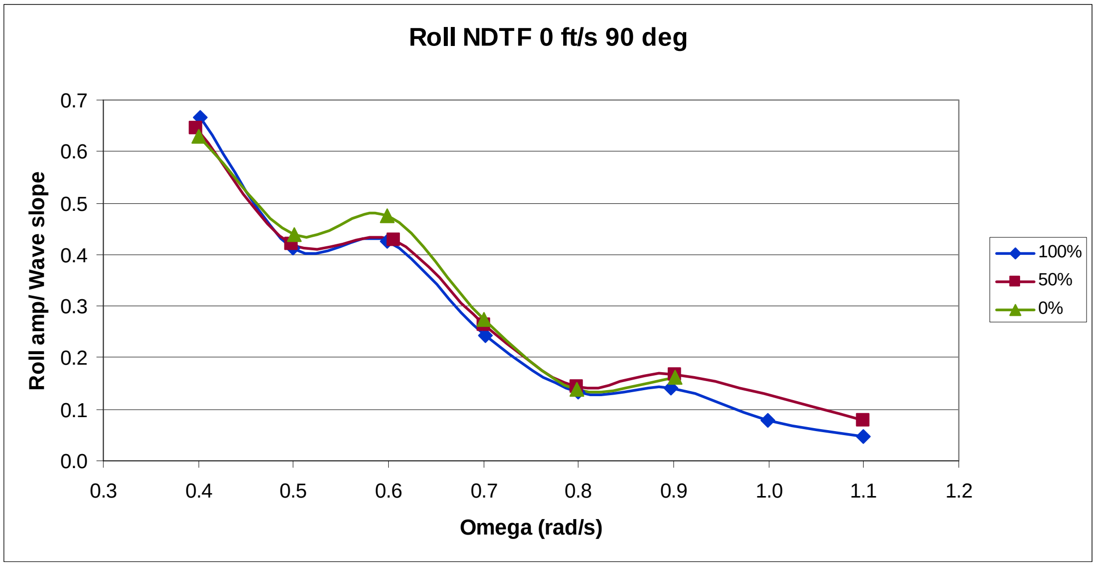

Figure 29: Roll Non-Dimensional Transfer Function at Zero Speed, Beam Seas

This figure shows that the trend produced by the 140 foot basin tests was not just isolated to the 100% cushion case, but it is the same for each cushion pressure. The figure also shows that cushion pressure does not have an effect on roll motions in waves.

Decay Tests

Decay tests were carried out to observe the damping effects of different cushion pressures. They were performed at 100%, 50% and 0% fan power for heave, pitch, and roll. Pitch decays were done with the model oriented longitudinally in the tank while heave and roll decays were done with the model oriented transversely. Heave decays were attempted with a longitudinal heading but were abandoned as it became apparent wave reflections from the side of the tank were greatly influencing motions.

To perform the decay tests, the model was fixed in all but the desired degree of freedom, and was then forced to oscillate in the free direction. Plots of heave, pitch, and roll versus time were then created and the natural period and rate of decay were observed. The results can be seen in Figure 30.

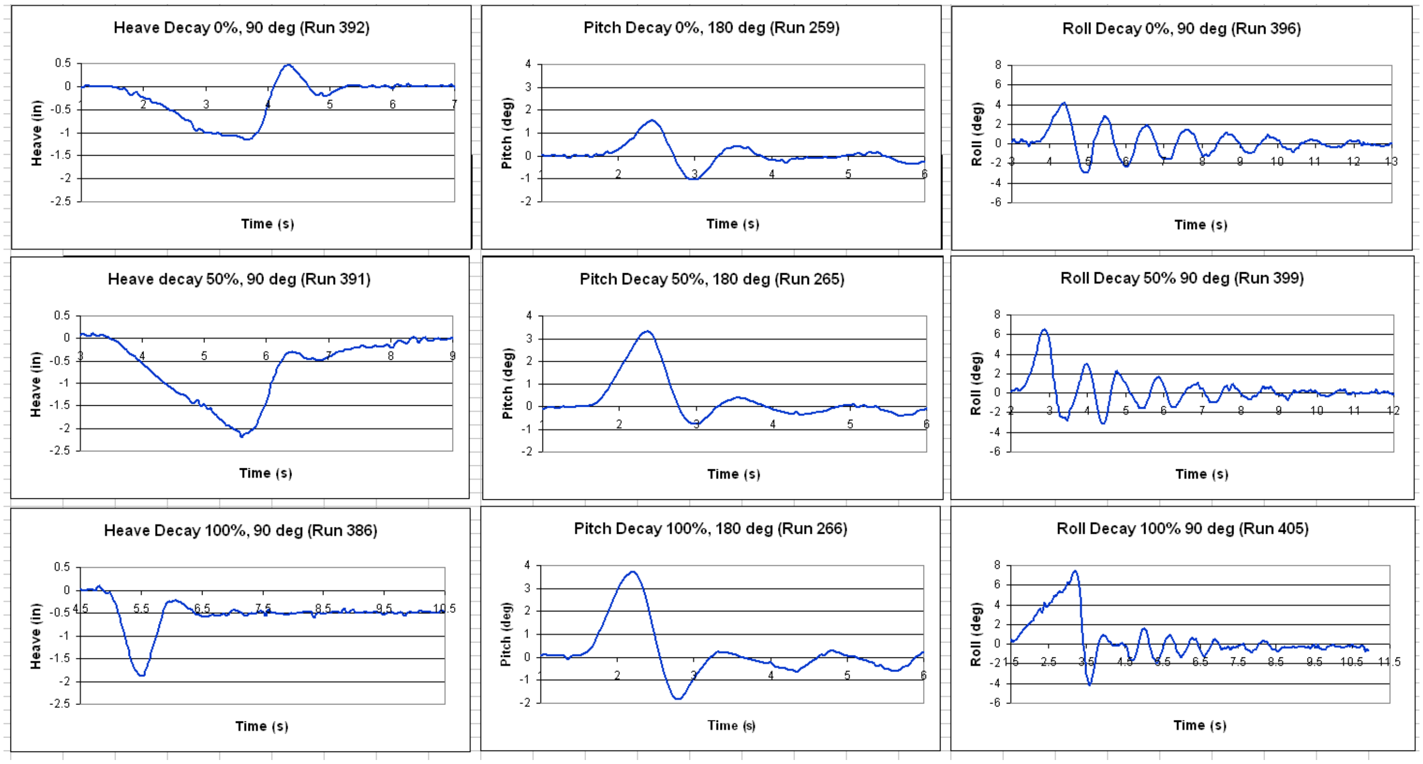

Figure 30: Decay Test Results

It can be seen that the cushion has a significant dampening effect on all motions when at full cushion power. In all cases, the motion decays gradually at 0% cushion, slightly faster at 50% cushion, and very quickly at 100% cushion. For example, the natural period for roll changes from a little over a second at 0% cushion to between half and three quarters of a second for 100% cushion. The 100% cushion case is considered heavily damped.

