# Effects of wind, waves, and current on tow loads generated by 1:7 model and full scale liferafts

Power, J.; Simões Ré, A.



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| Jonathan Power and Antonio Simões Ré | | | | |
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**SUMMARY**

The purpose of this report is to measure the tow force generated by commercially available 16, 42, and 150 person full and 1:7 model scale life rafts in varying environmental conditions. The environmental conditions include varying wave frequencies, wind speeds, and a steady state current. The goal for this project is to use data collected in controlled laboratory conditions to help fill in the knowledge gaps that currently exist in the operation of life rafts in weather conditions. This increase in knowledge would benefit marine operators, the regulatory bodies, the search and rescue planners, the training providers, and the manufactures in developing new designs.

**ADDRESS**

National Research Council
Institute for Ocean Technology
Arctic Avenue, P. O. Box 12093
St. John's, NL   A1B 3T5
Tel.: (709) 772-5185, Fax: (709) 772-2462

National Research Council Canada
Conseil national de recherches Canada

Institute for Ocean Technology
Institut des technologies océaniques

# EFFECTS OF WIND, WAVES, AND CURRENT ON TOW LOADS GENERATED BY 1:7 MODEL AND FULL SCALE LIFERAFTS

TR-2007-24

J. Power and A. Simões Ré

August 2007

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## 1.0 Introduction

Large and small ships travelling across the open ocean can sometimes meet with emergency situations. While many large ships and vessels are designed to withstand extremely hostile weather, they are not invincible to the elements. As a result they can become compromised and the order to abandon ship may need to be given. In order to further increase the chance of survival, ships are equipped with inflatable liferafts that can be deployed by a variety of methods. Even though liferafts are considered an extremely important piece of survival equipment, there currently exists a knowledge gap between regulations and the performance of these life saving appliances in rough weather. Current regulations only require liferafts to be certified for *calm water conditions*, which results in their performance in weather other than calm to be largely unknown.

Current operational standards for most commercially available life rafts have only been done in calm water, under the most ideal conditions. This is a cause for concern as it is quite possible that an emergency situation resulting in abandonment of the ship or could occur in less than ideal conditions. Due to safety concerns for people and equipment, it is not always possible to test full-scale liferafts in these weather conditions to address the knowledge gap that currently exists. Testing for weather conditions in a controlled environment provides two large advantages: 1.) You are able to select and produce/reproduce specific weather conditions (wave height, wind speed, etc.) 2.) The level of safety is greatly increased due to the level of control that is present in laboratory conditions.

The purpose of this report is to present the effects of varying wave frequencies, wind and current speeds on the drag loads for a small, medium, and large liferaft. The rafts selected are commercially available, and had full compliments of 16(small), 42(medium) and 150(large) persons. Also presented are drag results of 1:7 scale models of these rafts. The main goal is to collect data that can be used to fill in the current knowledge gap, which would benefit marine operators, regulatory bodies, search and rescue planers, training providers, and the manufacturers in developing new designs of life rafts.

## 2.0 Project Objectives and Scope

The overall objectivess of this experimental study are to examine the effects of varying wave frequencies, wind, and current speeds on the drag forces of full and model scale life rafts. Listed below are the specific objectives tested for:

1. Examine the effects of varying wave frequencies on drag force of a 16, 42, and 150-person life raft at both full and 1:7 model scale.

2. Examine the effects of varying wind speeds on drag force of a 16, 42, and 150-person life raft at both full and 1:7 model scale.

3. Examine the effect of current speed on drag forces of a 16, 42, and 150-person life raft; both full and 1:7 model scale.

The present series of tests were conducted on commercially available, typical SOLAS approved 16, 42, and 150-person life rafts. Custom fabricated 1:7 models of the full scale life rafts were tested as well. The tests were carried out in uni-directional waves, wind, and current in the Offshore Engineering Basin (OEB) at the Institute for Ocean Technology (IOT).

## 3.0 Test Program and Test Setup

### 3.1 Test Facility

The test program was conducted in the Offshore Engineering Basin (OEB) facility located at the Institute for Ocean Technology (IOT). The OEB is a rectangular tank 75m in length, 32m in width, and 3m deep. On the west and south walls of the OEB are 168 individual, hydraulically actuated wave makers capable of generating regular waves with a maximum height of 0.8m. A bank of 12 wind fans are capable of being mounted in the OEB that can generate wind speeds of up to 12 $m \cdot s^{-1}$ at a distance of 10m from the fans. Current is generated in the OEB by recirculating water. The bow thrusters push water in channels under the basin floor and re-circulate it..

