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IN THE NORTHERN ESTONIAN REGION

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I, ERIK TOMBERG of translation agency Dussan OÜ, located at Aedvilja 1, Tallinn 10120, phone number: +372 61 43 071, e-mail address: dussan@dussan.ee, ENGLISH LANGUAGE SWORN TRANSLATOR IN THE NORTHERN ESTONIAN REGION pursuant to Sworn Translator's Certificate No. 4 issued by the Republic of Estonia Minister of Justice on 23 January 2003, attest that this is a CORRECT AND TRUE TRANSLATION made by me. The translation has been made from a PDF file, the printout of which is attached hereto on pages 1 to 12.

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REPORT

of the Committee of Experts formed for the investigation of circumstances related to the transport of equipment for military use on the passenger ferry Estonia in September 1994

1. Background

By its Order No. 129 of 07.03.2005 the Government of the Republic of Estonia formed a Committee of Experts for the investigation of circumstances related to the transport of equipment for military use on the passenger ferry Estonia in September 1994 (hereinafter the Committee). Six questions were presented to the Committee in connection with possible transport of military equipment on three dates in September 1994. The Committee presented a report on its work on 01.09.2005.

On 06.10.2005 the Government of the Republic of Estonia extended the term of authorities of the Committee and asked to investigate additionally whether there were any substantial circumstances related to the causes of the wrecking of the passenger ferry Estonia that had not been investigated thoroughly enough. The Committee presented its second report on 10.03.2006.

On 31.03.2006 the Government of the Republic of Estonia extended the term of authorities of the Committee with an aim to ask for explanations of members of the Joint Accident Investigation Commission (hereinafter the JAIC), which operated from 29.09.1994 until December 1997, regarding the statements in the Committee's report of 10.03.2006. Questions compiled on the basis of the Committee's report were sent to the Chairman of the JAIC, Captain Uno Laur and the latter answered the questions in a memorandum of 26.07.2006 (hereinafter the Memo). In its third report, which was presented on 15.03.2007, the Committee took its position on the explanations given in the Memo by U. Laur.

On 01.11.2007 the Government of the Republic of Estonia extended the term of authorities of the Committee again, giving the Committee a task to intermediate the results of research studies on the sinking of the passenger ferry Estonia initiated by the Government of the Kingdom of Sweden. This Report provides an overview of these studies and their results.

2. Background of the studies

According to the JAIC Final Report, the cause that brought about the shipwreck was that the bow visor attachments broke, the visor fell into the sea and the bow ramp opened completely. A large amount of water that flooded to the vehicle deck from the open bow caused the ship quickly to heel starboard. When the list angle reached 40º, windows on deck 4 were submerged under water and broke due to waves and water pressure and water could enter the deck structure. The list continued to increase and when the ship had fallen on its side, the stern part started to sink. The ship disappeared completely from the water surface at about 01:48.

The criticism presented in special literature about such course of events can be summarised as follows. The list of a ship that has lost its stability cannot increase evenly from 0 degrees to 180 degrees. Instead, after water enters the deck structure, the ship capsizes in a few minutes. After that the ship may float on the water surface for hours or even days, because water inflow is prevented by air which cannot escape through the watertight bottom. Exactly the opposite happened with the Estonia – it capsized slowly (ca. 20 minutes) and sank immediately after that (or even simultaneously). The JAIC Final Report does not provide any explanation about such behaviour of the ship. Both questions, what prevented the ship from capsizing quickly and how could water reach below the vehicle deck already before capsizing to sink the ship quickly, are unanswered.

In March 2005 the Government of the Kingdom of Sweden gave the Swedish Governmental Agency for Innovation Systems VINNOVA a task to order a research study that would explain the sinking sequence of the passenger ferry Estonia and provide new knowledge in order to advance maritime safety. A year later VINNOVA ordered such studies from two different consortia.

The SSPA consortium comprised:

– Swedish consulting company dealing with maritime safety and shipbuilding, SSPA Sweden AB;
– Scottish consulting company dealing with maritime safety and shipbuilding, *Safety at Sea Ltd*, together with the Ship Stability Research Centre of the Department of Naval Architecture and Marine Engineering, which is a joint department of the Universities of Glasgow and Strathclyde;
– Chalmers University of Technology in Gothenburg;
– MARIN, Maritime Research Institute of Netherlands in Wageningen.

The research study is presented in 18 reports, which are published on the web sites www.sspa.se and www.safety-at-sea.co.uk/mvestonia/. A list of the reports is provided in the annex. References are made to the reports using the numeration provided in the annex. The positions of the consortium have been represented using also the information obtained from an interview on 06.11.2008 by the Chairman of the Committee with the Scientific and Technical Coordinator of the Consortium Dr. Andrzej Jasionowski (in references: Int).

The HSVA consortium comprised the Hamburg University of Technology and the Hamburg Ship Model Basin. Their research work is formulated in the final report, which is published on the web at www.vinnova.se/upload/dokument/Verksamhet/Transporter/Sjosakerhet/Estonia/HSVA1663FINAL.pdf. The positions of the consortium have been represented using also the information obtained from the TUHH working report, which has not been published, and an interview made on 05.11.2008 by the Chairman of the Committee with Dr. Petri Valanto from HSVA.