Experimental Issues

There were a few notable experimental issues which affected the results. First, the amplitudes of waves produced by the wavemaker were only half of what was planned. This error went unnoticed until it was discovered late in the test program that the wave probe calibration was in error by a factor of two, which lead the team to believe the waves were twice as high as they actually were. The waves were only half of the expected amplitude because the "amplitude" entered into the wavemaker function generator was the amplitude of the voltage input, whereas the "amplitude" generated by the function generator was a "peak to peak" amplitude, or wave height.

A potential source of error is related to the size of the 140 foot basin. The usable part of the basin is only about 110 feet long, and when the carriage run-up and stopping distance is accounted for, only about 8 seconds of usable data was obtainable for each run. This 8 seconds of data translates to about 3-6 wave encounters. Having so few wave encounters and such a small amount of time to collect data does not allow the computer to sample the instruments enough to provide a desired resolution.

A more problematic factor is that the basin is only 4.6 feet deep. The waves generated were intermediate depth waves at the highest frequencies and approached shallow water waves for the lowest frequencies. The wavelengths generated were between 20 and 30 feet which correspond to a depth to wavelength ratio (d/l) between about .2 and .15. The lower limit for deepwater waves is 0.5 and upper limit for shallow water waves is 0.05. As the waves get longer, they approach shallow water conditions and bottom interference causes the wave slope to drop off leading to smaller than anticipated waves.

Blockage effects are also a potentially serious issue. The basin is only 10 feet wide and the beam of the model is about 3 feet. Calm water and wave speed tests produced a very large wake which was observed to run up the sides of the tank, possibly affecting heave or sinkage motions. This wake could also interfere with motions data in wave tests as the waves reflect from the sides of the tank. During heave decay tests with the model oriented longitudinally, waves generated from pushing the model down reflected off the walls of the tank and substantially affected the results. Longitudinal heave decay tests were abandoned after these reflections were observed.

During speed runs in calm water and waves the bow seal was observed to be deflecting backward and creating an air pocket under the model as it was underway. This should not happen and could have contributed to increased resistance or inaccuracies in motions data. Some air was also observed escaping from the sides of the model when in waves. It is important to note that this particular model was designed only for zero speed cargo transfer testing, not high speed tow tank testing. Because of this, the skirts were not designed to stand up to the forces the model experienced during testing at speed which then allowed the skirt to be pushed back and creating more wetted surface area.

Conclusions

Based on the testing completed in the 140 foot basin a few conclusions about the generic SES T-Craft model can be drawn and others may require more testing. First, significant conclusions about resistance at the highest T-Craft speeds could not be reached due to the limitations of carriage speed. Carriage speed was limited to 10 ft/sec, consequently data for speeds above 32 knots full scale could not be measured. Therefore, the primary hump in the resistance curve was not reached and therefore the optimum operating speed could not be determined.

Conclusions could not be drawn about added resistance as well due to the limited speed range for wave tests. The wave heights and slopes were also likely too small to produce significant added resistance. It was, however, successfully shown that cushion pressure does not have an effect on ship motions in the zero speed, 2.5 foot wave scenario. This can be seen in the transfer function graphs as the plots for each cushion pressure fall almost exactly on top of each other. Another conclusion that can be drawn is that the cushion produces a significant dampening effect on the motions and shortens the natural frequency. As the cushion pressure was increased, the natural period found through decay tests was decreased and the motions were heavily damped.

Recommendations

The most significant recommendation is to investigate the differences between the tests in the 140 foot basin and the tests performed in the MASK. Analysis and/ or additional testing should be conducted to determine if bottom interference, blockage, or other factors contributed to the unexpected results in the zero speed tests. This would help validate the rest of the testing, and if a correction factor could be found, the rest of the data would become more meaningful. After the differences are accounted for, it is recommended that more tests be run at a wider range of frequencies and waveheights as the tests run concentrated on a specific range of frequencies and did not encounter the maximum responses as expected. Irregular wave testing is also recommended.

Additional testing of the generic T-Craft model is high recommended with the model modified for tow tank testing throughout the speed range. In particular, appropriate seals would have to be built and integrated with the hull. Most importantly the skirt seals should be made sturdy enough so they do not fold or bend back when at speed. A model incorporating a partially retractable bow seal as well would show the effect of added drag at partial cushion and improve resistance performance at partial cushion. The additional testing would best be accomplished in a longer and deeper tow tank to address bottom and blockage issues encountered in the 140 ft basin.

Appendix A: Test Matrix

Table 5: Test Matrix

Condition Number	Test Run Number	$Speed_m$ (kts)	$Speed_m$ (ft/sec)	$Speed_p$ (kts)	Wave Frequency (rad/sec)	$T_{e,p}$ (s)	$H_{s,m}$ (in)	$H_{s,p}$ (ft)	Cushion
1	145	2.729	4.607	15	2.810	8.765	0.759	2	100%
2	146	2.729	4.607	15	2.686	9.287	0.759	2	100%
3	147	2.729	4.607	15	2.629	9.547	0.759	2	100%
4	148	2.729	4.607	15	2.574	9.807	0.759	2	100%
5	149	2.729	4.607	15	2.521	10.067	0.759	2	100%
6	150	2.729	4.607	15	2.471	10.327	0.759	2	100%
7	151	2.729	4.607	15	2.376	10.846	0.759	2	100%
8	152, 333	2.729	4.607	15	2.289	11.363	0.759	2	100%
9	153	2.729	4.607	15	2.209	11.880	0.759	2	100%
10	188	2.729	4.607	15	2.810	8.765	0.993	2.5	100%
11	189	2.729	4.607	15	2.686	9.287	0.993	2.5	100%
12	190	2.729	4.607	15	2.629	9.547	0.993	2.5	100%
13	191	2.729	4.607	15	2.574	9.807	0.993	2.5	100%
14	192	2.729	4.607	15	2.521	10.067	0.993	2.5	100%
15	193	2.729	4.607	15	2.471	10.327	0.993	2.5	100%
16	194	2.729	4.607	15	2.376	10.846	0.993	2.5	100%
17	195, 348	2.729	4.607	15	2.289	11.363	0.993	2.5	100%
18	196	2.729	4.607	15	2.209	11.880	0.993	2.5	100%
19	198, 334	2.729	4.607	15	2.810	8.765	1.192	3	100%
20	199	2.729	4.607	15	2.686	9.287	1.192	3	100%
21	200	2.729	4.607	15	2.629	9.547	1.192	3	100%
22	201	2.729	4.607	15	2.574	9.807	1.192	3	100%
23	202	2.729	4.607	15	2.521	10.067	1.192	3	100%
24	203	2.729	4.607	15	2.471	10.327	1.192	3	100%
25	204, 335	2.729	4.607	15	2.376	10.846	1.192	3	100%
26	205	2.729	4.607	15	2.289	11.363	1.192	3	100%
27	155	3.639	6.142	20	2.810	8.000	0.795	2	100%
28	156, 157	3.639	6.142	20	2.686	8.500	0.795	2	100%
29	158	3.639	6.142	20	2.629	8.750	0.795	2	100%
30	159	3.639	6.142	20	2.574	9.000	0.795	2	100%
31	160	3.639	6.142	20	2.521	9.250	0.795	2	100%
32	161	3.639	6.142	20	2.471	9.500	0.795	2	100%
33	162	3.639	6.142	20	2.376	10.000	0.795	2	100%
34	163, 336	3.639	6.142	20	2.289	10.500	0.795	2	100%
35	164	3.639	6.142	20	2.209	11.000	0.795	2	100%
36	166	3.639	6.142	20	2.810	8.000	0.993	2.5	100%
37	167	3.639	6.142	20	2.686	8.500	0.993	2.5	100%
38	168	3.639	6.142	20	2.629	8.750	0.993	2.5	100%
39	169	3.639	6.142	20	2.574	9.000	0.993	2.5	100%
40	170	3.639	6.142	20	2.521	9.250	0.993	2.5	100%

