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Molyneux, W. D.; Cumming, D.

National Research Council Canada
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W.D. Molyneux and D. Cumming

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AUTHOR(S)

W.D. Molyneux and D. Cumming

CORPORATE AUTHOR(S)/PERFORMING AGENCY(S)

Institute for Marine Dynamics

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SUMMARY

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ADDRESS National Research Council
Institute for Marine Dynamics
P. O. Box 12093, Station 'A'
St. John's, Newfoundland, Canada
A1B 3T5

A MODEL EXPERIMENT TECHNIQUE FOR PREDICTING THE CAPSIZING OF DAMAGED RO-RO FERRIES

by

David Molyneux & David Cumming
Institute for Marine Dynamics
St. John's, Newfoundland

ABSTRACT

Pioneering model experiments to study the danger of wave action flooding the deck of damaged RO-RO ferries were carried out by Bird and Browne in the 1970's. Following the loss of the Herald of Free Enterprise in 1987 there was renewed interest in the subject, with studies in the United Kingdom and Denmark. Following this work, a further series of experiments was carried out in Canada, at the Institute for Marine Dynamics (IMD), with the prime objective of investigating the effectiveness of the SOLAS 90 regulations.

The experiments at IMD used a two-dimensional prismatic model to understand the process and provide data for validating numerical simulations. A key feature in the experiments carried out at IMD was the desire to measure the volume of water on the deck at all times during the flooding and capsize process. The design of the model, the data collected during the experiments and the methods of analysis are discussed in general terms. Finally recommendations are made for improving the techniques for use in future studies.

INTRODUCTION

Physical model experiments have played an important role in understanding the factors associated with the capsize prevention of damaged Roll On-Roll Off (RO-RO) ferries. The first major paper on the topic was by Bird & Browne [1]. This paper set the standard for methods and analysis techniques for further studies, [2, 3]. In all cases, the objective was to determine the limiting significant waveheight that a typical ferry would survive after sustaining collision damage at midships.

The Institute for Marine Dynamics, in partnership with Polar Design Associates of Vancouver, was asked by Transport Canada to investigate the implications of Safety of Life at Sea (SOLAS 90) regulations on Canadian Ferries. A test program was developed which attempted to address some of the limitations in the previous modeling programs recognized by Aston and Rydill [4].

The experiments described in this paper used a simplified hull shape in order to fully understand the important physical parameters of the problem, including the benefits of freeing ports fitted with flow control flaps. A secondary objective was to support the development and validation of a time domain simulation of ship motions up to and including capsize. To ensure that these objectives were met, the model was a larger scale than the previous studies [1, 2, 3], and it was fitted with more sophisticated instrumentation.

