FINAL INVESTIGATION REPORT

M/V "AL SALAM BOCCACCIO 98"

February 03th, 2006

R-054-09/DIAM

INTRODUCTION

The Investigation committee, composed of The Arab Republic of Egypt as a Lead State and the Republic of Panama as the Flag State, decided to merge resources in order to carry out the casualty investigation of the M/V AL SALAM BOCCACCIO 98.

The Committee agreed to work within the International framework and terms of references as established by the IMO CODE FOR THE INVESTIGATION OF MARINE CASUALTIES AND INCIDENTS, Resolution A.849(20), as amended, and the International conventions to which each State is Party.

Several factors while conducting the initial phases of the investigation and the discussion of the preliminary draft report resulted in the issuance of separate reports by each State.

The present report is based fully on the United Nations Convention on the Law of the Sea (UNCLOS), the International Conventions to which Panama is Party, Panama National Law and the IMO resolution A.849(20), as amended.

Note: The original version of the preliminary report was presented in the Spanish Language, however, for matters of cross reference, the present report has been made available in English.

OBJECTIVE

The sole objective of the investigation of the sinking of M/V AL SALAM BOCCACCIO 98 is to determine its cause(s), in order to prevent future accidents of the same nature, taking as a reference the IMO Code for the Investigation of Marine Casualties and Incidents, Resolution A. 849(20), as amended.

This investigation is not for the purpose of determining liability, or to apportion blame, however, the investigating authorities have not refrained from fully reporting the cause(s) because fault or liability may be inferred from the findings.

This is the final presentation of issues gathered relevant to the investigation of the sinking of the MV Al Salam Boccaccio 98, stating the facts and conclusions achieved through research, testing, interviews and surveys. We reiterate that the intent of this report is not to adopt a position of pointing out fault or blame. Nonetheless, we needed to identify errors, whether technical or human, in order to recommend corrective actions or institute or upgrade guidelines and procedures that would avoid recurrence of accidents of this nature.

SYNOPSIS

The M/V AL SALAM BOCCACCIO 98, was a Panama registered RO-RO passenger vessel that sank on February 03, 2006, at approximately 0133 hours Egypt local time (2333 hours UTC on February 02, 2006), during her journey across the Red Sea, a short international voyage where she departed from the Port of Duba, Saudi Arabia, with destination to Safaga, Egypt.

The vessel departed from the Port of Duba at 1651 hours UTC, with a total of 1418 persons on board including crew members, their luggage, and fully loaded with cars and some trucks. The voyage started as usual, while the vessel was on routine normal trading between the above mentioned ports.

Approximately 2 hours and 20 minutes after departure, at about 1909 hours UTC, the auto-pilot alarm sounded on the bridge and a few seconds later, the fire-alarm sounded.

The crew members started fighting the fire with different means on board and as a result of the fire mitigation efforts, the scuppers were partially blocked, and the accumulation of a large amount of water, coupled with the weather conditions, finally caused an excessive list of the vessel to starboard.

With the intention of correcting the list of the vessel, the master began ordering ballast water operations leading to a further increase of the list of the vessel. As a result of the list, sea water ingress into the vessel, eventually causing it to sink.

This accident was due to a sequence of events that started with a fire on board amidst bad weather. Evacuation orders were never given to the crew members or the passengers at any time and caused the loss of 1,031 persons, including some crew members, the total loss of the cargo and the vessel.

With the outcome of this investigation several recommendations have been made to the IMO, the Flag State, the Coastal State and the Management Companies of RO-RO passengers vessels, as a matter of urgent attention.

APPOINTMENTS

The following appointments were designated by the Panama Maritime Authority:

Reynaldo Garibaldi
Marine Engineer
Chief of the Technical Department and the Casualties Investigation Branch Panama Maritime Authority

Napoleon Smith
Marine Engineer
Panama Maritime Authority
New York Technical Office

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CHAPTER "A"

FACTUAL

INFORMATION

1. GLOSSARY AND ABBREVIATIONS

AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
CCTV	Close Circuit Television
CEC	Certificate of Equivalent Competency
COC	Certificate of Competency
CPA	Close Point of Approach
DOC	Document of Compliance
E/R	Engine Room
GMDSS	Global Maritime Distress and Safety System
GPS	Global Position System
GT	Gross Tons
IMO	International Maritime Organization
ISM	International Safety Management Code for the Safe Operation of Ships and for Pollution Prevention
ISSC	International Ship Security Certificate
KW	Kilowatts
LBP	Length between Perpendiculars
LT	Local Time
NM	Nautical Miles
PSC	Port State Control
PMA	Panama Maritime Authority
PSR	Panama Shipping Registrar
PSSC	Passenger Ship Safety Certificate
OOW	Officer On Watch

RINA	Registro Italiano Navale
C/E	Chief Engineer
C/O	Chief Officer
1/E	First Engineer
2/O	Second Officer
2/E	Second Engineer
3/O	Third Officer
3/E	Third Engineer
A/B	Able Seaman
OS	Ordinary Seaman
MDO	Marine Diesel Oil
HFO	Heavy Fuel Oil
LO	Lube Oil
FW	Fresh Water
SW	Sea Water
ROV	Remotely Operated Vehicle
RPM	Revolution Per Minute
SMC	Safety Management Certificate
SMS	Safety Management System
SOLAS	Safety of Life at Sea Convention 1974
STCW	International Convention on Standards of Training and Watch keeping for Seafarers
UTC	Universal Coordinate Time
VDR	Voyage Data Recorder

VHF	Very High Frequency (radio)
VTS	Vessel Traffic System

2. ACCIDENT SUMMARY

2.1	Name of the vessel:	M/V AL SALAM BOCCACCIO 98
2.2	Flag:	PANAMA
2.3	Date of Sinking:	FEBRUARY 02, 2006
2.4	Time of Sinking:	23:33 UTC (0133 Egyptian local time)
2.5	Position:	27º 08.0’ N, 034º 59.1’ E
2.6	Total on board:	1,418
2.7	Total Loss of Life:	1,031 (710 missing and 321 bodies recovered)
2.8	Rescued alive:	387
2.9	Owners:	Pacific Sunlight Marine Inc.
2.10	Management Company:	El Salam Maritime Transport Co.
2.11	Classification Society:	RINA
2.12	Other RO:	Panama Shipping Registrar (PSR)
2.13	Pollution:	None reported

3. SHIP DETAILS

3.1	RINA Number :	46913
3.2	IMO Number :	6921282
3.3	Former Names :	Boccaccio
3.4	Service :	Ro-Ro Passenger Ship
3.5	Owner :	Pacific Sunlight Marine Inc.
3.6	Flag :	Panama
3.7	Call Sign :	3FIH9
3.8	Port Nº register :	Panama- 28066 Pext
3.9	Characteristic of Service:	Unrestricted Navigation
3.10	Class Period:	5 : 0 : 0
3.11	Class Starting date :	March 31, 2003
3.12	First Entry date :	June 1, 1970
3.13	Special notations :	None
3.14	Equip Nº :	1898
3.15	Gross Tonnage:	11779
3.16	Net Tonnage:	5555
3.17	Overall length:	130.98 m
3.18	LBP:	118.00 m
3.19	Molded breath:	23.60 m With Sponsons
3.20	Tonnage height:	12 m Upper Deck
3.21	Free board:	1312 mm
3.22	Draught:	5900 mm
3.23	Hull information:	Steel/ordinary-SD-BuB-Mer-18Dk
3.24	Derricks and cranes:	1 crane
3.25	Electrical plant Gen:	4x750kVA 1x187.5kVA x 1x1162.5kVA 440 V 60 Hz AC.
3.26	Speed:	22 Knots
3.27	Power, in kw-r.p.m:	12180
3.28	Numbers of cars:	22
3.29	Numbers of trucks:	14 Truck with head
3.30	Number of trailers:	6 of 40 feet, and 1 of 20 feet

4. HULL

4.1	Builder:	Italcantieri s.p.s.-stab. Castellammare Di Stabia
4.2	Building Year :	1970
4.3	Building place :	Castellammare Di Stabia
4.4	Number of building :	4237

5. MACHINERY

5.1	Number – type – Designer :	2 Diesel Fiat
5.2	Year built:	1970
5.3	Manufacturer and place of build:	Cantieri Riuniti Dell`Adriatico (Fabbrica Motori S. Andrea.)
5.4	Power (k-W) and rpm:	12180 (2x6090) kw at 220 rpm
5.5	Characteristics:	2s 9cyl-line 600x800 Chp DR.

6. BRIDGE EQUIPMENT

6.1 Standard and spare magnetic compass
6.2 Gyro compass and heading/bearing reference
6.3 Autopilot
6.4 Echo sounder
6.5 GPS
6.6 Radars 9 GHz and 3GHz
6.7 Automatic radar plotting aid (ARPA)
6.8 Automatic identification system (AIS)
6.9 Speed and distance measuring device (through the water)
6.10 GMDSS equipment for area A1, A2, A3:
6.11 VHF radio installation
6.12 MF/HF radio installation
6.13 Secondary means of alerting
6.14 NAVTEX
6.15 EGC receiver
6.16 Satellite EPIRB – COSPAS – SARSAT
6.17 IMMARSAT SAT – A telex/voice/fax
6.18 IMMARSAT SAT – C (two).
6.19 VDR
6.20 Rudder indicator
6.21 Telephone to emergency steering position
6.22 Signaling lamp

7. RELEVANT SAFETY EQUIPMENT

7.1	Total number of Lifeboats:	10 (5 on each side)
7.2	Total persons accommodated by them:	890
7.3	Number of motor lifeboats:	2
7.4	Number of Lifeboats with search lights:	2
7.5	Number of Fast rescue boats:	1
7.6	Life rafts:	88
7.7	Number of persons accommodated by them:	2,200
7.8	Number of life buoys	18
7.9	Number of buoyant apparatus	6
7.10	Number of Life Jackets:	3,070
7.11	Immersion Suits:	36
7.12	Number of radar transponders:	2
7.13	Number of two way VHF radios:	3

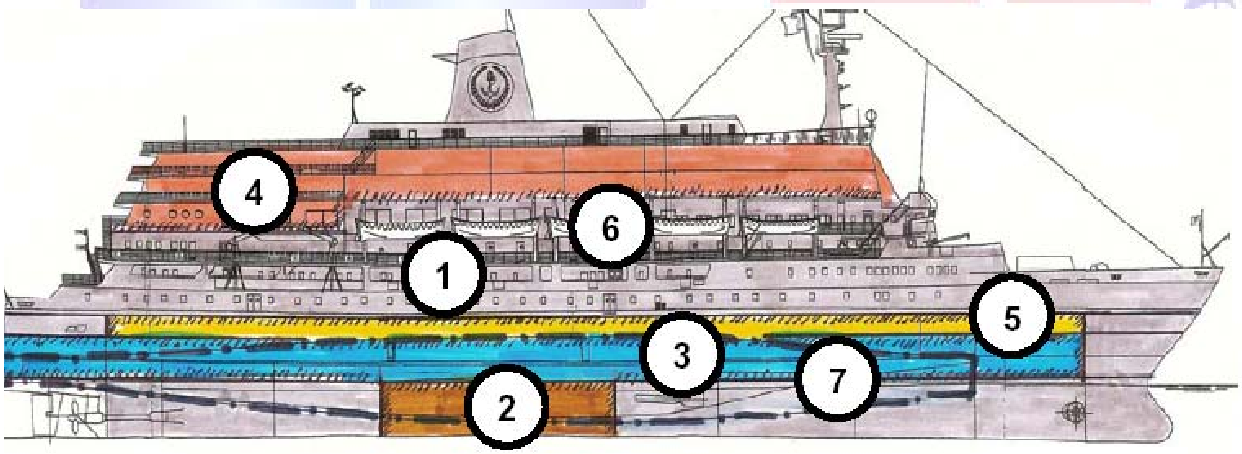


Figure 1

Notes:

1. Accommodation spaces as part of the original construction and fitted with sprinklers as per SOLAS 60.
2. Machinery spaces fitted with CO² in the M/E, auxiliary engine, stabilizer room, and electrical installation.
3. Main RO-RO cargo space (car deck) fitted with high pressure water spray fire extinguishing system.
4. Superstructure decks added to the vessel in 1990 and 1991 duly calculated and fitted with sprinkler system.
5. Upper Ro-Ro deck replaced with accommodation spaces
6. Survival crafts
7. Sponsons fitted on each side of the hull in 1990 and 1991.

8. CERTIFICATIONS AND INSTRUCTIONS

8.1 Registration certificate: Issued on **27/Nov/2002** and valid until **26/Nov/2006**

8.2 Radio Station License: Issued by PMA **07/Nov/2003** valid until **07/Oct/2007**

8.3 PSSC: Issued by PSR, issued on: **18/Oct/2005**, valid until **14/Sep/2006**

8.4 PSSC: Issued by the Egyptian Authority on **1/Feb/2006**, and expired **20/Feb/2006**

8.5 Class Certificates: Issued by RINA on **13/Nov/2003** and valid until **31/Mar/2008**

8.6 IOPP Certificate: Issued by RINA on **13/Jun/2003** valid until **31/Mar/2008**

8.7 LL Certificate: Issued BY RINA on **13/Nov/2003** valid until **31/Mar/2008**

8.8 SMC issued by RINA on **27/Oct/2005** valid until **26/Apr/2006** (Interim)

8.9 DOC issued by RINA on **12/Oct/2005** valid until **11/Oct/2006** (Interim)

8.10 MSMC: Issued by PMA on **04/Apr/1999**

8.11 ITC: Issued by RINA on **13/Jun/2003**

8.12 ISSC: Issued by RINA on **27/Oct/2005** valid until **26/Apr/2006** (Interim)

8.13 Last Dry dock: Issued by RINA on **13/Jun/2004**

8.14 Last Underwater Survey **Apr/2005**

8.15 Last ASI inspection **2003**

8.16 Exemption Certificate for oil water Separator valid until **31/Mar/2008**

8.17 Fixed CO^2 Certificate issued by Ultra Tec **4/Apr/2005**

8.18 CO^2 High Pressure tested by Ultra Tec **4/Apr/2005**

8.19 Breathing Apparatus tested by Ultra Tec **4/Apr/2005**

8.20 History of class and statutory surveys carried out by RINA (as from the last class renewal survey)

Date	Port	Class surveys	Statutory surveys
16-19/Mar/2003	Suez	• Renewal (commencement)	
26-31/Mar/2003	Suez	• Renewal (continued) • Annual • Continuous Machinery	• ILL Renewal
22-29/Jun/2003	Suez	• Renewal (completion) • Dry-dock • Tail shaft	• IOPP Renewal • SMC Intermediate
29/Oct/2003	Suez		• Inclining Test (Safety Passenger)
4-13/Jun/2004	Suez	• Annual • Dry-dock • Continuous Machinery • Hull Occasional	• ILL Annual, • IOPP Annual, • Safety Passenger Renewal
10/Jun/2004	Suez		• ISSC pre-verification
19/Jul-4/Ago/2004	Ancona	• Machinery Occasional	
2-5/Oct/2004	Suez		• SMC Renewal
26/Feb-3/Apr/2005	Suez	• Continuous Machinery	
25/Jun/2005	Suez	• Annual (commencement)	
30/Jun/2005	Suez	• Annual (completion) • Continuous Machinery	• ILL Annual • IOPP Intermediate
27/Oct/2005	Safaga		• ISSC pre-verification • SMC Interim Audit

