New Insights on the Sinking of MV Estonia

Andrzej Jasionowski
Safety at Sea Ltd (SaS), Glasgow, UK

Dracos Vassalos
The Ship Stability Research Centre (SSRC), Dept of Naval Architecture and Marine Engineering, The Universities of Glasgow and Strathclyde, UK

ABSTRACT

The paper presents the latest results from the ongoing research study on the sinking of Estonia, aimed at establishing a verifiable loss scenario by using state-of-the-art numerical and experimental tools to address all pertinent issues: flooding mechanism, coupled flooding-ship-sea dynamics, deterioration of watertight integrity and the abandonment process. The strategy in approaching this problem and the new insights derived from the adopted process are presented leading to early conclusions on the likely loss scenario.

KEYWORDS
MV Estonia, Forensic Study, Damaged Ship Stability, Time to Capsize

INTRODUCTORY INFORMATION FOR AUTHORS

Andrzej Jasionowski
Andrzej Jasionowski graduated from the Technical University of Gdansk (MEng, 1997), and the University of Strathclyde (PhD, 2002). His current role involves being the Technical Manager of SSRC and a Director of Safety at Sea Ltd, an engineering consulting company offering specialist services to the maritime industry on ship stability and safety and on the design of knowledge-intensive, safety-critical ships. His main interests comprise ship hydrodynamics, damaged ship dynamics, stability, modern risk assessment, inductive inference, modelling uncertainty, numerical algorithms development and the philosophy of safety. Andrzej Jasionowski is credited with a number of research awards and prizes and the publication of some 30 journals and conference papers.

Dracos Vassalos
Dracos Vassalos is Professor and Head of Department of Naval Architecture and Marine Engineering of the Universities of Glasgow and Strathclyde and the Director of SSRC, a world-leading centre of excellence on ship stability and safety. His life-long vocation has been to promote the use of scientific approaches in dealing with maritime safety and to create a critical mass in the research community by nurturing safety enhancement through innovation. He has lectured widely, published some 400 technical publications, won a string of prizes and awards, including some 100+ major research contracts totalling over £15M. Currently, Professor Vassalos is Chairman of the International Standing Committee of the "Design for Safety" Conference, a theme instigated and promulgated by SSRC and serves as member of the UK delegation to IMO for ship stability.

INTRODUCTION

The foundering of MV Estonia on 28 September 1994, with reported loss of 852 lives, is one of the biggest peacetime catastrophes of Western Europe. However, it seems that efforts expended on explaining the circumstances of this loss have not been commensurate with the magnitude of the disaster. No comprehensible description of the chain of events leading to the loss of the vessel has been derived to date.

This workshop paper aims to briefly summarise some findings during the studies undertaken in contribution to these efforts and carried out by the authors within the partnership of the SSPA Consortium[1].

The paper presents a judiciously chosen set of key information, which has been deemed pertinent to the argument presented. It is stressed here that it is only a brief summary of an on-going investigation, presented here for the purpose of exchange of information and public discussion.

STATUS OF THE EVIDENCE AVAILABLE

Heeling

Most survivors state that the vessel heeled substantially, see Figure 1. Many persons onboard have not managed to escape, and hence, quite likely, considerable heeling developed rapidly, within a few minutes from an initiating event and thus prevented persons to abandon the ship.

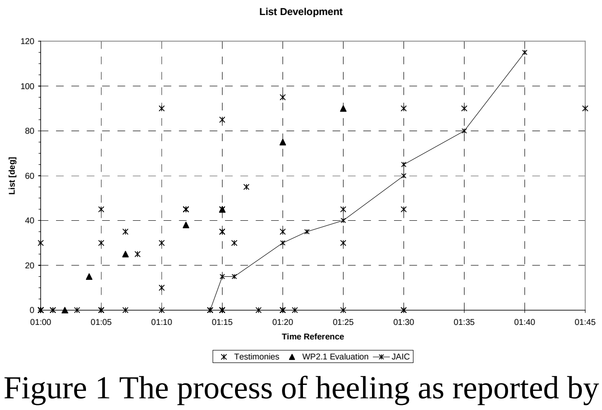

Figure 1 The process of heeling as reported by witnesses. Established by Rutgersson *et al*, [3].