The following overviews of the research studies have been coordinated respectively with SSPA Project Manager Dr. Claes Källström and HSVA Project Manager Dr. Petri Valanto.

3. Research study of the SSPA consortium

3.1 Overview

The objective of the research study was to understand the sequence and explain the underlying causes of the loss of the passenger ferry Estonia and to derive suitable recommendations in order to prevent such tragedy from happening again (18, page 11).

For this purpose, survivors' testimonies and other previously collected evidence were analysed at first. Then a model with simplified superstructure of the Estonia was built on the scale of 1:40 and water inflow from the open bow ramp and the development of the list were measured in model tests. Water inflow to various decks of the ship was studied at the same time by mathematical simulations and the resulting behaviour of the ship was observed. Also inflow of water to the deck structure and its further movement were studied by simulations and the model of deck 4 (at the scale 1:20). Finally, a complete model of the Estonia was built (at the scale 1:40) and the possibility of the scenario of the accident considered to be most probable on the basis of the previous work was checked by testing (18, pages 11 to 12).

It was concluded from the study that the sequence of events of the disaster was most probably the following:

– bow visor attachments failed and the visor shifted from its place, forcing the bow ramp also partly open. Water started to flow to the vehicle deck from the sides of the ramp, causing a slowly increasing starboard list;

– at about 01:05 the visor fell into the sea and forced the bow ramp fully open. A large amount of water flowed to the vehicle deck, causing in a few minutes a list of up to 40°;

– due to the list, vents on the side of the ship were submerged under water, and through these vents water started to flow to the watertight compartments below the vehicle deck;

– the windows of the superstructure that had also submerged under water due to the list resisted the water pressure, and therefore the ship did not capsize right away, but floated on its side for 15 to 20 minutes. All this time water flowed below the vehicle deck mainly through the ventilation pipes, but also through the centre casing;

– at last the windows still started to break, the upper decks were flooded and the ship capsized;

– the ship sank with aft first within some 10 to 15 minutes after it capsized, disappearing completely from the water surface at 01:48 (18, pages 6 and 72; 17 pages 96 to 98).

As this version presumes that the hull of the ship is intact and that the windows of the superstructure withstood substantial water pressure, but these circumstances have not been investigated earlier, the consortium strongly recommends:

- to observe thoroughly the entire hull of the ship and to make a documented record of the observation;
- to observe thoroughly the position of the bow ramp at the wreck, to make a documented record of the observation and then bring the ramp to surface for final observations;
- to bring at least three windows with frames to surface and to test them for breaking pressure (18, pages 6 to 7 and 72 to 73).

3.2 Major conclusions

From the point of view of the Committee's earlier reports and discussion on the ship disaster, the following are the major conclusions of SSPA consortium.

1) Mainly as a result of analysis of survivors' statements the consortium concluded that the falling of the visor into the sea and opening of the bow ramp took place 10 minutes earlier than hitherto estimated, at about 01:05. Thus the sequence of events of the accident is extended from 34 minutes to 43 minutes (18, page 19; 5 page 10).

Development of the list

2) If the bow ramp opens on a ship moving at a great speed, the ship develops a list of 40º in a few minutes. Tests with the Estonia model showed that if the ship is moving at a speed of 14.5 knots and the bow ramp is opened completely, sea water starts to flow to the vehicle deck at a speed of 1500 to 1800 tons per minute. As a result of it the list angle increases rapidly: in 30 seconds the list is 15º; in one minute the list is 25º and in about 3 to 4 minutes the list is 46-47º. In this position the ship stabilises and the list can increase further only if water can enter other decks of the ship (3, page 24; 4, page 6; 12, page 12).

3) If the ship is moving with a damaged visor and partly open bow ramp, water inflow is too small for a perceptible list to develop suddenly. Model tests showed that if the visor and the ramp are open in the extent of 1 m, water enters the vehicle deck at a speed of 20 tons per minute (3, pages 18 and 24). Simulations made on the basis of these data showed that at such inflow the list of 21° develops steadily in about 10 minutes (18, page 46).

4) A list of up to 20º can develop on a ship due to the flooding of various compartments below the vehicle deck, but the development of a list of over 20º presumes with great probability that the water has reached the vehicle deck (17, page 12, Art page 4). Yet, water can also reach the vehicle deck through the centre casing moving up from below. Simulations showed that the sinking mechanics, i.e. the known behaviour of the ship, does not allow to exclude scenarios that presume a hole in the bottom of the hull or entry of water to the vehicle deck other than through the bow ramp (14, pages 12 and 13; 17 page 107; Art page 5).

Capsizing

5) If the windows of the hotel section of the ship break at once after submerging, i.e. at

the list of 40º, the ship capsizes in a few minutes. Simulations showed that in case of broken windows the capsizing of the ship (increase of list from 40º to 180º) never took longer than 2 to 3 minutes (Art, page 6). Yet, presuming that the ship windows do not break at all, the ship does not capsize (Int).