Condition Number	Test Run Number	$Speed_m$ (kts)	$Speed_m$ (ft/sec)	$Speed_p$ (kts)	Wave Frequency (rad/sec)	$T_{e,p}$ (s)	$H_{s,m}$ (in)	$H_{s,p}$ (ft)	Cushion
41	171	3.639	6.142	20	2.471	9.500	0.993	2.5	100%
42	172	3.639	6.142	20	2.376	10.000	0.993	2.5	100%
43	173	3.639	6.142	20	2.289	10.500	0.993	2.5	100%
44	174, 337c	3.639	6.142	20	2.209	11.000	0.993	2.5	100%
45	208, 337	3.639	6.142	20	2.810	8.000	1.192	3	100%
46	209	3.639	6.142	20	2.686	8.500	1.192	3	100%
47	210	3.639	6.142	20	2.629	8.750	1.192	3	100%
48	211	3.639	6.142	20	2.574	9.000	1.192	3	100%
49	212	3.639	6.142	20	2.521	9.250	1.192	3	100%
50	213	3.639	6.142	20	2.471	9.500	1.192	3	100%
51	214	3.639	6.142	20	2.376	10.000	1.192	3	100%
52	215	3.639	6.142	20	2.289	10.500	1.192	3	100%
53	177	4.549	7.678	25	2.810	7.358	0.795	2	100%
54	178, 179	4.549	7.678	25	2.686	7.836	0.795	2	100%
55	180	4.549	7.678	25	2.629	8.076	0.795	2	100%
56	181	4.549	7.678	25	2.574	8.315	0.795	2	100%
57	182	4.549	7.678	25	2.521	8.555	0.795	2	100%
58	183	4.549	7.678	25	2.471	8.796	0.795	2	100%
59	184	4.549	7.678	25	2.376	9.277	0.795	2	100%
60	185	4.549	7.678	25	2.289	9.758	0.795	2	100%
61	186	4.549	7.678	25	2.209	10.241	0.795	2	100%
62	217	4.549	7.678	25	2.810	7.358	0.993	2.5	100%
63	218, 219, 220	4.549	7.678	25	2.686	7.836	0.993	2.5	100%
64	221	4.549	7.678	25	2.629	8.076	0.993	2.5	100%
65	222	4.549	7.678	25	2.574	8.315	0.993	2.5	100%
66	223	4.549	7.678	25	2.521	8.555	0.993	2.5	100%
67	225	4.549	7.678	25	2.471	8.796	0.993	2.5	100%
68	226	4.549	7.678	25	2.376	9.277	0.993	2.5	100%
69	227	4.549	7.678	25	2.289	9.758	0.993	2.5	100%
70	228	4.549	7.678	25	2.209	10.241	0.993	2.5	100%
71	230, 231, 329	4.549	7.678	25	2.810	7.358	1.192	3	100%
72	232	4.549	7.678	25	2.686	7.836	1.192	3	100%
73	233, 330	4.549	7.678	25	2.629	8.076	1.192	3	100%
74	234	4.549	7.678	25	2.574	8.315	1.192	3	100%
75	235, 331	4.549	7.678	25	2.521	8.555	1.192	3	100%
76	236	4.549	7.678	25	2.471	8.796	1.192	3	100%
77	237	4.549	7.678	25	2.376	9.277	1.192	3	100%
78	238	4.549	7.678	25	2.289	9.758	1.192	3	100%
79	105, 128	2.55	4.300	14	Calm	Calm	Calm	Calm	100%
80	106, 129	2.91	4.914	16	Calm	Calm	Calm	Calm	100%
81	107, 130, 337b	3.27	5.528	18	Calm	Calm	Calm	Calm	100%
82	108, 131	3.64	6.142	20	Calm	Calm	Calm	Calm	100%