The explanation of the cause of the heeling offered to date is the water on deck, reaching the car deck through open bow doors, see Figure 2.

Figure 2 The primary JAIC hypothesis of the loss of the vessel is the detachment of the bow visor, and subsequent ingress of floodwater onto the car deck through a partially opened ramp.

Capsizing

A visual picture taken by one of the survivors clearly demonstrates the ship at over 90 deg angle of heel. Therefore, the vessel capsized, that is she heeled beyond some 40deg, at which attitude the restoring capacity of the ship's watertight enclosure reaches its maximum, see Figure 3. Theoretically, once the vessel heels to this angle, capsizing becomes imminent.

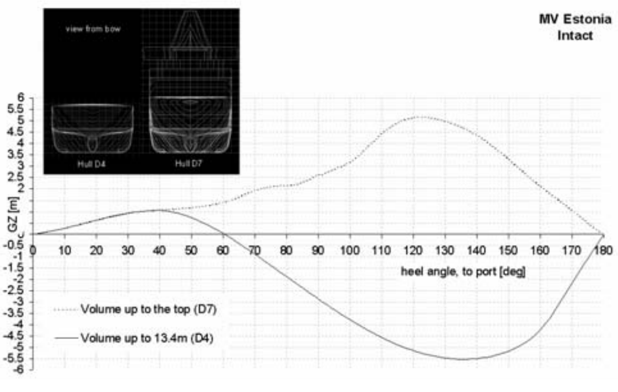

Figure 3 GZ curve for MV Estonia, when buoyancy is considered to either, top of the car deck (D4) or tip of the funnel (D7). The latter, obviously hypothetical, is shown to visualise the physics of the real capsizing process ignored in typical routine ship stability calculations. Loss of the buoyancy above D4 must take some time.

[1] www.safety-at-sea.co.uk/mvestonia

However, in practice, capsizing must take a finite amount of time, driven primarily by the process of flooding of all the spaces of the superstructure, [4].

Sinking

The vessel, see Figure 4, rests at the bottom of the Baltic Sea, and hence it is obvious that most of the buoyancy of the ship has been lost.

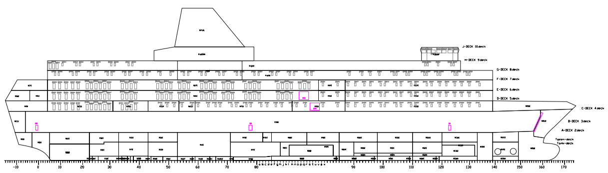

Figure 4 Side profile of MV Estonia, centre plane view.

As is shown in Figure 5 below, for the MV Estonia to sink, flooding must amount to at least **10,792 m^3** in the spaces below the car deck, in addition to complete flooding of all other spaces on the ship. In case of any air pockets remaining in any space from the car deck upwards, the flooding below would have to be higher, proportional to the volume of these air pockets.

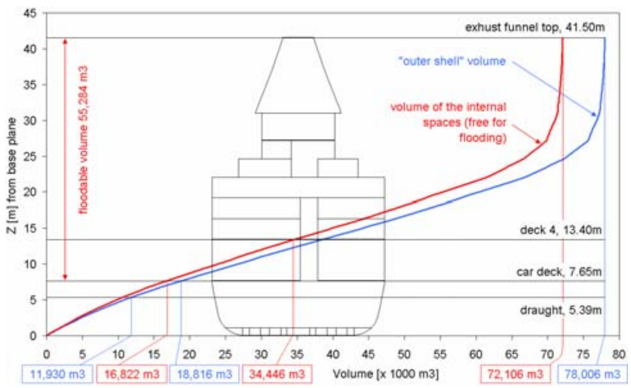

Figure 5 The whole "body" of the MV Estonia would displace 78,006 m^3 of water if fully submerged. The volume that could flood internal spaces from the car deck upwards to the tip of the funnel is 55,284 m^3. The ship's weight at the time of her loss would displace 11,930 m^3. Therefore, the minimum amount of floodwater required to ingress below the car deck spaces for the ship to sink is: **<u>10,792 m^3</u>** = 78,006 m^3 – 55,284 m^3 – 11,930 m^3, or **<u>64%</u>** of all the floodable space below the car deck.