Table 1

View of general arrangement of the ship

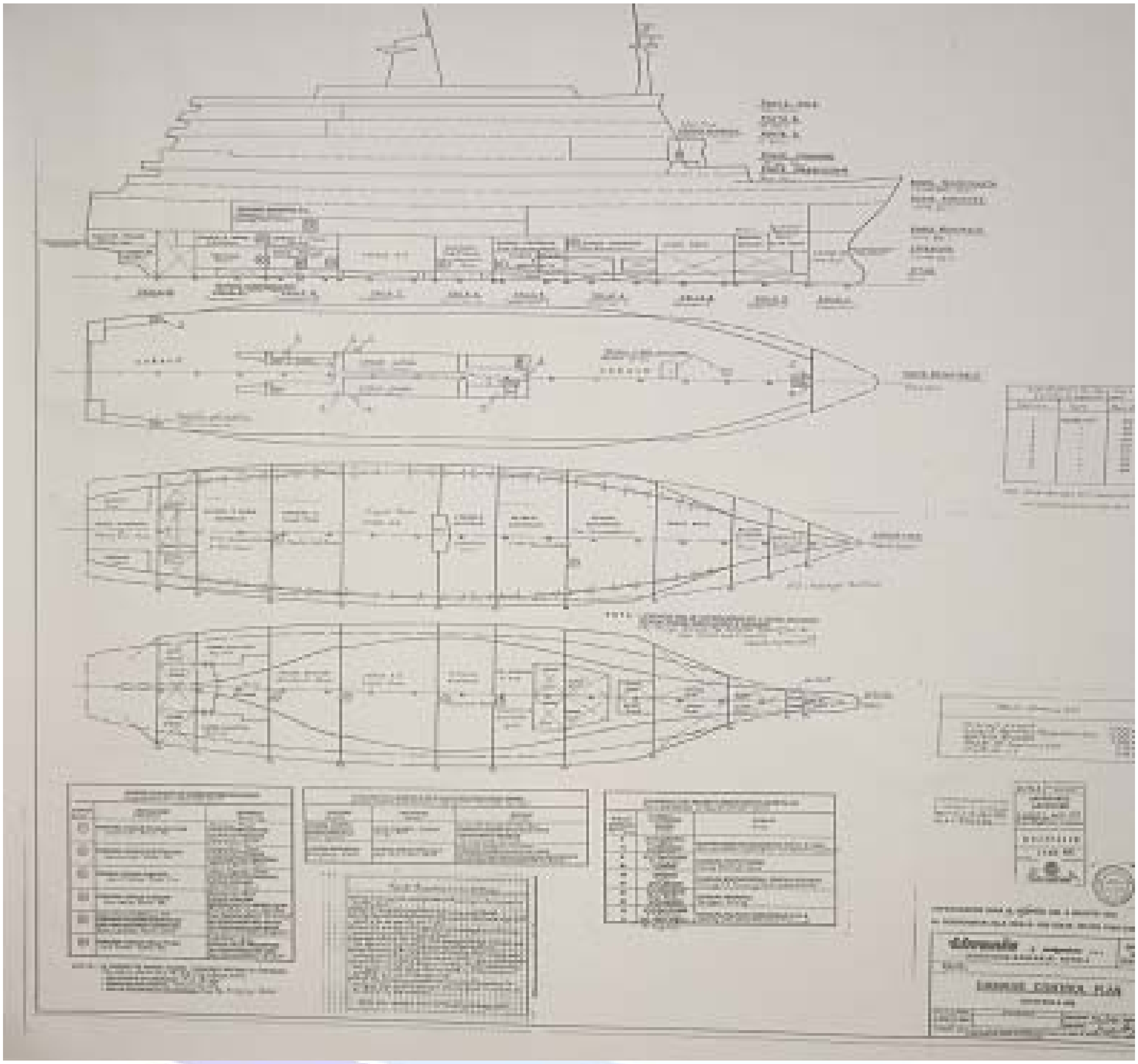


Figure 2

9. WORKING LANGUAGE

The entire crew of the M/V AL SALAM BOCCACCIO 98 was of Egyptian nationality, and their working language was Arabic. All communications and orders during the final voyage between the master, officers and ratings were conducted in their native language, hence the information recorded in the VDR was in Arabic. After its recovery it was translated into English[1].

10. BACKGROUND

10.1 **The ship**

The M/V AL SALAM BOCCACCIO 98 was built in 1970 in CASTELLAMMARE DI STABIA, Naples, Italy, and owned by TIRRENIA DI NAVIGAZIONE; and operated in the Mediterranean waters for 28 years.

In 1990, the ship underwent modifications at SEBM Shipyard in Naples, Italy, in order to fit car decks at the mid height in the main car deck, between frames # 26 and 160. Moreover, in 1991 she was modified at the same yard with the addition of 3 superstructure accommodation decks, and sponsons were fitted on each side of the hull. Also a fixed CO^2 fire-extinguisher system was fitted in the machinery spaces in lieu of high expansion foam system.

All modifications and calculations were carried out in accordance with the International Conventions and RINA rules. After all modifications, RINA approved the new stability book in accordance with SOLAS 74 stability standards, as amended. The car decks previously fitted in 1990 on the main car deck were removed at Suez in 1999.

The ship changed flag from Italy to Panama in the year 1999. In the year 2000, the ship was modified with new accommodation areas fitted in lieu of the upper car-deck, and the work was carried out at Suez, Egypt. RINA carried out the plans approval and also the supervision during the modifications work according to RINA classification rules and SOLAS requirements.

[1] Transcription and translation of the VDR from Arabic to English was done by a translator of the Committee.

M/V AL SALAM BOCCACCIO 98

Figure 3

10.2 Management Company

From 1970 to 1999, the ship was operated by TIRRENIA DI NAVIGAZIONE trading between Civitiavecchia and Cagliari, Genova and Olbia.

In 1999 the vessel changed management company to EL SALAM SHIPPING AND TRADING. This company was already certified with an ISM Document of Compliance issued by RINA on behalf of the Panamanian Administration since 1997.
Ever since the company acquired the vessel, she had been trading in the Mediterranean Sea and the Red Sea, depending of her commercial obligations.

In October 2005, the management of the M/V AL SALAM BOCCACCIO 98 was changed to EL SALAM MARITIME TRANSPORT COMPANY. This new managing company was certified by RINA in 2005, according to the ISM Code Part B, section 14 for Interim certification. The EL SALAM MARITIME TRANSPORT Company currently operates 15 vessels in the Red and the Mediterranean Seas.

The M/V AL SALAM BOCCACCIO 98, ex BOCCACCIO, had 3 sister ships: AL SALAM MANZONI 94, AL SALAM PASCOLI 96, and AL SALAM CARDUCCI 92. All of these vessels went through the same modifications as the M/V AL SALAM BOCCACCIO 98.

10.3 Maintenance

The maintenance of the M/V AL SALAM BOCCACCIO 98, according to records and interviews, was carried out at proper intervals with no significant or related outstanding remarks.
A maintenance plan was in place for the fleet, and the company carried out the last inspection of the vessel on January 26, 2006. The Vessel’s Superintendent informed us that, as a matter of policy, the company carries out monthly inspections on their vessels.

11. SOURCE OF INFORMATION AND INTERVIEWS

The information contained in this report was gathered from recordings extracted from the VDR, interviews with crew members rescued, authorities and company personnel, as well as documentation from the Flag State, the Port State and Recognized Organizations, accordingly. Depite the efforts to obtain more details about the SAR operation it was not possible to carry out the interviews of the SAR Coordination Center or to the Saudi Arabia Authorities.

11.1 **Persons interviewed**

- Crew members.
- Egypt Port State Control officers who carried out the last Port State Control inspection.
- A previous master of the M/V AL SALAM BOCCACCIO 98.
- A previous chief engineer of the M/V AL SALAM BOCCACCIO 98.
- Superintendent of the Company.
- Designated Person ashore.
- A Red Sea Port Authority member.
- The Safaga agent on duty at the time of the accident.
- The Safaga Agency manager.
- Radio Qusseir personnel on duty at the time of the accident.
- General Manager of the Company.

- Flag State surveyor.

- PSR surveyor and RINA surveyor.

- Fleet Manager of the Company.

- Human Resources manager of the company.

Table 2. Detailed list of persons interviewed by name and job title

S.N	Name	Job
1	Medhat Abbas Mahmoud Abdel-Meguid	O/S
2	Ahmed Essayed Fath-Allah Mohamed Amin	Cabin - supervisor
3	Mostafa Mohamed Essayed Metwalli	Cabin - supervisor
4	Abu-Bakr Gaber Abdel-Rahman Abú-Bakr	Cabin - supervisor
5	Mohamed Hamed Mohamed Hamed	Market head
6	Ahmed Mohamed Ahmed Ateya Abdel-Hadi	A/B
7	Rani Kamal-Eddin Mohamed Mounir	3rd officer
8	Ahmed Nasr-Eddin Mahmoud Suleiman	3rd officer
9	Mamdouh Mohamed Abdel Kader	Fleet Manager
10	Salah Eddin Mahmoud Gomaa	St. Catherine master
11	Essayed Abdel Moniem Essayed	2nd officer
12	Nabil Essayed Ibrahim Shalabi	Al Salam Safaga manager
13	Omar Fathi Abdel-Rahman Ahmed	Cabin - supervisor
14	Mohamed Tawfeek Abdel-Meguid El-Tayeb	Cabin - supervisor
15	Tamer Fikri Hakim Slouanas	Cabin - supervisor
16	Rani Kamal-Eddin Mohamed Mounir	3rd officer
17	Ahmed Nasr-Eddin Mahmoud Suleiman	3rd officer
18	Ali Youssef Mahmoud Selim	Welder man
19	Mohamed Bayoumi Hashem Abdel-Rahman	Baker
20	Essam Fouad Mahmoud Hashem	Trainee Cabin - supervisor
21	Mohamed Abdel-Mohsen Mahmoud Hanafi	Trainee Cabin - supervisor
22	Mohamed Saleh Abdel-Wahed	Wiper
23	Ahmed Essayed Kasem Suleiman	A/B
24	Yaseen Mohamed Waziri Ismael	Mechanic
25	Waleed Fawzi Ismael Ibrahim	Storekeeper
26	Waleed Helmi Zaki Ibrahim	Asst. Steward
27	Ali Ibrahim Ali Eldehna	Cabin - supervisor

28	Maher Saed Mahmoud Reda (1/2)	Inspection Expert
29	Mohamed Emad-Eddin M. Abu Taleb (+ hand written statement)	Vice-Chairman High-seas master
30	Magdy Saady_1-2	Q & S Controller
31	Medhat Abbas	O/S
32	Ahmed Helmi 1-2-3	Fleet Manager
33	Hossam-eddin Ismael	Recruitment manager
34	Ashraf Nazmi Ibrahim	Marine inspector
35	Ihsan Shagar Badawi	PSC officer
36	Ahmed M. Youssef Oleiba	Inspection and auditing GM
37	AlModdather M. Youssef	Safaga Deputy Manager
38	Ahmed Helmi_2	Fleet Manager
39	Shehab Al Matbouli+ Keith Java	RINA
40	Fathi Abbas	Previous chief engineer aboard Al Salam Boccaccio 98
41	Basem M. M. Al-Amir	Previous chief engineer
42	Ahmed Ateya	Radio Quseir
43	Ibrahim Sayyed M. Ahmed	Al-Salam, Safaga
44	Salah Gomaa	St. Catherine master
45	Nabil Shalabi	Al Salam Safaga Manager
46	Hayder Abdel-Aleim	Central Marine Inspection manager
47	A. El-Shal	Marine Inspector
48	A. ElHousini	Ex – Hurghada manager
49	A. Abdel-Karim	Hurghada Marine Inspection manager
50	Adm. Hussein Gamil El Hermeel	Ex – EAFMS Chairman

12. NARRATIVE

12.1 The previous voyage

The M/V Al SALAM BOCCACCIO 98 arrived at the Port of Duba in Saudi Arabia at about 0945 hours local time on February 2, 2006, with the following conditions:

FO 90 MT

DO 75 MT

FW 200 MT

1400 persons

14 Cars

12 Trucks

7 luggage Trailers (six 40 feet and one 20 feet)

12.2 The voyage of the accident

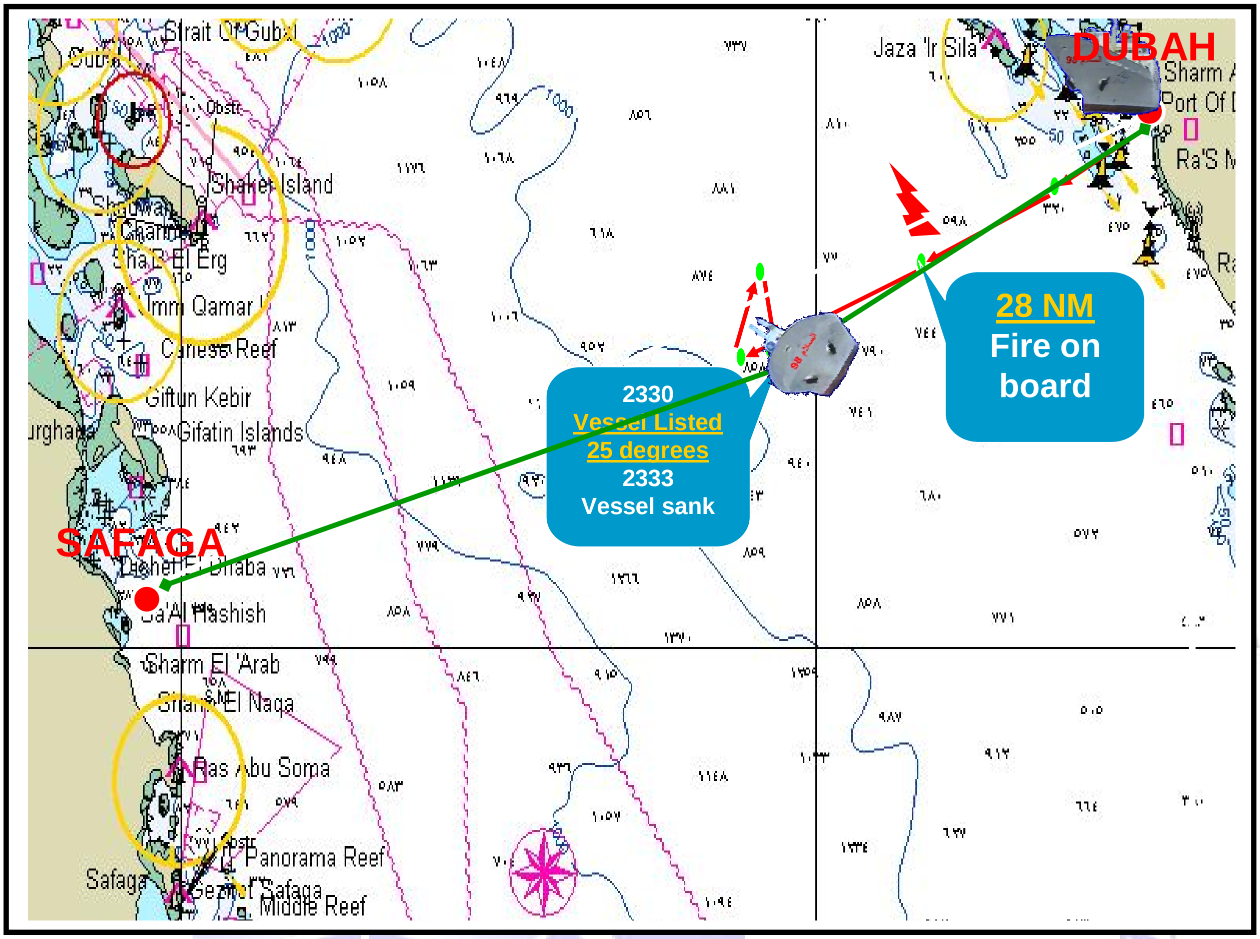
While the vessel was at the Port of Duba she was loaded with 14 trucks, 6 trailers of 40 feet and one trailer of 20 feet, all of them open top type, containing the passenger luggage, and 22 privately owned cars.

The total cargo declared was 76.32 tons not including the passengers' luggage.

According to the master's arrival and departure condition, the vessel departed from Port of Duba with approximately 90 tons of HFO, 99.8 tons of MDO, and 187.86 tons of FW. There were 1,321 passengers and 97 crew members for a total of 1,418 persons onboard. She sailed from the Port of Duba at 1651 hours UTC, and reported a draught of 5.7 meters.

At 0133 hours Egypt local time, on February 3, 2006 (2333 hours UTC February 2, 2006) according to the VDR information, the 11,779 GT Panama registered RO-RO passenger vessel, M/V AL SALAM BOCCACCIO 98, sank approximately 57 miles from its port of destination, the Egyptian Port of Safaga, and 41 nautical miles from her port of departure, the Saudi Arabian Port of Duba. As a result of this accident, there were 1,031 lives lost, of which 387 persons, including 24 crew members, were rescued and 710 are missing and presumed dead.

Figure 4. Route of the vessel from the Port of Duba heading to the Port of Safaga.



12.3 **Weather Conditions**

The weather condition, according to the departure information reported by the master, was approximately 6 to 7 on the BEAUFORT SCALE, but according to the VDR information, weather conditions were 7 to 8 on the BEAUFORT SCALE, moderate gale, with a southeasterly wind.

According to the information collected from the survivors, vessels in the vicinity and other authorities, the weather conditions were not the usual for that area. This was also confirmed by the statement and subsequent interview with the master of the M/V SAINT CATHERINE, who declared that the weather was bad with an 8 BEAUFORT SCALE, and wind speed gusting up to 60 knots WNW based in the positions of his vessel.

More details of the weather conditions are presented in chapter B1.

12.4 **Departing condition of the ship**

Before departure, the operations were carried out as usual by the ship's crew. Loading cars and passengers on board the vessel followed normal procedures. While she was at port, a Port State Control inspection was conducted with no significant remarks and therefore found satisfactory and allowed to sail, and the crew members were present at the time of the inspection.

According to the interviews, prior to departure, the ship's crew started verifying the securing and lashing of the cargo as per the ISM manual. The ramps and doors were closed and secured before departing; the vessel sailed with her cargo, plus the 1,418 persons. Additionally, all of the vessel's statutory certificates were valid as required for the intended voyage.