Condition Number	Test Run Number	Speed$_m$ (kts)	Speed$_m$ (ft/sec)	Speed$_p$ (kts)	Wave Frequency (rad/sec)	$T_{e,p}$ (s)	$H_{s,m}$ (in)	$H_{s,p}$ (ft)	Cushion
83	110, 132	4.00	6.757	22	Calm	Calm	Calm	Calm	100%
84	111, 133	4.37	7.371	24	Calm	Calm	Calm	Calm	100%
85	112, 134	4.73	7.985	26	Calm	Calm	Calm	Calm	100%
86	113, 135	5.09	8.599	28	Calm	Calm	Calm	Calm	100%
87	115, 136	5.46	9.214	30	Calm	Calm	Calm	Calm	100%
88	116, 137, 337d	5.82	9.828	32	Calm	Calm	Calm	Calm	100%
89	117, 126	2.55	4.300	14	Calm	Calm	Calm	Calm	50%
90	118, 125, 341	2.91	4.914	16	Calm	Calm	Calm	Calm	50%
91	119, 124	3.27	5.528	18	Calm	Calm	Calm	Calm	50%
92	121, 122, 123, 342	3.64	6.142	20	Calm	Calm	Calm	Calm	50%
93		4.00	6.757	22	Calm	Calm	Calm	Calm	50%
94		4.37	7.371	24	Calm	Calm	Calm	Calm	50%
95		4.73	7.985	26	Calm	Calm	Calm	Calm	50%
96		5.09	8.599	28	Calm	Calm	Calm	Calm	50%
97		5.46	9.214	30	Calm	Calm	Calm	Calm	50%
98		5.82	9.828	32	Calm	Calm	Calm	Calm	50%
Zero Speed									
99	240	0	0	0	2.1984	2.8580	0.993	2.5	100%
100	241	0	0	0	2.7480	2.2864	0.993	2.5	100%
101	242	0	0	0	3.2974	1.9055	0.993	2.5	100%
102	243	0	0	0	3.8470	1.6333	0.993	2.5	100%
103	244	0	0	0	4.3923	1.4305	0.993	2.5	100%
104	245	0	0	0	4.9460	1.2704	0.993	2.5	100%
105	246, 332	0	0	0	5.4937	1.1437	0.993	2.5	100%
106	247	0	0	0	6.0457	1.0393	0.993	2.5	100%
107	250	0	0	0	2.1984	2.8580	0.993	2.5	50%
108	251	0	0	0	2.7480	2.2864	0.993	2.5	50%
109	252	0	0	0	3.2974	1.9055	0.993	2.5	50%
110	253	0	0	0	3.8470	1.6333	0.993	2.5	50%
111	254	0	0	0	4.3923	1.4305	0.993	2.5	50%
112	255	0	0	0	4.9460	1.2704	0.993	2.5	50%
113	256	0	0	0	5.4937	1.1437	0.993	2.5	50%
114	257	0	0	0	6.0457	1.0393	0.993	2.5	50%
115	273, 321	0	0	0	2.1984	2.8580	0.993	2.5	0%
116	274, 322	0	0	0	2.7480	2.2864	0.993	2.5	0%
117	275, 323	0	0	0	3.2974	1.9055	0.993	2.5	0%
118	276, 324	0	0	0	3.8470	1.6333	0.993	2.5	0%
119	277, 325	0	0	0	4.3923	1.4305	0.993	2.5	0%
120	278, 326	0	0	0	4.9460	1.2704	0.993	2.5	0%
121	279, 327	0	0	0	5.4937	1.1437	0.993	2.5	0%
122	280, 328	0	0	0	6.0457	1.0393	0.993	2.5	0%

Condition Number	Test Run Number	Speed$_m$ (kts)	Speed$_m$ (ft/sec)	Speed$_p$ (kts)	Wave Frequency (rad/sec)	$T_{e,p}$ (s)	$H_{s,m}$ (in)	$H_{s,p}$ (ft)	Cushion
123	266, 267, 268, 269, 270	Pitch Decay	0	0	0	0	0	0	100%
124	271, 272	Heave Decay	0	0	0	0	0	0	100%
125	262, 263, 264, 265	Pitch Decay	0	0	0	0	0	0	50%
126		Heave Decay	0	0	0	0	0	0	50%
127	258, 259, 260, 261	Pitch decay	0	0	0	0	0	0	0%
128		Heave Decay	0	0	0	0	0	0	0%
129	283, 287	2.184	3.686	12.002					100%
130	285, 289, 291	2.184	3.686	12.002					50%
131	284, 288	2.725	4.6	14.978					100%
132	286, 290	2.725	4.6	14.978					50%
133	294, 295								
134	292, 293								
135	299	4.549	7.678	25.000	3.1437	6.28	1.192	3	100%
136	300	4.549	7.678	25.000	2.9174	6.98	1.192	3	100%
137	301, 302, 347	4.549	7.678	25.000	1.8951	12.55	1.192	3	100%
138	303	4.549	7.678	25.000	1.5931	15.71	1.192	3	100%
139	307, 308, 309, 386, 387, 388	Heave Decay	0	0	0	0	0	0	100%
140	315, 316, 317, 318, 401, 402, 403, 404, 405	Roll Decay	0	0	0	0	0	0	100%
141	389, 390, 391	Heave Decay	0	0	0	0	0	0	50%
142	398, 399, 400	Roll Decay	0	0	0	0	0	0	50%
143	392, 393, 394	Heave Decay	0	0	0	0	0	0	0%
144	395, 396, 397	Roll Decay	0	0	0	0	0	0	0%
145	352	0	0	0	2.1984	2.8580	0.993	2.5	100%
146	353	0	0	0	2.7480	2.2864	0.993	2.5	100%
147	354, 381	0	0	0	3.2974	1.9055	0.993	2.5	100%
148	355, 356	0	0	0	3.8470	1.6333	0.993	2.5	100%
149	257	0	0	0	4.3923	1.4305	0.993	2.5	100%
150	359, 362	0	0	0	4.9460	1.2704	0.993	2.5	100%
151	360, 363, 382	0	0	0	5.4937	1.1437	0.993	2.5	100%

Condition Number	Test Run Number	Speed$_m$ (kts)	Speed$_m$ (ft/sec)	Speed$_p$ (kts)	Wave Frequency (rad/sec)	$T_{e,p}$ (s)	$H_{s,m}$ (in)	$H_{s,p}$ (ft)	Cushion
152	361, 364	0	0	0	6.0457	1.0393	0.993	2.5	100%
153	365	0	0	0	2.1984	2.8580	0.993	2.5	50%
154	366	0	0	0	2.7480	2.2864	0.993	2.5	50%
155	367	0	0	0	3.2974	1.9055	0.993	2.5	50%
156	368	0	0	0	3.8470	1.6333	0.993	2.5	50%
157	369	0	0	0	4.3923	1.4305	0.993	2.5	50%
158	370, 383	0	0	0	4.9460	1.2704	0.993	2.5	50%
159	371, 384	0	0	0	5.4937	1.1437	0.993	2.5	50%
160	372, 385	0	0	0	6.0457	1.0393	0.993	2.5	50%
161	343	4.549	7.678	25.000	3.144	6.279	0.993	2.5	100%
162	344	4.549	7.678	25.000	2.917	6.981	0.993	2.5	100%
163	345	4.549	7.678	25.000	1.895	12.551	0.993	2.5	100%
164	346	4.549	7.678	25.000	1.593	15.709	0.993	2.5	100%
165	339, 340, 373	0			1.652	0.3	0.993	2.5	
166		0	0	0	2.1984	2.8580	0.993	2.5	0%
167	374	0	0	0	2.7480	2.2864	0.993	2.5	0%
168	375	0	0	0	3.2974	1.9055	0.993	2.5	0%
169	376	0	0	0	3.8470	1.6333	0.993	2.5	0%
170		0	0	0	4.3923	1.4305	0.993	2.5	0%
171	378	0	0	0	4.9460	1.2704	0.993	2.5	0%
172	379	0	0	0	5.4937	1.1437	0.993	2.5	0%
173	380	0	0	0	6.0457	1.0393	0.993	2.5	0%

Nomenclature:

$(*)_m$ = model scale

$(*)_p$ = prototype (full) scale

$T_{e,p}$ = wave period of encounter, prototype scale

$H_{s,m}$ = significant waveheight, model scale

“Cushion” refers to cushion power

It should be noted that this test matrix includes the tested wave heights, not necessarily what was planned. The waveheights tested were half of what was intended.

