On the Experimental Investigation on the Capsizing of Small Fishing Vessels

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ABSTRACT

The safety of seafarers and the protection of the marine environment can be enhanced by identifying the circumstances and causes of marine casualties and incidents.
The maritime accidents of the ships "O Bahía" and "Enrique el Morico" which took place in front of the Spanish coast in 2004 set up the beginning of the research presented in this paper. The purpose of it was to find how the ships sunk and if the stability regulations for this type of vessels are appropriate. To come to a conclusion, hydrodynamic tests for models of these two boats were carried out at the UPM and CEHIPAR model basins. The experiments methodology and results are here presented.
Free running tests have been performed in regular waves, with the models reproducing the accident's load condition but within regulation of watertightness. Wave steepness, vessels' asymmetry and inefficient water draining are considered relevant and influent parameters on capsizing.
It was nearly impossible to lead the models to capsizing, in spite of the rough conditions studied and the barely fulfilment of the stability criteria that these boats had at the accident. Only one of them overturned, and they are considered to be stable enough. The methodology developed in these tests is considered adequate to validate numerical calculations on capsizing

KEY WORDS

Capsizing, broaching, surf-riding, following and quartering seas.

INTRODUCTION

Seakeeping is a very difficult field to investigate where many aspects are not known enough. One of these aspects is how a ship reacts in following and quartering seas and more specifically how this can resolve on capsizing.

In the year 2004 some shipwrecks involving small fishing vessels occurred at the Spanish coast. As known, the commercial fishing industry is one of the most dangerous and deadly occupations in many countries, so the analysis of the casualties results helpful to determine the accident causes and prevent future sinkings. Two of the sunk boats have been considered for an investigation, with the intention of reproducing their capsizing. (Perez Rojas, 2003)

Those selected for the analysis were the "O Bahía" and the "Enrique el Morico".

The "O Bahía" is a purse seiner built in steel the year 1999. On June 2^{nd} 2004, she sank at the waters near Sisargas Island on her way from Burela Port (Lugo) to Vigo estuary.

The “Enrique el Morico” is a long liner built in FRP the year 1999.On August 3rd 2004, she sank in front of Almeria’s coast (South of Spain) due to two successive sea strokes.

The paper published in 2006 on the accidents of these fishing vessels (Perez Rojas, 2006), indicated that the load conditions at the accident, differed significantly from those considered in the “Stability Booklets”. These results pointed out that the purse seiner did not fulfil the IMO stability criteria at the moment of the wreck and the long liner fulfilled them very slightly.

The IMO stability criteria are empirically developed with statistics of Northern European fishing vessels. In the last few years, some investigations have been carried out, trying to analyse if the fulfilment of these criteria results in real safety for capsizing or not. In this line of action, the article “Comparison of European and Asian Trawlers.-Stability in Seaways-” written by Umeda (2002), compares Japanese and European vessels from the viewpoint of the stability in seaways. As a result of difference of regulation for managing fishing efforts, hull forms of Asian fishing vessels are quite different from the European ones. European vessels under the regulations utilizing ship length are much wider and deeper than Japanese ones under the regulation utilizing gross tonnage. As the stability criteria were based on data from European vessels, in general, the Asian ones do not comply with them. The mentioned article concludes that the European fishing vessels, fulfilling the IMO stability criteria, are much safer than the Japanese ones, but they are easier to suffer broaching in quartering seas and parametric resonance in head seas.

The ships analysed in this paper are two quite representatives of the Spanish fishing vessels fleet. Nevertheless, there are important differences between the two boats, because they used to sail at very different zones. The boats could be considered typically Europeans vessels, but, in spite of this, they had many difficulties complying with the IMO stability criteria at the moment of the accident. Even so, this work points out that these boats do not suffer neither stability problems nor capsizing, even sailing in very harsh conditions. Only the “O Bahía” model turned over, but it was nearly impossible to reach this situation.

Previously to this work, experimental tests on capsizing were carried out at the CEHIPAR. A larger model of the “O Bahía” was used in these trials. These previous experiments were presented in 2006 (Maron, 2006) and suggested that a model made to a smaller scale was necessary to achieve capsizing.

According to these previous experiments (Maron, 2006), only regular waves have been studied due to the long time needed for the irregular wave experiments. The models have been studied in beam and longitudinal regular waves.