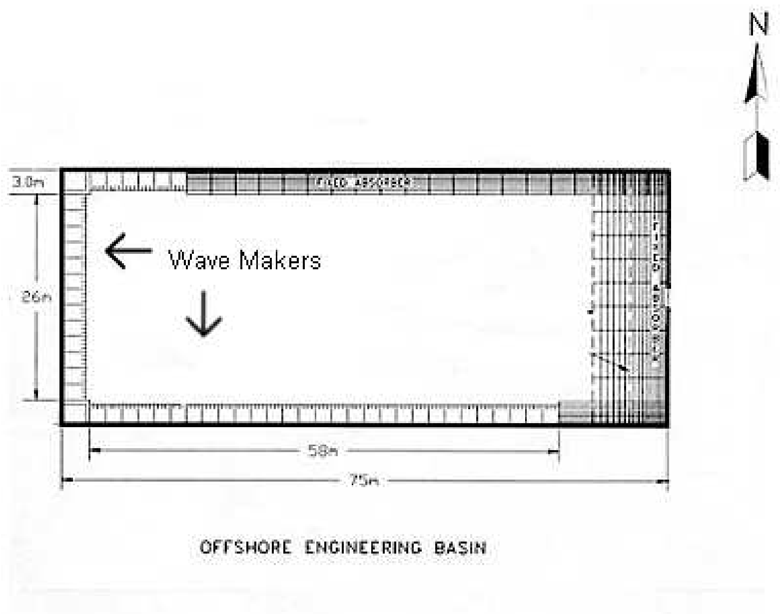


Figure 3.1: Drawing of Institute for Ocean Technology's Offshore Engineering Basin (all distances in meters).

### 3.2 Full Scale Life Rafts

Commercially available SOLAS approved 16, 42, and 150 person life rafts were used. The liferafts were all ballasted to 75% of the total capacity, assuming 75 kg occupants. This resulted in 900 kg of ballast being added to the 16 person raft, 2362 kg to the 42 person raft, and 8437kg to the 150 person life raft. Flexible 200 litre water tanks were filled with fresh water to act as ballast for the life rafts.

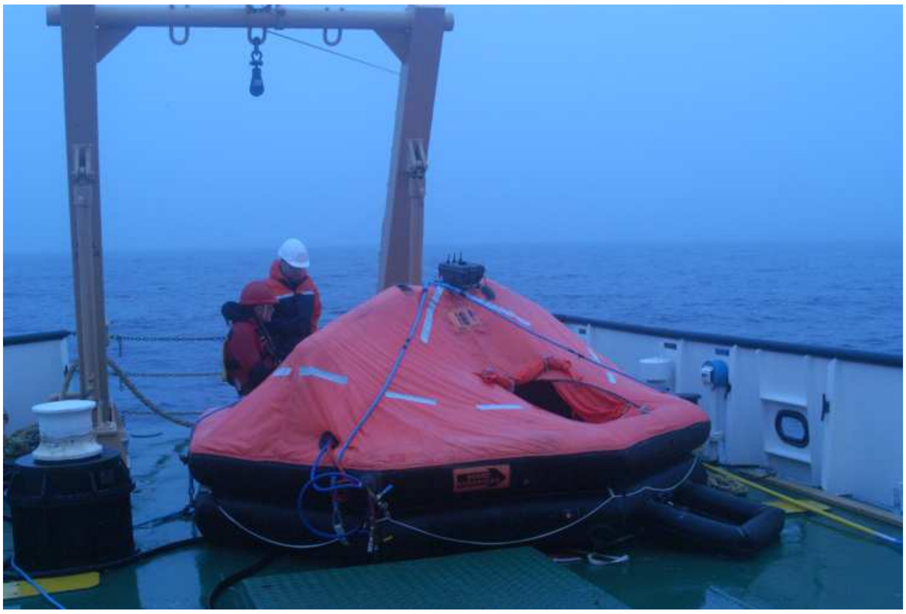

Figure 3.2: 16 person raft.


Figure 3.3: 42 person raft.

Figure 3.4: 150 person raft.

### 3.3 Model Scale Life Rafts

IOT model life rafts IOT 721, IOT 722, and IOT 723 were fabricated to represent a 1:7 scale model of a 16, 42, and 150 person liferafts, respectively. The model life rafts were ballasted with enough weight to scale correctly to their 75% full counterparts. Small lead weights weighing ~142 grams were used to ballast the 16 and 42 person rafts, while in the 150 person raft, ~240g weights were used.

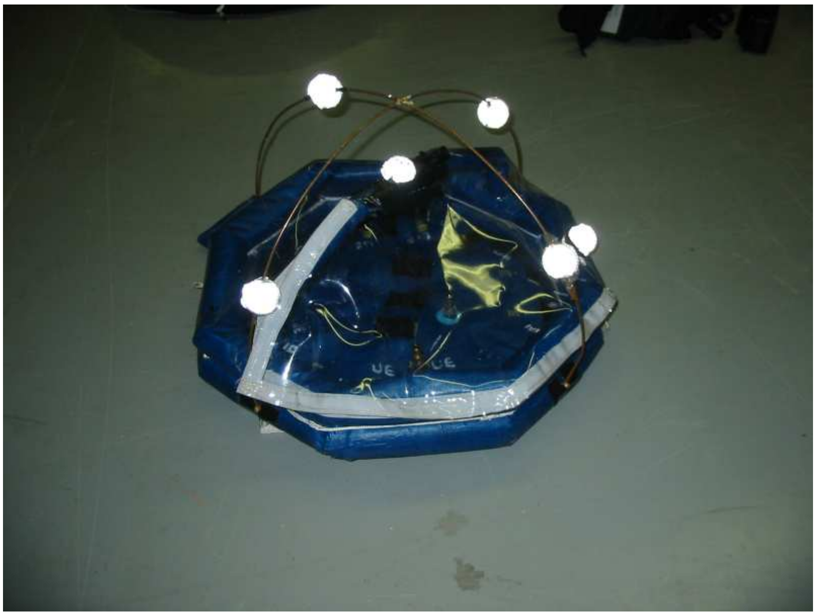

Figure 3.5: Model IOT 721 of a 16 person life raft.