Figure 31: Wave Calculation Spreadsheet

Regular Waves		Model Length	8.292 ft	Scale	30.209 ft				
		Prototype L	250.48 ft	Depth	4.61		Prototype Depth	139.26349	
$Speed_p$ (knot)	$Speed_p$ (ft/s)	$Speed_m$ (ft/s)	$Speed_m$ (knot)	Fr_m	Fr_p			Encounter Period Macro	All sheets linked here. Input depth, then goal seek for wave number related to desired encounter period.
15	25.320	4.607	2.729	0.2819	0.2819	1			
20	33.760	6.142	3.639	0.3759	0.3759	2			
25	42.200	7.678	4.549	0.4699	0.4699	3			
30	50.640	9.214	5.458	0.5639	0.5639	4			

2.729 knots | 4.607 ft/s

									Full	Model ft		Full	Model ft		Full	Model ft				
										$H_{s,p}$=4ft	0.1324	1.5889	$H_{s,p}$=5ft	0.1655	1.9862	$H_{s,p}$=6ft	0.1986	2.3834	d/L	tanh(kd)
ω_m (rad/s)	$T_{e,p}$ (s)	$\omega_{e,m}$ (rad/s)	$\omega_{e,p}$ (rad/s)	$T_{e,m}$ (s)	T_m (s)	T_p (s)	L_m (ft)	Wave $Number_m$ (k)	Frequency (Hz)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)		
2.810	8.76	3.940	0.717	1.595	2.236	12.291	22.133	0.284	0.447	0.202	2.428	4.856	0.253	3.035	6.071	0.304	3.642	7.285	0.208	0.864
2.686	9.29	3.719	0.677	1.690	2.339	12.858	23.601	0.266	0.428	0.216	2.589	5.179	0.270	3.237	6.473	0.324	3.884	7.768	0.195	0.842
2.629	9.55	3.617	0.658	1.737	2.390	13.140	24.326	0.258	0.418	0.222	2.669	5.338	0.278	3.336	6.672	0.334	4.003	8.006	0.190	0.831
2.574	9.81	3.521	0.641	1.784	2.441	13.421	25.044	0.251	0.410	0.229	2.748	5.495	0.286	3.435	6.869	0.343	4.121	8.243	0.184	0.820
2.521	10.07	3.430	0.624	1.832	2.492	13.701	25.757	0.244	0.401	0.235	2.826	5.652	0.294	3.532	7.065	0.353	4.239	8.478	0.179	0.809
2.471	10.33	3.344	0.608	1.879	2.543	13.980	26.465	0.237	0.393	0.242	2.904	5.807	0.302	3.629	7.259	0.363	4.355	8.711	0.174	0.799
2.376	10.85	3.184	0.579	1.973	2.644	14.535	27.864	0.225	0.378	0.255	3.057	6.114	0.318	3.821	7.643	0.382	4.586	9.171	0.165	0.778
2.289	11.36	3.039	0.553	2.067	2.745	15.088	29.245	0.215	0.364	0.267	3.209	6.417	0.334	4.011	8.021	0.401	4.813	9.626	0.158	0.758
2.209	11.88	2.907	0.529	2.162	2.845	15.637	30.608	0.205	0.352	0.280	3.358	6.716	0.350	4.198	8.395	0.420	5.037	10.074	0.151	0.738
9																				

3.639 knots | 6.142 ft/s

									H=4ft	0.1324	1.5889	$H_{s,p}$=5ft	0.1655	1.9862	$H_{s,p}$=6ft	0.1986	2.3834	d/L	tanh(kd)	tanh(kd)
ω_m (rad/s)	$T_{e,p}$ (s)	$\omega_{e,m}$ (rad/s)	$\omega_{e,p}$ (rad/s)	$T_{e,m}$ (s)	T_m (s)	T_p (s)	L_m (ft)	Wave $Number_m$ (k)	Frequency (Hz)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)		
2.810	8.00	4.317	0.785	1.456	2.236	12.291	22.133	0.284	0.447	0.202	2.428	4.856	0.253	3.035	6.071	0.304	3.642	7.285	0.208	0.864
2.686	8.50	4.063	0.739	1.546	2.339	12.858	23.601	0.266	0.428	0.216	2.589	5.179	0.270	3.237	6.473	0.324	3.884	7.768	0.195	0.842
2.629	8.75	3.947	0.718	1.592	2.390	13.140	24.326	0.258	0.418	0.222	2.669	5.338	0.278	3.336	6.672	0.334	4.003	8.006	0.190	0.831
2.574	9.00	3.837	0.698	1.637	2.441	13.421	25.044	0.251	0.410	0.229	2.748	5.495	0.286	3.435	6.869	0.343	4.121	8.243	0.184	0.820
2.521	9.25	3.733	0.679	1.683	2.492	13.701	25.757	0.244	0.401	0.235	2.826	5.652	0.294	3.532	7.065	0.353	4.239	8.478	0.179	0.809
2.471	9.50	3.635	0.661	1.728	2.543	13.980	26.465	0.237	0.393	0.242	2.904	5.807	0.302	3.629	7.259	0.363	4.355	8.711	0.174	0.799
2.376	10.00	3.453	0.628	1.819	2.644	14.535	27.864	0.225	0.378	0.255	3.057	6.114	0.318	3.821	7.643	0.382	4.586	9.171	0.165	0.778
2.289	10.50	3.289	0.598	1.910	2.745	15.088	29.245	0.215	0.364	0.267	3.209	6.417	0.334	4.011	8.021	0.401	4.813	9.626	0.158	0.758
2.209	11.00	3.139	0.571	2.001	2.845	15.637	30.608	0.205	0.352	0.280	3.358	6.716	0.350	4.198	8.395	0.420	5.037	10.074	0.151	0.738
9																				