6) Consequently a part of the upper deck windows still had to break, but at a higher water pressure than usually assumed. Resistance of the windows is the only physical explanation to why the ship was floating on its side for 15 to 20 minutes and did not capsize rapidly. When it was presumed in the simulation that windows started to break at the depth of 5 m, the capsizing of the ship (increase of the list from 40º to 180º) took 7 minutes; and presuming that windows withstood until the depth was 10 m, the capsizing took 20 minutes (17, pages 13 and 73). The Estonia model, which did not have 6 windows out of 172 windows on decks 4, 5 and 6, turned its bottom up in about 25 minutes (17, page 99).

7) After the windows have broken, the list cannot increase evenly from 40º to 180º, but at some point of time the ship capsizes relatively quickly. Simulations showed that due to the resistance of windows the ship stayed at the list angle of 40 to 45º for 15 to 20 minutes, but when the list angle reached 50º, the ship turned its bottom up in less than 5 minutes (17, page 100). The capsizing of the model started somewhat later – after the opening of the ramp the model developed a list of 45º in a few minutes, which increased over 20 minutes by 80º, after which the model turned its bottom up in less than 5 minutes (17, page 99). During public presentation of the model test on 03.04.2008, which was filmed by the Chairman of the Committee, the capsizing took place even more rapidly – the list increased from 90º to 160º in about 2 minutes.

Sinking

8) When the superstructure of the ship is flooded, the ship always capsizes at first and only then starts to sink, i.e. it is not possible that the ship, which has lost stability, would start to sink already at a list of 90º or 120º. Both simulations and tests with the model showed that no considerable trim developed before the list was 170º. Until that time the ship stayed nearly in a horizontal position. Moreover, both simulations and tests showed that the ship stayed nearly in a horizontal position, i.e. it was floating upside down, also some time after the capsizing (17, pages 99, 100).

9) The ship sinks regardless of whether the doors dividing the ship into watertight compartments under the vehicle deck are closed or open. Still, the position of the doors affects the speed of sinking – simulations showed that the ship with open doors sank in 5 to 10 minutes, depending on the strength of windows, and the ship with closed doors sank in 10 to 30 minutes after capsizing (14, pages 8 and 10). The Estonia model, which had openings instead of doors, sank according to the report in about 5 minutes (17, page 99); yet, at the public presentation which was filmed by the Chairman of the Committee the sinking took 12.5 minutes.

10) The ship sinks only when the vehicle deck and all the compartments above it are filled with water and 83% of the compartments below the vehicle deck are submerged under water. In other words, until 2104 m^3 of the 12895 m^3 space below the vehicle deck are filled with air, the ship does not sink, but floats on the water surface upside down (17,

pages 12 and 50). Depending on where the air is, the ship can float with one end submerged, but it does not sink completely. As stated above, if the ship is in the list, water can flow into the spaces below the vehicle deck first through the vents at the side of the ship and later on also through the broken doors and other openings of the centre casing.

Yet, there were three compartments with a total volume of 2050 m^3 below the vehicle deck, which were not vented from outside the ship and which were not connected to the centre casing other than by a small emergency exit. Thus, if the watertight doors were closed, the entry of water to these compartments could start only after the capsizing of the ship. It means *inter alia* that at the time of capsizing of the ship there was enough water-free space below the vehicle deck to keep the ship afloat (17, pages 14 to 15). The respective simulation showed that if the said emergency exit remains closed, the ship does not sink within simulation time (14, pages 8 and 10).

3.3 Committee's comments

Several circumstances, which limited the activities of the researchers, have to be considered when using the conclusions made on the basis of simulations and model tests. Some of the more significant of these limitations are described below.

Air evacuation

1) Simulation software used does not take into account the phenomenon of so-called trapped air. Namely, for a ship to sink, the air contained in it must be replaced by water. As there are no openings in the bottom of the ship, the air on the lower decks remains trapped in case of capsizing of the ship and it is compressed by the influx of water. Depending on the volume of trapped air, a ship may float on the water for hours or even days. Simulation programs used cannot take account of this phenomenon, which means that the rated inflow of water continues at the same rate also after capsizing of the ship until all the compartments are filled (14, page 7).

The phenomenon of trapped air is a problem also in model tests. Namely, water compresses air less in a small-scale model than in the actual ship, due to which the proportionately same volume of air takes less space in the actual ship than in the model. To compensate for it, 20% of the air trapped in the ship was allowed to exit through remotely operated valves during model tests. In the tests, where air was not allowed to exit, the ship model did not sink, but remained floating upside down (18, pages 60 to 62).

Yet, although the consortium researchers are unable to evaluate the precise impact of trapped air on the sinking of the ship, they are on the position that this impact is marginal and uniform in case of all presumed scenarios (14, page 13).