The “O Bahía” tests presented at this paper, are the development of those planned previously, that could not be performed due to the model scale.

Based on the previous experience obtained from the purse seiner results, the “Enrique el Morico” was tested in waves considerably higher than those assumed to be present at the time of the accident.

The report presented by Umeda at the 6th International Ship Stability Workshop (Umeda, 2002) shows that it is necessary to quantitatively predict capsizing, to systematically examine all factors relevant to capsizes in following and quartering seas. Efficient computer codes that could be very helpful in this issue are being developed rapidly, but the complexity of the involved phenomena and the high degree of nonlinearity in many characteristics together pose a formidable challenge that will require years of hard work. The Report of the Seakeeping Committee (ITTC, 1993) presents the need for model test data related to extreme wave conditions that will provide the required information to validate simulation methods. These can consist of captive, partly captive and free running tests results. The results deduced from the experiments presented in this paper satisfy these requirements, and could be very useful for validation purposes.

MODEL DESCRIPTION

Ship Data

A model of each analysed ship was used to develop the experimental studies on the maritime accidents described before. The model of the ship “O Bahía” was made to scale 1:13.7 meanwhile the model of the ship “Enrique el Morico” was made to 1:13.5. The following figures show the general arrangement and body plans of the ships and some photographs of the models.

Fig. 3 Model of the ship "O Bahía"

Fig. 4 Model of the ship " O Bahía"

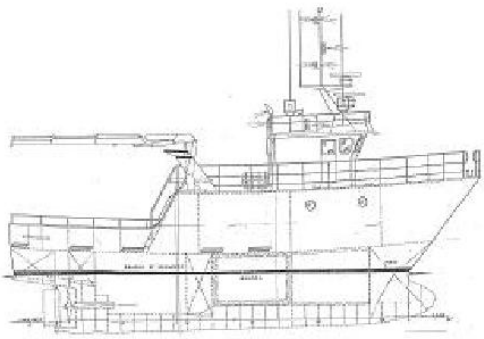

Fig. 1: "O Bahía” General Arrangement

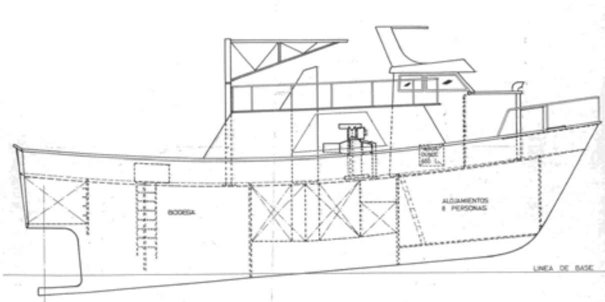

Fig. 5: “Enrique el Morico” General Arrangement

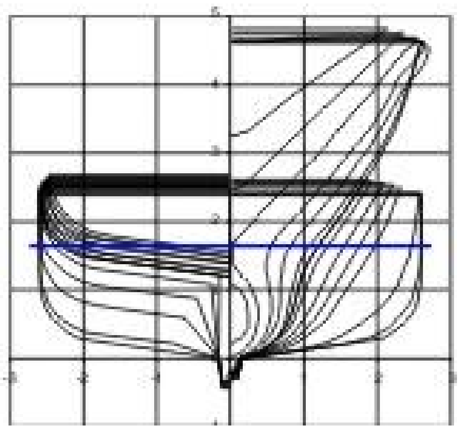

Fig. 2 :"O Bahía” Body Plan

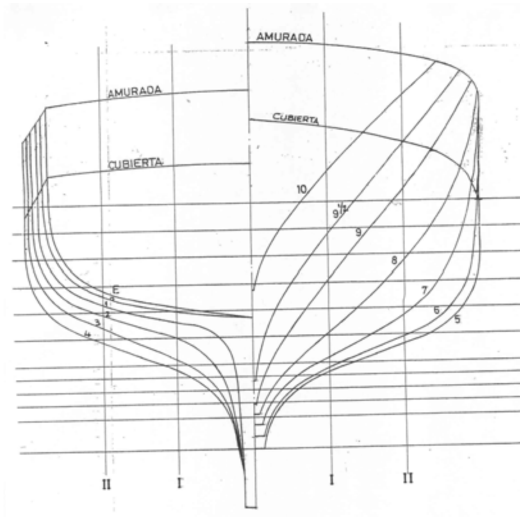

Fig. 6: “Enrique el Morico” Body Plan

Fig. 7: Model of the ship “Enrique el Morico”