12.5 **Scupppers, design and details**

The M/V AL SALAM BOCCACCIO 98 was fitted with 13 scuppers on each side of the ship, and each scupper had a diameter of 125 mm. The scuppers were fixed with two non-return valves, one high up and the other at the lower part of the scupper, near to where it discharged below sea level. The scuppers had been designed with the capacity to evacuate the water coming from the fire-fighting system.

It is important to highlight that immediately after the accident, several inspections and evaluations were carried out on the sister ships in order to obtain a similar view of the drainage system, but especially regarding the stability, fire-fighting systems, and behavior of the crew as well as the scuppers performance.

Scuppers testing with the sprinklers

Figure 5

Note: According to the evaluation carried out on board one sister ship, in ideal conditions, it was clear that in a short period of time (i.e. 10 minutes), the accumulated amount of water can rapidly increase in the car deck.

As a matter of consideration, RINA, the RO acting on behalf of the Flag State, carried out an analysis of the design and performance of the scuppers in different scenarios, therefore we considered it important to have the design and engineering calculations of the scuppers as factual important information.

These details and the analysis of the results are in the Chapter B.

The above mentioned details are specified as follows:

The simplified mathematical model is based on the following:

1. Calculation of the drainage flow rate that a single scupper is able to maintain as a function of the positive (driving) head.
2. Calculation, as function of the time, of the water mass accumulation on the freeboard deck, taking into account an input flow rate from the drencher system and fire-fighting hoses as well as an output flow rate from the scuppers.

The aim of this head loss calculation is to quantify the flow rate that a piping is capable to discharge given a certain hydrostatic head.

Definitions of Scuppers details and calculations.

H: total hydrostatic head (driving head) in [m]

h_f: head loss due to distributed friction in pipes in [m]

A: internal area of the pipe in [m^2]

Q: Volumetric flow rate in [m^3/s]

B: Average speed of fluid in the pipe in [m/s]

Diam: Internal diameter of the pipe [m]

h_c: Concentrated head losses in [m].

K: Concentrated head loss factor, depends on each fitting, adimensional.

f: friction coefficient in Darcy-Weisbach equation, adimensional.

- Equation that relates the total driving head to the sum of all the head losses present in the piping system, both distributed and concentrated:

$$heads\_equation := H = h\_f + 2\ Check\_Valve + Elbow + Inlet + Outlet$$

- Equation that expresses the internal area of a circular pipe given the internal diameter

$$A := \frac{1}{4} \pi Diam^2$$

- Equation that expresses the volumetric flow rate, given the internal area and the average speed of the fluid

$$Q := \frac{1}{4} \pi Diam^2 V$$

- Concentrated head loss in [m], general formula.

$$h\_c := \frac{K V^2}{2 g}$$

- Head loss of each swing check valve from Frank M. White "Fluid Mechanics" 5th edition Chapter 6 Table 6.5. "Resistance Coefficients for Open Valves, Elbows and Tees" thus K = 2.

$$Check\_Valve := \frac{1.000000000 V^2}{g}$$

- Head loss of each tee from Frank M. White "Fluid Mechanics" 5th edition Chapter 6 Table 6.5. "Resistance Coefficients for Open Valves, Elbows and Tees" taken as K = 0.8 (on the safe side)

$$Elbow := \frac{0.4000000000 V^2}{g}$$

Sharp edge inlet, from Frank M. White "Mechanics of Fluids" 5th edition Chapter 6 Figure 6.21 taken as K = 0.5

$$Inlet := \frac{0.2500000000 V^2}{g}$$

- Sharp edge outlet, from Frank M. White "Mechanics of Fluids" 5th edition Chapter 6 Figure 6.22 taken as K = 1.0

$$Outlet := \frac{0.5000000000\, V^2}{g}$$

- Distributed head loss Darcy-Weisbach equation, from Frank M. White "Fluid Mechanics" 5th edition Chapter 6 Eq 6.30

$$h\_f := \frac{f\, L\, V^2}{2\, g\, Diam}$$

- Colebrook equation, from Frank M. White "Fluid Mechanics" 5th edition Chapter 6 Eq 6.64

$$Colebrook\_equation := \frac{1}{\sqrt{f}} = -\frac{2.\ \ln\left(\frac{0.2702702703\, rough}{Diam} + \frac{2.51}{Reynolds\, \sqrt{f}}\right)}{\ln(10)}$$

- Reynolds Number definition:

$$Reynolds := \frac{\rho\ |V|\ Diam}{\mu}$$

- Resulting system of equations in V and f:

$$H = \frac{f\, L\, V^2}{2\, g\, Diam} + \frac{3.150000000\, V^2}{g}$$

$$\frac{1}{\sqrt{f}} = -\frac{2.\ \ln\left(\frac{0.2702702703\, rough}{Diam} + \frac{2.51\, \mu}{\rho\ |V|\ Diam\, \sqrt{f}}\right)}{\ln(10)}$$

- Density of sea water, in [kg/m^3]

$$\rho := 1025$$

- (Dynamic) viscosity of sea water, in [kg/m*s]. The fluid is considered to be Newtonian.

$$\mu := 0.00089$$

- Internal diameter of the considered pipe, in [m]

$$Diam := 0.125$$

- Total length of considered pipe, including the length of swing check valves and elbow, in [m]

$$L := 5.5$$

- Absolute roughness in [m], from Frank M. White "Fluid Mechanics" 5th edition Chapter 6, Table 6.1 "Recommended roughness values for commercial ducts" for rusted steel pipes with full 50% uncertainty on the safe side.

$$rough := 0.003$$

- Gravity acceleration, in [m/s^2]

$$g := 9.81$$

- Total hydrostatic head (driving head) in [m]

$$H := 1.3$$

Q_out_s: volumetric flow rate, in [m3/s] ;

Q_out_h: volumetric flow rate, in [m3/h]

$$\left\{ 1.3 = 2.242609582\, f\, V^2 + 0.3211009175\, V^2,\ \frac{1}{\sqrt{f}} = -\frac{2.\ \ln\left(0.006486486487 + \frac{0.00001743531707}{|V|\ \sqrt{f}}\right)}{\ln(10)} \right\}$$

$$\{V = 1.721757556, f = 0.05236271714\}$$

$$Q\_out\_s := 0.02112914410$$

$$Q\_out\_h := 76.06491876$$

$$Reynolds := 2.478653786\ 10^5$$

Note: See Chapter B for the results.

12.6 **Lashing of cargo in the car-deck**

The lashings in the car deck were secured properly using the chain blocks and lashing instruments accordingly.

The car deck was constructed with 2 angle stiffeners as well as fixed deck eyes in which the portable shoes could be slid. It is important to bear in mind that there are no bulkheads for lashing points.

The vessel was normally operated with a three step lashing system for different weather conditions:

- The lashing step 1 comprises wheel chocking wedges and chains for lorries and trailers, and the number of lashing depended on the size of the vehicles.

Also the information collected indicates that the lashings of the cars and wheels were done with straps.

- The lashing system 2 is very similar to the lashing system 1, but with additional belts with ratchets for tightening. According to our investigations, this system has only been used for the vessels of the fleet in the Mediterranean Sea during the winter time.
- The lashing system 3 is in addition to systems 1 and 2 mentioned above, and they involve the use of heavy lashing chains, but we could not obtain any indications that they had been used during the vessel operations.

According to the records, it appears that the vessel was operating normally with lashing system 1 only.

Picture of a trailer for luggage and cargo lashing, looking from starboard aft to fwd.

Normal place for the stowage of luggage.

Figure 6

12.7 **Fire detection system in the car deck**

The car-deck fire detection system was composed as follows:

Fitted with automatic heat detectors, model NIFE ITALIA MODEL SWM-1KL, distributed through out the cargo space, and the system was connected to the fire alarm control panel located in the bridge.

The heat detectors were capable of being activated at a temperature of 57º C.

The alarm panel system indicated the trouble zone in which a heat detector had been activated.

The ship was provided as per SOLAS 74, Chapter II-2 regulations 41-2.6.4 (SOLAS 92 as amended) as follows: “The activation of any detector should initiate a visual and audible alarm in the control panel and indicating units. If the signal has not been acknowledged within 2 minutes, an audible alarm shall be automatically turned on through the crew accommodation, service spaces, control station and machinery spaces of category “A”.”

The fire detection system was divided into 5 zones and, as an additional measure a watchman was on duty in the car-deck, during the entire navigation period.

12.8 Fire fighting pumps and hoses

The car-deck was provided with 9 fire hydrants connected to the fire main system, which was fed by three main fire pumps, with an approximate capacity of 90 M^3/h each one, and a head of 7 Bars. One of the three main fire pumps was an emergency fire pump.

Additionally the vessel was provided with three fire pumps as follows:

- One pump dedicated to the ballast system.
- One pump dedicated to the sprinkler system.
- One pump dedicated to the water spraying system in the garage.

12.9 Fixed fire-extinguisher system

The vessel was fitted in the car deck, with a fixed fire extinguishing system (water spray type) reach to protect 5 distinct zones, with the capability of delivering 430 M^3/h through the nozzles. Each section can be manually operated independently from the two different control stations.

12.10 Qualification of Crew

The crew members of the vessel were of Egyptian nationality, properly certified according to the STCW 78 Convention, as amended, and the vessel was manned according to the Minimum Safe Manning Certificate.

Most of the senior officers were holding certificates of higher ranks than their current positions, and an important issue observed was that there were extra officers on board to help the principals in their duties.

12.11 **Training**

All crew members, including officers, had successfully completed courses and training to obtain the required certificates for seamanship at the Arab Academy for Science & Technology and Maritime Transport at Alexandria, Egypt.

The persons interviewed showed clear knowledge of their duties in case of emergencies, as per their instruction manuals.

Drills were carried out in accordance to SOLAS 74 requirements, and records of drills and training were verified during the visit to the management company. However, many of the checklists of familiarization are not available, due to the fact that they were maintained on board; during the investigation the sister ship AL SALAM CARDUCCI 92 was visited and inpected, the isnpetion included a fire and abandond ship drill to review the performance of the company, the results were satisfactory.

12.12 **The Master**

Captain Sayed Ahmed Omar was the master of the M/V AL SALAM BOCCACCIO 98 at the time the vessel sank. He was of Egyptian nationality, 60 years old, and had been working at sea for about 28 years and for the company for about 8 years. He also served as master on the same vessel in the Mediterranean Sea for approximately 2 years. The master rejoined M/V AL SALAM BOCCACCIO 98 on January 26, 2006 with all required documents up to date.

12.13 **The VDR recovery**

On February 19, 2006 at 1300 hours a team of experts departed onboard M/V Skandi Bergen to the area where apparently the wreck was. The operation was divided in two phases: the location of the wreck, and the retrieval of the VDR, which was carried out by experts Mike Travis from MAIB and Adrian Borrows from the AAIB, as well as Mr. Reynaldo Garibaldi as the principal investigator for the Flag State, together with the specialized crew of the vessel.

The VDR was manufactured by Broadgate who was tasked with downloading the data at the UK Marine Accident Investigation Branch in Southampton.

The VDR capsule was found at the following position: 27º 08.0’ N, 034º 59.1’ E

Around 97 percent of the data was recovered by the technician of Broadgate, and was very useful in clarifying most of the aspects of the investigation.

At the time of the recovery of the VDR, the wreck was found at a depth of 912 meters lying on her starboard side. The ROV carried out a survey where the ramp of the vessel was observed to be still closed.

The recovery of the VDR is the most important pease of the investigation that leads to clarify the causes as well as dismiss worng assumptions.

ROV used to recover the VDR

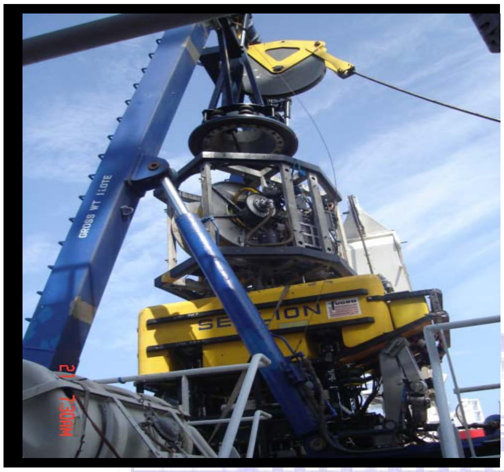


Figure 7

The vessel for the recovery

Figure 8

UK Experts looking for the VDR beacon signal.

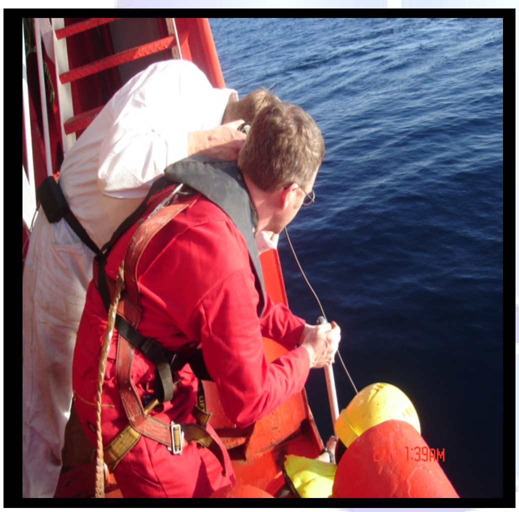


Figure 9

The recovered VDR of the AL SALAM BOCCACIO 98

Figure 10

12.14 **The role of PSR**

Panama Shipping Registrar (PSR) is a Recognized Organization (RO) authorized by the Panama Maritime Administration to issue statutory certifications since 1987; PSR has been issuing different statutory certificates for the M/V AL SALAM BOCCACCIO 98 since the year 2000. The most significant role of PSR in relation to the ship is the relative issuance of the PSSC and related matters.

12.15 **The role of RINA**

RINA is also an RO duly authorized by the Panama Maritime Administration, to issue statutory certification on their behalf. RINA has been involved with the M/V AL SALAM BOCCACIO 98 since her construction as a classification society and an RO.

RINA rules were applied to the design, details and performance of the ship during her entire life, therefore, RINA rules and criteria played a significant role in the analysis of the accident.
The certificates issued by RINA, as previously mentioned, were valid at the time of the accident.

12.16 **The ISM**

It was noted that an ISM audit for interim certification was carried out by RINA according to Part B Section 14 of the ISM code, in October 12, 2005. This audit resulted in no recommendations or non-conformities.
In accordance with the ISM Code, RINA had issued an interim DOC on behalf of the Panamanian Administration to El Salam Maritime Transport, valid until October 11, 2006 and an interim SMC on behalf of the Panamanian Administration to the M/V AL SALAM BOCCACCIO 98, valid until April 27, 2006.

The records pertaining to the M/V AL SALAM BOCCACCIO 98 were reviewed at the company and found satisfactory. Moreover, a review of the management system for the entire fleet was also accomplished while visiting the company and the sister vessels.

The ISM implemented on these vessels addressed actions to be taken in case of fire, abandon ship, many other emergency procedures, and preparedness. In all cases, the manual indicated that the master should take actions to notify the authorities and the company in emergency situations.

CHAPTER "B"

ANALYSIS

The sinking of the Al Salam Boccacio 98 was the result of a series of events each one leading to the other, and at some time there were parallel events and scenarios taking place simultaneously. For clarity, it was decided to separate the main events in order to conduct effective analysis of the circumstances.

1. The Fire

The investigation remounted the beginning of the whole ordeal to a fire situation that took place in the car deck or garage. The relevance of how the fire was reported and what fundamental course of action pursued determined the outcome of any effort invested in mitigation attempts.

Comment: It is probable that the fire started sometime before it was identified, because the presence of black smoke <u>filling the entire garage</u> had to have taken some time to be generated after the ignition.

At 1909 hours the fire alarm of the M/V AL SALAM BOCCACCIO 98 had activated giving a visual and audible alert signal on the control panel in the bridge. The auto pilot alarm had sounded just seconds prior to the fire alarm activation. A minute later, the 3/O on watch, Ahmed Nassar, reported by phone to the master in his cabin the alarm activations that were registered at the bridge. At about 1910 hours, the A/B who was on watch in the car- deck arrived at the bridge and verbally reported to the 3/O that the car-deck was full of black smoke.

The 3/O reassigned the A/B to take the control of the helm, due to the fact that the A/B on duty on the bridge was not present. The A/B who was supposed to be on duty at the bridge was called on the public address system.

The master arrived at the bridge at 1910.36 hours and asked for the C/O (Captain Masoud).

As soon as the master arrived at the bridge, he inquired if the fire was visible and what type of smoke was coming from the car-deck at which the A/B replied that it was black smoke.

The master requested the A/B to provide more information regarding the fire. The A/B reported that he thought the fire was coming from the E/R, and he had reported this initially to the 3/O.

The master then tried to contact the E/R in an attempt to talk with the C/E, but it was not clear if he actually got in contact with him.