Model tests

2) As stated above (see section 3.2.4), other scenarios of the loss of the ship cannot be excluded on the basis of existing information. Yet, the consortium did not have resources for making final model tests to verify more than one scenario. It was decided to test the so-called visor scenario, because in the opinion of the consortium the majority of

evidence confirms this version. Yet, the design of the ship model used for the final tests was not based on the circumstances thoroughly studied and considered to be most likely on the basis of previous work, but the ship model was built so that the movement of water and air in the ship would be as free as possible. Attention should be paid primarily to the following solutions:

– after opening of the bow ramp, it was kept open by means of a magnet until the end of the test (18, page 60), although an earlier test had shown that without a magnet the ramp would not stay in place, but would ram up and down (4, page 6). The consortium has also stated in its final conclusions that the ramp may have been fluctuating up and down due to the interaction between waves and the pitch motions (18, pages 6 and 72);

– the model lacked all staircase and elevator fire doors leading to the centre casing vehicle deck, in total 10 doors on the starboard side and 6 on the port side (12, page 9). Considering that already with a list of 35º all the starboard side doors are fully submerged under water, it means that almost immediately after opening of the bow ramp the lower decks remained open to unhindered water inflow through an opening of about 20 m^2 (10 doors, 2 m^2 each). As this is an opening about 10 times larger than all the vent openings together (ca 1.842 m^2), then consequently in the model tests the spaces below the vehicle deck were flooded from the beginning mainly through the doors of the centre casing. Yet, it does not appear from the consortium reports that the actual strength of these doors had been studied separately, as for instance the windows of the deck structure were studied. It is only known that none of the 21 passengers who survived from deck 1 mention that any of the vehicle deck doors were open or broken; but many of them remember that when passing the vehicle deck they saw how water was forcing into the staircase through closed doors;

– of the 21 watertight doors below the vehicle deck, the model had all but one open (i.e. there was an opening instead of a door), allowing thus free flow of water that had reached below the vehicle deck from compartment to compartment and exit of air (12, page 8). Yet, it was known from earlier simulations that the position of watertight doors has a considerable impact on the speed of sinking of the ship (see section 3.2.9 above) and it was concluded from the analysis of testimonies that the watertight doors were closed about 3 minutes after the opening of the ramp (18, page 19; 5 page 22; see also Final Report page 126);

– to allow for better control of exit of air, portside exterior doors opening to the stern and one door in the starboard side opening to the bow were left open, 5 doors in total (12, page 9).

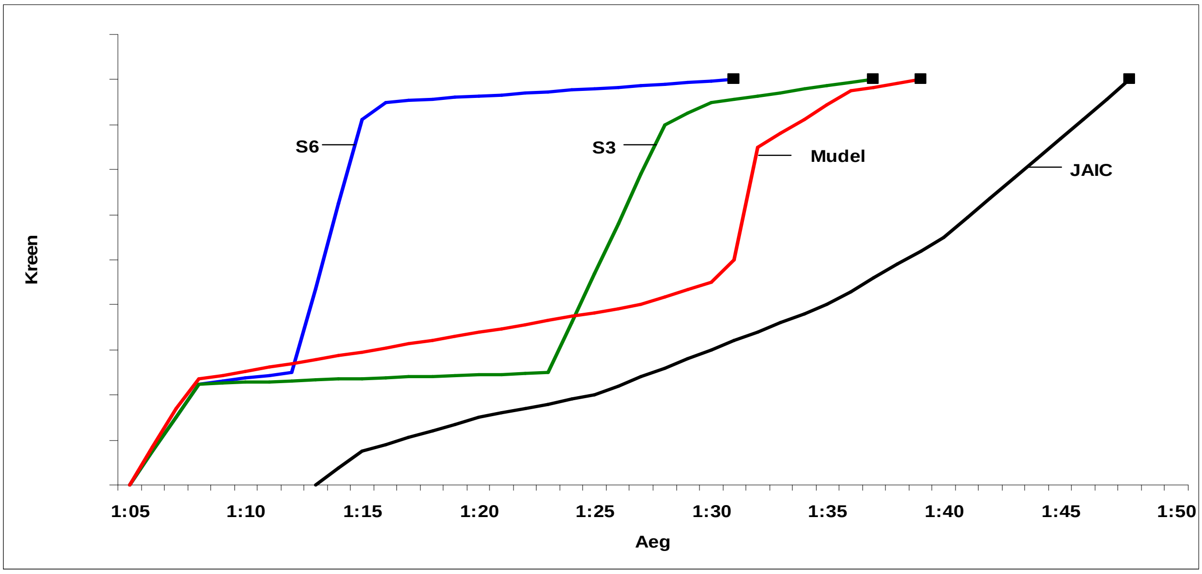
While some assumptions used in the model tests were unverified (e.g. the strength of centre casing doors) and some were unlikely (e.g. that the watertight doors were open), one must be careful when drawing conclusions on the actual accident from the results of the tests. The Committee understands the difficulties in designing a model and therefore the above remarks are not meant as a criticism to the work of the consortium.

3.4 Contradictions with the conclusions of the JAIC

Regarding the primary cause of the accident, the consortium agrees with the JAIC, finding that the accident was caused by failure of the visor and opening of the bow ramp. Yet, the consortium has described the sequence of events of the accident with the following significant differences.