Fig. 8 : Model of the ship “Enrique el Morico”

The following characteristics and load conditions are deduced from the accident reports:

Table 1 : Ships Characteristics

Ship	O Bahía	Enrique el Morico
Displacement (t)	74.20	39.05
Lpp (m)	13.50	13.80
Beam (m)	5.20	4.57
GM (m)	0.589	1.104
T (m)	1.63	1.78
TRIM (m)	0.45	0.11
Longitudinal gyradius (%B)	44.00	37.00
Transverse gyradius (%Lpp)	32.70	33.00
Pitching Period (s)	3.15	3.10
Rolling Period (s)	6.00	3.20

Model Construction and Fitting

The models were built in FRP, reproducing underwater hull and also superstructure.

The “O Bahía” model was provided with bulwark ports and their closures, which reproduced those in the shipwrecked vessel.

Detailed plans of “Enrique el Morico” boat were not available, so the information about the situation of the scuppers was obtained from a ship built in the same mould. The situations of the scuppers are supposed to be similar in both boats, as they were built at the same shipyard, and in the same mould.

Tests were carried out with all the openings closed, because the aim is to study the accident situations, but keeping the models within regulation conditions of watertightness, and without cargo movements.

They were loaded to reproduce the accident’s displacement. This done, the weights were moved fore and aft, to get longitudinal inertia, vertically to obtain proper GM, and crosswise to achieve transverse inertia.

Instrumentation

The models were provided with a gyrostabilized equipment composed of two stations communicated by radio link. The on-board station sent the measured data to the land station. The broadcast information was acceleration and angular position for each axis. The system can also be used as a 16 input/output channel control station. The rudder and the engine were servo-controlled by two of the mentioned channels.

Equipment main characteristics are:

- Maximum acceleration (vertically) 10 G
- Maximum angular velocity 300 º/s
- Angular position measurement resolution 0.05º
- Sampling Frequency 50 Hz
- Differential GPS

An ultrasonic device installed in the towing tank carriage was used to measure waves during the tests. The device main characteristics are:

- Range of measurement: 200-1300 mm

- Sampling frequency: 200 kHz
- Resolution: 0.18 mm

TESTS DESCRIPTION

Two groups of tests were accomplished for each model, first of them, at the ETSIN Model Basin, and the second group at the CEHIPAR Model Basin.

Tests at the ETSIN Model Basin.

Once the models were built and fitted, their velocity was calibrated. They were run at different velocities by changing the position of the potentiometer that controlled the engine. Velocity was measured when there was not relative motion between the vessel and the towing carriage.

The “O Bahía” was tested in longitudinal waves. The wave amplitude was the maximum possible at the facility (3.5 m and 5.5 s to real scale). Excessive rolling or manoeuvring difficulties were not noticed.

They were also tested in beam seas.

Tests at the “CEHIPAR Model Basin.”

As said before, the tests for the “O Bahía” executed at the “CEHIPAR Model Basin” could be considered as a continuation of those completed previously for a model to a greater scale. These trials revealed the need of carrying on with the investigation, but using a smaller one, that would allow complying with the planned experiments, which could not have been completed because the wave generator limit had been reached.

Sea conditions at the moment of the accident were calculated by the CEDEX according to the data obtained by the Spanish Network of Buoys and the Spanish Meteorological Centre, and the studies on wave generation from the “Puertos del Estado” Institution. These studies suggested irregular seas with the following characteristics for each boat:

Table 2 : Waves Characteristics

Ship	O Bahia	Enrique el Morico
H (m)	2.7	1.3
T (s)	6.2	5

Previous studies in regular and irregular waves, (Maron, 2006), showed that the irregular waves did not lead the “O Bahía” to a situation that could be considered especially risky. These results denoted that the most interesting waves for the analysis were higher than those predicted for the moment of the accidents.

As a huge amount of tests was needed to obtain acceptable results in irregular seas, a deterministic study was selected, and the models were analysed in those regular waves that had a low but appreciable probability of appearance.

Other fact that also justified studying the phenomena in regular waves was that numerical simulations demonstrated that a big wave is usually accompanied by a previous and a following which have similar characteristics. Generally, the overturn is more frequent in regular waves.

