Investigation on the Capsizing of a Small Fishing Vessel in Following Seas

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ABSTRACT

The hydrodynamic aspects of the investigation on the causes of the sinking of a Spanish fishing vessel are presented. The ship was sailing in following seas with a significant wave height of 2.7 meters when she suddenly capsized and sunk without any previous distress communication. There were no survivors among the ten members of the crew.

Model tests in regular and irregular waves were carried out at CEHIPAR in wave conditions similar to those known to exist at the time of the accident. The paper describes in detail the characteristics of the model, the characteristics of the wave field, the seakeeping tests and the results obtained.

Keywords: *capsize, following seas, model tests*

1. INTRODUCTION

A small purse seiner 13.5 m in length capsized in June 2004 near Sisargas Islands in the North of Spain. The ship was sailing at 10.5 knots in, approximately, following seas with a significant wave height of around 2.7 m.

The first distress signal was received from the automatic released distress buoy without any previous communication of problems from the crew. This suggests that the capsizing was a very quick event.

The circumstances in which the ship was sailing (speed, heading, ship size) fall directly into the conditions that IMO guidelines for masters consider dangerous and should be avoided. This fact and the sudden way of capsizing clearly indicated that the accident could be a direct consequence of the sea conditions.

For this reason the CEHIPAR carried out model tests to investigate the possible influence of the wave conditions in the accident.

Different kind of tests were performed with a self propelled model sailing in confused sea conditions similar to those thought to be present at the accident time but also in regular waves. Initially, only irregular tests were foreseen but the initial results suggested the convenience to try also with some specific regular waves.

The wind, which could have also a negative influence in the ship behaviour, was not considered in the tests.

Many circumstances of the accident remember those of the sinking of fishing vessel “Artic Rose” which lead to similar investigations as described in USCG report (2003) or Borlase (2002).

In the following, the model construction and instrumentation, the test realization and the results obtained are presented.

2. PREPARATION OF THE TESTS

2.1 Model Construction

The model had to be used for two completely different kinds of tests: self propelled seakeeping tests and sinking tests in calm water with simulation of water flow through the internal compartments. These two kind of tests implied very different requirements that have to be fulfilled with a single model for cost and schedule reasons.

To comply with the requirements of these two kind of tests, the model had to reproduce the typical characteristics of seakeeping models like weight, inertias, COG, etc. but it also had to reproduce as exactly as possible the internal distribution of bulkheads, communications between compartments, openings to the sea, permeabilities and, of course, watertighness of the closed compartments.

To further complicate things, the seakeeping characteristics that have to be reproduced included details like the full superstructure, bulkwards, obstacles on the working deck and freeing ports. These elements would affect the flow and water accumulation on deck and therefore could have an important influence in survivability.

Taking into account those requirements the model has to be built with the following characteristics:

- The scale was chosen to be 1:7.732. This was a compromise between the minimum necessary displacement to fit motor, batteries and instrumentation, and the availability of and stock propeller similar the one fitted on the actual ship.
- The model was self-propelled and auto-piloted to eliminate any influence of cables in the model response to the waves.
- Most of the “ballast” weight was provided by the batteries in order to get the maximum testing time before recharging. These batteries were moved around the model inside to adjust inertias and GM.
- The general disposition of the ship has to be reproduced both in the inside as well as in the working deck and superstructure. Details like freeing ports, hatches, doors, ventilation and exhaust openings and so on had to be reproduced as exactly as possible.
- The model has to be fully watertight during the seakeeping tests but has to allow easy access to the inside compartments for ballast redistribution and battery charging.

Therefore the model was built with the following physical characteristics:

- Hull, decks, superstructure and bilge keels were made in FRP.
- Internal bulkheads and double bottom top were made in marine plywood 10 mm thick.
- Access to the interior was provided through commercial yacht hatches.
- Shafts for propeller and rudder were provided with rubber seals fitted on Teflon supports.

A female mould in two shells was used for the hull while a male mould was used for decks. This manufacturing system allowed the inside of the hull to remain opened for easy access to work in the bulkhead and double bottom installation as well as the arrangement of instrumentation.

All the moulds were made in extruded polystyrene with a three axis numerical control milling machine.

