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7th Canadian Marine Hydromechanics and Structures Conference [Proceedings], 2005

Practical Considerations Related to Carrying Out Seakeeping Trials on Small Fishing Vessels

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ABSTRACT

Over the last two years, the Institute for Ocean Technology (IOT) has participated in seakeeping trials on four small fishing vessels ranging in length from 10.64 m (34'11") to 19.80 m (64'11") as part of an effort to acquire full scale data to validate physical modeling methodology as well as numerical simulation tools under development. The project is just a small component of a larger initiative to understand and mitigate the health and safety risks associated with employment in a marine environment. Eventually, tools will be developed and validated to evaluate the number of Motion Induced Interrupts (MIIs), induced by sudden ship motions, and their impact on crew accidents to develop criteria to reduce MIIs. This paper describes the challenges associated with acquiring full scale seakeeping data on small vessels in the harsh North Atlantic environment. Typical results will be provided along with a description of the instrumentation suite, data acquisition system, test program and data analysis procedure used with emphasis on some of the factors that can degrade the correlation between ship and model scale data.

1. BACKGROUND

Fishing is the most dangerous occupation in Newfoundland and Labrador and is increasingly so: over the past ten years, the rates of reported injuries and fatalities have nearly doubled. These trends have the effect of reducing the sustainability of the fishery, increasing health care and compensation costs, and straining the available Search & Rescue resources. Addressing these issues has been hampered by a lack of research required to understand the factors that influence seafood harvester occupational health and safety. The Fishing Vessel Safety Project is just a small component of a broad multi-disciplinary, inter-departmental and inter-sectorial research effort, initiated by SafetyNet – a Community Research Alliance on Health and Safety in Marine and Coastal Work, designed to reduce the accident rate on fishing vessels. Since there is a strong correlation between the number of MIIs that occur on a vessel and the accident rate [1], a dedicated research project was developed to investigate this issue on fishing vessels. The outline of the project consists of carrying out a series of seakeeping trials on a number of typical Newfoundland based fishing vessels operating in the Canadian Coast Guard Auxiliary (CCGA) fleet and using the acquired data to validate numerical prediction tools under development at Memorial University of Newfoundland (MUN) as well as improving physical modeling procedures for small vessels at IOT.

It was desirable to acquire full scale data for typical conditions encountered during fishing operations. The four selected fishing vessels, ranging in length from 10.64 m to 19.80 m, were loaded to nominally half load condition and the target environmental conditions would be rough enough to excite significant motions but, in the opinion of the individual Captains, would not be too rough to suspend fishing operations. The target sea conditions would typically range from sea state 2 to 3. All trials were carried out nominally 10 nm east of St. John's in the fall of the year and are described in detail in [2 to 5]. The project plan involves fabricating and testing three of the four fishing vessels in IOT's Offshore Engineering Basin (OEB). Researchers at MUN plan to use the acquired full scale data to validate MOTSIM, a non-linear time domain code described in [6] that simulates six degrees of freedom motion and has been modified to output MIIs.

2. DESCRIPTION OF THE FISHING VESSELS

A brief description of the four subject fishing vessels including nominal principal particulars is provided as follows:

CCGA Atlantic Swell (Fig. 1): Length Overall = 10.64 m, Breadth = 4.27 m, Draft = 1.52 m, Displacement = 16.87 t. The 'Atlantic Swell' is a fiberglass round bilge, single screw, single flat plate rudder with a large centerline skeg and no dedicated anti-roll device. Built by King's Boat Building, St. Jones Within, NL 2001.

Figure 1: CCGA Atlantic Swell

CCGA Nautical Twilight (Fig. 2): Length Overall = 13.69 m, Breadth = 7.01 m, Draft = 3.05 m, Displacement = 78 t. The 'Nautical Twilight' is a fiberglass round bilge, single screw, single flat plate rudder with a large centerline skeg and no dedicated anti-roll device. Built by Jackson's Boatyard, Whiteway, NL 2003.

Figure 2: CCGA Nautical Twilight

CCGA Miss Jacqueline IV (Fig. 3): Length Overall = 19.80 m, Breadth = 7.32 m, Draft = 3.05 m, Displacement = 205 t. The 'Miss Jacqueline IV' is a steel hulled double hard chine, single screw, single flat plate rudder with a large centerline skeg, large bulbous bow and paravane anti-roll device. Built by Bay D'Espoir Enterprises Ltd., St. Albans, NL 1989.