4.549 knots | 7.678 ft/s

										H=4ft	0.1324	1.5889	$H_{s,p}$=5ft	0.1655	1.9862	$H_{s,p}$=6ft	0.1986	2.3834	d/L	tanh(kd)
ω_m (rad/s)	$T_{e,p}$ (s)	$\omega_{e,m}$ (rad/s)	$\omega ep_{,m}$ (rad/s)	$T_{e,m}$ (s)	T_m (s)	T_p (s)	L_m (ft)	Wave $Number_m$ (k)	Frequency (Hz)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)	Stroke (ft)	Stroke (in)	Stroke (V)		
3.144	6.28	5.500	1.001	1.142	1.999	10.987	18.703	0.336	0.500	0.171	2.052	4.104	0.214	2.565	5.130	0.256	3.078	6.156	0.246	0.914
2.917	6.98	4.947	0.900	1.270	2.154	11.839	20.953	0.300	0.464	0.192	2.299	4.598	0.239	2.874	5.747	0.287	3.448	6.897	0.220	0.881
2.810	7.36	4.693	0.854	1.339	2.236	12.291	22.133	0.284	0.447	0.202	2.428	4.856	0.253	3.035	6.071	0.304	3.642	7.285	0.208	0.864
2.686	7.84	4.407	0.802	1.426	2.339	12.858	23.601	0.266	0.428	0.216	2.589	5.179	0.270	3.237	6.473	0.324	3.884	7.768	0.195	0.842
2.629	8.08	4.276	0.778	1.469	2.390	13.140	24.326	0.258	0.418	0.222	2.669	5.338	0.278	3.336	6.672	0.334	4.003	8.006	0.190	0.831
2.574	8.32	4.153	0.756	1.513	2.441	13.421	25.044	0.251	0.410	0.229	2.748	5.495	0.286	3.435	6.869	0.343	4.121	8.243	0.184	0.820
2.521	8.56	4.037	0.734	1.557	2.492	13.701	25.757	0.244	0.401	0.235	2.826	5.652	0.294	3.532	7.065	0.353	4.239	8.478	0.179	0.809
2.471	8.80	3.926	0.714	1.600	2.543	13.980	26.465	0.237	0.393	0.242	2.904	5.807	0.302	3.629	7.259	0.363	4.355	8.711	0.174	0.799
2.376	9.28	3.723	0.677	1.688	2.644	14.535	27.864	0.225	0.378	0.255	3.057	6.114	0.318	3.821	7.643	0.382	4.586	9.171	0.165	0.778
2.289	9.76	3.539	0.644	1.775	2.745	15.088	29.245	0.215	0.364	0.267	3.209	6.417	0.334	4.011	8.021	0.401	4.813	9.626	0.158	0.758
2.209	10.24	3.372	0.614	1.863	2.845	15.637	30.608	0.205	0.352	0.280	3.358	6.716	0.350	4.198	8.395	0.420	5.037	10.074	0.151	0.738
1.895	12.55	2.751	0.501	2.284	3.315	18.226	36.917	0.170	0.302	0.338	4.050	8.101	0.422	5.063	10.126	0.506	6.075	12.151	0.125	0.655
1.593	15.71	2.198	0.400	2.858	3.944	21.681	45.130	0.139	0.254	0.413	4.951	9.903	0.516	6.189	12.378	0.619	7.427	14.854	0.102	0.566
1.268	20.92	1.651	0.300	3.805	4.956	27.243	58.058	0.108	0.202	0.531	6.370	12.739	0.664	7.962	15.924	0.796	9.554	19.109	0.079	0.461
0.904	31.43	1.099	0.200	5.718	6.950	38.208	83.028	0.076	0.144	0.759	9.109	18.218	0.949	11.386	22.773	1.139	13.664	27.327	0.056	0.335