To date, no plausible explanation of the process, by means of which this flooding took place during the ship loss, has been offered.

Loss scenario

Many different and more or less complete scenarios that offer to explain an appropriate sequence of occurrences of the above three elements of the loss have been proposed, as reviewed in [4]. However, none has put forward a consistent sequence of events which could be considered plausible.

In particular, no clear explanation exists for:

(a) The perceived prolonged capsizing process, that is heeling beyond 40deg until capsize/sinking. It seems from Figure 1 that some 20-30 minutes are assumed for this process to take place.
(b) The sinking process, that is, an explanation of how and when 10,792 m^3 of water reached below the car deck for the vessel to disappear from the radars at 01:52.

The following is a hypothesis addressing these gaps.

STUDY ON POSSIBLE LOSS MECHANISMS

Heeling

It is conceivable that a considerable heeling angle could be induced by flooding spaces below the car deck.

As is shown for a hypothetical flooding case into the forward spaces, such heeling angle can reach some 20deg, see Figure 6.

A study has been undertaken to investigate the possibility of larger angles of heel occurring due to transient flooding effects. The study has comprised a series of numerical simulations of the vessel response when subject to damages below the car deck occurring randomly according to historical data on collisions, see Figure 7.

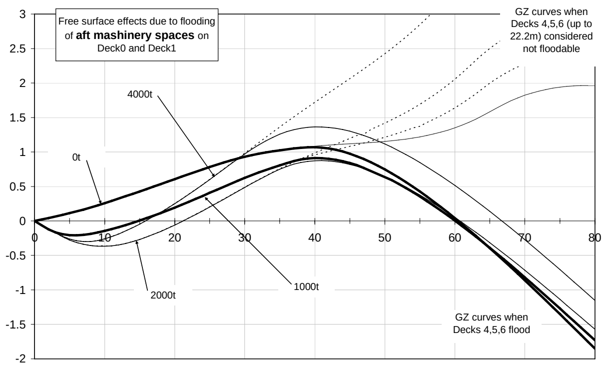

Figure 6 Free surface effects due to flooding of the forward spaces below the car deck.

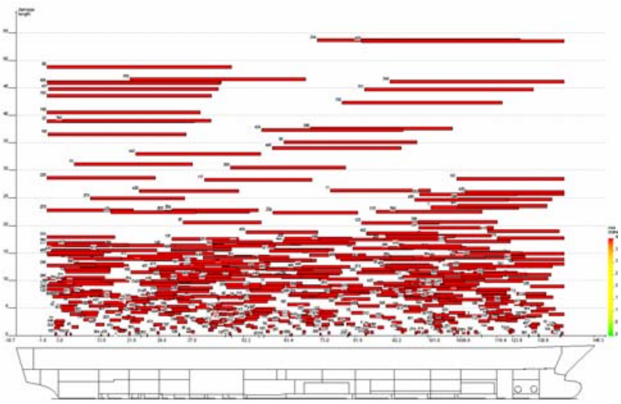

Figure 7 Sample MC simulations set-up, distribution of damage location, length and Hs. Damages assumed below the car deck.

A model of MV Estonia, Figure 8, has been subjected to these damages, Figure 9, and a statistic derived of the maximum heel angles recorded during the initial stages of flooding, as shown in Figure 10.