Figure 3: CCGA Miss Jacqueline IV

CCGA Roberts Sisters II (Fig. 4): Length Overall – 19.79 m, Breadth = 7.01 m, Draft = 3.81 m, Displacement = 227.5 t. The 'Roberts Sisters II' is a fiberglass round bilge, single screw (propeller fitted in fixed nozzle), single flat plate rudder with a large centerline skeg and a passive anti-roll tank fitted just aft of the bridge. Built by Universal Marine Ltd., Triton, NL 2001.

Figure 4: CCGA Roberts Sisters II

All the fishing vessels investigated primarily fish for snow crab but have the ability to fish for other species such as codfish, turbot and capelin when these stocks are available. Charter of each vessel was arranged by the Canadian Coast Guard (CCG) at a prescribed rate defined as a function of vessel length for vessels in the Auxiliary fleet. Funding was available for nominally nine days per ship.

3. Description of Instrumentation

Due to the fact that multiple trials were planned where essentially the same parameters would be acquired, a dedicated trials instrumentation suite was designed by IOT staff that could be set up quickly.

Ship's Motions: A MotionPak measuring three orthogonal linear accelerations and three orthogonal angular rates was installed as close to the ship's center of gravity as feasible – normally fitted to the fish hold deck head. From these six parameters, software was available to compute the following 18 channels – roll/pitch/yaw angle/rate/acceleration and surge/sway/heave displacement/velocity/acceleration. These motions could be computed in either a body or earth co-ordinate system, and moved to any location on the rigid platform. In addition to the MotionPak, three linear accelerometers in an orthogonal tri-axial mount were fitted on the Bridge measuring linear accelerations in a body co-ordinate system. The rate sensors were calibrated using manufacturer's data sheets while the accelerometers were physically calibrated by placing the sensors on a set of precision wedges and computing the acceleration relative to the acceleration due to gravity.

Ship Position/Course/Speed: A Global Positioning System (GPS) was installed to acquire ship position, speed over ground (SOG) and course over ground (COG). A differential correction signal broadcast via VHF radio from Cape Race, NL by the CCG was used to provide improved GPS accuracy.

Rudder Angle: Rudder angle was measured by winding the cable, with wax string extension, from a 10 inch yo-yo potentiometer linear displacement transducer around a groove cut in a circular Plexiglas plate clamped to the top of the rudder stock. On a larger ship, it would be a requirement to have a surveyed rudder angle template fitted adjacent to the rudder stock in the tiller flat. This template is what would normally be used by IOT to calibrate trials rudder angle measurement instrumentation. This convenience was unavailable on all the fishing vessels investigated and thus it was necessary to calibrate rudder angle relative to a computer drawn protractor glued to the top of the circular plate. Amidships rudder angle was determined relative to the Bridge rudder indicator.

Propeller Shaft Speed: Shaft speed was measured using an optical sensor acting on a piece of reflective tape on the shaft. The pulse train from the optical pickup was fed to an IOT designed and built frequency-to-voltage circuit that converts the digital pulse train to a linear DC voltage proportional to shaft RPM. The RPM was calibrated relative to the output from a laser tachometer acting on the reflective tape.

Wind Speed/Direction: Larger ships are fitted with the instrumentation to measure wind speed and direction however none of the fishing vessels investigated were so equipped. IOT procured a modest directional anemometer that was clamped to an aluminum mast, which in turn was attached to a convenient stanchion on the deck above the Bridge. Relative wind speed and direction were manually recorded each run once the ship achieved a steady state course and direction.

Sea Water Temperature/Density: To determine whether there was any large variation in water density between St. John's harbour where the ship's draft is recorded and the trials area, a portable battery operated hand-held salinity, conductivity and temperature meter was used to assess ambient water density.

Wave Height/Direction: Since some of the fishing vessels scheduled for trials were not equipped with davits capable of launching/recovering a large ocean wave buoy, a small (0.75 m diameter, 15.7 kg) wave buoy manufactured by Neptune Sciences, Inc. of Slidell, LA was procured. This buoy was designed for the U.S. military for short term deployment in shallow water to provide sea condition information in support of an amphibious landing. MUN Oceanography staff designed a mooring for a 165 m water depth however poor wave direction and questionable wave height data was acquired probably due to the negative influence of the relatively long mooring on this lightweight buoy. When the Neptune buoy data proved questionable, a 0.9 m diameter, 212 kg directional wave buoy manufactured by Datawell bv (Netherlands) and leased from Oceans Ltd. of St. John's was launched/recovered by the M/V Louis M. Lauzier – a training vessel operated by the Marine Institute of Memorial University. Wave information from the Datawell buoy was transmitted to a shore station however and thus the data from this buoy was not available to the trials team during the trial.