For the first time we used a new method of FRP lamination based on the use of PVC tape and epoxidic resins. This method happened to be very effective, allowing a shorter lamination time and a very precise and smooth finish of the surfaces.

The final weight of the empty model was 31 kg (about 20% of the displacement) leaving a good margin for instrumentation, batteries and weight adjustment.

The model was kept watertight for the seakeeping tests. For the sinking tests, the openings suspected to be open at the time of capsizing were cut on the model. These openings corresponded to some hatches, doors and accesses to the engine room.

The permeability of each compartment was attained by adding foam blocks as adequate after discounting the volumes of batteries, bulkheads and so on.

In any case, this work will deal with the seakeeping tests only.

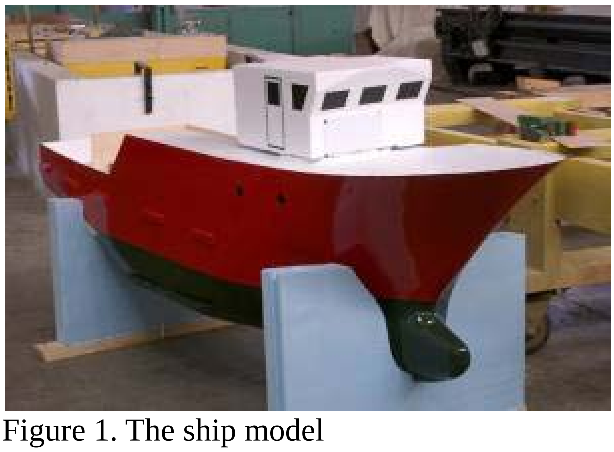
Figure 1. The ship model

2.2 Instrumentation

As said before, the model was instrumented for free running tests and therefore it was self-propelled and auto-piloted, having all the instrumentation on board and communicating with “land” by radio link.


Figure 2. Detail of the working deck

The heart of the system was an integrated control, navigation and telemetry system developed originally for unmanned aerial vehicles (UAV). The main characteristics of which were:

- Inertial navigation system. It was composed of three gyroscopes and three accelerometers that by double integration provided the position and attitude of the model. The integration of the accelerometer measurements give rise to some position “drift” that in the typical use of this system is corrected by comparing to GPS signals but, regretfully, this could not be done in our case because the GPS signals are not available inside the tank. In any case, this was not an important drawback because the most interesting signal in our case was roll (not affected by drift) and also because the test time was not as large as for the drift to become serious.
- Radio link communication. Although the system was very small it had power enough to communicate up to 100 km. This power allowed us to put the emitter

and antenna inside the fully watertight hull without having any reception problems.

An embedded PC which is capable of:

- PID control of servos, where control constants could be changed in real time.
- Possibility of control override from “land” and response to manual control.
- Data acquisition from the inertial system and servo feedback signals.
- Control on up to 16 servos simultaneously.
- Recording of up to an hour of video signal. This was used for an onboard camera to observe water flow on the working deck.

The propeller was powered by a DC motor controlled by a motor driver. The command signal was provided by one of the servos from the autopilot. Another servo signal was used for the rudder control. The rudder response was limited to 3.5°/s (full scale) as for the real ship.

2.3 Load conditions tested

The accurate reproduction of the load condition at the time of the accident was very important specially regarding stability and rolling period. A very precise definition of weights on board was available trough the forensic investigation but there were doubts about the state of the two aft ballast tanks.

Table 1. Main particulars of the two load conditions tested.

	Cond. 1	Cond. 2
L_{bp} (m)	13.5	13.5
B (m)	5.2	5.2
T (m)	1.622	1.76
Trim (m)	0.46	0.905
(t)	74.28	79.93
X_g (m)	-0.524	-1.021
GM (m)	0.589	0.613
KG (m)	2.22	2.21
Long. gyradius(% L_{bp})	32.7	34.1
Trans. gyradius (% B)	43.2	42.5

These tanks were found filled by the divers but no evidence was present as to whether they were fill or empty when sailing. Therefore the two conditions where tested. This was an important question because the filling of the tanks reduced the freeboard aft appreciably (by 0.4 m) but some sailors feel that the ship is easier to steer in this condition. The two load conditions are described in Table 1.