1) Maybe the largest difference between the positions of the JAIC and the consortium is related to the position of the ship at the time of sinking. According to the Final Report the ship started to sink towards the stern already at the list angle of 80º and a large part of the ship was submerged under water at the list angle of 110º (pages 165 and 167, see also 79). In the opinion of the consortium this is not possible, because a ship that has lost stability always capsizes first and only then starts to sink. In simulations, the ship with an intact bottom never started to sink towards the stern before the list angle was at least 170º. The same was confirmed by the test with the Estonia model.

2) The treatment of the JAIC and the consortium of the development of list is also significantly different. According to the Final Report the ship which was moving at full speed developed quickly after opening of the ramp a list of 15º, which remained stable for some time. During this time the speed was lowered, watertight doors were closed and a turn to the left was started. During the turn the list started to increase and it increased further more or less evenly until the sinking of the ship (pages 165 to 167). Model tests carried out by the consortium showed that if the bow ramp is opened on the ship which is moving at a great speed, the list increases evenly and quickly to an angle of 45º. But from then on the list cannot increase evenly. Instead, after the windows break or water enters the deck structure, the ship capsizes in a few minutes. Depending on the strength of windows the capsizing may start sooner or later, but in any case it happens quickly (see section 3.2.6). The differences in the development of the list are shown in the following figure.



[Text in the figure:] List / Time

JAIC (black line) – JAIC version on the basis of the Final Report
Model (red line) – Model test, where the watertight doors and vehicle deck doors were open

S3 (green line) – Simulation, where the strength of windows was 10 m and the watertight doors were open

S6 (blue line) – Simulation, where the strength of windows was 5 m and the watertight doors in the aft were open

■ – The moment, when the ship disappeared completely from the water surface

3) According to the Final Report the windows on deck 4 started to break at a list angle of 40º, allowing water to enter the upper decks. Although the JAIC does not state directly that all the windows broke, the wording of the Final Report indicates that the breakage of windows was extensive (pages 153 to 154, 165, 171, 207, see also Memo, page 7). The study of the consortium showed that if the breakage of windows had started so early and if it had been so extensive, the ship would have capsized in a few minutes. But as it clearly appears from the survivors' statements that it did not happen, the consortium inferred that only some windows broke and even these broke at higher water pressure than usually assumed.

4) The JAIC has expressed a view that a hole in the hull below the water line would have brought along an entirely different course of events compared to what actually happened (Memo page 7; annex page 3). Yet, simulations carried out by the consortium showed that the penetration of water to the ship below the water line may cause the same chain of events as the opening of the bow ramp on the vehicle deck as regards the main points (list – capsizing – sinking, see section 3.2.4). The only difference was that in case of the so-called hole version the increase of the list was more even and sinking started earlier, 2 to 3 minutes after capsizing (14, page 12). These two differences by the way differentiate the version of the JAIC compared to that of SSPA consortium (see sections 1 and 2 above).

3.5 Contradictions with the testimonies

Angle of the first list

1) In the description of the most likely scenario of the accident the consortium has taken a view that before the visor fell into the sea the damaged visor and ramp stayed in a forward-shifted position, due to which water could enter the vehicle deck on the sides of the ramp and the ship developed a list of 5 to 10 degrees in about 5 minutes. Survivors' statements do not support this presumption. Namely, all the witnesses who were awake remember that the ship slanted to the right rapidly. Some people talk about one, others about two or three consecutive falls of the ship, but in any case people remember that the ship achieved a considerable list within a short period of time. The fact that the list angle was not actually inconsiderable, can be concluded in addition to people's estimations (15 to 45 degrees) from the description of the situation, according to which many people fell (also from the bed to the floor) or things fell (tables, chairs, cupboards, wall mirrors etc.) around them.

Monitor in the engine control room

2) The Consortium's version of the course of the accident does not agree with the testimony of the three crew members who saw at the monitor of the engine control room that the bow ramp was in a closed position when the ship had already developed a

perceptible list. As consortium took a position that the list started to increase rapidly and exceeded the angle of 10º only after the ramp had fully opened due to detachment of the visor, they presumed that the men were looking at the monitor at the time when the visor and the ramp stayed in a forward-shifted position. When the visor fell to the sea, the men were in the engine control room, but did not look at the monitor any longer (18, page 18; 5 page 20).

Such explanation is not convincing to the Committee primarily for the following reason. Like all other people who were awake, the above crew members also remember that the ship was suddenly in a permanent list. Namely that was the reason why the third engineer stood up from the chair and looked at the monitor and the motorman and system engineer decided to leave from the workshop and sewage room, respectively, and go to the engine control room to find an explanation to the situation. None of the men have said that later on, when they were already in the engine control room, a new, much faster and bigger heeling took place. But this is exactly what they should have remembered, because according to the consortium's conclusions the increase in list after the detachment of the visor was more than 10 times steeper (ca 25º per minute) than the slanting caused by the water pressing in between the sides of the ramp (ca 2º per minute).

Distress traffic

3) It was concluded on the basis of model tests that at 01:24 the list of the ship had to be about 70º and at 01:29 about 90º. Based on the simulations, the list angles should have been 45 and 100 degrees, respectively.