IOT investigated the potential of procuring WaMos II wave monitoring instrumentation from Sea-Image Communications Ltd. of Victoria, B.C. This device is interfaced with a standard marine X-band navigation radar and processes the radar image to derive wave height and direction by analyzing the spatial and temporal changes of the radar backscatter from the sea surface. The WaMos system has the advantage of avoiding the inconvenience and risks associated with launching/recovering a wave buoy from a small vessel in a heavy sea however a minimum 244 cm long radar scanner is recommended combined with a minimum of 7.5 to 8 m elevation above the sea surface – requirements that precluded its use on small fishing vessels.

Data Acquisition System (Fig. 5): A dedicated data acquisition software package [7] was written that could accommodate both analog data from the shipboard sensors acquired at a sampling rate of 50 Hz in parallel with 1 Hz update digital data from the GPS. Two ruggedized notebook computers were used - one to acquire and store the data while the other was used to carry out online verification at the end of each run. The computers and signal conditioning hardware were fastened to a plywood board clamped to the mess table.

Figure 5: Data Acquisition System

4. TRIALS PROGRAM

The trials program was the same for all the vessels:

- Instrumentation and data acquisition system installed with required cabling.
- Vessel loaded to nominally half load displacement condition.
- Once the vessel was loaded and all instrumentation installed, an inclining experiment was carried out by a private contractor to determine the static stability attributes.
- A 10 minute zero forward speed run was carried out in the middle of the harbour to estimate the roll and pitch natural frequency.

Once the vessel was outfit with trials equipment and loaded, the trials were carried out in one long (12 to 14 hour) day when appropriate environmental conditions prevailed. The test program was executed as follows:

- At the dock: draft was recorded before and after the trial. The water density was measured at the dock before and after the trial – and several times at the trials site.
- Transit from St. John's 10 nm to the trials site – transit time approximately 1.5 hours.
- The Neptune wave buoy was deployed. The dominant wave height and direction were determined after a 25 minute drift run.
- A set of five seakeeping runs were carried out (head, following, bow, beam, quartering) (Fig. 6) at low speed adhering to a pattern as recommended in [8] - followed by a second zero speed drift run.
- Return to the wave buoy to download wave data. A second set of five runs was carried out at high speed.
- The Neptune wave buoy was recovered and transit back to St. John's (1.5 hours).

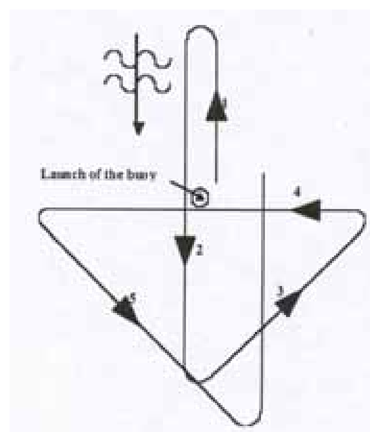

Figure 6: Seakeeping Run Pattern

Low speed was defined as trawl speed (1 – 2 knots), however the only way to maintain a constant heading at this low speed would involve actually deploying a trawl. The option of deploying a trawl was rejected, as this would complicate the trial logistics as well as the numerical and physical model prediction. Thus low speed would generally be 3 to 4 knots – the lowest speed that each vessel was capable of maintaining heading in a seaway. High speed was defined as normal cruise speed – normally 7 – 8 knots. For vessels fitted with anti-roll devices, an additional three runs were carried out in bow, beam and quartering seas at low speed with the anti-roll devices deployed.

Online data analysis at sea consisted of plotting all channels in the time domain after each run and computing/reviewing the basic statistics. After the trial, the basic statistics were computed/compiled for motions at the vessel CG as well as the helmsman's position. As a verification of the MotionPak data, the orthogonal accelerations were computed in the body co-ordinate system and moved to the location of the tri-axial accelerometer mount for comparison. Example standard deviation roll angle results are provided in Table 1 for the CCGA Roberts Sisters II at 4 knots with and without the Anti-Roll Tank (ART) operational.