Figure 3.6: Model IOT 722 of a 42 person life raft.

Figure 3.7: Model IOT 723 of a 150 person life raft.

Table 3.1: Cross sectional areas (values are in $m^2$) of the liferafts.

| | 150 Person - Beam | | 150 Person - Head | | 42 Person | | 16 Person | |
|---|---|---|---|---|---|---|---|---|
| | **Full Scale** | **Model Scale** | **Full Scale** | **Model Scale** | **Full Scale** | **Model Scale** | **Full Scale** | **Model Scale** |
| **Above Water** | 28.16 | 0.57 | 10.72 | 0.17 | 4.61 | 0.10 | 2.1 | 0.04 |
| **Below Water** | 2.63 | 0.05 | 0.88 | 0.02 | 0.10 | 0.002 | 1.03 | 0.02 |

## 3.4 Wind

Two banks of six analog controlled fans mounted side-by-side generated wind. The centers of the fans were positioned 1.65m above the surface of the water. Each fan is powered by a DC motor and has a diameter of 530mm. Mounted on the fans are horizontal louvers that allowed the wind flow to be directed upward or downward. The louvers were positioned at an angle of 20º down from the horizontal plane. The fans were controlled by an operator in the main control room of the OEB (the fans could be set to produce wind speeds up over 8 $m \cdot s^{-1}$.)

Figure 3.8: Wind fans mounted in the Offshore Engineering Basin.

## 4.0 Instrumentation

### 4.1 Data Acquisition

A single data acquisition system was used in this test program. All signals were acquired by GDAC (GEDAP (Generalized Experimental Control and Data Acquisition Package) Data Acquisition and Control) client-server acquisition system. The following table shows the list of signals collected during the test program:

Table 4.1: Signal acquisition during the test program.

| Signal | Instrumentation | Sample Rate |
|---|---|---|
| Tow Force | Load Cell | 50 Hz |
| Wave Probe | Capacitance Wave Probe (x2) | 50 Hz |
| Wind Speed | Wind anemometers (x6) | 50 Hz |
| Wind Drive | Volt meter | 50 Hz |
| Current Speed | Current Probe | 50 Hz |

## 5.0 Test Program

The test program was divided into three main components:

1. Measuring the drag loads generated on both the full and model scale life rafts by waves of varying frequencies.
2. Measuring the drag loads generated on both the full and model scale life rafts by varying wind.
3. Measuring the drag loads generated on both the full and model scale life rafts by current.

Listed in the table below are the wave frequencies tested for each full scale raft:

Table 5.1: Wave frequencies used for the rafts.

| **Raft** | **Full Scale** | | **Model Scale** | |
|---|---|---|---|---|
| | **Wave Frequency (Hz)** | **Wave Height (m)** | **Wave Frequency (Hz)** | **Wave Height (m)** |
| 16 | 0.36 | 0.8 | 0.94 | 0.12 |
| | 0.39 | 0.69 | 1.01 | 0.10 |
| | 0.42 | 0.60 | 1.08 | 0.09 |
| | 0.45 | 0.52 | 1.15 | 0.08 |
| | 0.47 | 0.47 | 1.22 | 0.07 |
| | 0.50 | 0.41 | 1.30 | 0.06 |
| 42 | 0.37 | 0.77 | 0.97 | 0.11 |
| | 0.39 | 0.68 | 1.03 | 0.10 |
| | 0.41 | 0.61 | 1.09 | 0.09 |
| | 0.43 | 0.55 | 1.14 | 0.08 |
| | 0.45 | 0.50 | 1.20 | 0.07 |
| 150 Head | 0.37 | 0.78 | 0.97 | 0.11 |
| | 0.38 | 0.73 | 1.00 | 0.10 |
| | 0.39 | 0.68 | 1.03 | 0.10 |
| | 0.40 | 0.64 | 1.06 | 0.09 |
| | 0.41 | 0.61 | 1.10 | 0.09 |
| 150 Beam | 0.37 | 0.77 | 0.97 | 0.11 |
| | 0.39 | 0.68 | 1.03 | 0.10 |
| | 0.41 | 0.61 | 1.09 | 0.09 |
| | 0.43 | 0.55 | 1.14 | 0.08 |
| | 0.45 | 0.50 | 1.20 | 0.07 |

Table 5.2 Wind and current speeds for all life rafts.

| Raft | Wind Speed ($m \cdot s^{-1}$) | Current Speed ($m \cdot s^{-1}$) | |
|---|---|---|---|
| | Full and Model Scale | Full Scale | Model Scale |
| 16 | 5,6,7,8,9,10 | 0.155 | 0.078 |
| 42 | 5,6,7,8,9,10 | 0.114 | 0.072 |
| 150 Head | 5,6,7,8,9,10 | 0.165 | 0.074 |
| 150 Beam | 5,6,7,8,9,10 | 0.127 | 0.082 |

### 5.1 Test Methodology

After the completion of the standard Institute for Ocean Technology wind, wave, and current calibration procedures, the investigation of the performance of the life rafts began.

Testing began with the model scale life rafts. Prior to the liferafts entering the water, they were ballasted to 75% of full compliment and all inflatable chambers were inflated to 10.3 kpa pressure. The raft was connected to a 222N load cell with a line attached to its tow point. A tag line was attached to the aft end of the life raft to prevent the liferaft from drifting forward after the run was completed.