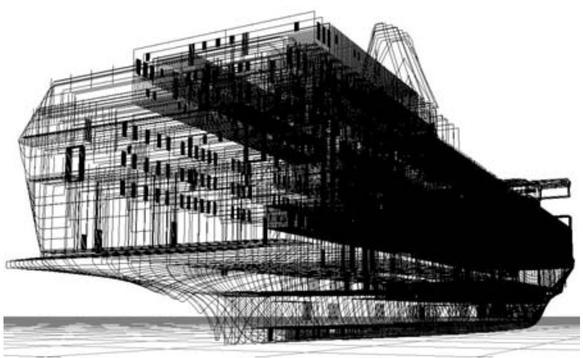

Figure 8 Digital model of MV Estonia, aft and front views, PROTEUS3.

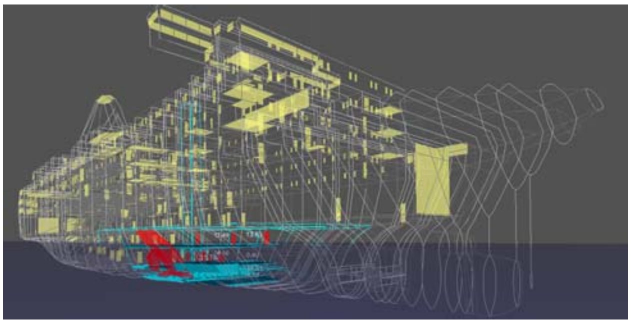

Figure 9 A sample snapshot of the simulation of flooding below the car deck.

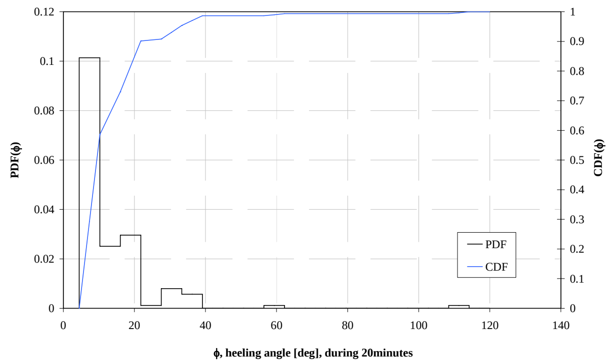

Figure 10 Probability distribution for heel angles recorded during the first 20 minutes from hull breach. Angles in excess of some 20deg result from up-flooding the car deck.

It is evident from this study, as performed to date, that angles of heel in excess of some 20deg could not result from flooding of the spaces below the car deck alone. The car deck (CD) must have also flooded.

It could be argued that such flooding on the CD could indeed result from firstly flooding of the spaces below through breaching the hull below a height of 7.65m from the base plane, and then the car deck through either up-flooding or also a breach of the hull somewhere between 7.65m and 13.4 m height.

Availability of the information on the likelihood of occurrence of different collision damages recorded historically as well as the likelihood of the expected time for capsizing for each of these damages allows for identifying which of the damages would be the most likely to conform to assumptions such as the period of about 30 minutes time to capsize. Use can be made of the Bayesian theory, which states that the conditional probability that a specific space d became flooded, given that a damage occurred in an "ordinary" collision and capsizing occurred subsequently within $t = 30\,\text{min}$ time, can be expressed by the following equation (1):

$$p_{D|T}(d|t) = \frac{p_D \cdot \sum_E p_{E|D} \cdot p_{T|D\&E}}{\sum_D \sum_E p_D \cdot p_{E|D} \cdot p_{T|D\&E}} \qquad (1)$$

Where $p_{E|D}$ is the probability mass function that a specific environmental condition occurred during a collision event; $p_{T|D\&E}$ is the conditional probability that capsize occurs within specific time and for given damage and environmental condition; and p_D is the prior probability that specific damage extent d occurred.

The result is shown in Figure 11.

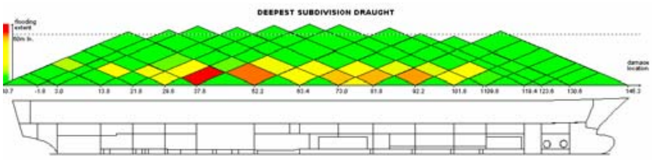

Figure 11 Distribution of conditional probability $p_{D|T}$ that damage $D = d$ occurred (given that a capsize event occurred within time $T = t$), see the dimensionless color scale on the LHS.