	Roll Angle (deg.) – No ART	Roll Angle (deg.) – With ART
Bow	4.039	2.089
Beam	4.696	3.028
Quartering	4.104	2.747

Table 1: CCGA Roberts Sisters II Roll Results

5. TRIALS COMPLICATING FACTORS

Although carrying out seakeeping trials on any ship in the North Atlantic is never a risk free exercise, the additional complicating factors that IOT encountered when acquiring quality data on small fishing vessels are described in detail as follows:

Ship Hull Geometry Information: An accurate hull geometry description is required to both fabricate a physical model and prepare the input file for a numerical model. Accessing the hull geometry of a large vessel from the ship owner, operator or designer is not generally a problem. The geometry of the subject vessel is usually available in some standard electronic format or at least described by a good set of paper drawings. For small fishing vessels, the situation is different. The vessels are built by small independent boat yards to the owner's specifications and the quality of the hull geometry information available varies widely.

For the 'Atlantic Swell', there was simply no hull geometry information available whatsoever. The fiberglass hull had been formed from a mold that had been in use at a local boat yard for many years and neither the vessel's owner nor the builder could supply adequate lines. It proved necessary to hire a private contractor to manually measure the hull offsets of the vessel while on dock, and prepare a set of faired lines in a suitable electronic format. The rather crude set of lines derived in this manner required considerable additional fairing by IOT design office staff and there was a significant difference between the trial displacement estimated during the inclining experiment and the value computed from the hydrostatics implying a poor quality geometry file.

As for the other vessels investigated, the 'Nautical Twilight' had a good geometry file in electronic format, the 'Miss Jacqueline IV' had an adequate set of paper drawings with the exception of an electronic format file for the bulbous bow – a recent addition to the hull. There was no information available for the 'Roberts Sisters II' as well however there was an electronic file available for a vessel assumed to be a sister ship.

Ship General Arrangement: There was a desire to measure the motions at the vessel's nominal center of gravity (CG). The MotionPak was fitted in the general vicinity of the CG however the motions would normally have to be moved, using dedicated software, from the location of the instrumentation to the actual CG as determined during the inclining experiment. Without a General Arrangement (GA) drawing for all decks as well as profile, the position of the MotionPak relative to the CG could not be determined with accuracy.

There was no GA available for the 'Atlantic Swell' however this small vessel had an uncomplicated layout so the relative position of the MotionPak could simply be physically measured. Adequate GA drawings were available for both the 'Nautical Twilight' and the 'Miss Jacqueline IV' however the owner of the 'Roberts Sisters II' took delivery of a fiberglass hull and finished the internal layout himself - thus no detailed GA was available. For the 'Roberts Sisters II', IOT had to rely on crude sketches in the vessel's Stability Booklet to estimate the position of the MotionPak relative to the CG.

Crew Training: On a large vessel, there are fairly stringent requirements for crew training and qualifications. Engineers and deck officers must have standardized training and Transport Canada certification. Fishers are self-employed businessmen with crewmen hired on to assist. Although there are certain minimum qualifications required by fishers, there is a wide range of training that to some extent is correlated with vessel size. There appears to be two distinct groups of personnel now operating Newfoundland based fishing vessels:

1) Generally older individuals with little formal education who learned fishing practice from other fishers - often family members.
2) Recently, a younger post-secondary educated fisher is becoming prevalent. This

better educated group is computer/internet literate and much more willing to embrace modern technology if it can be demonstrated that the new technology will lead to improved productivity for their seafood harvesting assets.

Thus there is often a range of electronics technology on the Bridge and lately, fishers have become much more amenable to including propeller nozzles, bulbous bows, passive anti-roll tanks etc. on their vessels. There is some question as to whether the fishers have a full appreciation of the implications of including these devices on their ships. Recent accidents have, in particular, raised concerns regarding the design and crew training related to the safe operation of anti-roll tanks [9].

Fishing Vessel Design Trends: Since there are regulatory limits on fishing vessel length and, with the demise of such important economic species as the Newfoundland cod stocks, fishers are now compelled to travel long distances offshore to harvest crab and shrimp. To improve the overall economic viability of their fishing enterprise, new vessels are getting wider and higher to the point where there are serious questions regarding both the loaded static and dynamic stability of the ships. The market demand for fresh seafood is also imposing design changes and the traditional flake ice stored in fish holds is being replaced on the larger vessels by refrigerated salt water live product tanks. These design issues must be noted and taken into consideration during a seakeeping trial planning.

Intact Trim and Stability Booklet: Key information regarding the static stability of a vessel is included in a vessel's 'Intact Trim and Stability Booklet' – a document that must be reviewed and approved by Transport Canada. The information included in this document is also important for planning a seakeeping trial. During the IOT sea trials, both the 'Miss Jacqueline IV' and 'Nautical Twilight' were operating with draft Intact Trim and Stability Booklets which may have contained errors or omissions.