It was thought that the value of longitudinal and transversal gyradius normally taken for larger ships could not be adequate for this small ship. Therefore field tests where made with a twin vessel to measure the natural periods for both kind of motions. These periods, after corrected for the different weight distributions, allowed us to adjust the model inertias. The resulting estimated gyradius are those given in the previous table.

3. ENVIRONMENTAL CONDITIONS

Spanish shores are covered by an ample net of oceanographic buoys operated by the harbour authority. One of the buoys was located 60 miles northwest to the point of the accident and provided very helpful information on the wave point spectra as well as on its directionality.

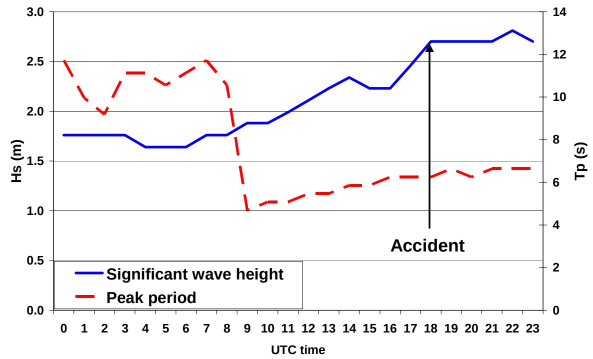

Figure 3. Sea states on the day of the accident as recorded by the nearby buoy.

Figure 3 shows the evolution of significant wave height and peak period as recorded by the buoy. It is interesting to see that nine hours before the accident there is a change in wind direction and intensity resulting in a large reduction of wave periods and a growing of wave height. This indicates that the waves became much steeper at the time of the accident.

As the buoy was 60 miles from the accident, there was a doubt on weather the actual wave field could be different at the site of the accident. Therefore we run a wave propagation model taking into account the different variables:

- The wind speed and direction measured by the buoy.
- The current speed and direction. This was estimated in 1.5 knots by the drift of the distress buoy released at the time of the accident.
- Bathymetry.

The results indicated that the wave field should be very similar to that measured by the buoy and therefore we kept the buoy data as our target for the tests.

As the ship was sailing relatively near some rocky islands some very local effects could happen, but those are difficult to evaluate and therefore they are not considered in this work.

The wave point spectra measured by the buoy and that reproduced at the laboratory are shown in Figure 4.

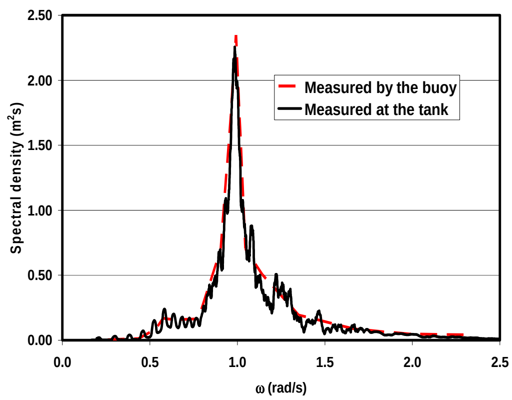

Figure 4. The point spectrum measured by the buoy compared to that reproduced at the laboratory.

The buoy was of the pitch & roll type and therefore it give us information on the wave direction and spreading. The mean wave direction recorded was due west as it was the estimated heading of the ship, confirming that she was sailing in following seas as the crew had indicated by radio communications.

The spreading was that corresponding to an exponent of s=2.2 in a cosine squared distribution.

The directional resolution of this kind of buoys is relatively poor and therefore the actual spreading can be very different from the measured one. For this reason, we tested both long crested seas (no spreading) and short crested seas with the spreading measured by the buoy.

4. SEAKEEPING TESTS

The initially planned experimental program consisted in testing the model in irregular waves similar to those assumed to be present at the time of the accident and varying the load condition, heading and directional spreading within reasonable margins. But, as it will be explained after, the initial results suggested the interest of testing the model in some specific regular wave trains. The tests are described in the following.

4.1 Irregular Wave Tests

The model was tested in irregular waves with the spectrum described before. The tests covered the two load conditions and long crested as well as short crested seas. Most of the tests were in pure following seas (0º heading) but some runs where carried out in quartering seas (±30º).