It would appear that the most likely damage, given the above assumptions, would be a 2-compartment flooding in the aft, where the machinery is located.

A sample simulation of one of the damages possible at this location is shown in Figure 12. It seems that at least qualitatively, the mode of the loss conforms to some rather established facts, such as sinking with the stern first.

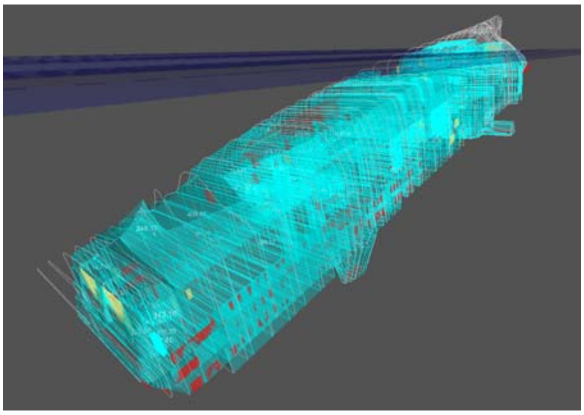

Figure 12 Capsize and sinking of MV Estonia after flooding through damage in the way of engine room and car deck.

Hence, a hypothesis that the initial heeling resulted from flooding of spaces below the car deck, in conjunction with an event of the car deck becoming subjected to water inflow (up-flooding, bow visor loss, etc) carries substantial credibility.

However, according to statements of the three engine room crew, who were present in some 2/3 of the length of the vessel at the very onset of the accident, see Figure 13, no substantial flooding was reported. In total, 22 people from spaces below survived, and none reported any substantial flooding. Hence, any scenario initiating with a breach below the car deck is highly unlikely.

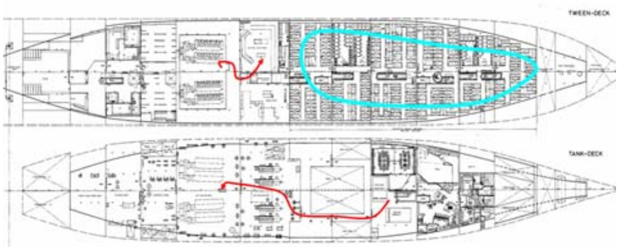

Figure 13 Sketch by the crew (red) and passenger (blue) survivors marking their presence at the initial phase of the vessel foundering. None reports seeing any substantial amount of water in these spaces.

Therefore, it is concluded that the heeling of the ship was caused primarily by water flooding the car deck as the initiating event.

Whether the water entered through bow doors or through any other means is left out of discussion at present.

It is worth noting that through a reverse engineering argument, it can be established that an amount of some 2,500 m^3 of water entered the car deck, leading the vessel to 40deg + heel, which accumulated within some 30 minutes, between 01:00 and 01:30 (last radio communication). It is hypothesised here that at this time the vessel entered the capsize phase, as discussed later on.

Capsizing

The capsizing process is one of the more puzzling elements of the loss mechanisms.

The interpretation of the survivors' statements leads to the perception that the capsizing process (heeling beyond 40deg) has taken "considerable" time.

From Figure 3 it can be inferred that for such prolonged capsizing to materialise, the process of filling the superstructure spaces by water must have delayed the capsizing process, and hence that it took rather longer time than intuitively expected.

Therefore, considerable effort has been spent on verifying numerical and indeed common sense assumptions on how fast these spaces could flood.