Loading the Vessels: A fishing vessel is essentially a cargo ship that loads at sea. To meet the goals of the seakeeping trials, there was a desire to load the vessels simulating partial completion of a fishing trip. Although the vessels have a finite fish hold capacity, in terms of volume, the species loaded can result in very different displacement and stability properties. A full load of cod is much heavier than a full load of crab – for example. A normal cargo ship has significant ballast tank capacity that, when these tanks are pressed up, can be used to represent a partially loaded ship. Fishing vessels do not have large ballast tanks and thus different strategies were used to load the vessels.

For the 'Atlantic Swell', the smallest vessel investigated, the most convenient method to increase the displacement was to fill eight water bags, each with a 200 l capacity, and secure these bags in the fish hold. The total weight added was approximately 1,590 kg or roughly 30% of a crab load. At the end of the trial, the bags were simply drained. The 'Nautical Twilight' was loaded with 14 t of flake ice in the fish hold while both the 'Miss Jacqueline IV' and 'Roberts Sisters II' had refrigerated salt water live product tanks that could be pressed up.

At the beginning of each trial, the fuel tanks were pressed up and an effort was made eliminate all free surface although some of the vessels were fitted with small tanks with no level indicators to determine their status.

Draft Determination: Determining the draft of a large vessel is not generally an issue as draft marks are clearly visible. There were no draft marks on the 'Atlantic Swell' and the draft marks on the stern of the 'Nautical Twilight' were covered with an aluminum wear plate to protect the fiberglass hull from damage during trawling operations. In these situations, it proved necessary to measure the freeboard and try to determine the draft from the ship profile drawings.

Lifesaving Issue: Extra lifesaving capacity to accommodate a few sea trials personnel is not a problem on most ships. For the small 'Atlantic Swell' however, the vessel's lifesaving capability was augmented with a four person inflatable life raft and floater suits on loan from the CCG. In addition, due to the perception that carrying out rough weather sea trials on small fishing vessels involved an elevated level of risk, all IOT trials team members were required to take a three day CCG approved Marine Emergency Duty (MED) course.

Electrical Power: It is standard IOT practice to protect IOT instrumentation and data acquisition computers from power glitches by filtering the shipboard power through an uninterruptible power supply (UPS). The 'Atlantic Swell' had only DC power available, however, and thus it was necessary for IOT to fit a propane powered 4.8 kW portable generator in addition to a UPS. Some problems were experienced with a generator not designed to operate in a marine environment and eventually a 6 kW generator was added as a backup.

Autopilot: An autopilot with a specified yaw angle and yaw rate gain values are used to control the heading angle of both a numerical and physical model. Heading input information to the autopilot of a large ship is generally provided by an electro-mechanical gyro. On fishing vessels, the most common autopilot uses a flux gate compass for heading angle input. Both the 'Nautical Twilight' and the 'Roberts Sisters II' had flux gate compass based autopilots. The owner of the 'Miss Jacqueline IV' recently installed a gyro to control the autopilot since it was felt that the superior heading angle control provided by the gyro would save fuel and reduce operating costs. When an autopilot is installed on a ship, it is standard practice to tune the autopilot by adjusting set screws controlling the gain attributes. Every ship has different performance characteristics however the gain values themselves are unknown. The methodology of emulating the performance of an autopilot controlled by a flux gate compass or a gyro in a physical or numerical model presents some interesting challenges since accurately representing the heading control will result in more accurate motion predictions. For future seakeeping trials, IOT is considering carrying out specific calm water manoeuvres and deriving a technique to estimate the autopilot gain factors.

The 'Atlantic Swell' represented a totally different problem as the vessel was not fitted with any autopilot and the trial was carried out on manual steering control. Here the skill and experience of the helmsman becomes a variable in the experiment virtually impossible to duplicate in either a physical or numerical model. The helmsman of the 'Atlantic Swell' appeared to intuitively control the vessel heading in an effort to efficiently negotiate the incident waves rather than maintain a desired course. This control strategy resulted in standard deviations in heading angle in excess of 20 degrees at low speed and from 15 to 20 degrees at the higher speed with subsequent significant impact on the ship motions.