Two wave probes were utilized, located at a fixed position, approximately 12.86m forward of the wind fans to measure upstream waves, and another mounted in line with the model to measure encounter waves. Two arrays of 3 wind anemometers were mounted on the other side of the life raft to measure wind speeds.

The wave tests consisted of 5 different wave frequencies, of 2 minutes in duration each. After each run, there was a 10-15 minute wait period before the next one to allow the tank to settle between runs.

The wind speed test consisted of multiple speeds acquired in a single run. The operator would start at the lowest wind speed and step through the different speeds at 30 second intervals.

A single current speed of $\sim 0.1 \mathrm{m \cdot s^{-1}}$ was used in the program. The OEB operator would set the above speed using the current control equipment. A wait period of 2 hours was used in order to ensure that the current speed was stable and remained constant. The model life rafts were then tested one after the other while the current remained steady in the OEB.

Testing of the full-scale life rafts was done in a similar method as the models. The rafts were evenly ballasted to a weight equivalent to 75% of the maximum passenger capacity (assuming 75kg people) using flexible water tanks filled with fresh water. All tubes in the liferafts were inflated to their blow off pressure of 20.67 kpa. Once the rafts were inflated, they were ballasted and then connected to a towline that attached to a load cell, anchored to the OEB’s west wall. For the 16 and 42 person life rafts, a 11,100 N load cell was used; for the 150-person life raft a 22,200 N one was used.

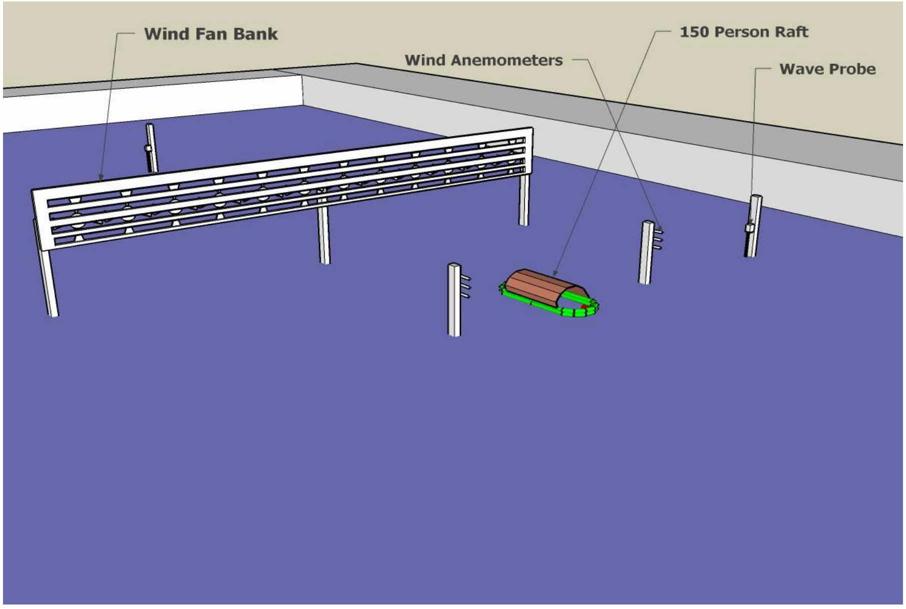


Figure 5.1: OEB setup (150 person model scale life raft pictured).

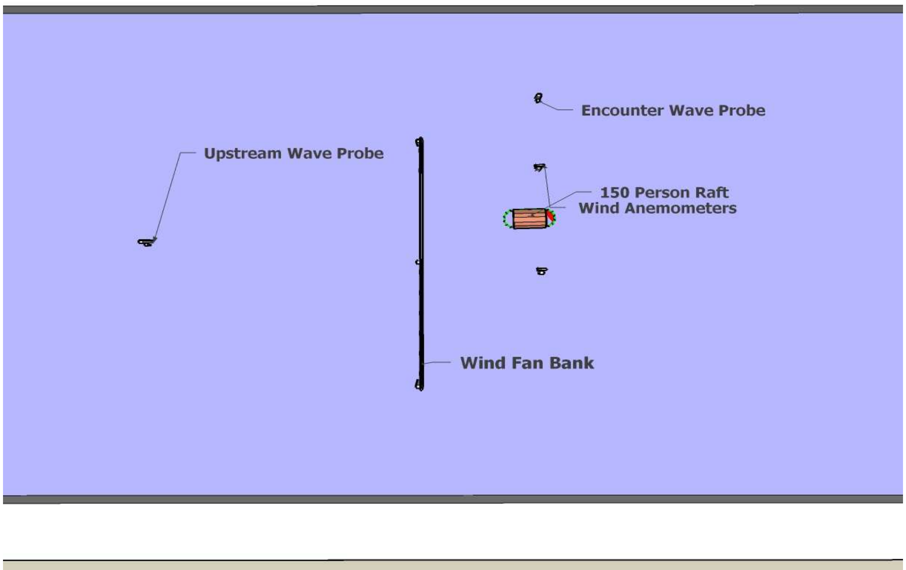


Figure 5.2: Overhead view of OEB setup (150 person model scale life raft pictured)

## 6.0 Results and Discussion

### 6.1 Wave Frequencies

The following figures show the effects of the varying wave frequencies on both the model and full scale life rafts:

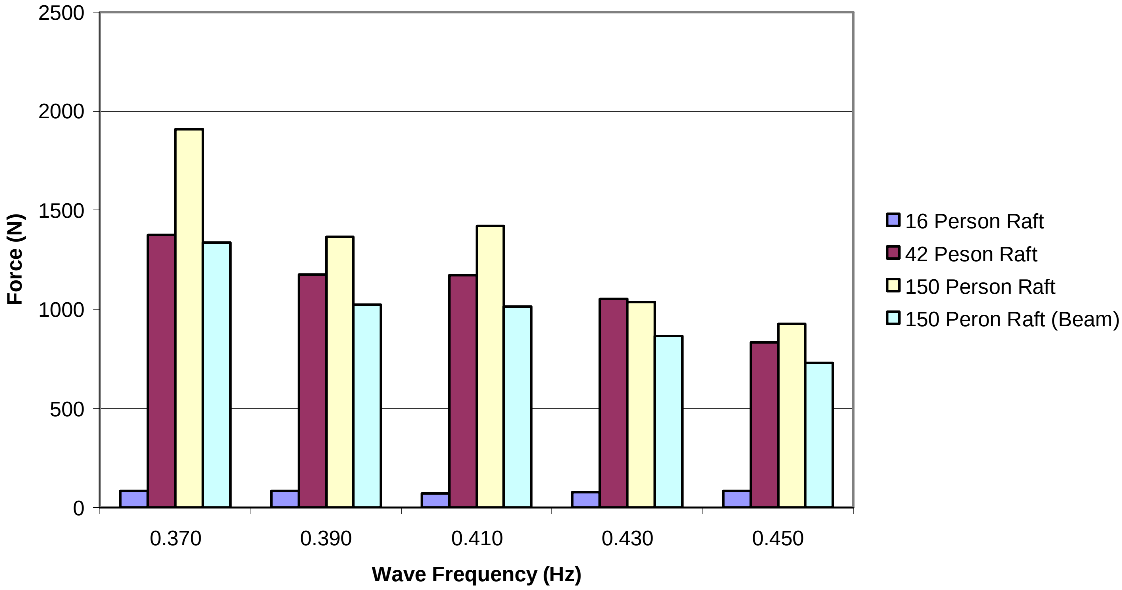


Figure 6.1: Mean tow force plus 2 standard deviations for full scale life rafts across varying wave frequencies.

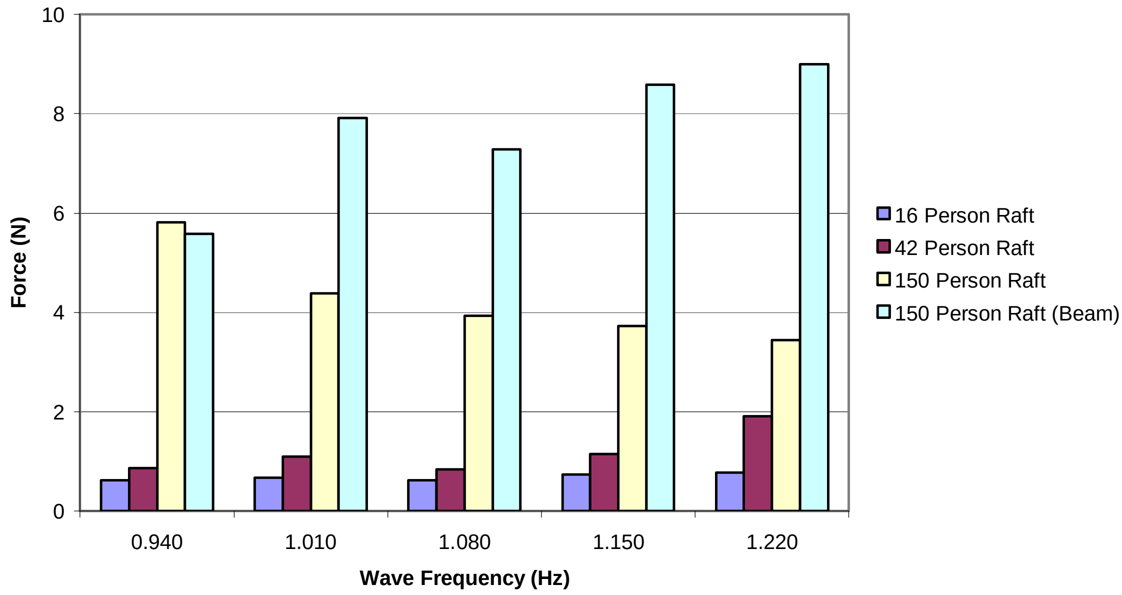


Figure 6.2: Mean tow force plus 2 standard deviations for model scale life rafts across varying wave frequencies

For the full scale life rafts, increasing the wave frequency results in a decreasing drag force. As expected, the 16 person raft generated the lowest drag force and the 150 person raft the greatest. The 16 person raft generated forces of about 83 N at the lowest wave frequency and 68 N of force at the highest. There is a large increase in drag force for the 42 person raft compared to the 16. The 42 person raft generated 1377 N of force at the lowest wave frequency, and 834 N at the highest wave frequency. The full scale 150 person raft generated the greatest tow force values for all the full scale life rafts. At the lowest wave frequency it generated 1909 N of force; at the highest wave frequency it produced only 927 N of force. When the 150 person raft was turned beam on to the wave direction, it resulted in a decrease in tow forces measured. At the lowest wave frequency, it generated 571 N less than when it was head on to the waves. At the highest wave frequency it generated ~ 200 N of force less than when it was turned head on into the wave field.