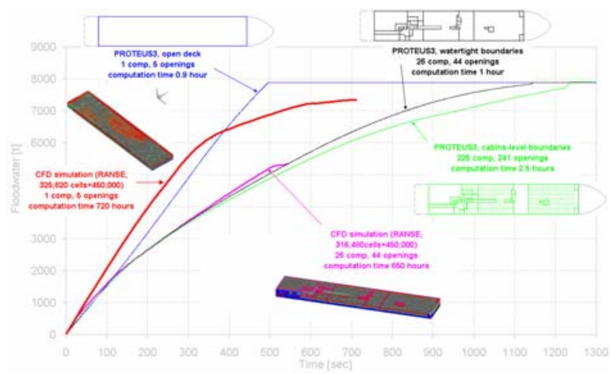

Figure 14 Comparison of the predictions of the process of flooding across Deck 4 in idealised conditions, performed by PROTEUS3 and FLUENT models, [5].

Figure 14 shows that a "decent" degree of detail in representing the internal geometry of the upper spaces is sufficient for representing the flooding process and thus for accurate modelling of the time it took the vessel to capsize. According to results from these simulations the capsizing has never taken more than 2-3 minutes with all the windows assumed broken.

Although puzzling initially, it becomes more plausible that in fact capsize happened relatively fast. Compensating for some simplifications in the model, it is suggested that according to predictions it took some 3-4 minutes.

This would imply that MV Estonia has de-facto floated up-side down.

Considering the conditions prevailing at the time, it may in fact be argued that the survivors testimonies support this hypothesis. Namely, 30 survivors claim that MV Estonia sank by stern. However there are 9 survivors who saw MV Estonia sinking by the bow, since they saw the stern, e.g. propellers. It is suggested here that there is no contradiction in these statements and that all of them saw the vessel in an up-side condition.

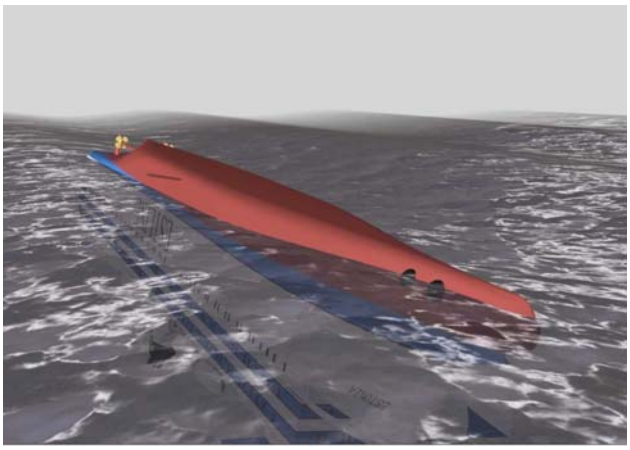

Figure 15 MV Estonia in an up-side attitude; 30 survivors claim that MV Estonia sank by stern, and 9 survivors state that the vessel sank by bow, with one statement about visible propellers. Could all these survivors have seen MV Estonia floating bottom-up?

Sinking

If the ship did float up-side down, then the centre casing becomes submerged some 2 to 8m below the free surface and hence is subject to considerable pressure. Since the design of the centre casing was only as a fire-resistant structure and was fitted with many non-watertight doors, see Figure 18, it is highly likely that it would break and let water into the spaces "below" the car deck. In fact, at a water head pressure of 5m and an opening of $2m^2$ (1 door), the amount that could flood into these spaces in 15-18 minutes would be sufficient for the vessel to sink, see Figure 5.