- At 1910.40 hours, the master ordered the C/O to investigate the car-deck area.
- By 1911 hours, it was now confirmed by the A/B that the smoke was filling the car-deck area.
- At 1912 hours, the master ordered to send fire hoses to the car-deck, to quickly check and tackle the fire, and instructed the electrician to activate the water spray in the car-deck.
- At about 1916 hours a passenger informed the master that something was on fire. The master's reply was: "do not disturb us, let us work". Many passengers knocked at the bridge giving reports of the ongoing fire conditions.
- At 1918 hours a communication between the master, the 1/E and the 2/O revealed that the 2/O was confirming to the master on his request, that the sprinklers in the car- deck were already operating since the beginning of the fire.
- Since the first fire alarm, several other notifications of fire in the garage were verbally given to the master.

***Comment:** Despite the amount of notifications and alarms received, there was no indication that a general fire alarm was sounded to alert the passengers and crew of an ongoing fire condition on board. The relevance and importance that the amount of smoke signaled together with the amount of alarms received, <u>should have justified immediate sounding of the general alarm.</u>*

Failure to sound the general alarm may have reduced the time to prepare the passengers to be ready for a probable abandon ship procedure and for the crew to perform their duties to assist in the mitigating efforts.

By 1921 hours, the bridge team was still uncertain as to whether the fixed fire-fighting extinguisher system was actually in operation due to the lack of communication with the E/R. The crew could not identify the real source of the fire due to the thick smoke in the car deck. At this time, the master ordered to turn off the bridge lights to prevent other vessels in the vicinity from seeing them and avoid others finding out about their situation.

At 1923 hours, the master ordered to double check and make sure that the fixed water extinguisher system (spray) was operating in zones 2, 3, and 4.

Comment: It may have been possible that these instructions were given because of the alarm panel indications indicating trouble in these zones, and also due to all the notifications received by the master.

Until 1925 hours, the crew was under the impression that the fire was in the *Caterpillar* generator located in the forward midship section of the ship right under the cabins. The 1/E confirmed to the master that there was not any sign of fire in the caterpillar generator, but the 2/O insisted that the fire was starting to catch the floor of the slipway.

At 1926 hours, the situation had intensified for the “400” series cabins, which had begun to fill up with smoke, but reports of that being under control were fed back to the master, and confirmed by the 1/E who stated that there was only smoke and no signs of fire in the garage area beneath these cabins. The master instructed the 1/E to “operate water” in order to mitigate the smoke, a procedure that required merely ventilating.

At about 1936 hours the 2/O identified the location of the fire in a trailer containing luggage at the forward port side of the ship.

Comment: It was not until 28 minutes had transpired, that the master was convinced that the main fire situation was in the car deck, somewhere near the port bow, below the 200 series cabins situated over the car-deck.

The fire conditions prevailed despite the fact that the sprinklers, the fire pumps and hoses were in ongoing operation. Mitigation efforts were in progress, and the crew's response consisted of three teams composed of six persons each. Because of the dense smoke, the crew could not identify at the beginning where the seat of the fire was. One team began to advance to the car deck, and the others were depending on orders from the master or to spot the presence of fire itself.

According to the VDR information, the spray and fire hoses were fully operating since the onset. This was confirmed by the conversation recorded at 1918 hours.

The 2/O (Captain Sheriff), together with the hotel crew were cooling down the suspected areas in the accommodation with fire hoses per the master's orders, yet it was always reported that there was no fire- that it was only smoke. The fire teams were trying to find and extinguish the fire moving from one location to the other and merely encountering smoke.

Comment: The interviews confirmed that some of the crew members were acting on their own without instructions as to when, how, and where to proceed.

The crew members could not control the fire, and the large quantity of water used for the fire fighting operation had increased. The wind was coming from the port side of the vessel .

Comment: Constantly, as it was drawn, wherever smoke was detected, the master interpreted a fire condition, and ordered to spray water or send a team or an attack hose line to apply water. It is <u>not certain if serious consideration was given to what effects deploying all that water on board would've had.</u>

The tendency of smoke and hot gases is to seek the path of least resistance in order to rise and vent itself. By virtue of how the smoke was filling up the compartments, it was taken as a given that a mean fire situation was spreading and water had to be applied. Smoke tends to fill up an area faster than the heat would transfer from one location to another. It is a propensity that a smoke detector device would have been activated at any instance before a heat sensing detector would. Applied fire ventilation techniques would have assisted greatly at this stage.

At approximately 1939 hours, consideration was given to start coordinating the pumping of water out of the car deck. The 3/O had reported that the pumps were in operation, but the discharged water was accumulating back on the starboard side due to the fact that the water taken from the starboard side was pumped to the port side and because of the list, the water returned to the starboard side.

The master, during the first minutes of confusion in fighting the fire, gave instructions to the helmsman to maintain the actual course 220º. While the vessel was not really responding to the orders, it actually made a complete round turn of about 358 degrees in approximately 10 minutes; the master realized that the vessel was not going in the desired heading. He later regained control of the heading of the vessel bound to the Port of Safaga. At this stage the list was of approximately 5 to 7 degrees to starboard.

The crew was confused as to why the fire seemed to appear in different zones. The fire was fought by the crew for approximately 4.5 hours and the use of water to extinguish the fire was never successful. The **fire was never extinguished** and it extended to several places and decks.

2. The list of the ship and related events

The 2/O informed the bridge at 1938 hours, that there was an increasing level of water in the car deck. This of course was the result of water pooled up from the firefighting efforts, a situation that led into another phase of situation crisis. Added water onto a vessel with free surface conditions prevailing, will certainly impact on the stability.

At 1940 hours, the master instructed to use a portable pump to discharge water from the car deck. Initially, it was noticed that there were complications in the use of the portable pump to discharge the water from the car-deck. The pump did not have fixed arrangements to pump the water *out of the vessel*. The operation was not satisfactory and the water was suctioned from the starboard side and pumped to the port side. Then the water scurried back to the original position due to the list of the vessel.

At 1941 hours, a communication between the 1/E, R/O and master revealed that the 1/E recommended to open the pilot door in order to drain the water from the car-deck; the master accepted the suggestion, but the R/O advised the master not to open the pilot door because it may ventilate and increase the fire.

The 1/E insisted in wanting to open the pilot door if he felt obligated as a way of freeing water from the deck, and the master replied to him to do it if the situation obligated do so".

Comment: It was never confirmed whether or not the pilot door was opened. Our assumption is that it was never opened at any time, and it could be possible that if the pilot door was opened only in the starboard side it could reduce the accumulation of water in the car-deck; however, due to that amount of water, the positions of the cars, the heavy smoke and high temperatures, it would have been difficult to open or close it at a later stag which could be risky.

The 2/O reported that the fire was ongoing under the slipway on the port side. The master's reaction was to apply salt water to cool it. At around 1943 hours, communications between the 1/E and the master led to understand that they were uncertain as to the vessels accurate position because of the equipment's irregular function.

Comment: Fire conditions probably damaged the wirings.

The master was concentrating on the fire situation and expressed that he was confident that the vessel was at sea in a clear zone with minimal risk to other vessels, based on the R/O stating that the radar screen was clearly showing no vessels or other objects in the vicinity.

The master turned his attention to the fire and the accumulated water on board. He instructed the fire teams that cooling was still essential, but consideration for pumping the water out of the vessel was also necessary.

- At about 2016 hours, the 3/O asked the master if they could contact the vessels in the area to request assistance. The master did not reply to this suggestion.

Comment: If communication was made to the authorities or the vessels in the vicinity informing of the situation on board the M/V AL SALAM BOCCACCIO 98, and assistance had been requested, it may have minimized the danger and advanced the possibilities to abandon the ship and save lives.

A decision to abandon the ship at an early stage would have been appropriate, considering that the water used in the fire-fighting operation could have caused an excessive list and, subsequently, the sinking of the vessel.

- Approximately one hour had passed and the fire and uncertainty of situations were still baffling the crew.
- At 2104 hours, the master discussed with the C/O if they could *stop spraying* the car deck because the list had increased to approximately 7 degrees to starboard.
- Between 2141 hours to 2227 hours, the list further increased to 11 degrees to starboard. Meanwhile, a confused firefighting was still taking place in several areas.
- At 2222 hours, once again, the vessel started making a turn, and at that time the master did not have a clear view of where the vessel was heading. The crew was still fighting the fire and spraying water in the car-deck.
- At 2227.40 hours the master asked about the course and the 3/O replied that the course was 345º.
- At 2227.47 hours the list was reported by the 3/O to have further increased to 15º to starboard. Things began falling down in the bridge and an alarm sounded.
- At 2228 hours the master ordered: "ALL THE WHEEL TO THE RIGHT". After that, the master asked to deballast tank number 18 in the starboard side while filling the tank number 25, which had a capacity of 131.62 tons.
- At 2229 hours the master asked the C/O if there was a possibility to deballast tank number 18 located on the starboard side. The ship was listing 15 degrees to starboard.
- The C/O asked the master, through the R/O, if they could pump water to fill tank number 25 located on the port side.

According to the interviews, it was clear that the scuppers were partially blocked due to garbage generated during the fire-fighting operation and the movement of water containing these residuals.

- At 2231 hours the 3/O informed that there was nobody responding in the E/R.
- At approximately 2233 hours, the cargo was reported to have shifted to the starboard side. At the same time, it was reported by the 3/O in the bridge that the vessel was listing 11 degrees to starboard. The speed was about 6 knots, and the course was 090 degrees. The master ordered again, 5 minutes later, to fill tank

number 25 on the port side (heeling tank).

At 2240 hours, the 3/O informed the master that the vessel was heading back and that the course was 241 degrees. He stated that the wind was blowing before from the port side and the master replied, “now its from the right side”. Then the 3/O agreed and said that the course was 090 degrees and possibly this was the reason why the list decreased a little.

At 2242 hours, the heading was 090 degrees and the 3/O informed the master that the list had increased considerably; and the 3/O asked the master if he wanted to change the course.

Comment: At this stage, an abandon ship order would have been the correct decision, it is assume and explained further on this report that the cargo shifted due to the list of the ship

The master, showing signs of indecision, asked the C/O what could be the solution for this situation. At 2307 hours, the list continued at 15 degrees to starboard and the master ordered to ballast more tanks due to fact that he thought that the capacity of tank number 25 on the port side was very small. Also taking into account the quantity of water accumulated on the car-deck, and that the sprinklers were still working, it would not be a significant ballast operation to correct the list.

At that time, the master realized that the quantity of water was more dangerous than the fire.

- At 2312 hours, he ordered an unknown person in the accommodation area who was cooling down the cabin floors which were over the car-deck, to stop the use of hoses.

Comment: Since the ballasting operation started, the list had increased. It is still not clear if the longitudinal free surface of the water in the tanks caused an irreversible increase of the list or if there was a mistake from the engineers and crew in opening valves, following orders from the master to correct the list.

The master, concentrating on correcting the list, ordered to turn the ship to port 20 degrees in order to reassume the heading of 240 degrees.

The bridge team was still confused about the heading, the wind, the course and correct decisions to take, and things were starting to fall apart in the bridge.

The recording showed that after starting the ballast operation, the list increased to 18 degrees to starboard at around 2324 hours, and the master was still asking why, if the port side tanks were being filled the ship continued to list more and more to starboard.
While ordering to pump ballast water into the port side tanks, the vessel's list increased to 20 degrees at about 2326 hours. Soon after, at 2328 hours, the vessel had continued to increase its list to starboard to 22 degrees.

The bridge team was still confused about the direction of the wind. After that, the 3/0 ordered the helmsman to pull all the wheel to the starboard, and the R/O asked the master twice "what was the wheel order, hard to starboard or hard to port ?".
The master confirmed the order to put the rudder all to starboard, and he was reminded that the list was 20 degrees to starboard, but the master requested to be patient.
Few minutes before the sinking, the master was advised by the 3/O to abandon the ship and the master's reply was: "just wait".

At that time the master ordered to turn the wheel all to the port.
The list was now 25 degrees to starboard and someone asked the master, around 2330.28 hours, if they should send the "May-Day" distress signal, and the master's reply was: "send a may day send may day" but no evidence was gathered proving that such may day was sent taking into account that there was no costal station or vessels in the area which had reported receiving a may day from the vessel before or after the vessel sank at 2333 hours.

3. Scuppers

RINA analysis results

The resulting Reynolds number (around 2.5*10^5) tells us that the flow is within the region of complete turbulence. For rough pipes (as is our case) this means that the friction factor is almost constant with the Reynolds number, being thus function only of the relative roughness (see Frank M. White "Fluid Mechanics" 5th edition, Chapter 6, this result means that the system of equations is only slightly non-linear and can be made linear with a negligible mistake).

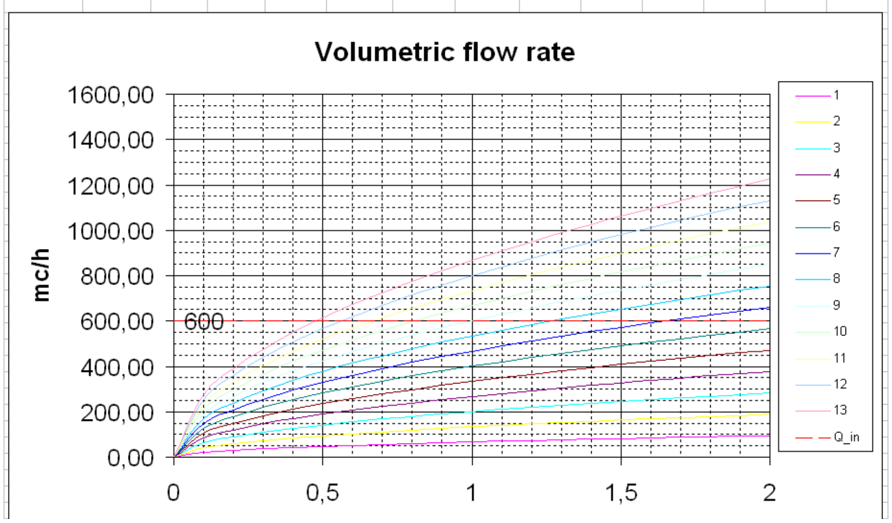
As a practical effect, the volumetric flow rate calculated for a driving head H = 1.3 [m] may be used to predict the flow rates for bigger and smaller driving hydrostatic heads H.

The final result is a linearized equation that gives the volumetric flow rate for one scupper as a function of the total hydrostatic head H.

$$Q\_out\_h(H) = 66.70903296\,\sqrt{H}$$

The results are summarized in the following Table, where the output flow rate is calculated for a finite set of total hydrostatic head values (in columns) and number of scuppers (in rows). A value of input flow rate of 600 [m^3/h] is assumed. The combinations H / number of scuppers that are sufficient to discharge the input flow rate are printed in green while those that are not sufficient are printed in red. The same results are shown in a graphical form with the volumetric flow rate as a function of the total hydrostatic head and the number of active scuppers as a parameter.

H [m]	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
0,1	21,10	42,19	63,29	84,38	105,48	126,57	147,67	168,76	189,86	210,95	232,05	253,14	274,24
0,2	29,83	59,67	89,50	119,33	149,17	179,00	208,83	238,67	268,50	298,33	328,17	358,00	387,83
0,3	36,54	73,08	109,61	146,15	182,69	219,23	255,77	292,30	328,84	365,38	401,92	438,46	474,99
0,4	42,19	84,38	126,57	168,76	210,95	253,14	295,33	337,52	379,71	421,90	464,10	506,29	548,48
0,5	47,17	94,34	141,51	188,68	235,85	283,02	330,19	377,36	424,53	471,70	518,87	566,04	613,22
0,6	51,67	103,35	155,02	206,69	258,36	310,04	361,71	413,38	465,05	516,73	568,40	620,07	671,74
0,7	55,81	111,63	167,44	223,25	279,06	334,88	390,69	446,50	502,32	558,13	613,94	669,75	725,57
0,8	59,67	119,33	179,00	238,67	298,33	358,00	417,66	477,33	537,00	596,66	656,33	716,00	775,66
0,9	63,29	126,57	189,86	253,14	316,43	379,71	443,00	506,29	569,57	632,86	696,14	759,43	822,71
1	66,71	133,42	200,13	266,84	333,55	400,25	466,96	533,67	600,38	667,09	733,80	800,51	867,22
1,1	69,97	139,93	209,90	279,86	349,83	419,79	489,76	559,72	629,69	699,65	769,62	839,58	909,55
1,2	73,08	146,15	219,23	292,30	365,38	438,46	511,53	584,61	657,68	730,76	803,84	876,91	949,99
1,3	76,06	152,12	228,18	304,24	380,30	456,36	532,42	608,48	684,54	760,60	836,66	912,72	988,78
1,4	78,93	157,86	236,79	315,72	394,66	473,59	552,52	631,45	710,38	789,31	868,24	947,17	1026,11
1,5	81,70	163,40	245,10	326,81	408,51	490,21	571,91	653,61	735,31	817,02	898,72	980,42	1062,12
1,6	84,38	168,76	253,14	337,52	421,90	506,29	590,67	675,05	759,43	843,81	928,19	1012,57	1096,95
1,7	86,98	173,96	260,93	347,91	434,89	521,87	608,85	695,82	782,80	869,78	956,76	1043,74	1130,71
1,8	89,50	179,00	268,50	358,00	447,50	537,00	626,50	716,00	805,50	895,00	984,50	1073,99	1163,49
1,9	91,95	183,90	275,86	367,81	459,76	551,71	643,66	735,62	827,57	919,52	1011,47	1103,42	1195,38
2	94,34	188,68	283,02	377,36	471,70	566,04	660,39	754,73	849,07	943,41	1037,75	1132,09	1226,43
Input Volumetric Flow Rat	600	[mc/h]		Nom. Output Vol. Flow Rate			988,78	[mc/h]					



Calculation of water mass accumulation

Purpose:

The purpose of this calculation is to predict the evolution in the time domain of the stagnancy of water on the freeboard deck as a function of the input flow rate (from the drencher system and fire-fighting hoses) and output flow rate (from a variable number of scuppers) until a certain amount of water is accumulated.