Our intention was to use an autopilot with a reasonable PID control in order to avoid any subjective influence from the controlling man, but reality shows us that it was almost impossible to keep the model on course with an automatic control so that, finally, the tests were made with a manual control. This is in line with the IMO guidelines that recommend not using the autopilot in following seas.

The tests were carried out for a duration equivalent to one hour full scale. The worst condition resulted to be that corresponding to the second load condition in following seas so that following results refer to this case.

Apart of the, already discussed, difficulty of maintaining heading, a strong roll is observed (4.6º rms in short rested seas and 6.2º rms in long crested seas) but it does not seem to be excessive for this kind of ship. Actually, the crew did not show any concern about this in their previous radio communications neither they take any corrective action.

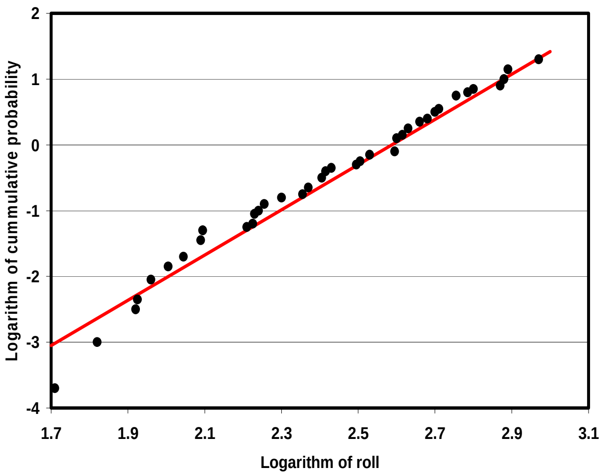

Figure 5. Weibull fit to the distribution of roll angles.

The roll amplitude distribution follows approximately a Weibull distribution as shown in Figure 5. Using this fitted distribution we can estimate the probability of exceedence of some critical values of heel like those corresponding to the flooding angles for certain openings that we suspect to be open at the time of the accident. If we consider three hours of duration of the sea state we can found the following probabilities of immersing some openings:

- The engine room and dinning room access doors have a negligible probability of been flooded.
- The engine room hatch has a probability of one per cent to be reached by the water. This low probability together with the small size of this opening suggests that it was not the origin of the accident.
- The freeing ports had a probability of immersion of 100%. This is in line with the observations made during the tests that water was shipped frequently through them into the working deck. But the amount of water shipped does not seem to be excessive.
- The probability of immersing the aft bulkward was almost zero.

The previous values are only approximate as they are based on the flooding angles for the calm water condition and therefore they do not include the wave profile influence.

In general, these tests in irregular waves did not show any situation where the model could be considered to be at an appreciable risk.

4.2 Regular Wave Tests

The previous results explain why the crew was comfortable with the ship behaviour but this does not discard the possibility that a special combination of waves could produce the accident. But what the previous tests show, in any case, is that such an event will have a small probability.

For this reason, in order to completely discard the wave action as the cause of the capsizing, it would be necessary to test the model for an equivalent to many hours of sailing at full scale (300 hours?).

This was considered unfeasible. Instead we considered the possibility of testing the model in “deterministic” wave fields which were compatible with the known wave statistics at the time of the accident. And, in this line, we decided to test the model in regular wave fields with heights and amplitudes with a low but appreciable probability.

The first step was to generate synthetic time series of the wave elevation having a spectral density equal to the one measured by the nearby buoy. A total of more than 20,000 waves were included in the simulations.

The time series were analyzed by the zero crossing method in order to obtain the combined probability of heights and periods (H_z, T_z). Considering that the mean encounter period is about 15 seconds we can estimate the probability that a certain type of wave occurs in three hours of exposure to this sea state.

Of course, the probability of occurrence of a wave with a specific height and period is zero and therefore we considered the probability of occurrence of waves with “similar” characteristics. Somewhat arbitrarily but, we think reasonably, we considered the waves to be similar if they differed in less than 0.5 m and 0.5 s. Therefore we put the waves into bins of ($H_z \pm 0.25$ m, $T_z \pm 0.25$ s) and we obtained the probability distribution shown in the contour plot of Figure 6.