At the same time, there is a recorded emergency call from the Estonia at 01:24.46, where the navigator says: „We have a problem, a bad list to the right side. I believe that it was 20...30 degrees." It is hard to believe that the navigator who made the emergency call was so much mistaken in evaluating the list angle. With a list of 70º it is not possible to stand on the floor, because it has become a wall. Considering that the bridge of the Estonia was an open space 27 m wide, the navigator could not stand anywhere at the list of 70º, but he had to be hanging somehow from the control board. It is hard to believe that in such conditions he thought mistakenly that the list was 30º maximum.

It is also hard to believe that at 01:29.27, when the last emergency call was made from the Estonia, the list of the ship was already 90º, which besides other things means that about a half of the bridge was under water.

Position of the ship at sinking

4) The consortium's position that the ship remained on the water surface upside down for 10 to 15 minutes before sinking does not agree well with the survivors' testimonies either. None of the survivors have said that they saw the bottom of the ship floating on the water surface for a long time. At the same time there are several witnesses who remember that the ship sank under water immediately after capsizing or even simultaneously with capsizing. There are also people who claim that the stern of the ship started to sink already when the ship was on its side. Thus, the survivors' statements in aggregate rather support the version of the JAIC (and HSVA) about the final position of the ship than that of SSPA.

It must be noted here that it cannot be clearly understood from all interrogation records in which order people saw something, from where and for how long they saw it. This causes apparent contradictions and allows several alternative interpretations.

4. Research study of the HSVA consortium

4.1 Overview

The purpose of the study was to shed light on the sinking sequence of the Ro-Ro passenger vessel Estonia and to explain the underlying causes for its loss, in order to improve the maritime safety of this in general very successful ship type (page 4; here and hereinafter all references refer to the Final Report of the HSVA consortium).

The study was carried out by the Hamburg Ship Model Basin (HSVA) and the Hamburg University of Technology (TUHH) and it consists of four parts. At first the most probable scenario of the accident was determined on the basis of the earlier collected evidence and initial hydrostatic analysis. Then HSVA analysed by mathematical simulations the behaviour of the ship during and after the turn to port made after losing the visor. While respective software enables to reliably study ship behaviour until the time the ship list is 55º, TUHH made a separate hydrostatic analysis (calculation) to clarify the circumstances related to the final capsizing and sinking of the ship. As HSVA and TUHH carried out their analyses independently, the respective author is shown in case of each conclusion in the following overview (pages 4 to 5, 66).

In addition, HSVA analysed the evacuation of people from the ship by special software. Yet, the results of this analysis are not presented below, because these are not relevant considering the task of this Committee.

Although the consortium has not explicitly stated so in its report, the probable scenario of the loss of the ship can be formulated on the basis of HSVA and TUHH conclusions as follows:

– at 01:00 the bow visor fell into the sea and forced the ramp fully open;

– after that the ship continued to advance straight ahead at a speed of at least 14.2 knots for 2-3 minutes, allowing thus the entry of a large amount of sea water into the vehicle deck;

– after that the crew reduced the speed and turned the ship to port towards the waves, as a consequence of which a big list developed immediately;

– although the list decreased over the next few minutes, the vent openings on the side of the ship at the height of deck 4 remained still submerged under water and water started to flow below the vehicle deck. But even more importantly, water started to flow to lower decks also through the vehicle deck doors, of which some were open or broke;

– after 15 to 20 minutes single windows and doors of the deck structure started to break. Water that had flowed to the upper decks increased the list further, but the ship did not capsize. At the same time the ship started to sink slightly towards the stern;

– at 01:43, when the list was about 120 to 140 degrees, the stern hit the seabed. The bow disappeared from the water surface 9 minutes later, at 01:52.

4.2. Major conclusions

From the point of view of the Committee's earlier reports and discussion on the ship disaster, the following are the major HSVA and TUHH conclusions:

1) As a result of analysis of the evidence, the consortium concluded that the visor detached and the bow ramp opened at 01:00, which means that as compared to the JAIC the duration of the accident is extended by 14 minutes. This is *inter alia* proved by the distance between the places of finding the visor and the shipwreck. The JAIC timeline presumes that the ship drifted due to wind, waves and current at a speed of 1.5 knots also when the list exceeded 90º and a large part of the ship was submerged under water. In the opinion of the consortium this is questionable (page 59, see also 16 to 17).

Development of the list (based on HSVA simulations)

2) For the ship moving at a great speed to develop a perceptible list in a few minutes, the bow ramp must open completely. The initial analysis showed that if the ramp is open in the extent of 1 m, the development of a list of 10º takes 26 minutes or 7 minutes, depending on whether the visor is in place or not. But if the ship is moving with a fully open ramp, seawater enters the ship at a speed of 300-700 m^3/min and the ship therefore develops a list of 10º in 3 to 4 minutes. In all cases the list increases gradually without major variations (pages 27 to 29).