Procedure

A mathematical model is established. The equation that governs the system in the time domain is considered to be a non-linear first order differential equation as described below:

$$\frac{d}{dt} M(t) = \rho \, (Q\_in(t) + Q\_out(n, H))$$

$$H(M) = h(M) + f(M)$$

Where (see also Figure **B1** and Figure **B2** of this analysis specifically):

M(t): accumulated mass of water on the deck as a function of time in [kg]Q_in(t): volumetric flow rate in input as a function of time, in [m^3/s]

Q_out(n, H): volumetric flow rate in output as a function of the number of active scuppers and of the total hydrostatic head, in [m^3/s]

n: number of active scuppers

h(M): hydrostatic head on the deck as function of the accumulated mass M, in [m]

f(M): remaining freeboard as function of M, in [m]

H(M): total hydrostatic head as a function of M in m

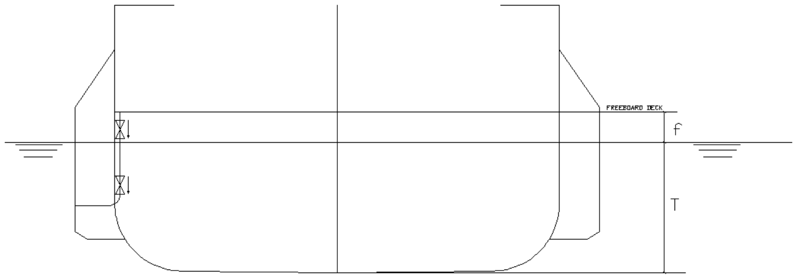


Fig B.1

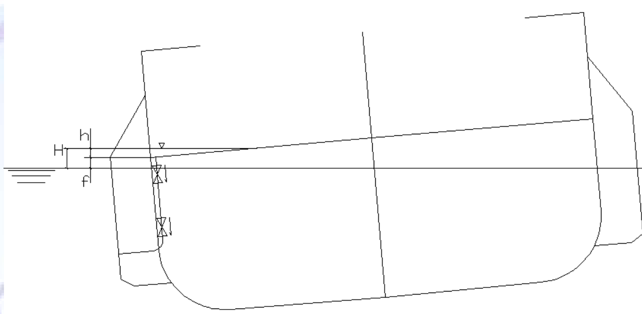


Fig B.2

In this differential equation, the difficult term to evaluate is the one that expresses the total hydrostatic head (H) as a function of the accumulated water on the deck. H depends directly from the current draught, heel angle of the ship, and internal head of water on the deck (h). All these parameters are related to the accumulated mass M. The ship "system" is thus heavily involved in this modelling process.

It was decided to numerically solve the differential equation written above using a finite difference iterative approach. The numeric values of H as a function of the accumulated mass M have been evaluated from the stability calculations results by means of linear interpolation and extrapolation from a set of calculated flooding conditions.

The consequence of using the results of the stability calculations (static in their nature) is that the accumulation process is considered as being a sequence of “quasi-static” states, thus no ship motions are taken into account in this model.

The time step used in the numerical integration was chosen to be fixed (i.e. not varying with time) and equal to 1 second.

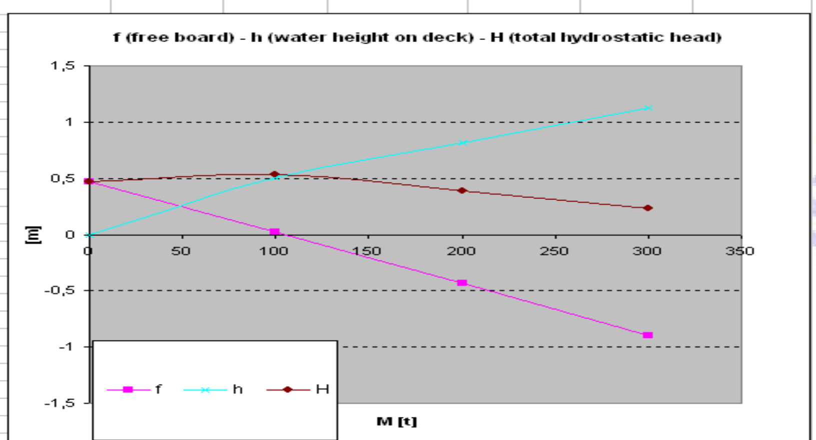
The time constant involved in a mass accumulation process of this kind should be a lot higher of this value, thus ensuring the convergence of the method and a sufficient precision of the resulting function M(t), calculated by points.

The mathematical problem has been attacked using the C++ programming language to implement a custom solver.

Example of calculation

A set of calculations with variable number of active scuppers is performed on the basis of the input data summarized below.

From SIKOB calculations with initial heel angle = 5° Critical Mass = 300 t						
Displacement [t]	T [m]	M [t]	Heel angle [°]	f [m]	h [m]	H [m]
9622	5,85	0	5,05	0,47	0	0,47
9722	5,892	100	7,35	0,02	0,51	0,53
9822	5,934	200	9,68	-0,43	0,82	0,39
9922	5,976	300	11,93	-0,9	1,13	0,23



The results obtained with a constant input flow rate of 600 [m^3/h] and an initial angle of heel of almost 5 degrees are shown in Figure B3 below.

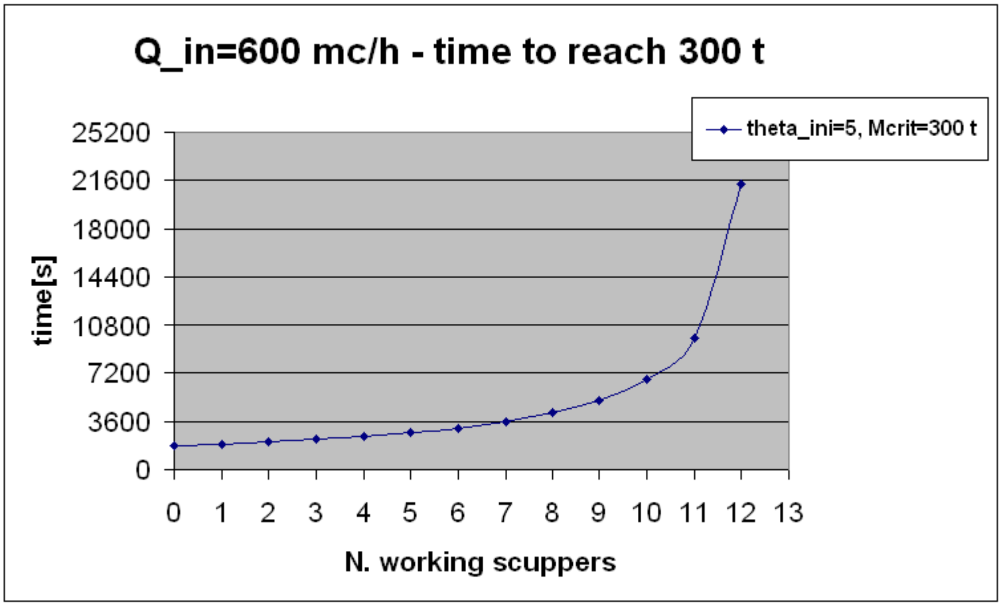


Figure B 3

The resulting time for 13 active scuppers has not been graphed because it can be considered as infinite.

These results show that even with 0 active scuppers almost half an hour is available before capsizing occurs; on the other hand this time frame does not increase at a high rate with the increment of the number of scuppers (e.g. with 7 active scuppers 1 hour is available). This behaviour depends from the fact that the initial condition (angle of heel equal to 5 degrees) impairs from the beginning the flow rate discharged from the scuppers with its low value of H. In any case with all the 13 scuppers active, the simulation predicts that the system does not tend to accumulate water.

4. Actions taken by the crew

According to the information gathered from the interviews, prior to the sinking of the vessel, most of the crew members and passengers were acting on their own initiative. The crew members were providing life jackets to the passengers, and tried to guide them to their mustering stations; however, the majority of the crew and passengers remained waiting for the abandon ship instructions from the master until the sinking of the vessel. During the last minutes they started looking for options to evacuate the vessel on their own, and most of them moved to the starboard side, where some crew members were fighting the fire. At the critical moment of sinking, as they indicated during the interviews, they started walking over the shell plating of the ship on the port side, to ultimately jump into the sea and start swimming, searching and trying to reach the un-opened life rafts, which were scattered randomly in the water. These life rafts had been inappropriately released from an uncoordinated operation of deploying the safety equipment during the chaotic moments before the vessel sank.

Many of the life rafts were floating unopened and the passengers and crew started opening them to save their lives.

The 2/O had boarded a life raft and had activated the SAR, since he was also holding a GMDSS portable radio. He also declared that he activated the EPIRB just before the vessel sank.

The vessel had electric power up to the moment she sank, and apparently the master refused to leave the bridge; the majority of the passengers who survives got in to the life raft and abandon the ship by themselves, this leads to believe that if the master had ordered them in the appropriate time to abandon many live would have been saved

5. The stability and important related matters

According to our records, the vessel was in compliance with SOLAS 90 requirements as a one compartment. During the investigations it was also noted that the number of passengers had been increased based on the Protocol of Space Requirements for Special Trade Passengers Ships of 1973, and the existing agreement between the Arab Republic of Egypt and the Kingdom of Saudi Arabia, for a Short International Voyage.

For the purposes of technical objectivity the calculations and runs carried out are based in the factual information and conditions present at the might of the accident.

RINA had also reviewed and approved calculations for the sister vessels and for the M/V AL SALAM BOCCACIO 98 for the 2,500 persons with satisfactory results. We had received the 2 intact stability conditions of departure and arrival for the vessel approved by RINA for a maximum of 2500 persons.

In the records appeared that RINA issued a certificate concerning the AA max value in 2002 indicating that the vessel was in compliance.

It was also noted that the quantity of passengers allowed on board at the time of the accident was less than the quantity required by SOLAS in Chapter II-1, Regulation 8.2.

The M/V AL SALAM BOCCACCIO 98 would have had to comply with regulation 8.2 as a two compartment ship by October 2010 taking into account the application of the regulation.

After reviewing the previous stability manual approved nº CDS0002315 dated February, 2004, we noted that the vessel was capable of allocating the quantity of passengers she was carrying at the time of the loss.

It is also a matter of concern that there was a possible discrepancy in the application and calculations required by resolution A.749(18), which required different GZ parameters, since the GZ specified in the stability manual was less than that required by this resolution.

However, it is important to underline that RINA states the following:

"…According to the principle of equivalence, in case of ships having a particular design, the RINA rules accept an angle of heel corresponding to the maximum righting g arm lower than 25º. In association with a larger area bellow the righting lever curve and higher GZ values, the comparison between the criteria of the intact stability code(here after referred "IS CODE") and the RINA equivalent criteria for ships of a particular design, indicates that, for a giving heeling moment, the static equilibrium angle for a ship having θ max lower than 25º and compliant with the RINA equivalent criteria is lower than the angle of equilibrium of a ship having a θ max between 25º and 30º.

The righting lever curve offered by the vessels is significantly high were tan the minimum required by both, the IS code and the RINA rules. An inclining arm close the maximum GZ value, requested by the IS code(0.2M), would list the vessel at an angle of about 5º, and in this final condition of equilibrium the vessel has still a large amount of intact and dynamic stability.

The same inclining arm applied to the minimum GZ curve in accordance with the IS CODE would cause a listing of about 27º and in this condition the intact and dynamic condition are compromised".

6. Events failures

- The sequence of failures may have started with the outbreak of the fire on board, which began at 1909 hours, or perhaps earlier.
- There was failure from the master to follow established procedures as contained in the company ISM manual, chapter 8, instructions 7, regarding procedures for fire on board.
- The decision to return to port when the vessel was only 28 miles from the port of departure could have been a significant and potential wiser decision.
- The general fire alarm was not activated at any time.
- There were not clear or correct orders given by the master to the crew members on how to proceed, according to the instructions contained in the established procedures, and some parties were voluntarily acting on their own.
- The crew was not able to clearly identify what had ignited or initiated the fire at an early stage, nor the exact point of origin.

- The fire teams were not able to extinguish the fire from the initial attack.
- The vessel's fixed fire-fighting system was not capable of controlling or extinguishing the fire from its initial stage, which allowed the fire to expand out of proportion.
- The crew and especially the master did not properly consider the implications of using such a large amount of water during the fire fighting operation onboard.
- Despite recommendations, given by the crew to seek for help or abandonship, the master declined to make contact with other vessels in the vicinity, the company, or the competent authorities, at any stage, to request instructions or to ask for help, except for the last minute when he asked to send a May-Day signal.
- The scuppers were not able to drain the water efficiently due to factors explained in chapter B1.
- The crew was not able to clear the partially blocked scuppers or to pump out the water from the car-deck.
- There were no orders issued for controlling the passengers in panic, and the master refused to prepare them for evacuation, and instead, he ordered to maintain the passengers in their cabins.
- It seems that the master was not clear regarding the capacity and the implications of the required ballasting operations.
- The master did not accept suggestions to notify the company, the vessels in the vicinity, or the authorities.
- The crew members and the passengers were unable to abandon the ship at a proper stage due to the lack of orders.
- The master did not consider it appropriate to abandon the ship as it was suggested by the 3/O. (This was recorded in the VDR and obtained from interviewed crew members)
- The SAR operation was not initiated at the time the EPIRB signal was received by the MRCC.

7. Search and rescue

The SAR operations played a significant role in this accident, especially in the amount of lives at sea that was possible to preserve. At this stage, we are still collecting valuable information, and it is important to underline that there may have been a critical delay in the search and rescue efforts.

Our analysis of the information gathered brings us to the observation that there was a lack of coordination between the authorities engaged in the rescue efforts. The first authority which could have saved some time in starting the rescue operations was the Safaga Port Authority, which was aware of the lack of contact with the ship, since they had been informed by the office on duty of the Management Company at approximately 0130 hours Egyptian local time about such situation. Moreover, they were requested to establish contact with the vessel and this was not possible.

It is important to remember that the vessel sank at approximately 0133 hours, Egyptian Local time.

Even though the authorities were advised of the loss of communication with the vessel, the SAR efforts started approximately 10 hours later. Additionally there is no indication that any action was taken by the VTS office, which might have lost the location of the vessel in the radar.

It was not until 0714 hours, Egyptian local time, that the chairman of the Red Sea Port Authority was informed by the vice president of the company that the vessel had sank, as reported by the 2/O of the M/V AL SALAM BOCCACCIO 98, who had later managed to establish contact with the master of the M/V Saint Catherine via VHF radio, while on a life raft near the site of the accident. Consequently, the master of the M/V Saint Catherine informed the Safaga office manager, who then informed the fleet manager and the operation director of the situation. According to the interviews, the operation director had relayed the information to the vice president approximately at 0700 hours, Egyptian local time.

However, during the communications established between the parties involved, the SAR operations started when a plane departed at approximately 1010 hours, Egyptian local time.

The first vessel arrived at the area of the accident at about 1500 hours, Egyptian local time, with reported bad weather conditions which led into a delay of approximately 12 hours.

However, the EPIRB signal was sent at the moment of the sinking, and according to the declarations of the 2/O, he was able to activate the EPIRB manually minutes before the ship sank.

The EPIRB signal was first received by Scotland Station Kindloss at about 2358 hours UTC, and then delivered to France and from France's coordination point to the USA, and from the USA to Algeria.

The United States coordination center delivered the signal to the Panamanian authorities, and the Algerian authorities delivered it to the Egyptian contact point in charge of the Search and Rescue, as explained below:

- *The EPIRB signal was first detected at 23:32 hours UTC on February 02, 2006, by Algerian Earth Station (GEOLUT) without position, because the beacon did not have the capability to provide the location in its message.*
- *Consequently, since the country coded on the beacon is Panama, the message alert was sent to Panama by USMCC according to the Cospas/Sarsat Data Distribution Plan (DDP).*

At 0037 hours UTC on February 03, 2006, Algerian MCC received an alert message, with position in Egypt area at (DOPPLER B - 27 10.1N 034 40.4E), and they delivered it to Official Egyptian SAR Point of contact.