Similar results are seen with the model scale life rafts compared to their larger counterparts. The model 16 person life raft generated the lowest tow loads for all the rafts, producing only 0.62 N of force at the lowest wave frequency, and 0.78 N of force at the highest one. An opposite trend is seen with the model 42-person raft. The raft generated one of its lowest tow loads, 0.87 N, at the lowest wave frequency and generated its largest tow loads, 1.914 N, at the highest wave frequency. The model 150 person raft follows the same trend as seen with the full scale version. The rafts highest tow loads were generated at the lowest wave frequency, 5.82 N, while a drag force of 3.44 N was measured at the highest wave frequency. When the model scale 150 person raft was turned beam on to the waves, it produces a different trend in tow force values across wave frequencies compared to the full scale version. The lowest drag force was at the lowest wave frequency, 5.58 N, while the greatest drag force was at the highest wave frequency. At the highest wave frequency, the drag force was 9.00 N.

The small differences observed in the tow force values of the model scale life rafts (< 1 N) may be the result of experimental uncertainty, and may not be accurate. The loads reported were for the lower ranges of the load cells, which may not be able to resolve the actual force for such small values. This may possibly explain why the model scale 42 person life raft did not follow the same trend of lower wave frequencies generating higher tow loads as its full scale counterpart did.

### 6.2 Wind

All rafts were tested in varying wind speeds while anchored on the towline and their mean drag recorded. All the wind speeds were tested in the one run, with each individual speed lasting ~ 30 seconds in duration. The results for the full scale rafts are split into two separate graphs since the 150 person raft was tested at a later date than the 16 and 42 person rafts. As a result, the measured wind speeds were of a different value for the 150 as compared to the 16 and 42 person life rafts. Due to low variations in the tow force measured, the tow force for the following graphs is reported with just the mean values.

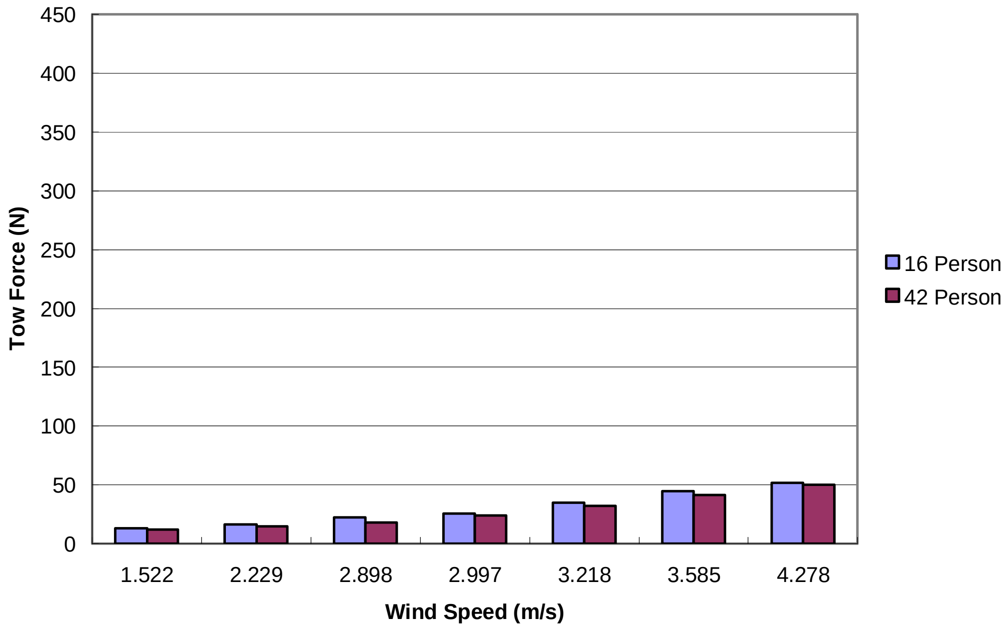


Figure 6.3: Mean tow loads for the full scale 16 and 42 person life rafts across varying wind speeds.