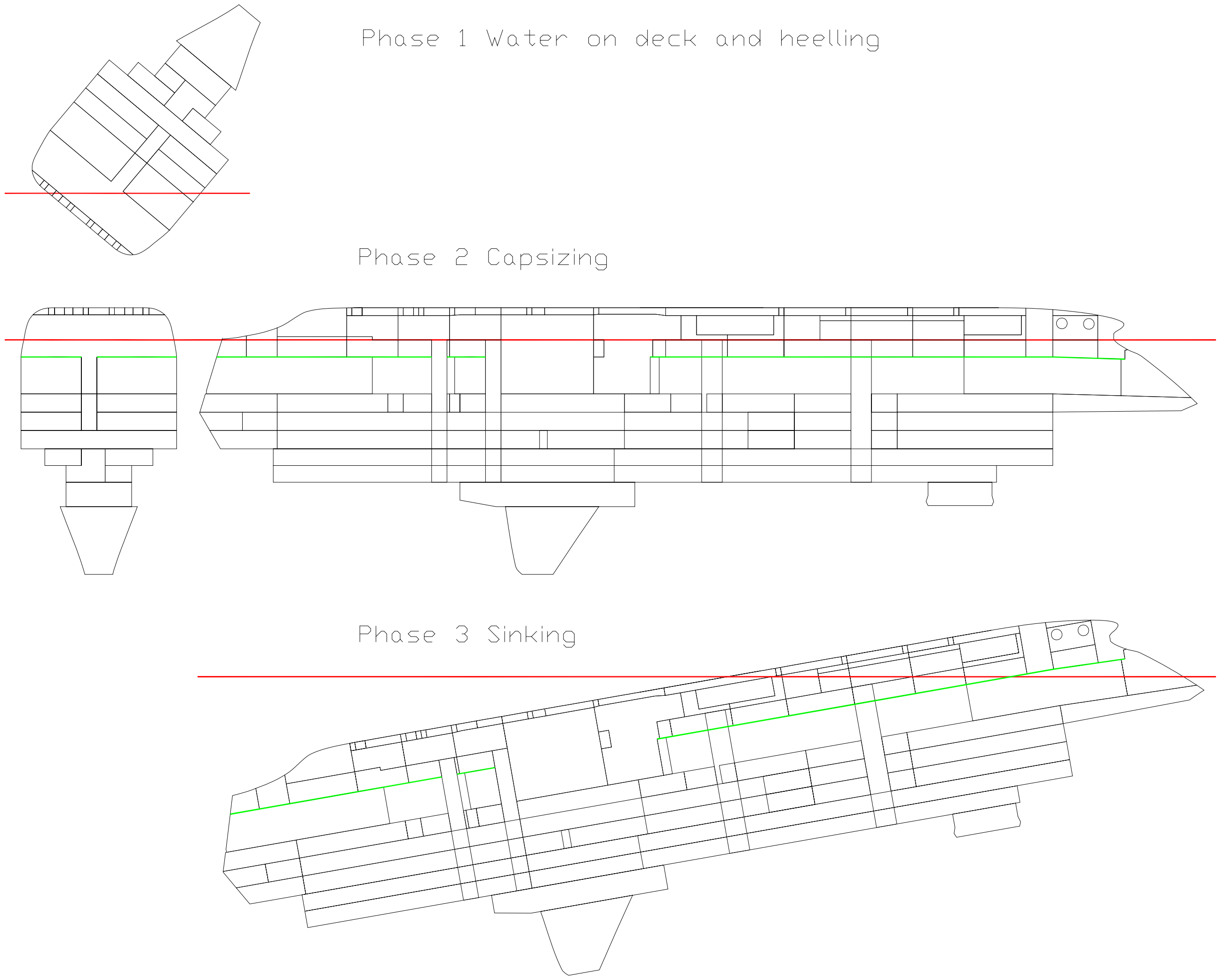

Figure 16 A likely loss sequence of the loss of MV Estonia. Flooding of the spaces below the car deck commenced once MV Estonia capsized. The multitude of doors in the centre casing collapsed due to excessive water head pressure of 2 to 8 m. Some **$2\ m^2$** of opening in the centre casing would be sufficient to allow for 10,792 m^3 of water to enter the spaces below the car deck within 15-18 minutes.

Loss scenario

Therefore, a complete sinking sequence can now be proposed.

As is shown in Figure 16, the sinking sequence can be broken into three phases.

(1) Firstly, water accumulation on the car deck took place. It must have started relatively rapidly with the vessel heeling to high angles

and thus preventing persons onboard from abandonment. At this stage of this investigation no firm suggestions on details of the initial water inflow are proposed, though from Figure 1, or Figure 17 repeated below, it would appear that the initial large heel of some 30deg developed within 5 minutes.

On average, the water inflow between 01:00 and about 01:30 must have been in the order of some 83 m^3/min.