At 0110 hours UTC, Algerian MCC received the resolution (confirmation) in position (RESOLVED 27 09.4N 034 54.8E), and they delivered it to the Official Egyptian SAR Point of contact.

For this alert the Algerian Cospas/Sarsat (MCC d'Alger) had sent 17 messages to the Official Egyptian SAR Point of contact.

Originator:	Algerian Cospas-Sarsat MCC
Recipient:	Official Egyptian SAR Point of contact
AFTN: address:	HECCYCYX
Communications System Used:	AFTN, messages sent "SS" priority Time of first Message: 00:37 hours (UTC) 3rd February 2006.

Time message received	number	time message sent
00:37 on 3rd Feb 2006	3796	00:40 on 3rd Feb 2006
01:10 on 3rd Feb 2006	3797	01:14 on 3rd Feb 2006
03:28 on 3rd Feb 2006	3800	03:34 on 3rd Feb 2006
08:26 on 3rd Feb 2006	3805	08:30 on 3rd Feb 2006
11:31 on 3rd Feb 2006	3808	11:34 on 3rd Feb 2006

Another important issue in the Search and Rescue operation is the action of the master of the M/V SAINT CATHERINE, registered in Panama, and managed by the same company of the M/V AL SALAM BOCCACCIO 98.

According to the information collected, and to the master's declaration, the vessel departed from Safaga Egypt to Duba, Saudi Arabia, at 0215 hours, and at that time he stated that no information was received from the M/V AL SALAM BOCCACCIO 98 concerning her arrival to Safaga Port. Nevertheless, he stated that around 0250 hours approximately, he started calling the M/V AL SALAM BOCCACCIO 98 every 30 minutes without response. Furthermore, at about 0500 hours, he was notified by the Safaga Office to keep calling the M/V AL SALAM BOCCACCIO 98.

According to the master's declaration, at about 0657 hours, he received a call from the 2/O of the M/V AL SALAM BOCCACCIO 98 informing that the vessel had sank, and that he was on board a life raft, specifying also the location of the sinking. He checked the location of the sinking and verified that his vessel was about 30 Nm from that location.

According to his declaration, he decided not to proceed to the place of the sinking to avoid putting in danger the passengers he was carrying. Additionally, he considered the bad weather conditions at the moment, which were estimated at 8 in the Beaufort scale.

He continued his voyage to the Port of Duba and, after disembarking the passengers, he returned to assist in the rescue operation. This took place at about 1800 hours Egyptian local time, the day after the sinking.

After requesting the available call reports and information collected, *there is no indication that the company contacted the vessel during the night time when she was sailing to the Port of Duba.* Additionally, we noted that the decision was made purely based on the master's own safety considerations.

List of the numbers of rescued passengers and bodies found during the search and rescue operations in accident of M/V Al Salam Boccaccio 98

Vessel Name	Survivors						Bodies					
	3/2	4/2	5/2	6/2	7/2	8/2	3/2	4/2	5/2	6/2	7/2	8/2
Sharm Elshiekh	101	15					6	46	62	86		
Italian units		7						2				
Green Island	39											
Regola Star	37											
Elanora	149						1					
BMS		6						61				
Eltaef		3						9		6		
El Salam 94								2				
Elmotaheda		1						1		27		
Elriad								7	5			
Coast Guard unit		22										
Sudanese vessel		1										
Hel Chenok plane			6									
Total	326	55	6				7	128	67	119		
Total until 6/2 at 22:00	387							Total till 6/2		410		

Table 3

Comment: **One important question still unanswered is why the rescue of the survivors took such long valuable time, even when the complete route was less than 100 Nm between the two ports in a normally well transited area.**

CHAPTER B-1

1. ADDENDUM

The following report constitutes the final findings on the sinking of the Al Salam Boccaccio 98, based on follow up investigations the Panama Maritime Authority carried out additional studies with evidence and information from more scrupulous testing and evaluations of the data retrieved from the VDR, witness evidence, modular analytical reconstruction of events and related issues. Subsequent pieces of data were subject to technical simulations and research from model generations to learn more of the incident and reconstruction of the loss, as well as cross check with real on board operational factors in emergency handling.

2. SCOPE AND OBJECTIVE OF CHAPTER B-1

The objective and sole purpose of the investigation of M/V AL SALAM BOCCACCIO 98 is to verify the cause/s of the accident in order to prevent future accidents of similar nature, taking as a reference the IMO Code for the investigation of Marine Casualties and incidents Resolution A. 849(20) as amended. This investigation ideally is not written with litigation in mind and pursuant to Resolution JD 0162005.

To support the overall knowledge of events that led up to the main causes of the accident, technical research and report of findings were studied by contracting a reputable and highly experienced independent firms, at the request of the Panama Maritime Authority, results has been analyzed by the PMA considering, design, and operational factors together.

The research addressed issues from various perspectives based on simulated models attempting to reconstruct the events stemming from available data obtained from the VDR, witness statements, authorities involved, company personnel, documentations from the Flag State, the Port State and recognized organizations.

The reconstructions were designed to look solely at the technical factors and did not consider the human actions, operational factors, human errors or practical shipping scenarios. The analyses were cross checked by the Panama Maritime Authority.

The intent of this report is not to adopt a position of pointing out fault or blame, none the less, the need to identify errors, whether technical or human in order to institute corrective actions and eliminate flaws to avoid recurrence of accidents of this nature.

3. INTRODUCTION

The Panama Maritime Authority, in order to clarify specifics that may have led to technical failures in the accident, had the final findings of the investigation carried out in stage projects designed to emulate the prevailing conditions of the vessel, existing guidelines and determine what went wrong. The findings were carried out in separate modules, a summary of which this final report is based on.

The Panama Maritime Authority placed strong consideration to areas of impacting importance that may explain,

- Handling behaviour for manoeuvring conditions until the disaster occurred,
- Possible actions which may have delayed or prevented capsize,
- An assessment of damage and intact stability, and
- The reconstruction of the loss.
- Detailed attention was added on the issues of the effectiveness of car deck drainage systems.
- Real probabilities in the operation of the ship, human errors, as well as emergency response.

4. OVERVIEW AND ANALYSIS OF THE ACCIDENT

4.1 Intact and Damage Stability - Departing Conditions

Loading cars and passengers was a normal operation and was carried out as usual by the ship's crew. While the vessel was at port, a Port State Control Inspection took place without any significant remarks. The crew members were present at the time of the inspection.

According to the interviews, prior to departure, the ship's crew started verifying the securing and lashing of the cargo per the ISM manual procedures; the ramps and doors were closed and secured, and the vessel had all statutory certificates valid according to the voyage projected.

While the M/V Al Salam Boccaccio 98 was at port, the initial information gathered was that she was loaded with 14 trucks, 6 forty-foot trailers, all of open top type containing the passenger's luggage, and 22 privately owned cars. The total cargo declared was 76.32 tons excluding the passenger's luggage. According to the Master's arrival and departure condition log, the vessel departed from Duba Port with approximately 90 tons of HFO, 99.8 Tons of MDO and 187.86 Tons of FW.

There were 1,321 passengers and 97 crew members for an accounted total of 1,417 persons onboard. The vessel was certified to carry more persons. With the factual evidence we calculated and recreated all facts with the real events on board as well as the number of passengers and crew. The vessel departed with the cargo secured and the ramps and doors were closed and secured before departing. She sailed from Duba at 1825 hours, local Saudi time, and was full away at 1918 hrs, with a reported draught of 5.7 meters

In the resulting loading condition the HFO, MDO and FW were distributed based on the loading conditions found in the stability booklet. L.O was introduced in the same amounts and tank locations as in the stability booklet. W.B was added to ballast the vessel down to the draught of 5.7m. Passengers, crew and provisions centre of gravity locations were taken from the stability booklet.

The cargo load was located at the same centre of gravity location as listed in the loading conditions. It was assumed that each car would weight 1.5 tonnes and each passenger would have 30kg of luggage. The declared cargo of 76.32 tonnes was then assumed to account for the weight of the 14 trucks, 6 open top trailers of 40 feet and the single trailer of 20 feet in length.

Since this cargo weight of 76.32 tonnes appears to be low for the number of trailers and trucks a second loading condition was produced with modified weights for the trucks and the open top trailers. In this condition it was assumed that each of the 14 trucks would weight 25 tonnes, the 6 open top trailers would weight 8 tonnes each and the single shorter open top trailer would weight 5 tonnes.

The two departure conditions at the time of the accident can be seen along with the existing stability booklet loading conditions in Figure 1.

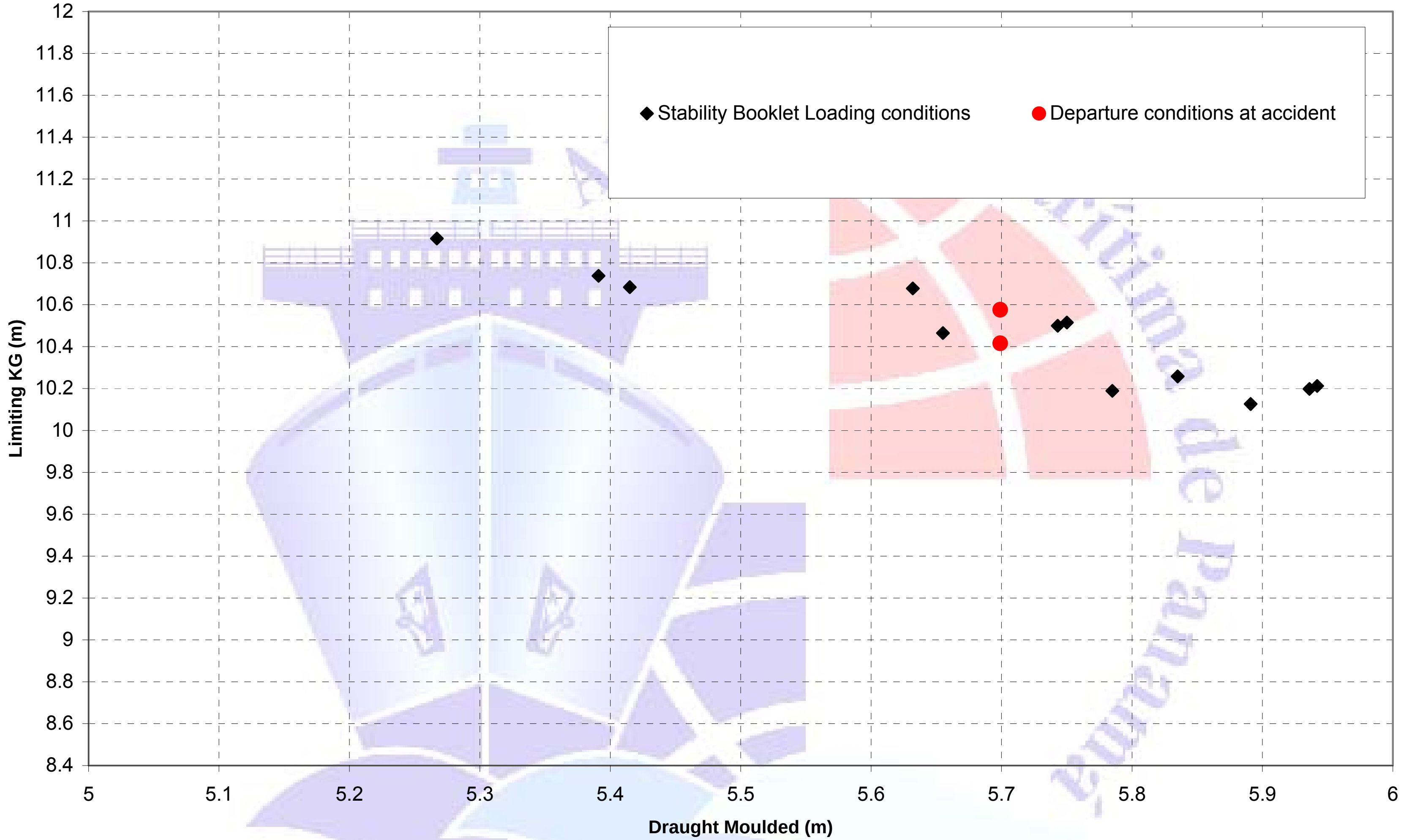


Figure 1 – Departure conditions at accident and stability booklet loading conditions

5. ASSESSMENT OF COMPLIANCE

To establish if the vessel was compliant with the relevant intact and damage stability criteria at the time of departure from the load port, each of the possible loading conditions fluid corrected KG value was checked against the limiting KG from the applicable criteria's.

The two conditions which were created to represent the vessel at the time of departure are summarized as follows:

DEPARTURE1 Vessel at time of accident (1321 PAX AND CARGO AS LISTED)

DEPARTURE2 Vessel at time of accident (1321 PAX AND HEAVIER CARGO)

Intact stability criteria as listed in Stability Booklet including relaxation in GZmax position by RINA

The results for the compliance check against this criteria set are shown in Table 1. As can be seen both loading conditions give positive margin to the maximum allowable KG.

CASE	Draught m	Trim m	KGf m	MAX KG m	KG Margin m
DEPARTURE1	5.699	-0.098	10.416	10.841	0.425
DEPARTURE2	5.699	-0.120	10.576	10.842	0.266

Table 1 – Compliance check with intact stability criteria as listed in Stability Booklet including relaxation in GZmax position by RINA

Damage stability criteria as listed in Damage Stability Calculation documents – calculated for each exact loading condition i.e. fluid in tanks

The results for the compliance check against this criteria set are shown in Table 2. As can be seen all loading conditions give positive margin to the maximum allowable KG.

CASE	Draught m	Trim m	KGf m	MAX KG m	KG Margin m
DEPARTURE1	5.708	0.012	10.416	10.704	0.288
DEPARTURE2	5.699	-0.120	10.576	10.585	0.010

Table 2 – Compliance check with Damage stability criteria as listed in Damage Stability Calculation documents – calculated for each exact loading condition i.e. fluid in tanks

The main task in this part of the report is related to the ship intact and damage stability at departure from the load port will be calculated to check compliance with the applicable regulations. This will be carried out using Naval Architecture package NAPA. The findings of these calculations are presented in this report

The general particulars for the Al Salam Boccaccio 98 are given below:

Main Ship particulars

Length, Over All	130.98m
Length, Between Perpendiculars	118.00m
Breadth Molded	23.60m
Draught	5.90m
Number of passengers – Mediterranean operation	1100
Number of passengers – Red Sea operation	2500
Number of crew	86
Service speed	22kn

There were two task taken into consideration for the development of this research.

- **Generation of ship database**

The objective of this task is to generate all necessary geometrical and topological information of the vessel for use in all subsequent analysis.

The commercial naval architecture package NAPA was used to generate the ship model as per departure loading condition from Duba. The NAPA ship model (database) included the definition of the hull geometry and internal compartments. Basic hydrostatic information was checked using the available stability book as a reference. Depending on the content of the database other areas such as compartment volumes, etc. were also checked against existing data provided from the preliminary findings.

- **Assessment of intact and damage stability**

The NAPA database was used to calculate the ship stability in departure condition and carried out checks on whether the ship complied with applicable regulations.