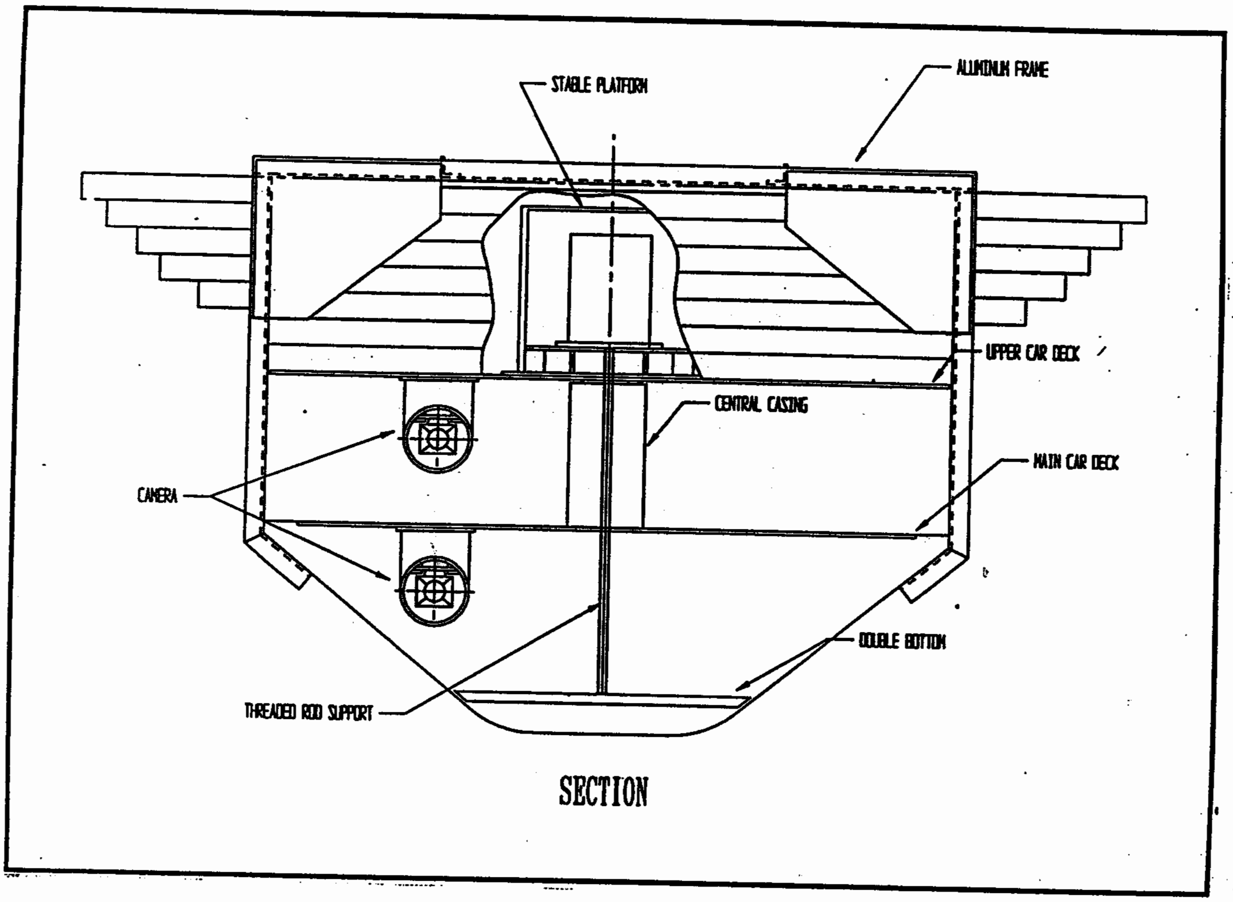

Figure 1, Section through constant cross-section model

	Model	Proto-Type
Scale	20	1
Length o. a. (m)	8	160
Beam o. a. (m)	1.33	26.6
Beam w. l. (m)	1.023	20.47
Draft, intact (m)	0.25	5.0
Displacement (m^3)	1.458	11666.55
KM (m)	0.645	12.909

Table 1,
Basic parameters, intact model

DESCRIPTION OF MODEL

The model used for this study had the transverse hydrostatic stability characteristics (intact and flooded) of the largest ferries operating in Canada. It had 'realistic' decks, super-structure, double bottom and casing arrangement (centreline or none) on the car deck but was a constant cross-section over the whole length of the hull, Figure 1. The study investigated a range of initial metacentric heights and three residual freeboards (0.5, 1.0 and 1.5m). The basic dimensions of the model are given in Table 1.

Damage to the ship was represented by holes in the side of the model, covered with sliding trap doors. The extent of the idealized damage to the hull and deck was set using the relationships given by the SOLAS regulations [5]. All of the damage holes were idealized as rectangles. The length of the damage was 7.8m, and the hole in the deck was 20 percent of the maximum beam. The midpoint of the damage was located at midships.

Freeing ports were fitted to the model at the level of the car deck, with openings 2.0 metres long by 0.6 metres high. All ports were covered by flaps, hinged so that water could escape from the car deck, but could not enter.

Several special features were included in the model. Large foam blocks were fitted at the bow and stern to prevent the model turning completely upside down after a capsize. Three high capacity pumps were fitted under the car deck to clear flood water and a recovery system using a 4:1 pulley system was used to right the model after the capsize.

DESCRIPTION OF INSTRUMENTATION

During the testing, the model was instrumented to measure motions and accelerations in six degrees of freedom using a Humphrey inertial reference system (stable platform), fitted inside a watertight casing on top of the upper deck.

The relative motion between the water surface and the deck was measured at the damage opening using a capacitance waterlevel probes. Arrays of capacitance waterlevel probes were used to measure water depth on the car deck (14 probes) and within the flooded hull (7 probes). Volume of water on each deck was determined from these arrays of probes.

All of the data described above were logged using a MicroVAX computer and a NEFF signal processor, which provided analogue signal conditioning, multiplexing, signal filtering and analogue to digital conversion. Sampling was at 20 Hz

Nominal Sig. Waveheight (m)	Modal Period (sec)
0.5	5.0
1.0	5.5
1.5	6.0
2.0	6.5
3.0	7.0
4.0	7.5
5.0	8.0
6.0	8.5
7.0	9.0

Table 2
Waveheights and modal periods used in irregular wave experiments

with 10Hz low pass filters. Video was taken of the views inside the hull and inside the car deck. A side view of the hull from the carriage and an end view of the model from the side of the tank were also taken.