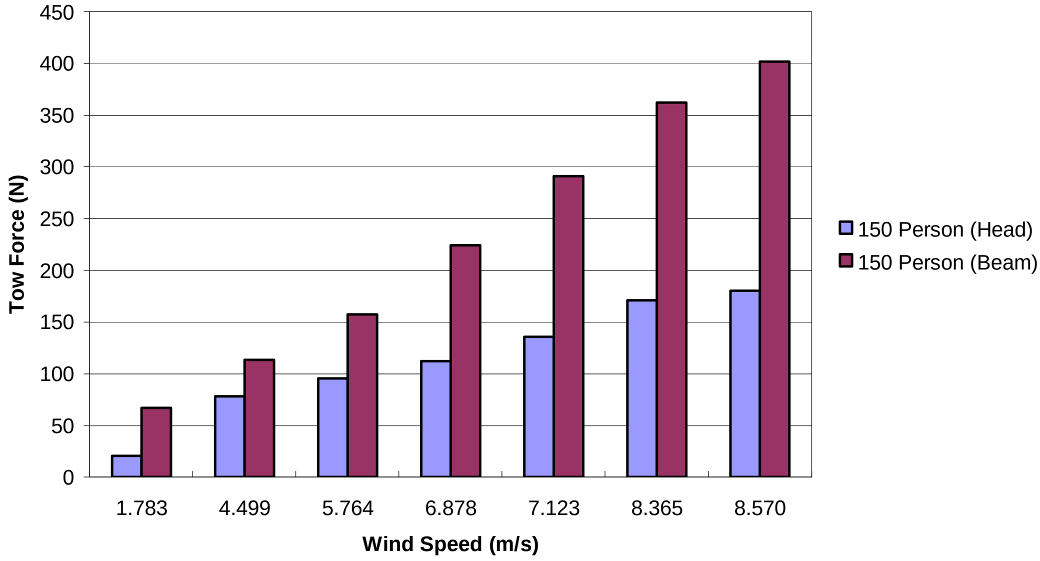


Figure 6.4: Mean tow loads for the full scale 150 person life raft, head and beam on to the wind field, across varying wind speeds

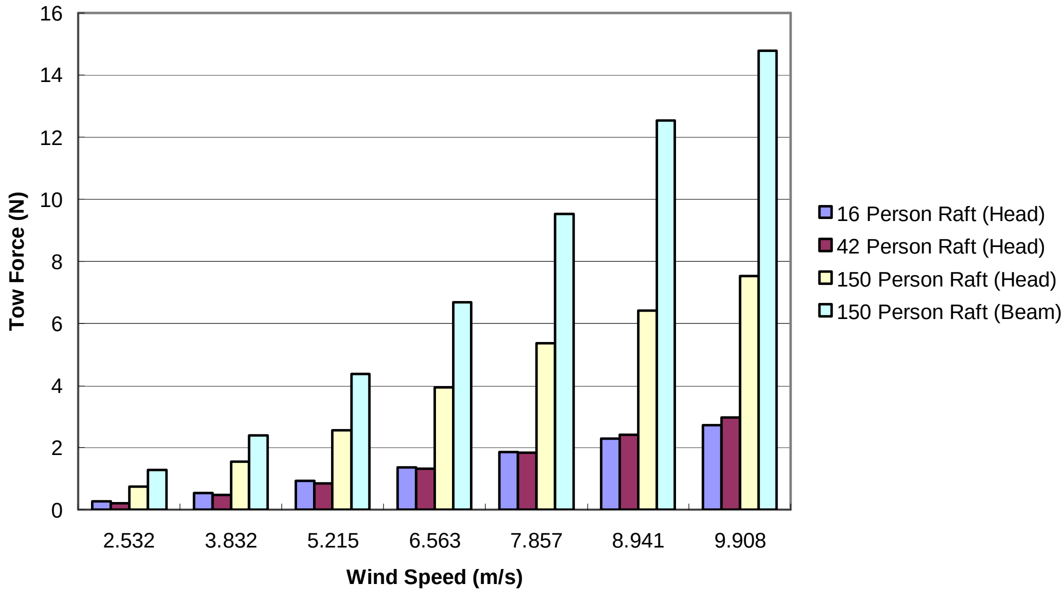


Figure 6.5: Mean tow loads for the model scale rafts across varying wind speeds.

The trend seen for the full scale life rafts is that as the wind speed increase, the measured tow force is greater. Even though the 42 person raft has a greater mass than the 16 person raft, the latter still generated slightly higher tow loads. The 150 person raft generated significantly larger tow loads compared to the other two rafts. This is to be expected since the 150 person raft has a much larger area compared to the previous two rafts. When the 150 person raft is turned beam on to the wind, the tow loads are more than double for some wind speeds compared to the head on condition. When the 150 is turned beam on to the wind field, it exposes the largest cross sectional area of all the rafts, generating the largest forces seen for all the full scale rafts.

The model scale rafts followed the same trend as their full scale versions. As the wind speed increased, the drag loads generated rose as well. A difference seen with the model scale results is that the 42 person raft generates a higher tow load than the 16 at certain wind speeds. This may be the result of the load cell not being able to resolve accurately the loads generated due to the values being at the lower limit of the unit's range (<1 N). For the model 150 person raft, the loads generated follow the same trend as the full scale version, with the beam setup condition producing values almost double the values of the head on configuration.

### 6.3 Current

All rafts, full and model scale, were tested in a single current speed. All model life rafts were tested on after the other due to the simple logistics of swapping liferafts in and out of the test setup. For the full scale life rafts, the current had to be turned off and reactivated for swapping the 16 and 42 person rafts in and out. The current generator was set to produce the highest speed possible in the water. During the course of the test program, the current speed varied when the liferafts were placed in the water. As a result, each of the full scale life rafts drag force is reported relative to the current speed measured at the time. The drag force was sampled for 10 minutes during each run for all the life rafts. The results are shown in the following graphs:

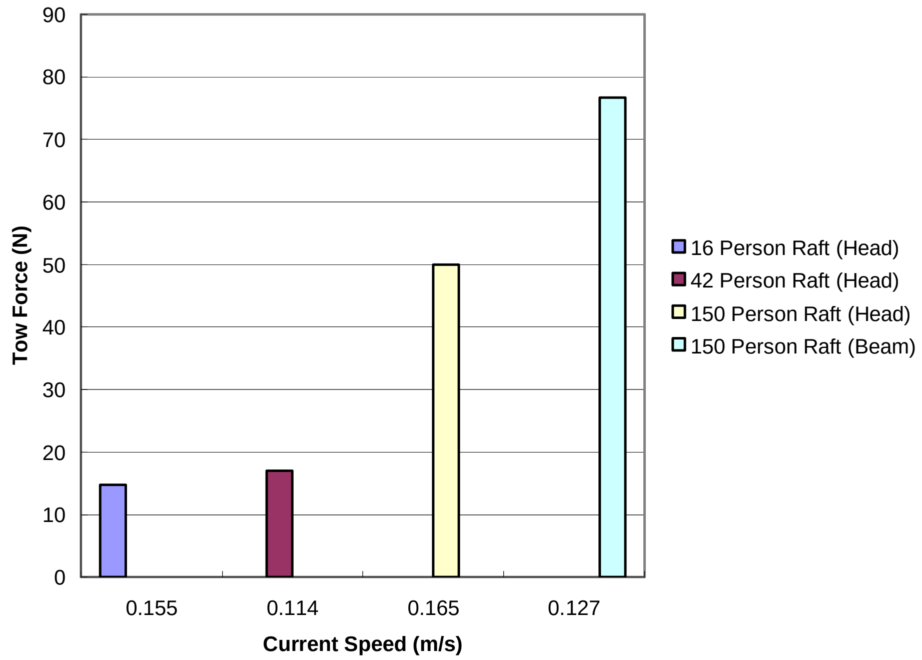


Figure 6.6: Tow force generated by each of the full scale rafts in varying current speeds.

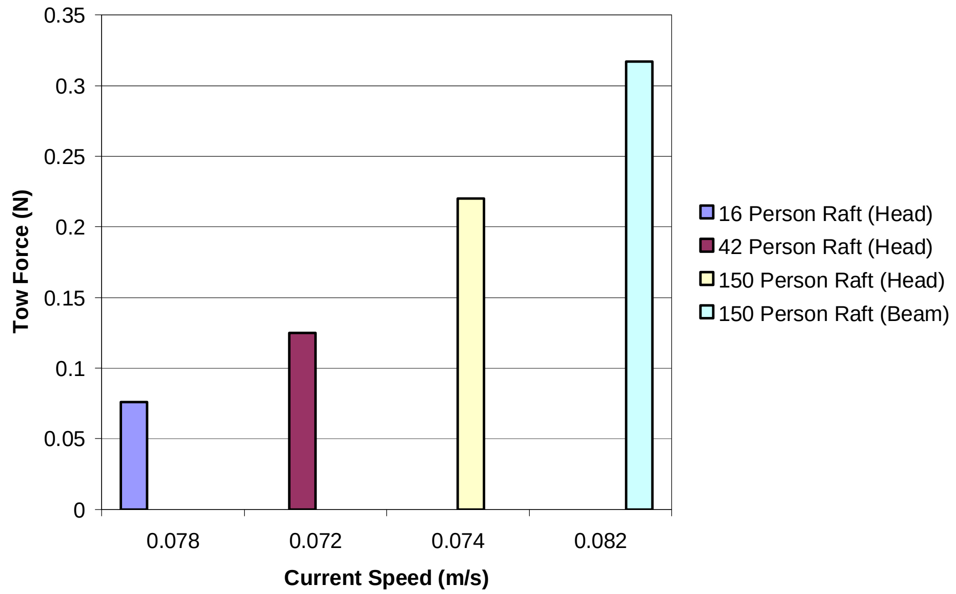


Figure 6.7: Tow force generated by each of the model scale rafts in varying current speeds.

The same trend in tow force generated is seen in both the full scale and model scale life rafts. As the size of the life raft increases, the tow force generated increases as well. The larger drag values are associated with the larger rafts due to their larger cross sectional area below the surface. This effect is most notable with the 150 person life raft, as when the raft is turned beam on to the current, the tow force generated greatly increases, even though the mass of the raft remains the same (both full and model scale).

**7.0 Conclusions**

1. Lower wave frequencies will result in greater drag loads for the rafts. This effect was seen at both model and full scale. There are inconsistent results in the measured tow force with turning the 150 person raft beam on to the waves. In the full scale trials, turning the 150 raft beam on resulted in lower tow loads being measured, while higher loads were seen when the model raft was turned into the same position. This may be the result of the full scale 150 getting into phase with the waves, resulting in a lower tow loads compared to the head on setup. The model scale 150 person may have been out of phase with the wave resulting in higher tow loads.

2. Higher wind speeds resulted in larger drag forces being generated as cross sectional area exposed to the wind field increase. An example of this is when the 150 person raft is turned beam on to the wind field, resulting in a significantly higher tow load compared to the head on setup.

3. Faster current speeds resulted in higher tow loads for all the rafts, both at model and full scale. As the rafts increase in size so did the cross sectional area and thus the force generated. This effect is most notable when the 150 person raft is turned beam on to the current, resulting in a much higher tow load compared to its head on setup.

## 8.0 Acknowledgements

We would like to express our gratitude to the New Search and Rescue Initiative Fund for their financial support. We would also like to thank the staff of the OEB at IOT for their knowledgeable help and assistance during these experimental trials. Finally we want to extend our thanks to all the individuals in the electronics, software engineering group and fabrication for their support through the duration of the trials.