<u>Wave Environment:</u> Since there was a desire to complete each sea trial within one day, this limited the trials area to about 10 nm off St. John's. Although the bottom is fairly level in this area with a depth of some 165 m, the proximity to land and the constantly changing wind speed/direction results in a confused multi-directional sea state. The ship roll period ranged from 3.22 s for the 'Atlantic Swell' to 7.94 s for the 'Miss Jacqueline IV' – thus the high frequency wave energy had the greatest impact on the motions of these small vessels. In a head sea, for example, high frequency secondary waves acting oblique to the dominant wave direction could stimulate significant lateral motions.

Problems were experienced with the small Neptune wave buoy. This is the instrument IOT was depending on to define dominant sea direction to select the appropriate heading angle with respect to the incident waves. Due to the negative influence of the mooring on this light weight buoy, there were often errors in the acquired data resulting in an incorrect operational definition of what constituted a head sea. The buoy failed half way through the 'Atlantic Swell' sea trial prior to IOT contracting for the deployment of the Datawell buoy. Thus the wave data for the high speed runs for this trial were an extrapolation of wave height and direction acquired during the morning. The wave buoy failed entirely for the first 'Nautical Twilight' trial [10] and this trial had to be repeated [4].

The IOT standard procedure under development for seakeeping trials stipulates the initial measurement of the wave height and direction to define the dominant wave direction. The first forward speed run (Head Sea) would be carried out opposite the defined dominant wave direction. For the 2004 'Nautical Twilight' trial, the measured wave spectrum had two well defined peaks: 1) a low frequency swell with a peak period of 12 s - the legacy of a severe storm from due north that had lasted several days, and 2) a 5.8 s period rising wind generated wave from almost due south (160 degrees TRUE). There was far more energy associated with the 12 s peak than the 5.8 s peak and thus, using the IOT preliminary seakeeping standard, a Head Sea would be defined as sailing towards the north. With a measured natural roll period of 3.9 s however, the low frequency swell would stimulate little motion other than some low frequency heave whereas the high frequency wind generated wave would stimulate significant six degrees of freedom motion. Thus in future, IOT will study the wave spectrum carefully in relation to the natural frequency of the subject ship prior to defining the dominant wave direction.

<u>Trial Schedule:</u> A sea trials date can be established weeks in advance for most ships. For the fishing vessel seakeeping trials however, although they were generally planned for the fall of the year, it was necessary to work around the fishing schedule of the various vessels – a schedule that could change on very short notice. For example, the outfit of the 'Nautical Twilight' was scheduled to commence Monday October 4th, 2004 however additional shrimp quota was allocated to the Newfoundland fleet the weekend of October 2nd and IOT learned that the vessel was over 100 nm offshore on the 4th. This situation played havoc with the trial logistics but the

disruption was mitigated by the fact that all the trials were to be executed from St. John's.

6. Model Correlation Issues

The only physical model test program completed to date was carried out on a 1:4.697 scale model of the 'Atlantic Swell' in the IOT OEB January/February 2005 [11]. The correlation between full scale and model scale results can only be described as very poor – more than 100% difference in some cases. Four primary sources of error are suspected of accounting for the most of the discrepancy:

1) The poor ship geometry information and stability information available;
2) The lack of an autopilot and resulting poor match between model and full scale steering quality;
3) Difficulty emulating the confused multi-directional seas in a model basin – especially the high frequency components responsible for the motions for this size of ship. The roll natural period for the model was only ~ 1.5 s and generating much energy in this frequency range presented a challenge for the OEB wavemakers.
4) The very poor quality of the full scale wave data and lack of measured wave data for the high speed runs.

Model experiments are planned on the 'Roberts Sisters II' and the 'Miss Jacqueline IV' over the next year or so and, with a more accurate ship geometry file, higher ship motion natural periods and better wave information from the Datawell buoy available for these vessels, an improved correlation with full scale data is anticipated.

Acknowledgements

The authors would like to thank all the crews of the participating fishing vessels for their enthusiastic and professional support during the sea trials, Mr. Jack Foley, MUN Dept. of Physics and Physical Oceanography and Mr. Reg Fitzgerald of Oceans Ltd. for their wave buoy support, the crew of the M.V Louis M. Lauzier for their assistance in deploying/recovering the Datawell wave buoy, Oceanic Consulting Corp. for transport support, the Canadian Coast Guard for the loan of life saving equipment, the Offshore Survival & Safety Center for IOT staff Marine Emergency Duty training and IOT technical staff for their efforts throughout the planning and execution of the sea trials. Funding support from the Search & Rescue New Initiatives Fund (SAR/NIF) and the Canadian Institutes of Health and Research (CIHR) is gratefully acknowledged.

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