Appendix B: Placement and Layout of Instruments

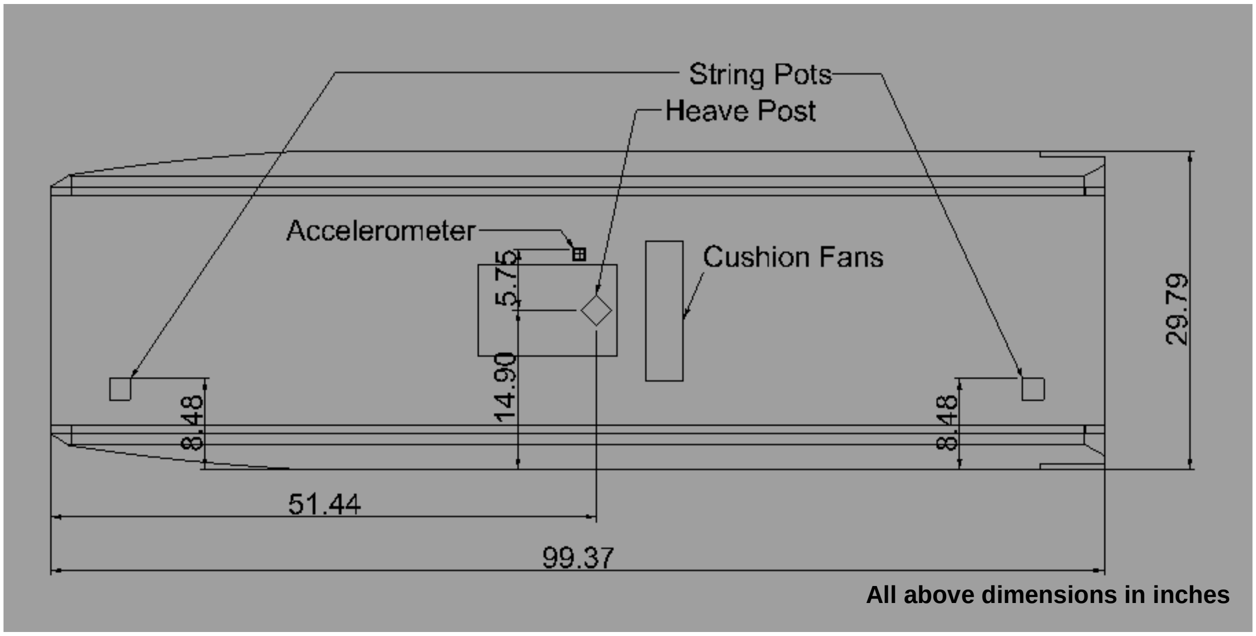

Figure 32: Dimensions of the T-Craft Model

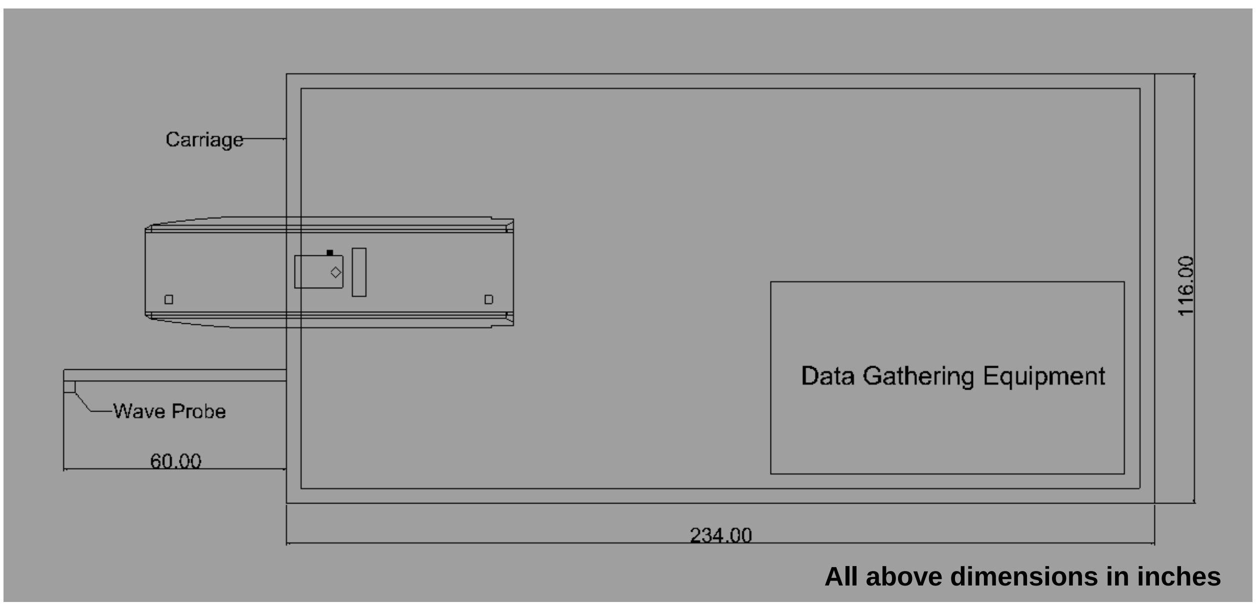

Figure 33: T-Craft Model with Carriage

Appendix C: Results

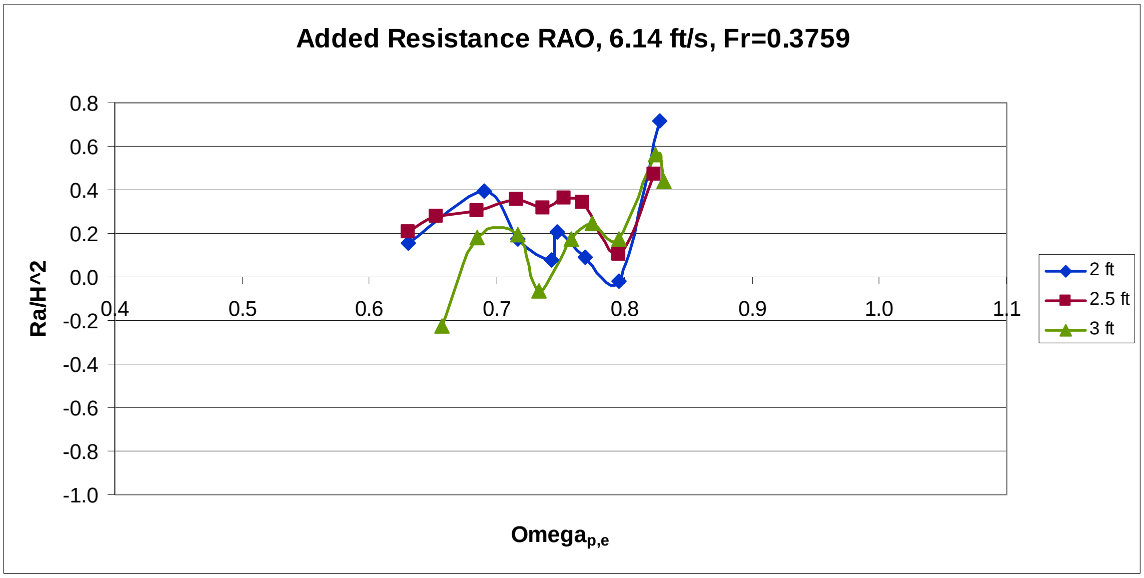

Figure 34: Added Resistance RAO, Fr=0.3759

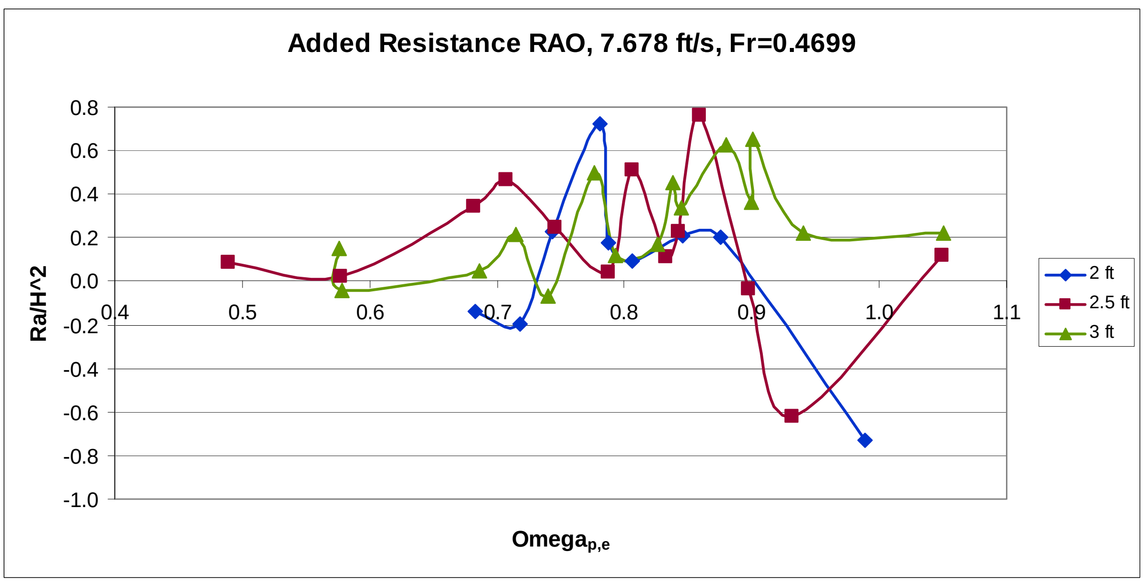

Figure 35: Added Resistance RAO, Fr=0.4699

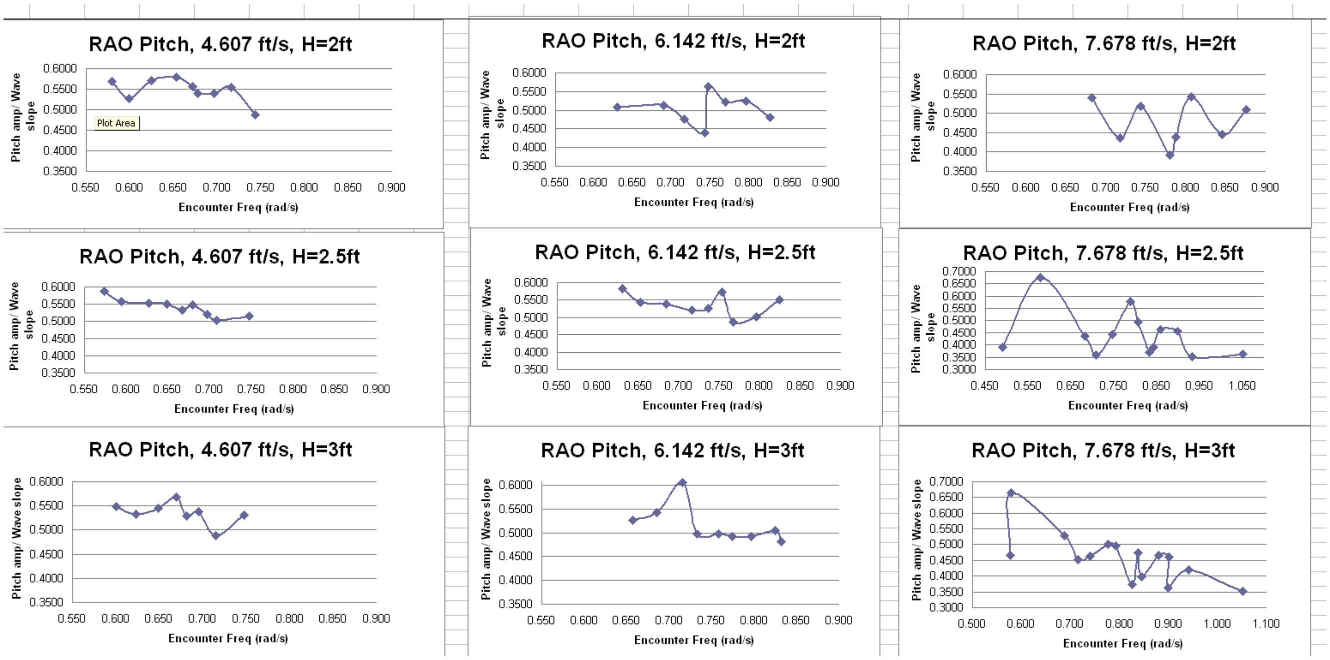

Figure 36: Pitch RAO Graphs

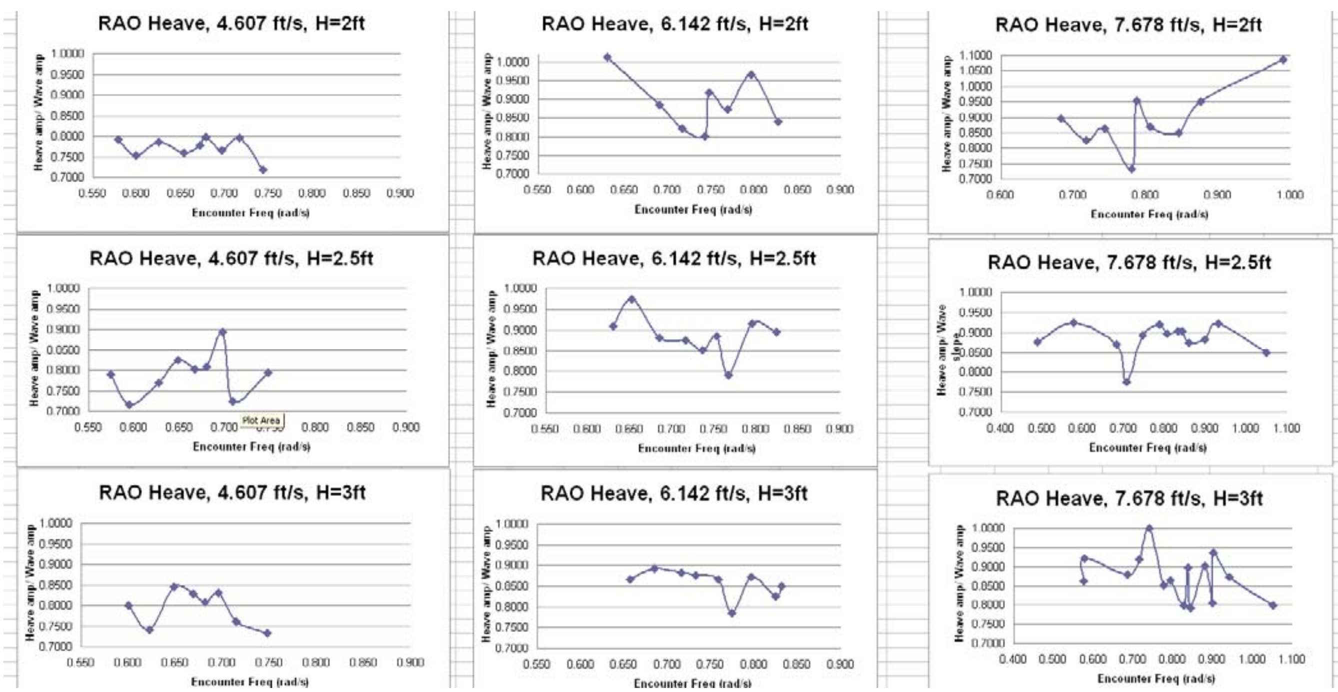

Figure 37: Heave RAO Graph

References

Bishop, R.C., A.L. Silver, D. Tahmasian, S.S. Lee, J.T. Park, and L.A. Snyder, "T-Craft Seabase Seakeeping Model Test Data Report," NSWCCD-50-TR-2009/055, August 2009.

"Catamaran air cushion ship with folding, retractable seals - Patent 7464657." Patent Searching and Inventing Resources. 20 May 2009 <http://www.freepatentsonline.com/7464657.html>.

Dean, Robert G. and Robert A. Dalrymple. Water Waves Mechanics For Engineers and Scientisits. Toh Tuck Link, Singapore: World Scientific Publishing Co. Pte. Ltd, 1991.

Zubaly, Robert B. Applied Naval Architecture. Centreville, Maryland: Cornell Maritime Press, 2000.

"Navy picks companies to build T-Craft model | Military Tech - CNET News." Technology News - CNET News. 20 May 2009 <http://news.cnet.com/8301-13639_3-9854633-42.html>.

Nortrade - Official Norwegian trade portal and export directory. 20 May 2009 <http://www.nortrade.com/graphics//profile_images/b3543-36796387858.jpg>.

Randall, Robert E. Elements of Ocean Engineering. Jersey City, Ney Jersey: The Society of Naval Architects and Marine Engineers, 1997.

Tupper, Eric. Introduction to Naval Arcitecture. Third Edition. Jersey City, New Jersey: The Society of Naval Architects and Marine Engineers, 1996.