3) The sudden heeling motion reported by all the survivors may have been caused by the ship's turn to port. The initial analysis showed that when turning the ship sharply to port, the list increases instantly by 20º if the ramp is open in the extent of 1 m and by 26º if the ramp is fully open. The assumption that the list was caused by a big wave is very unlikely, however (pages 30 to 33).

4) Water inflow from the open bow is significantly influenced by the speed of the ship and by how long the ship advanced straight ahead after the opening of the ramp. The amount of water on the vehicle deck before starting the turn is in its turn of critical importance to further course of events. Simulations showed that if the speed of the ship was 16 knots, the ship capsized quickly even before the turn was completed. When the initial speed was 15 knots, the list increased at starting the turn to 50º within a couple of minutes, then decreased in a couple of minutes to 30-25 degrees, remained at that level for about 20 minutes and then started to increase quickly again. At last the ship still capsized. But when the initial speed was reduced by half a knot, to 14.5, the ship was able to survive the U-turn (pages 49 to 51).

The simulations also showed that the ship had to advance straight ahead with an open ramp for 2-3 minutes. Had this time been significantly shorter, the ship would have survived; and had the time been significantly longer, it would have capsized quickly (pages 46 to 47, 63).

5) Water must have started to flow below the vehicle deck through the vent openings and the centre casing doors already at the time of the turn. Otherwise the ship would have either capsized quickly or survived the turn (page 40). Simulations showed that the entry of water below the vehicle deck through the vehicle deck centre casing doors is namely of critical importance. When it was presumed that 1/3 of these doors were open and the vent openings were closed, the ship developed a large sudden heel, but was still able to survive the turn. Yet, in the contrary case, when the vent openings were open and the centre casing was watertight, the ship developed a relatively small list and most of the water flowed out of the vehicle deck already during the turn (pages 57 to 58).

6) Turning the ship with an open bow to starboard away from the waves would have been even more dangerous. Simulations showed that the ship would have capsized quickly in this case. During the turn to port more water enters the ship, but due to larger pitch motions much water flows out, too. At the same time, in case of a turn to starboard the amount of water entering the ship is smaller, but almost all the water remains in the ship and increases the list (page 61 to 63).

Capsizing and sinking (based on TUHH calculations)

7) Breaking of the superstructure windows does not necessarily bring along quick heeling of the ship. Instead, the list may increase gradually without major leaps until sinking of the ship. It was presumed in the calculation that big windows at the ship stern broke at the depth of 3.3 meters, the first ones approximately at the list of about 45º, and small windows in front of the ship at the depth of 8.2 meters. This resulted in a relatively steady increase of the list. The ship sank finally without turning upside down, at a list of approximately 125-140° (pages 71, 72 and 150).

8) The ship capsizes and sinks fully in about 50 minutes even if the vehicle deck doors and watertight doors in the lower part of the ship are closed (page 69).

9) The ship that has lost stability may start to sink also when on its side and remain for up to 9 minutes so that the ship stern is on the seabed and the tip of the bow is above water. According to the calculation at 01:30 the ship's list was 70º and the trim 4º. At 01:43, when the list was more than 120º, the stern hit the seabed, i.e. the trim was about 22º (pages 72 to 73).

10) It suffices to sink the ship when the cabins section, engine control room and workshop on deck 1 and the auxiliary engine room and sauna area on deck 0 are filled with water only in the half extent, i.e. there is about 3500 m^3 of water-free space in the bottom part of the ship. When the stern of the ship hit the seabed, i.e. the ship was already partly sunk, there was still 5700 m^3 of air inside the ship (pages 70 and 73).

4.3. Contradictions

1) There are considerable differences between the conclusions of TUHH and SSPA concerning the conditions of capsizing and sinking of the ship:

– SSPA claims that the list of the ship that has lost its stability cannot increase steadily until sinking, but after the windows of the deck structure break the ship capsizes relatively rapidly. But the position of TUHH is that rapid capsizing need not take place;

– SSPA claims that the ship which has lost its stability always capsizes first and only then starts to sink. The opinion of TUHH is that such a ship sinks fully also at the list of about 135 degrees. At the same time, both consortia find that the survivors' testimonies support namely their opinion about the ship's position at the time of sinking (see e.g. SSPA 14, pages 12 and HSVA page 19);

– SSPA claims that if there is a minimum of 2104 m^3 of water-free space in the ship, the ship does not sink, but floats, upside down, on the water surface. The position of TUHH is that even 3500 m^3 of air does not prevent the ship from sinking.

2) There are also notable differences between the conclusions of HSVA and SSPA concerning the inflow of water through the open bow ramp. SSPA tests showed that water forced in through the fully open bow ramp at a speed of 1500-1800 t/min, causing a list of 46º in 3-4 minutes. But HSVA analysis showed 2 to 5 times smaller water inflow, which means *inter alia* that in 3-4 minutes the ship developed only the list of 10º.

3) In theoretical issues the positions of the HSVA consortium and <u>the JAIC</u> do not differ much. Yet, as a result of analysis of the evidence, the consortium concluded that the disaster started 14 minutes earlier. It may also be suspected that the JAIC presumed more extensive breakage of deck structure windows and doors than TUHH and HSVA.