Selected waves were steep and sometimes breaking waves. Test conditions were rougher than those at the accident. Although ships were loaded in the same way as at their accidents, cargo movements and water retention have been neglected at the experiment. The waves used when performing the experiments are presented at the following tables:

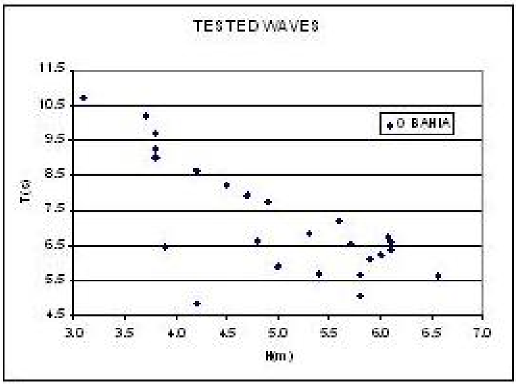

Fig. 9 : Tested waves for the model of the "O Bahía"

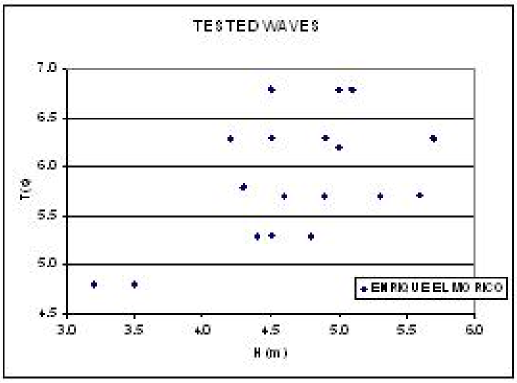

Fig. 10: Tested waves for the model of the "Enrique el Morico"

Tests Methodology

Tests started with each model stationary at the tank end. Waves with the theoretical amplitude and period were generated. The run commenced some waves after the first ones reached her. When the waves were considerably high, the test began with the boat heading the sea. Then, she bore away when the waves were regular, and the measuring began. Slalom courses, manually controlled were performed. The vessels sailed in quartering and following seas. An automatic regulation for the course was tried at the previous tests, in order to prevent any influence from the remote control skipper, but it was nearly impossible to maintain the course this way. For this reason a hand-operated heading control was selected.

The rudder was kept fixed during the tests, and only moved when the ship was near the walls of the basin. After setting a new course it was centered again.

The model course was modified at 20 m from the other tank end, and she sailed back to the department point, in head seas.

"O Bahía" and "Enrique el Morico" velocities during the tests were approximately 10 and 12 knots respectively.

As said before, the waves were measured during the tests using an ultrasonic device. The calibration wave was obtained at the same time as the experiments were carried out, in order to avoid other series of tests to make the calibration. So, for each test, real wave height and period was obtained.

A file containing time, acceleration and angular position for each axis was recorded for every run. Next, only the part where the ship was sailing in following and quartering seas was considered, neglecting the other situations. Trim data was corrected after every run, in order to refer this data to the water line. This correction was needed because the inertial unit was installed at its base trimmed. Yawing data was only used to know the beginning and the end of the run (that corresponded to appreciable variations in the heading), so this information was deleted once the data was analysed.

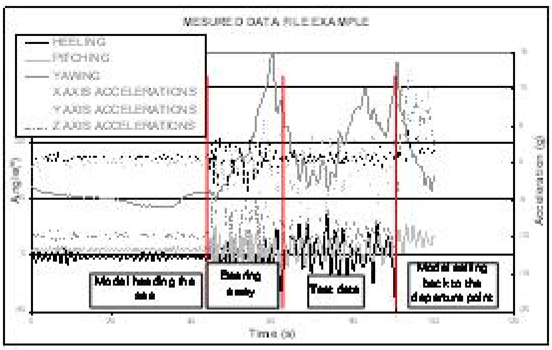

Fig. 11: Measured data during the tests

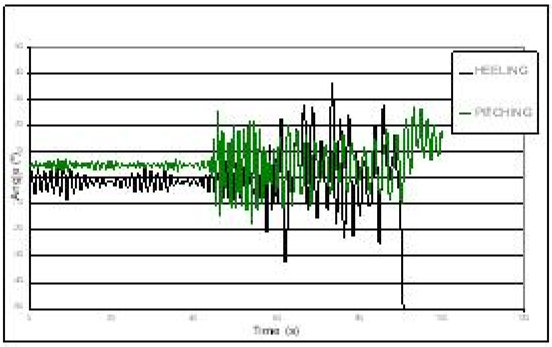

Fig. 12: Definitive data file

RESULTS

The maximum rolling and pitching data are here included for each model. These results have been deduced from the files mentioned above.