In order to have a clear view of the study you will be able to see the vessels complete external and internal geometry which was modeled using the commercial naval architecture package NAPA. The hull geometry can be seen in Figure 2 and the internal geometry in Figure 3

6. HULL GEOMETRY

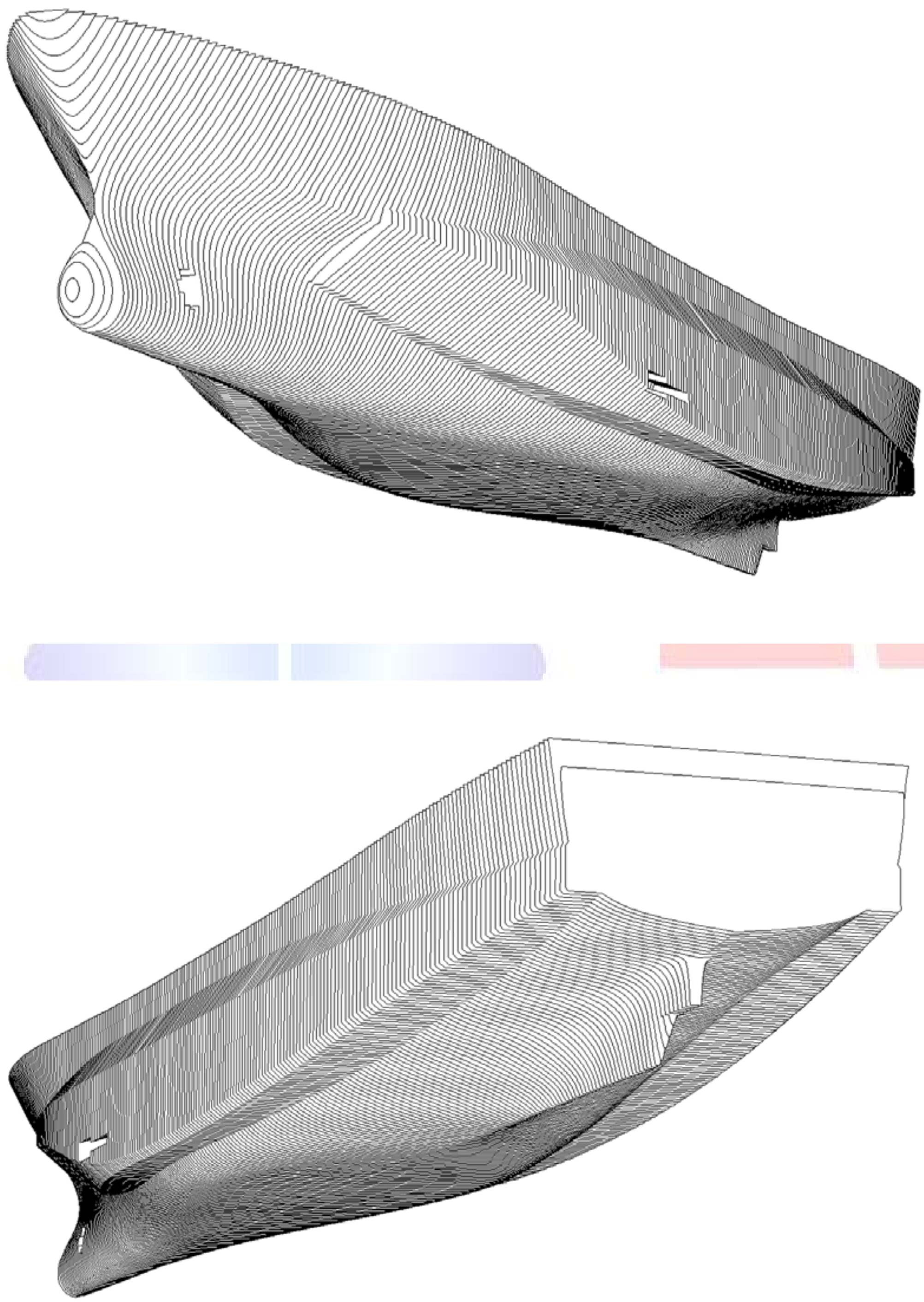


Figure 2 – Hull geometry

7. INTERNAL GEOMETRY

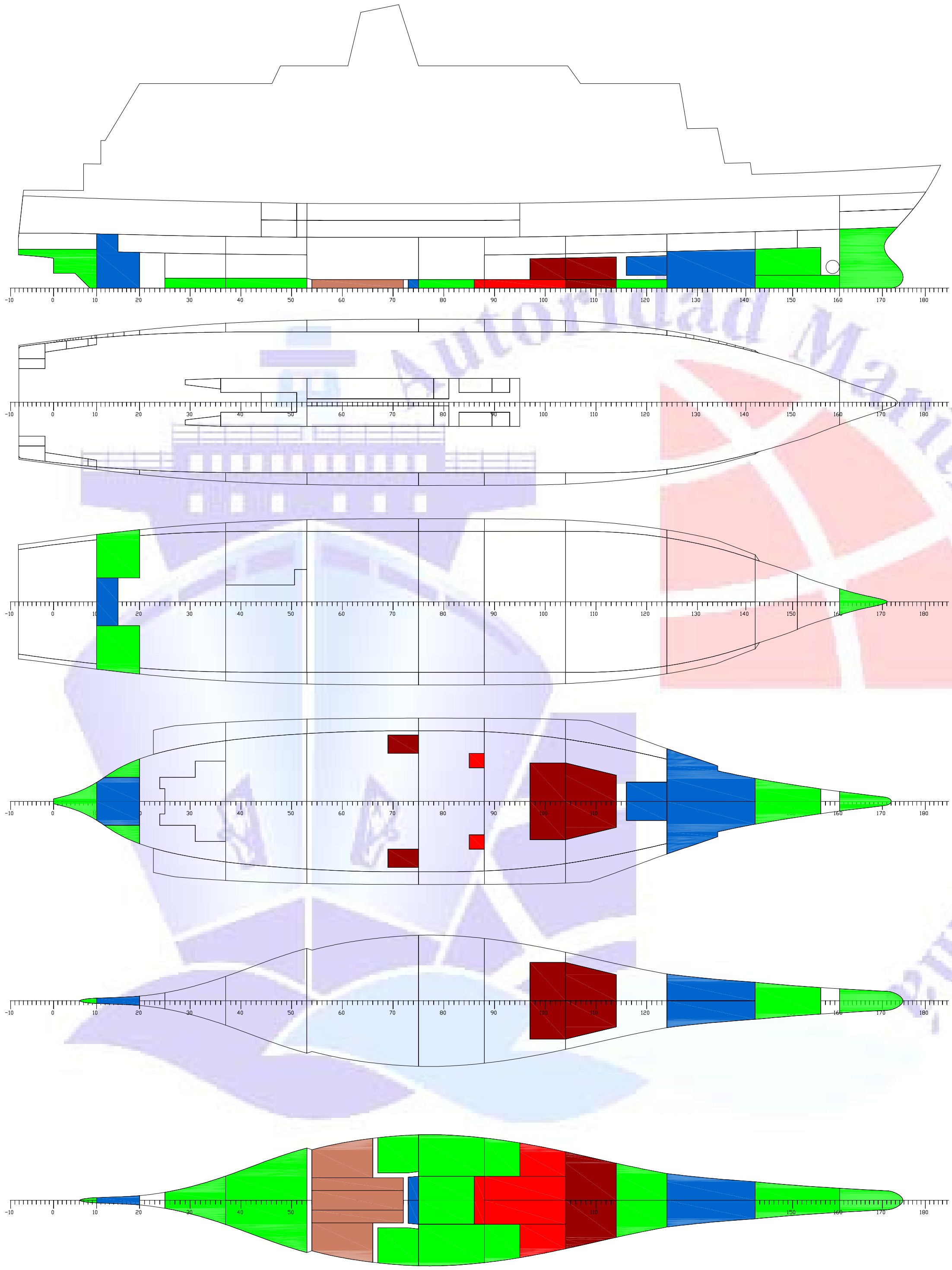


Figure 3 – Internal Geometry

All hull hydrostatics and compartment/tank volumes were checked and calibrated against the data provided in the stability booklet and also the capacity plans.

A detailed breakdown of the individual criteria in each set is provided in the following section.

RECOMMENDED INTACT STABILITY CRITERIA AS LISTED IN STABILITY BOOKLET INCLUDING RELAXATION IN GZMAX POSITION BY RINA

- *The area under the curve of Righting Levers (GZ Curve) shall not be less than:-*
    1. 0.055 metre-radians up to an angle of 30 degrees.
    2. 0.090 metre-radians up to an angle of the lesser of 40 degrees or the angle at which the lower edges of any openings in the hull, superstructures or deckhouses, being openings which cannot be closed watertight, are immersed.
    3. 0.030 metre-radians between the angles of heel of 30 degrees and 40 degrees or such lesser angle us referred to in (2).
- The Righting Lever shall be at least 0.20 metres at an angle of heel equal to or greater than 30 degrees.
- The initial transverse metacentric height (GM) shall not be less than 0.15 metres.
- According to RINA Rules, in cases of ships with a particular geometry of the hull, the maximum righting arm GZ may be accepted to occur at an angle of heel less than 25°, but in any case not less than 15°, provided that the area A below the righting lever curve is not less than the value obtained from the following formula: A = 0,055 + 0,001 (30° - θ max), where θ max is the angle of heel (in degrees) corresponding to the maximum righting arm.

DAMAGE STABILITY CRITERIA AS LISTED IN DAMAGE STABILITY CALCULATION DOCUMENTS

Intermediate stages of flooding

- None were specified

Final stages of flooding

The following requirements must be fulfilled in the final stage of flooding (equilibrium position)

- The positive residual righting lever curve shall have a minimum range of 15° beyond the angle of equilibrium.
- The area under the righting lever curve shall be at least 0.015m.rad, measured from the angle of equilibrium to the lesser of:
    1. the angle at which progressive flooding occurs;
    2. 22° in the case of one compartment flooding.
- The maximum residual righting lever (GZMAX) shall be the greater of 0.100m and the value obtained by the following formula:

1.1.1.1.1.1.1.1.1.1 $$GZ = \frac{\text{Heeling Moment}}{\text{Displacement}} + 0.04 \text{ (in metres)}$$

When taking into account the greatest of the following three heeling moments:

1. Due to the crowding of all passengers towards one side;
2. Due to the launching of all fully loaded davit-launched survival craft on one side;
3. Due to wind pressure.

- In the case of unsymmetrical flooding the angle of heel must not exceed 7° for one compartment flooding
- The margin line should not be immersed

Technical research made use of the Naval Architecture Package or NAPA to generate the model of the ship, define the hull geometry and internal compartmentation, and was the tool used to define the ship's stability in departure condition and carry out checks on whether the ship complied with the applicable regulations. The documentation for the vessel stated that it was a one compartment standard applied, and therefore the adoption of one compartment standard had to be applied for the damage stability criteria.

The cargo load was located at the same center of gravity location as listed in the loading conditions. A cargo load of 76.32T was a dubious figure, In the analysis, a parallel load condition that would match a real value of 5.7m for the draught line declared in the established data concluded that *475.6T was a more realistic weight.* Test a run using the NAPA program was ran for both weights and the results showed that both loading conditions gave positive margin to the maximum allowable KG. To establish if the vessel was compliant with the relevant intact and damage stability criteria at the time of departure from the load port, each of the possible loading conditions fluid corrected KG value was checked against the limiting KG from the applicable criteria.

The Assessment of Intact and Damage Stability Research detailed that the vessel was in compliance at departure from the load port with applicable stability requirements. The report details the calculations of loading conditions for the time of the incident and the compliance check with relevant stability requirements. The RINA stability rules were found to meet the vessels loading condition at the time of the incident.

Both tests conditions created to prove that the loading conditions were accurate at the time of the Al Salam Boccaccio 98 departure gave a positive margin to the maximum allowable KG compared to the compliance margins listed in the Stability Booklet, to include the relaxation in GZmax position by RINA. RINA rules allow the GZmax position to occur at an angle lower than the recommended angle of 25 degrees provided the stability curve demonstrates additional area up to an angle of 30 degrees. Though the intact requirements differ from those recommended by IMO for passenger vessels (Section A.749.(18), both loading conditions were found to in compliance with the relevant stability standards. The conclusion of the work was that the loading condition at the time of the incident complied with RINA Stability Rules and the vessel's draught was within the maximum draught, therefore complying with the Loadline Convention.

8. THE WEATHER

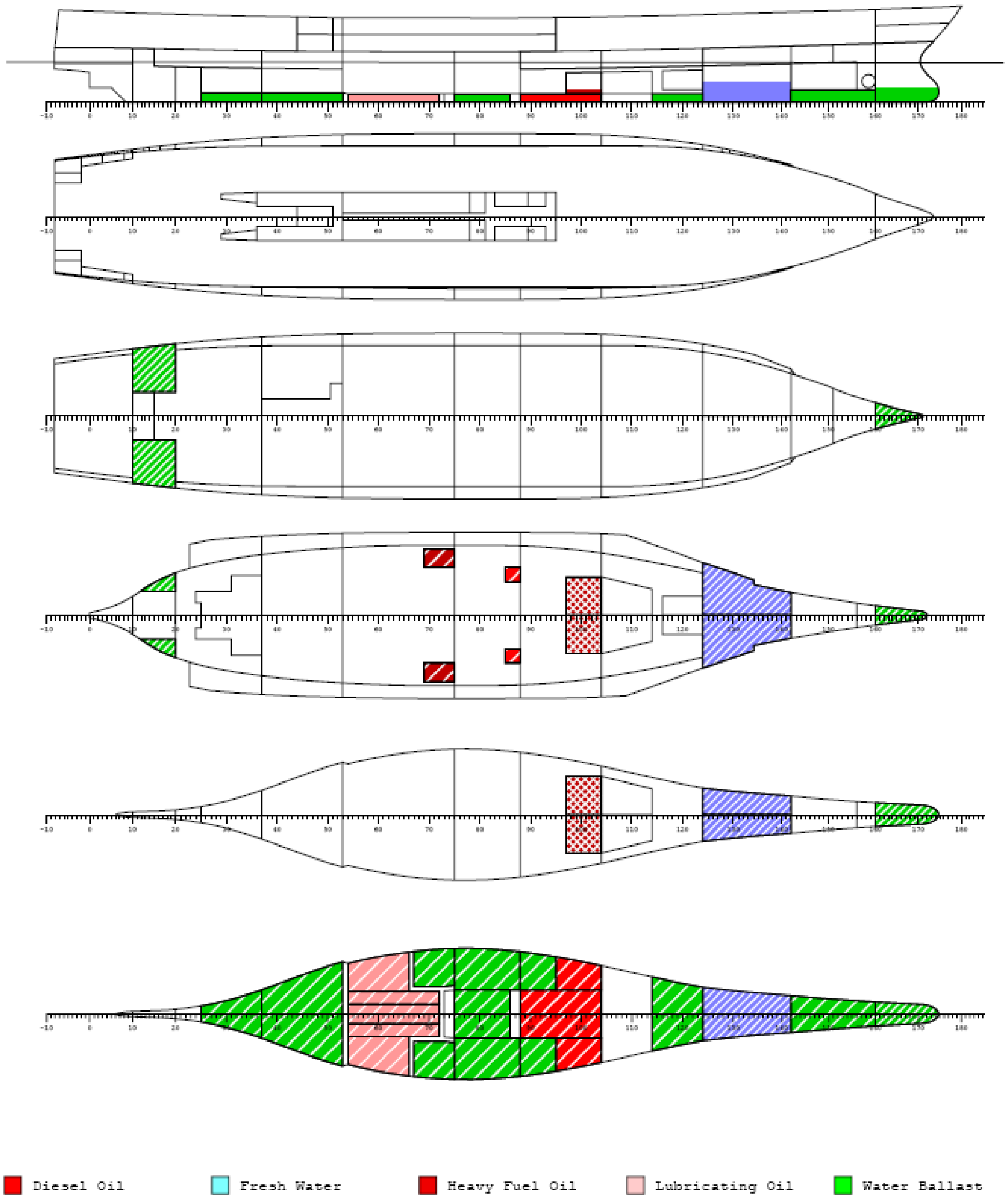
Weather condition was consistent from basically two witness sources that were at sea the night of the incident, the Master of the M/V Al Salam Boccaccio 98 and the Master of the St. Catherine, another vessel owned by El Salam Maritime and operating on the same route the night of the incident. According to the departure information reported by the master, the weather was about 6 to 7 Beaufort scale. This was also confirmed by the statement from the interview with the master of the MV Saint Catherine, who declared that the weather was bad, with a 7/8 Beaufort Scale with 3m waves, and wind speed gusting at 60knots WNW based on the positions of his vessel. Information collected from the survivors, vessel in the vicinity and other authorities added that the weather condition was not as usual in this area. The VDR information provided data that the weather was in the scale of 7 to 8 moderate gale with a southeasterly wind.

Supportive weather conditions were attained from the World Metrological Organization that revealed a mean wind speed of 30knots, Beaufort force of 7, with a sea state of 6.