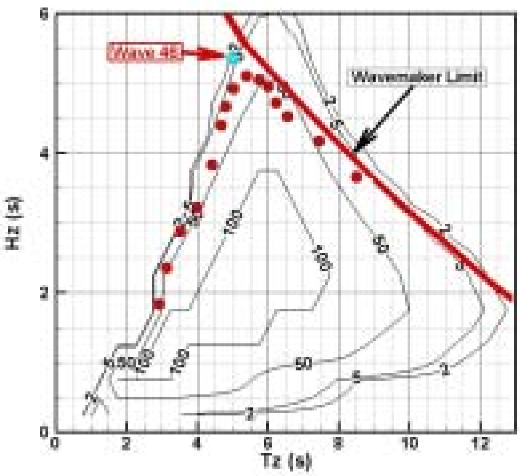

Figure 6. Probability distribution of waves for the buoy measured spectra. The dots show the regular waves selected for the regular wave tests (see the text for additional explanations).

This diagram was used to select the characteristics of regular waves that had a probability of at least 2% of occurring (the outer contour line in the plot corresponds to this probability). The selected waves are shown as dots in the same figure.

Regretfully, the model scale was too big to cover some of the intended areas because of limitations on the wave making capabilities. In the same Figure 6 the wavemaker limit is shown. It can be seen that there is a zone around 6 seconds and more than 5 meters height with relatively high probabilities of occurrence in three hours (more that 5% in some cases) that could not be reproduced at the laboratory.

We expect to explore this zone in the near future using a smaller model that is under construction.

Of the regular waves tested only wave 46 (see Figure 6) resulted in the capsizing of the model, and this happened in load condition number 2 (reduced freeboard aft). This wave had a period of 5 seconds and a height of 5.4 meters. The probability of occurrence of a “similar” wave was about 2%.

It is interesting to see the evolution of the stability as this wave passes the ship. Among the different parameters defining stability we have chosen the maximum righting arm GZ (see Figure 7). Other stability parameters show a similar behaviour.

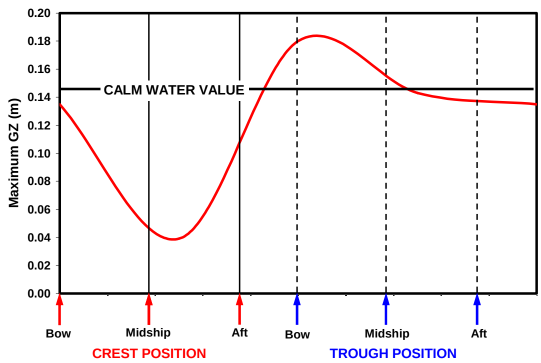

Figure 7. Maximum righting arm on wave 46.

The figure shows that when the crest is a little aft of midships the maximum righting arm is less than one third of the value corresponding to the calm water situation.

This coincides with what is observed in the test. When the model is over the first crest it heels to one side and water is shipped on the working deck. This amount of water is not released quickly enough by the scuppers so that when the next crest reaches the model it is already dangerously heeled to one side and the lost of stability makes the model to overturn.

The importance of water shipping on the working deck by immersion of the aft bulkward has already been emphasized by Grochowalski (1989).

It can be argued that the ship would not have encounter “regular” waves in the middle of a confused sea. But the numerical simulations show that when a big wave like this appears, the previous and following wave have similar characteristics (the known grouping effect). The encounter period for those waves is relatively long, of the order of 15 seconds, and therefore, if the ship encounters such a wave, we can consider that it will surf on an almost regular wave train for an appreciable amount of time. And, as described by Womack (2205), the situation becomes more dangerous for the ship when it is excited by regular waves rather than random ones.

5. CONCLUSIONS

Several conclusions related to this accident and resulting from the tests had being given previously. The main one is that the capsizing could have been a result of a lost of stability in following seas accompanied by massive water shipping on the working deck.

The experiments suggest that due attention should be given to some design aspects of these small fishing vessels:

- The dimensioning of freeing ports and scuppers.
- The stability on the wave.
- The minimum freeboard aft for safe navigation.

The experiments also support the concern of IMO on the dangers of sailing in following seas.

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