TEST PROCEDURES AND ANALYSIS

The model was ballasted to the nominal intact draft, trim and vertical centre of gravity and checked with an inclining experiment. The model was then flooded and the residual freeboard and trim checked. Small adjustments to this weight distribution were made to ensure that the model remained level after flooding. Roll decay tests were carried out in the intact and damaged conditions and natural roll periods were determined.

A summary of the nominal significant waveheights and modal periods used during the testing is given in Table 2. All seastates were generated using JONSWAP spectra.

An important part of the study was to determine the effectiveness of freeing ports in preventing a capsize and so freeing port area was varied as part of the experiment program. The basic condition had no freeing ports open. The areas of the ports for the other conditions are summarized in Table 3.

All experiments took place in the IMD Towing Tank (200m x 12m x 7m) in St. John's, Newfoundland. Each run was started with the centreline of the model parallel to the wavemaker flap. Data acquisition began in the period before the wave train reached the model. The model was held on the centreline of the tank until the first few transient waves had passed. Once

Number of Ports	Total Area m^2	Area/unit length m
86	103.2	0.323
46	55.2	0.173
22	26.4	0.083

Table 3
Summary of freeing port configurations

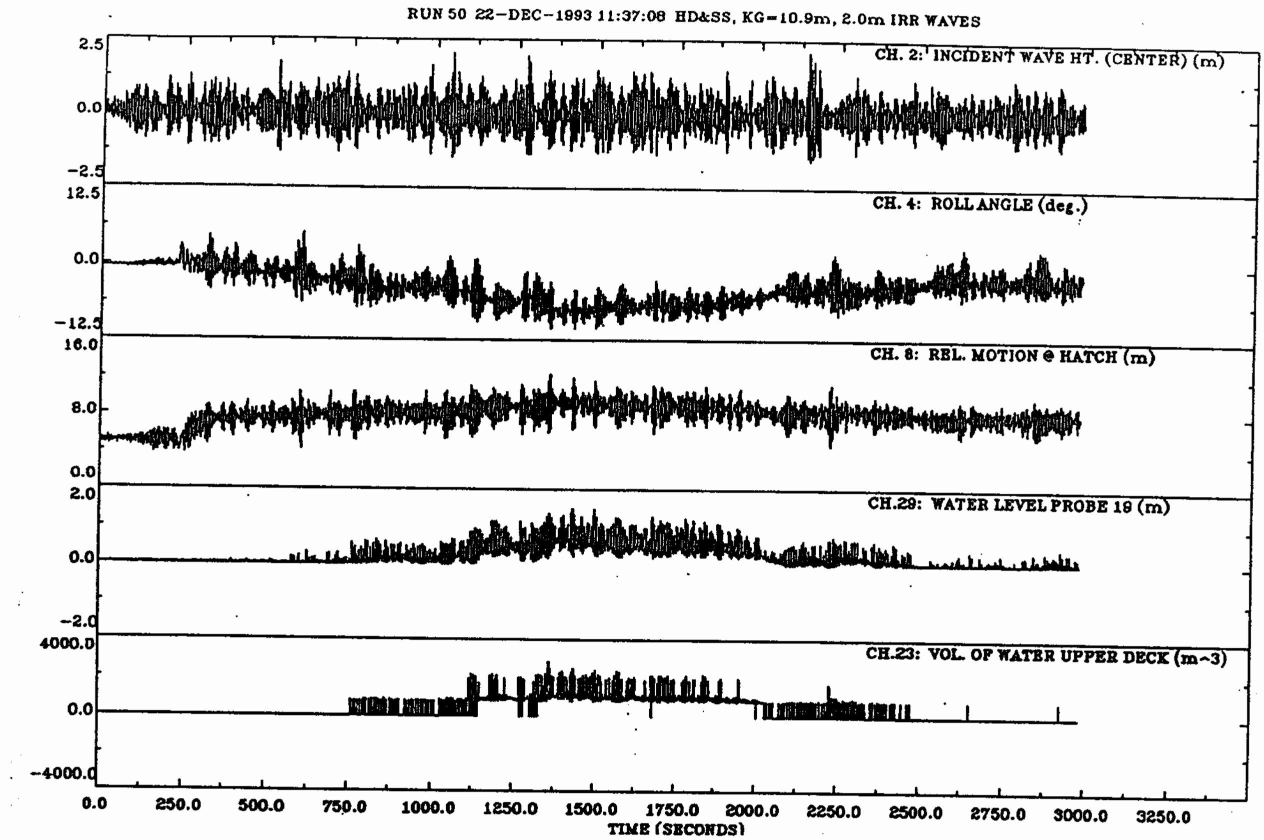

Figure 2, Typical time history for run without capsize

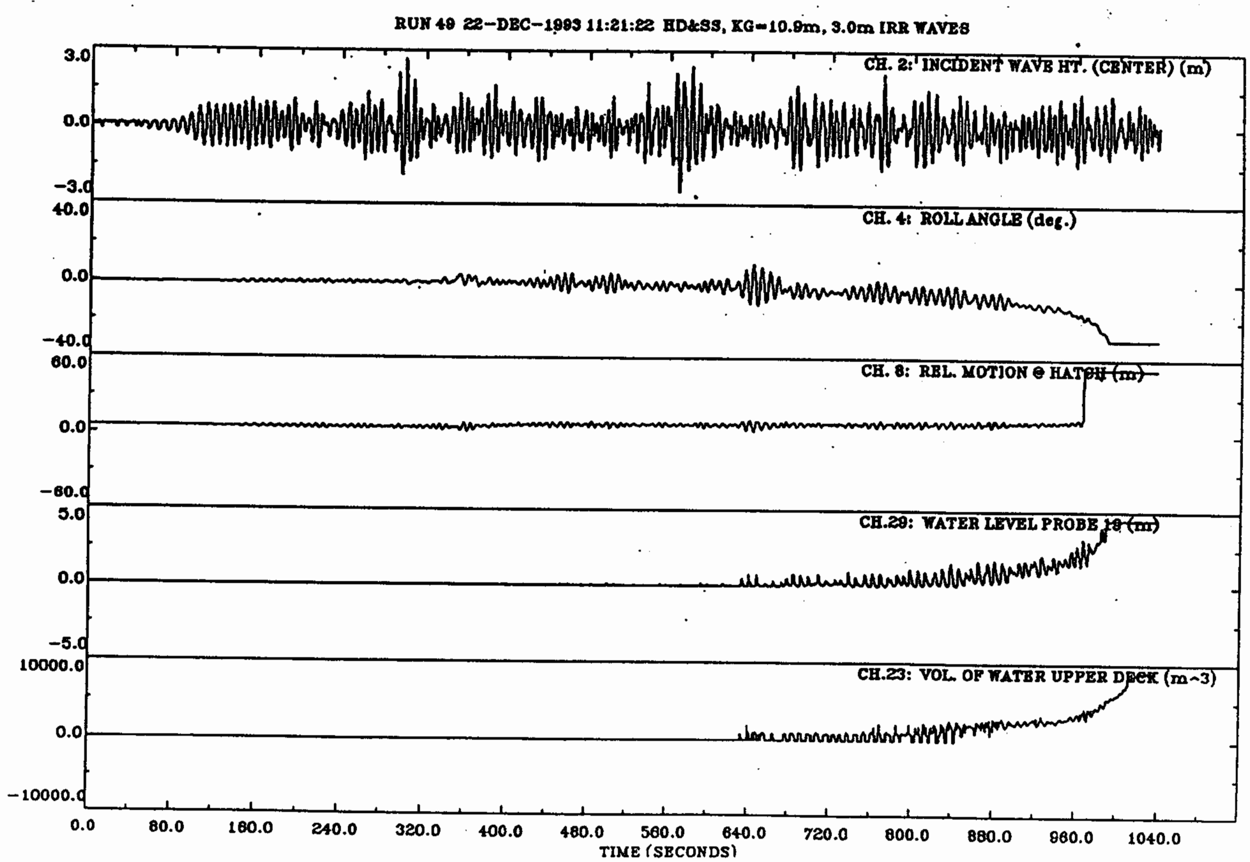

Figure 3, Typical time history for run with capsize

Mean Volume (m^3)	Standard Deviation	
2520	312.6	·124
4830	371.2	·0768
6570	356.7	·0543

346·8

Table 4
Variation in volume during calm water rolling

the 'steady' waveheight had developed the damage doors were then opened and the hull allowed to flood. The model then drifted down the tank and the operator manually adjusted the carriage speed to maintain a constant distance (+/- 1m) from the model.

The run was completed as soon as a capsize occurred. In the cases when the model did not capsize the full scale equivalent time corresponded to approximately 40 minutes. The model was then righted, pumped dry and configured for the next experiment.