Table 3 : Results of the "Enrique el Morico" tests.

H (m)	T (s)	MAX. ROLLING ST (º)	MAX. ROLLING PT (º)	MAX. PITCHING (º)	MIN. PITCHING (º)
4.3	5.8	53.7	30.2	19.8	-26.7
4.9	5.7	34.8	38.5	18.4	-24.3
4.6	5.7	20.6	28.0	14.4	-17.2
5.3	5.7	20.6	28.0	14.4	-17.2
5.6	5.7	55.0	35.7	20.0	-23.2
4.2	6.3	28.1	27.8	14.8	-16.6
4.5	6.3	32.1	21.6	16.8	-21.2
4.9	6.3	37.8	35.0	18.4	-18.7
5.0	6.2	32.7	44.4	21.9	-24.6
5.7	6.3	54.0	43.7	29.4	-22.7
4.5	6.8	20.6	28.0	14.4	-17.2
5.0	6.8	19.1	19.7	17.4	-21.8
5.1	6.8	34.0	23.4	17.1	-20.4
5.0	6.8	21.4	28.9	19.6	-17.8
4.5	5.3	36.2	39.0	21.6	-21.8
4.8	5.3	41.6	39.3	24.2	-26.4
4.4	5.3	20.6	28.0	14.4	-17.2
3.2	4.8	32.1	36.9	23.0	-22.4
3.5	4.8	51.9	32.3	36.2	-12.9

The following table presents the data obtained from the "O Bahía" model tests. The results accompanied by an S or an F are those from the runs performed to a velocity lower or higher than the nominal one, respectively.

Table 4 : Results of the "O Bahía" tests

H (m)	T (s)		MAX. ROLLING ST (º)	MAX. ROLLING PT (º)	MAX. PITCHING (º)	MIN. PITCHING (º)
4.2	4.9		34.0	26.3	12.1	-10.8
5.8	5.1		CAPSIZING			
5.8	5.1	S	CAPSIZING			
5.8	5.1	F	CAPSIZING			
5.8	5.7		39.6	34.1	17.7	-15.4
6.6	5.6		26.4	34.4	12.7	-22.6
6.6	5.6	F	23.6	23.2	18.1	-20.2
5.4	5.7		34.8	35.2	13.4	-12.4
5.4	5.7	S	27.9	21.6	19.4	-18.9
5.0	5.9		15.0	23.4	21.7	-18.3
5.9	6.1		25.7	28.9	13.3	-11.9
6.0	6.3		28.6	26.5	13.5	-14.1
6.1	6.4		29.1	27.6	13.3	-18.4
3.9	6.5		22.5	20.5	8.1	-10.1
5.7	6.6		18.1	19.2	9.5	-12.2
6.1	6.6		16.0	16.7	10.7	-160.0
4.8	6.6		34.8	24.2	12.7	-12.2
6.1	6.8		22.5	20.6	12.2	-11.8
5.3	6.9		9.9	15.1	7.7	-9.3
5.6	7.2		17.9	16.9	7.1	-10.9
4.9	7.8		13.5	14.7	10.7	-8.3
4.7	7.9		6.8	13.0	4.9	-7.2
4.5	8.2		8.5	11.0	4.8	-6.5
4.2	8.6		7.4	7.9	7.5	-6.4
3.8	9.0		7.6	7.2	5.8	-5.5
3.8	9.3		6.9	7.8	5.5	-6.1
3.8	9.7		11.6	7.7	4.4	-5.2
3.7	10.2		4.4	6.1	4.7	-4.8
3.1	10.7		6.7	8.7	5.2	-3.6

Experimental data and information from the tests yield to the following results for the ship "O Bahía":

When the vessel, without initial motion, sailed in beam seas, she suddenly headed into the waves without any rudder manoeuvring.

In head seas and with the engine stopped, she kept the bow to the waves.