4) As regards contradictions with the <u>testimonies</u>, the following should be considered significant. The scenario of the HSVA consortium, like that of SSPA and the JAIC, does not agree with the testimonies of the three crew members, who saw the closed ramp at the monitor of the engine control room after the ship had developed a sudden list. As the consortium tries to adapt the statements of the three men to its scenario in principle in the same manner as SSPA, the Committee does not repeat here the discussion presented in section 3.5.2.

5. Conclusions of the Committee

In the opinion of the Committee, the following general conclusions can be drawn on the basis of the reviewed research studies:

1) The sinking of the passenger ferry Estonia due to the causes and in the manner described by the JAIC is possible, and based on the hitherto collected evidence it must be considered to be the most likely scenario of the sinking of the ship;

2) Yet, the sinking mechanics, i.e. the known behaviour of the ship, does not allow to exclude scenarios that presume a hole in the bottom of the hull or entry of water to the vehicle deck other than through the bow ramp. Therefore, such theories cannot be convincingly refuted by theoretical studies based on the existing evidence. If it is

desirable to prove that the hull is intact, the exterior of the wreck must be systematically studied and the study activities must be duly recorded. As we know, this has never been done;

3) The survivors' statements as recorded after the accident in the interrogation records can be used to confirm different, even contradicting theoretical opinions and scenarios. Therefore, yet another revision of the testimonies would not give any more certainty about any of the suggested scenarios of the sinking of the ship.

Tallinn, 16 February 2009

Margus Kurm

Chairman of the Committee
Leading Public Prosecutor

Annex

List of SSPA consortium reports

1. Vassalos, D, Jasionowski, A, Prigara, J, Guarin, L: "WP2.2 Definition of foundering scenarios, WP3.5 CFD Computations and validations, WP4.1 Comprehensive modelling of MV Estonia", Safety at Sea Report No VIES01-RE-001-AJ, September 2006.

2. Rutgersson, O, Schreuder, M, Bergholtz, J: "WP2.1 Review of evidence and forming of loss hypothesis", Department of Shipping and Marine Technology, Chalmers, Technical Report, October 2006.

3. Allenström, B, Thorsson, S: "Manoeuvring tests and bow ramp flooding tests" SSPA Report 4006 4100 – 1, March 2007.

4. Allenström, B: "Bow ramp flooding tests with complete car deck", SSPA Report 4006 4100 – 2, May 2007.

5. Bergholtz, J, Rutgersson, O, Schreuder, M: "WP2.1 Review of evidence Report No. 2 Conceivable course of events", Department of Shipping and Marine Technology, Chalmers, Technical Report, May 2008.

6. Blok, J J, Luisman, H: "Model experiments on MV Estonia: Flooding tests of superstructure deck No. 4", MARIN Report No. 20374-1-RD, April 2008.

7. Carette, N F A J, van Daalen, E F G, Ypma, E L: "Computations on MV Estonia: FREDYN Simulations of flooding of superstructure deck No. 4", MARIN Report No. 20374-2-RD, April 2008.

8. Tukker, J, Blok J J: "Model experiments on MV Estonia: PIV Measurements of flow velocity in flooding tests of superstructure deck No. 4", MARIN Report No. 20374-3-RD, April 2008.

9. Blok, J J, van Daalen, E F G, Tukker, J, Ypma, E L: "Overall summary report of MARIN research", MARIN Report No. 20374-4-RD, April 2008.

10. Schreuder, M: "WP4.1-4.3 Numerical simulations of foundering scenarios", Department of Shipping and Marine Technology, Chalmers, Technical Report, April 2008.

11. Ottosson, P: "SEAMAN simulations of course of events before foundering", SSPA Report 4006 4100 – 3, April 2008.

12. Allenström, B: "Foundering tests", SSPA Report 4006 4100 – 4, April 2008.

13. Strasser, C: "CFD Simulations on MV Estonia: Flooding simulations of superstructure deck No. 4", Ship Stability Research Centre (SSRC), Universtity of Strathclyde, Report No VIES01-RE-003, May 2008.

14. Jasionowski, A: “PROTEUS3 Simulations of foundering scenarios”, Safety at Sea Report No VIES01-RE-002-AJ, May 2008.

15. Jasionowski, A: “Virtual demonstrator”, Safety at Sea Report No VIES01-RE-004-AJ, May 2008.

16. York, A: “Stability analysis MV Estonia”, Safety at Sea Report No VIES01-RE-005-AY, May 2008.

17. Jasionowski, A and Vassalos, D: “Technical Summary of the Investigation on The Sinking Sequence of MV Estonia”, Safety at Sea Report No VIES01-RE-006-AJ, May 2008.

18. SSPA Consortium: ”Final Report- Research Study on the sinking sequence of MV Estonia”, SSPA Research Report No. 134, ISBN 91-86532-47-2, ISSN 0282-5805, May 2008.

This document contains thirty (30) pages corded under my seal, including the printout of file, from which the translation was made.

19 February 2009.

SWORN TRANSLATOR