Figures 2 and 3 show typical time histories of waveheight, roll angle, relative motion at the damage and water depth on the car deck, immediately inside the door and volume of water on the deck. Figure 2 is for a case which did not capsize and Figure 3 is for a case which did capsize. The time histories of water volume on the deck were used to compute the volume of water required to capsize the model.

During the preliminary experiments it became clear that the volume of water on the deck was a critical factor influencing the vessel's ability to withstand a capsize. It was essential to establish the level of accuracy of the volume estimates derived from the array of waterlevel probes and so a special series of calibration experiments were carried out. For these experiments the car deck was flooded and the volume of water on deck was calculated directly from the measured geometry of the water. This was checked against the equivalent values from the waterlevel probes and found to be in good agreement.

The model was then rocked by hand and the volume of water against time was calculated. This experiment was carried out to determine the level of variability in the estimates of volume on deck. The software used in the calculation of volumes assumed linear interpolations between water depths and so there was a certain amount of error inherent within the program.

The level of variation was calculated from the standard deviation of the calculated volume as a function of time. From the static values at the beginning and end of each test it was established that the volume of water during the test was constant and any other variation was assumed to be due to the calculation method. Results of the dynamic calibration are given in Table 4.

The variation in volume from the rolling tests is approximately constant over most of the of volumes likely to result in a capsize. The minimum volume of water require to capsize the model was approximately 1500 m^3, and it increased with an increase in metacentric height for the flooded model.

DISCUSSION OF RESULTS AND RECOMMENDATIONS

The conclusion from the study was that relative motion between the damage opening and the water surface was the best predictor of the volume of water entering the car deck and the stability of the model was the factor limiting its survivability. Thus to prevent a capsize, the model required sufficient freeboard in relation to the waveheight to limit the volume of water entering the deck and sufficient stability to support the volume of water which did enter the car deck. No capsizes were observed with small volumes of water on the deck, and the minimum volume to cause a capsize was approximately 1500 cubic metres.

The model tests at IMD also showed the importance of freeing ports fitted with flow control devices in preventing a capsize. In every case when the freeing ports were open to 100% the highest safe waveheight was increased. In the worst case (at 0.5m residual freeboard) the maximum safe significant waveheight was increased from 1m to 2m. In the best case (at 1.5m residual freeboard) it was increased from 3m to almost 7m. However, the effectiveness of the freeing ports also depended on the residual freeboard. Small areas of freeing ports were much more effective at the highest residual freeboards than at the lowest. The scale of the model was picked to ensure good hydraulic scaling of the drainage through the freeing ports.

The effect of the centreline casing was to trap the water on the damaged side of the car deck. When the casing was removed the water was free to flow to the undamaged side, and the model heeled away from the waves. This increase in freeboard increased the waveheight required to capsize the model. When the model was tested with freeing ports and no casing, it had the best survivability of all, since water could drain out from the ports on the undamaged side.

There are clearly some limitations for the prismatic model compared to a scaled model of an actual ship. The two dimensional hull shape precludes the use of the data for anything but developing an understanding of the important physical parameters and the validation of numerical models. These data have been used in this context by the SNAME Ad Hoc Panel on RO-RO Safety [6].

One important point to note is that flooded length of the prismatic hull was considerably longer than for the equivalent ship with 'normal' waterlines. To assess this difference, one set of tests was carried out with the intact displacement and flooded length adjusted so that the volume of water in the prismatic model was equivalent to the volume of water in a normal ship. When the results of these tests were compared with the equivalent condition from the main test series it was found that the relative motion of the two conditions in the same waveheight was clearly different. However, the limiting waveheight for survivability was unchanged.

This indicated that the extent of the flooding should be modeled correctly. Future work should also include the effects of varying wave period for a given wave height, since this too could have a substantial effect on the dynamics of the situation.

CONCLUSIONS

The physical model experiments described in this paper provided an effective method of understanding the complex problem of the flooding and capsizing of damaged RO-RO ferries. A simplified hull model, instrumented for relative motion between the damage and the waves as well as depth of water on the deck gave good insights into the parameters which prevent a capsize. The results were analyzed from the perspective of the complete system to determine the maximum safe waveheight for a given ship condition. The detailed interactions between the ship and the waves were used to predict the amount of flooding on the deck

The data also provided a valuable resource for the validation of numerical models, which are essential for the in-depth understanding of this problem.

The capsize limits determined from this series of experiments should be used with caution when interpreting real world situations. There are uncertainties caused by the dynamics of the exaggerated volume of water under the car deck and the added mass and damping effects associated with an un-realistic hull shape.

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