The wave that turned over the model was a breaking wave. As recommended at Circ. 707, (IMO, 1997), the model was not only examined to the nominal velocity (10 knots), but also faster, and slower. The same wave caused capsizing sailing either at the expected velocity or at a greater or lower velocity.

The most influent parameter on causing capsizing was the slope of the wave, as a high wave without a short period did not cause the overturn.

Water shipping by immersion of the stern and inefficient water draining are significant factors on capsizing. Difficulties to evacuate the shipped water were also shown at the previous experiments.

In the runs where capsizing occurred, the first wave heeled the ship dangerously. Therefore the working deck submerged, and then she did not have enough time to drain this water so the next wave caused the turn over.

"O Bahía" model always overturned on the port side. The asymmetry in the course of the shipped water seemed to be a determinant factor on capsizing, producing a complex composition of motions which endangered the ship.

She had problems maintaining the course, and started surf-riding, when the wave amplitude was considerably high.

"Enrique el Morico" model did not shipwreck, in spite of the rough conditions examined. She is considered to be stable enough.

When the long liner was tested in beam seas, without initial motion, she headed slightly into the waves.

Large heeling angles were reached sailing in following seas, but there were not stability problems. She surfed on the waves in following seas, making difficult keeping the course, but without water shipment. Broaching phenomenon appeared causing abrupt and sudden heading variations. Surf-riding phenomenon appeared during long periods when sailing in following and quartering seas. Fish handling area superstructure avoids water shipping during the surf-riding.

The tests preformed in regular waves, with the height and period corresponding to the acccidents', did not cause any significant result for any boat.

CONCLUSIONS

Even though the harsh conditions proposed for the experiments, and the slightly fulfilment of the stability criteria, only the model of the "O Bahía" overturned.

Actually, the response to heavy seas of the two vessels can be considered adequate. The vessels did not capsize because of their seakeeping conditions, but due to other causes such as sailing with the openings not closed or in conditions where they were not perfectly watertight.

It is known that water shipping is a really important factor that can endanger the ship, and lead her to capsizing. The results obtained show that there was not water shipment in the long liner tests, due to her superstructure. Nevertheless, the water in the purse seiner´s deck, and her difficulties to drain it, caused large heeling angles, and sometimes the capsizing.

Deficient evacuation of shipped water is an influent factor on capsizing that should be further studied.

Broaching phenomena appeared in the "Enrique el Morico" tests, even though the length of the waves generated was bigger than the one that is considered to be the riskiest. For example, as it is shown in the book "Stability and Safety of Ships. Volume I" (Kobylinski , 2003), the range of danger of a ship sailing in following and quartering seas is one to two times the ship length. The length of the waves in our tests exceeded twice the ship length.

As it is mentioned in the Introduction, the “O Bahía” and the “Enrique el Morico” were built following European regulations and criteria, so they are fully representative European ships. However, the latter almost did not comply with the Stability criteria at the moment of the accident, which correspond to the studied situation; and more dangerously, the former did not comply with it.

In reference to the conclusions of the article “Comparison of European and Asian Trawlers.-Stability in Seaways”(Umeda,2002), which establish that European boats can suffer a situation of stable surf-ridding which ends with a broaching, the tests performed show this attitude in the “Enrique el Morico” experiment. ”. Surprisingly, the results of the “O Bahía”, fit in with the typical response of Asian boats. Even though, both ships have a more than good seakeeping.

The results of the experiments presented in this work show two boats with great difficulties in the fulfilment of the IMO stability criteria that do not capsize in the major part of the tests. This seems to suggest that the non-fulfilment of these stability criteria is not a synonym of danger for capsizing for the type of boats and waves considered in the experiment.

The data and results presented before (tables 3 and 4) represent useful information on the response of a vessel sailing in following and quartering seas when extreme wave conditions are considered. The methodology developed in the tests presented in this paper, and their results are considered adequate to validate numerical calculations on capsizing or prediction of extreme motions.

ACKNOWLEDMENT:

This work was supported by the Spanish Maritime Administration under a contract signed between Dirección General de la Marina Mercante and Universidad Politécnica de Madrid. The authors express their gratitude to the different students and other people involved in the work carried out by the Model Basin Research Group in the Escuela Técnica Superior de Ingenieros Navales. Specially, the authors would like to thank Jaime Moreu for his contribution to the investigation and the development of this paper.

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