(2) Secondly, once the amount of some 2,500m^3 accumulated on the car deck the vessel capsized, that is, it turned up-side down, within some 3-4 minutes. It is suggested here that 3-4 minutes would be sufficient for many to remember the vessel to have been at 90deg+ attitude "for some time".

(3) Thirdly, the sinking would commence as described above, through the submerged centre casing.

The hypothetical (yet to be verified) time sequence is shown in Figure 17 below.

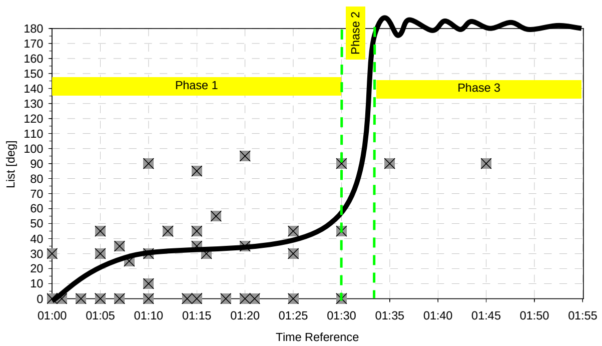

Figure 17 Could it be that heeling, capsizing and sinking followed such trend? Some 83 m^3/min on average have flooded into the car deck between 01:00 and 01:30. Capsizing would take place in some 3-4 minutes. As the vessel turned turtle, all spaces from a height of 7.65 m upwards fill up with water at a rate of some 15,000 m^3/min through many broken windows. Finally, at 01:34 water starts flooding the spaces "below" the car deck (now up) at some 600 m^3/min through the centre casing. In total, over 72,106 m^3 of water enters MV Estonia between 01:00 and 01:52.

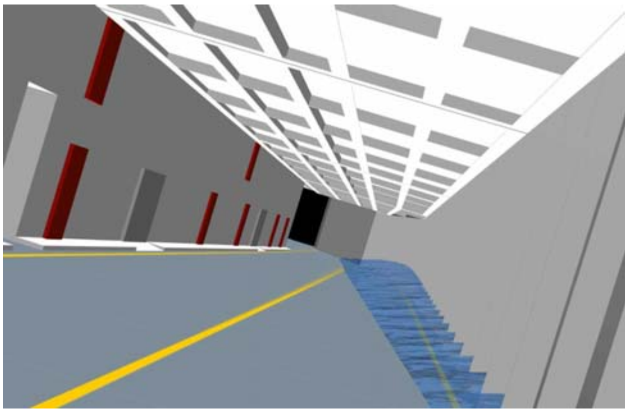

Figure 18 The centre casing was fitted with many fire doors. In an up-side down attitude the centre casing is some 5m below the sea surface, hence it would buckle under pressure and let water reach spaces "below" the car deck.

CONCLUSIONS

This article is a summary of the findings of the investigation carried out within the SSPA partnership to date.

The preliminary conclusions are that:

- MV Estonia heeled because of an inflow of some 2,500 m^3 of water on the car deck between 01:00 and 01:30. The cause of the inflow is not addressed at present. Any substantial flooding below the car deck is unlikely to have been the initiating event because (a) many survivors come from the lower deck spaces forward and (b) the three engine room crew report no substantial amount of water in any of the spaces aft at the onset of the foundering.
- Because of the water on deck, MV Estonia capsized within a course of some 3-4 minutes, during which all the spaces from 7.65 m upwards filled up with 55,284 m^3 of floodwater. It would seem possible that 39 survivors report MV Estonia floating up side down.
- The centre casing on the car deck becomes submerged to some 5 m water head pressure on average. Some doors collapsed and allowed the spaces below the car deck

to fill up with water. An opening of 2 m^2 is sufficient for the requisite 10,792 m^3 to enter these spaces between 01:34-01:52, most likely with the aft spaces flooding faster.

- MV Estonia sinks stern first.

This is offered as a preliminary explanation of the mechanism of the loss of MV Estonia. The investigation is ongoing.

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