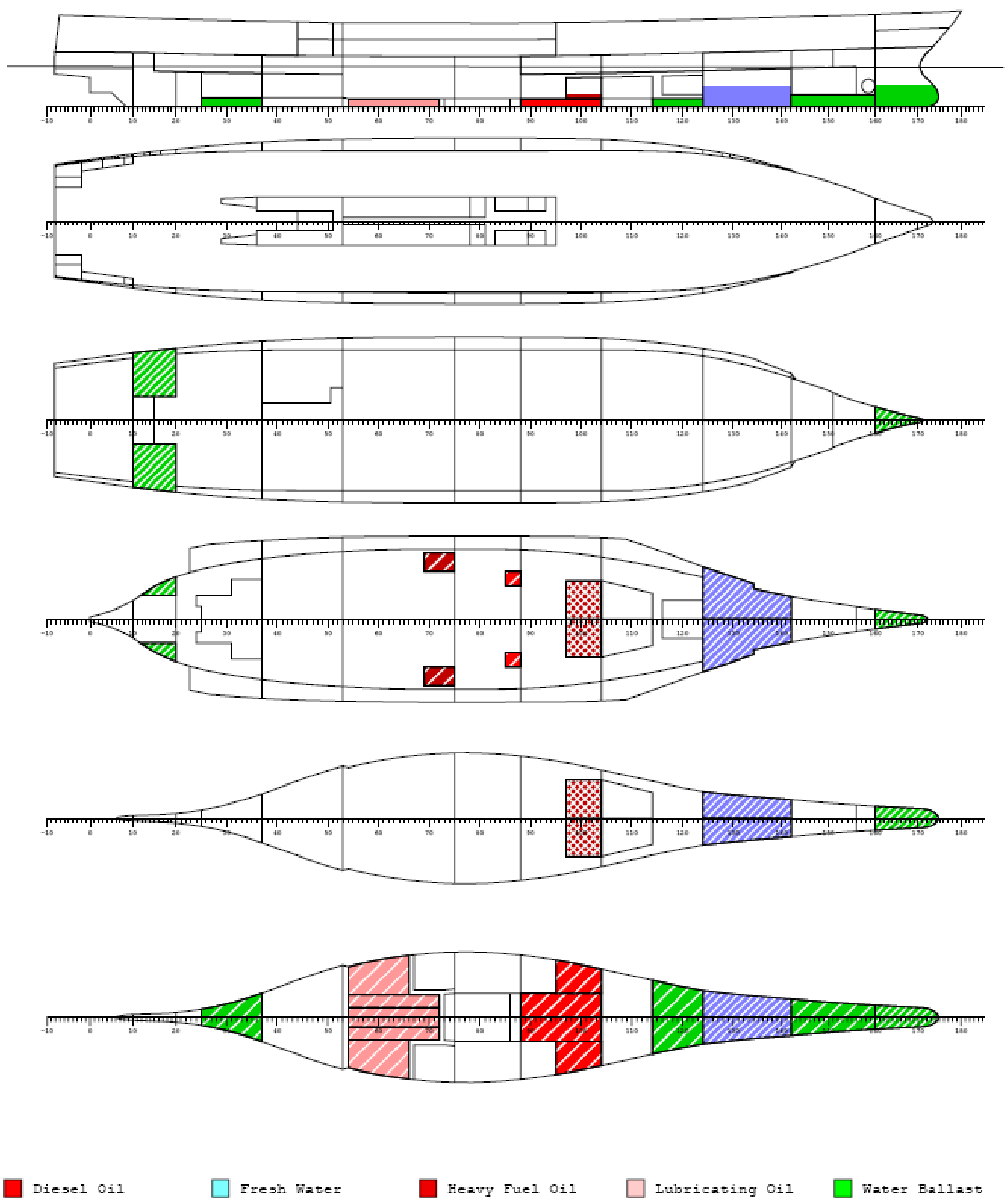
This describes a very rough sea with a mean significant wave height of 5m. Global Wave statistics for the months of December through February shows that a 5m wave height is extremely uncommon for this area of the Red Sea..

The use of the PROTEOUS dynamic software there was a recreation carried out using NAPA software to achieve the started draft a considerable quantity of ballast water was required also an alternative loading condition was created with increase of weights for the trailers both loading conditions are shown graphically in Figure 2 and Figure 3 below. D1 is the original condition stated at the departure of the vessel and D2 is the condition where the cargo weights were amended.

General arrangement showing the load case based on the Master's information (D1)



General arrangement showing the load case with amended weights for the cargo (D2)



Analysis of the weather condition was carried out using the PROTEUS dynamic software for both the 5m and 3m conditions reported. The results of the 5m simulation as reported by WMO showed that the ship's response did not match the conditions reported by the VDR data. The conditions described would affix the vessel with violent rolling conditions, a situation that would significantly task the crew from moving around on the deck to perform a safe fire attack. The 3m wave height simulation showed results that would better match the report of the VDR. Since these were reports collaborated by masters of the Al Salam Boccaccio 98, the St. Catherine, and witness crew members statements in their interviews, it was accepted as the most accurate weather condition during the voyage of the accident.

The night of the incident, the ship was heading South West. The wind and seas were from the South East with readings of Beaufort 7/8 and the seas as 3m. This means the ship was heading across the wind and seas. When beam on, the wind would exert a steady force on the ship producing a static heel angle, and as declared and estimated by the 3/O in his statements and the VDR, somewhere around 5 degrees.

The master had given instruction to the wheel man to maintain the actual course 220, but after the fire started in the car deck the vessel was not responding and made a complete turn of about 358 degrees in approximately 10 minutes. The sea conditions would then cause the ship to roll about the steady heel angle caused by the wind. This may have caused the list of approximately 5 degrees. The optimum course would have been to steer roughly either into or away from the seas and wind.

Water accumulating on the deck played around with free surface effect and created an unstable condition to the stability of the vessel. The weather on the night of the incident had a detrimental effect on the ability of the scuppers to remove the firefighting water. In ideal conditions, without any wind or waves, capsize time would have taken much longer.As a result of this, several documents have been submitted to the relevant committees and sub committees of the IMO in order to modify the regulations for the design of the scuppers as well as its performance in real sailing conditions and real emergencies scenarios

9. MANEUVERING CONDITIONS

At the time of the accident it was reported of the bad weather condition and a fire that started in the car deck. Simultaneously, a steering problem was reported at the start of the fire and followed by malfunctions of the steering pump presenting problems and not responding to orders according to the voices recorded in the VDR.

During the fire fighting there are records showing possible temporal rudder malfunctioning due to problems of the steering pump, assumptions lead to believe this was possible due to a loss of electric powers or signal from cables passing through the car deck ion the way to the steering gear room or confusions among the officers. On several occasions there were notifications by the 3/O to the Master that the steering gear was not responding, however it is also recorded that after some time the control over the heading has been recovered. The ship's course from 1933hrs until capsize at 2333hrs cannot be defined due to the lack of GPS data and the repeated failure of the steering gear left not accurate definition of the heading. Since the start of the fire (approx

The ship position and heading was recorded in the VDR normally until the start of the fire, after this, about 1937 hours UTC the VDR did not recorded normally the information from the GPS, and according to the conversations between officers it can be assume that the steering pump was not effectively working, or working on and off, allowing the ship to lose control several times, it is also possible that a confusion of orders and navigational errors may lead to this loss of heading. The possible failure of the steering gear and rudder jams made the ship lost significant distance with an uncertainty of her intended travel route, additionally there is evidence in the VDR that shows there were not clear and continuous supervision from the master or officers at the bridge over the heading and position of the ship.

Speed tests and turning maneuver at different settings, based on information attained from the VDR data was checked and validated by means of the maneuvering suite SIMX. Tests were ran under various conditions to try and establish changes, speed and deviations from the intended route from Duba to Safaga that aid in clarifying lost of direction, maneuvering problems encountered and delays. Because of incomplete data recorded from equipment malfunctions, some of the data were interpreted based on trajectory.

Tests were ran to determine and reconstruct the ship navigation route the night of the incident. As the VDR data revealed and witness statements, the crew was experiencing steering problems with uncertainty of direction. It was concluded that the Al Salam Boccaccio 98 had steering qualities similar to other ships of her size provided the steering devices are functioning normally.

Based on preliminary findings, the ship steering pumps were not responding immediately after the time of the report of the fire, around 1909 hrs. The results prove that after a six minute span of time, the ship made turns to starboard and dropped speed to 7 knots, and continued turning, then returned to her original course after a 10 minute span. This situation suggests the rudder was possibly jammed, and the results matches the witness statements that the ship completed a full turn of 360 degrees in about ten minutes. It gives to the understanding that the vessel was underway with uncertainty of direction and still at sail during the fire operation.

The length between the last GPS position and the final sinking position, when plotted on an Admiralty chart, and assuming a straight line was in order of 14 NM for a programmed journey, the time elapsed between the two positions is almost 4 hours with a average ship speed of 3.6 knots. This figure does not match the speeds reported by witness statements in the order of 6-8 knots and reduced 5-6 knots at the last stages prior to capsizing.

The vessel sinking position is far north from her projected navigation route. Due to the possible failure of the steering gear and possible rudder jam or navigational errors, and weather conditions, the ship lost significant distance on her intended travel route. If the steering gear was functioning normally and there were no navigational errors, the ship would likely have sunk about 34.4 NM from Safaga Port. Had the ship stayed on her route she would have been much closer to the port of Safaga from where the search and rescue were eventually launched.

10. THE FIRE AND RELATED ISSUES

At 1909 hrs the fire alarm of the AL SALAM BOCCACCIO 98 sounded and a couple seconds after the auto pilot alarm had activated. The 3/O on watch (Ahmed Nassar) reports via phone to the captain in his cabin of the alarms in the bridge. The AB on watch in the car deck had arrived to the bridge at 1910 hours and reported to the 3/O on duty that the car deck was full of black smoke and he assumed it was a fire in the engine room.

There was uncertainty about the exact location of the fire. First it was reported that it was the engine room on fire, then it was said to be the emergency Caterpillar diesel generators, and finally, around 1925 hours the 1E confirmed that *the fire was located in the luggage trailers parked on the port side in the middle of the garage*.

At 1918 the 2/O informed the captain that the sprinklers in the car deck were already operating ever since the beginning of the fire. The fixed firefighting system in the garage was activated shortly after the fire broke out. It is questionable but reasonably sound to admit that the fire sprays remained on for the majority of time until the vessel capsized.

The fire continued and the sprinklers together with the fire pumps and hoses were in operation. Orders were not clear on how to start mitigation, however three teams composed of 6 persons each, were dispatched to fight the fire, one of them attacking the fire in the car deck specifically. Despite their best efforts, the crew was unable to extinguish the fire on the deck, resulting in prolonged use of firefighting water on the garage deck and on the accommodation deck above. The Master became aware that the Al Salaam Boccacio 98 faced the great dangers of a propagating fire and the risk of capsize due to the accumulated fire fighting water.

According to the VDR information the spray and fire hoses were fully operating from early, but due to the fact that there were several areas affected by the fire the master ordered to spray partially the car deck, and to continue fighting the fire in other areas such as the cabins located in the upper part of the suspected area of the fire.

The 2/O Sheriff and various crew members and hotel assistance personnel were cooling down the accommodation after heat and smoke spread around different cabins.
The crew members could not control the fire and the large quantity of water used for the fire fighting operation was increasing on the deck. (The wind was coming from the port side of the vessel). Little consideration was given to the free surface effect of water on the deck. The fire was never completely extinguished and it expanded in several places and decks. The fire was fought by the crew for approximately 4.5 hours and the use of water to extinguish the fire was never successful.

The VDR showed requests at various times from the Master to either reduce the spray to specific zones or to stop it altogether. This hints that he was aware of the impact it would bear on stability. Due to the fact that these requests were often repeated, it was unclear whether they were actually carried out. The pumps supplying the spray heads were rated at 430m3/hour.
Simulation of the flooding effects was based on the assumption that the fire fighting spray remained on from the onset of the fire until the capsizing. The uncertainty of fire hose placements, how many were in place during an avid fire attack and for how long also bears weight on water flow measurements.

Fire pumps supplying the hose lines were discharging at 90m3/hour. Though the vessel was designed and built with the capacity on either side of the garage deck to be able to drain the deck at a greater rate than the fire sprays and fire hoses combined could deliver, the port beam seas condition on the night of the incident, was a factor that enabled the average flow out to be insufficient in removing all the water flowing in through the fire spray system. This condition allowed the scuppers to flow out an average 330 m3/hr compared to the 430 m3/hr that the system pushes. It was clear that the control team believed all the scuppers were not operating effectively. The crew confirmed that the scuppers were partially blocked, at least partially by debris. From the information available, it appears that the flow through the scuppers is a key factor in the capsizing of the vessel.

11. THE LIST AND RELATED ISSUES

According to the VDR data, the master made various attempts to try and reduce the heel by requesting to stop the fire sprays and hose operation, making use of submersible pumps to remove accumulated water and filling and emptying tanks.

11.1 ***Scuppers***

Under intact conditions, there is no doubt that the Al Salam Boccaccio 98 had high initial stability, a condition that dramatically changed with the genesis of the incident, the fire.

The fixed firefighting system in the garage was activated shortly after the fire broke out, and it was certain that the sprays remained on for the majority of the fire fighting operation until the vessel capsized. VDR data showed that there were efforts to fight the fires with attack hose lines. It is not clear what were the exact hose placements, how many were in use and for how long. This made assessing the hose flow a bit inaccurate. One thing was certain, and it was that water accumulated on the garage deck and created devastating effects on the stability of the vessel.

The Al Salam Boccaccio 98 was designed and built with 13 scuppers on either side of the garage deck with the capacity to be able to drain the deck at a greater rate than the fire sprays and fire hoses combined could deliver during a given operation. According to the information provided by RINA during the ships life, the vessel was fitted 2 additional scuppers, resulting in 15 scuppers on each side of the ship; each scupper having a diameter of 125mm and fixed with two non-return valves high up and at the lower part of the scupper near to where it exits below sea level. Immediately after the accident, several inspections and evaluations were carried out to the sister ships measuring different aspects in order to obtain a similar performance of the drainage system; but especially to the effect it would have on stability, the fire fighting systems, and the behavior of the crew, as well as the scuppers inspections. Many assumptions were made regarding the frictional losses when calculating the full unrestricted flow through the scuppers due to the lack of detailed information.

It was assumed that the additional scuppers were constructed in a similar way. In 1990 – 1991 sponsons were fitted at the same time as additional accommodation decks were added. At this time the outlet pipes of the scuppers in way of the sponsons were extended by approximately 1.8 metres horizontally through the sponsons. 5

Table 3
Scupper locations

Scupper No.	Frame Location (P&SB)	Overboard dist. From deck
0*	-3 / -4	Unknown
1	22 / 23	3.5
2	25 / 26	3.5
3	31 / 32	3.4
4	34 / 35	3.4
5	53 / 54	3.2
6	66 / 67	3.2
7	73 / 74	3.4
8	80 / 81	3.2
9	96 / 97	3.3
10	101 / 102	3.6
11	109 / 110	3.4
12	123 / 124	3.7
13	141 / 142	3.9
14*	150 / 151	Unknown
* Denotes additional scupper		

Figure 4

Plan showing the location of the scuppers

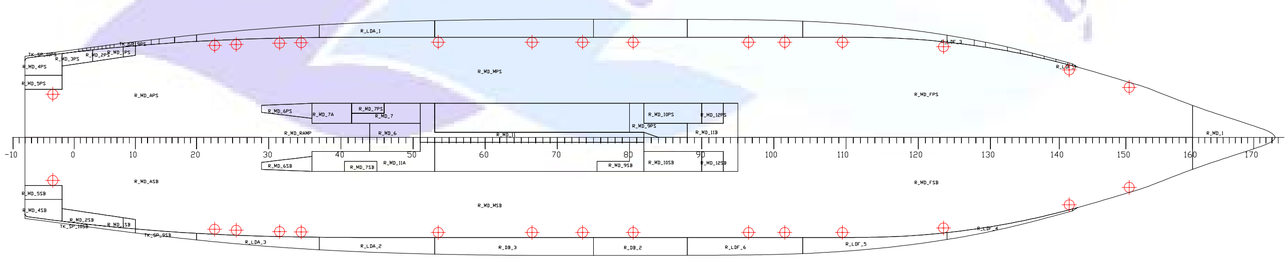
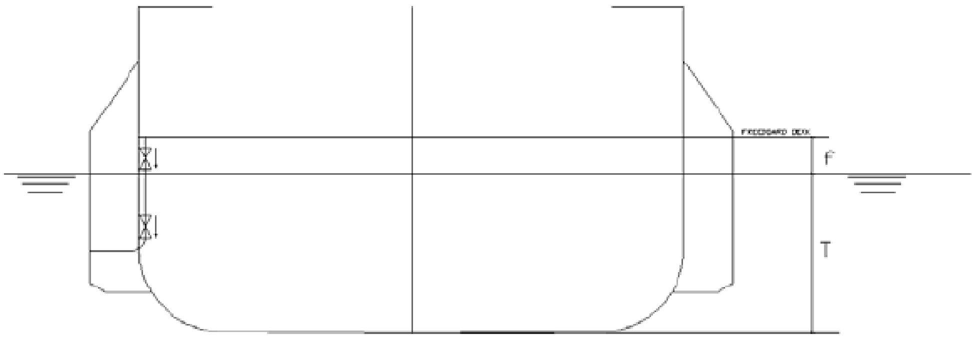


Figure 5

Diagram of scupper layout



Tests excluded the fire hose flow factor from the reconstruction, but in a separate sensitivity test based on the assumption that all three of the fire pumps on the vessel were in operation during the fire, it would take a determinate amount of scuppers to evacuate the flow safe and expeditiously. Testing was done on an 18,000-second flooding simulation, with progressive op*ening of scuppers to determine how many were in operation before the capsizing. Tests were ran using conditions of 1, 2 or all 3 pumps in operation. The results of the number of scuppers and time frame for capsize were a bit irrelevant since it was inconsistent with VDR data. A result showed that if all 3 fire pumps had been in operation for the entire duration then the equivalent of between 11 and 13 scuppers would have had to be in operation for the capsize time to match the VDR data.*

11.2 ***Static Analysis***

Static analysis was carried out using the naval architecture package, NAPA, focused in verifying the effect of water accumulating on the garage deck and its effect of the GZ curve of the vessel. Water on the deck was noted as a growing problem, and showed a pronounced effect on the GZ curve once the listing gradually increased Figure 6 shows the GZ curve produce in NAPA for the intact ship: This shows that in the intact condition the Al Salam Boccaccio 98 has high initial stability.

GZ of ship with no water on the deck. HPHI is the GZ curve, EPHI is the area under the GZ curve

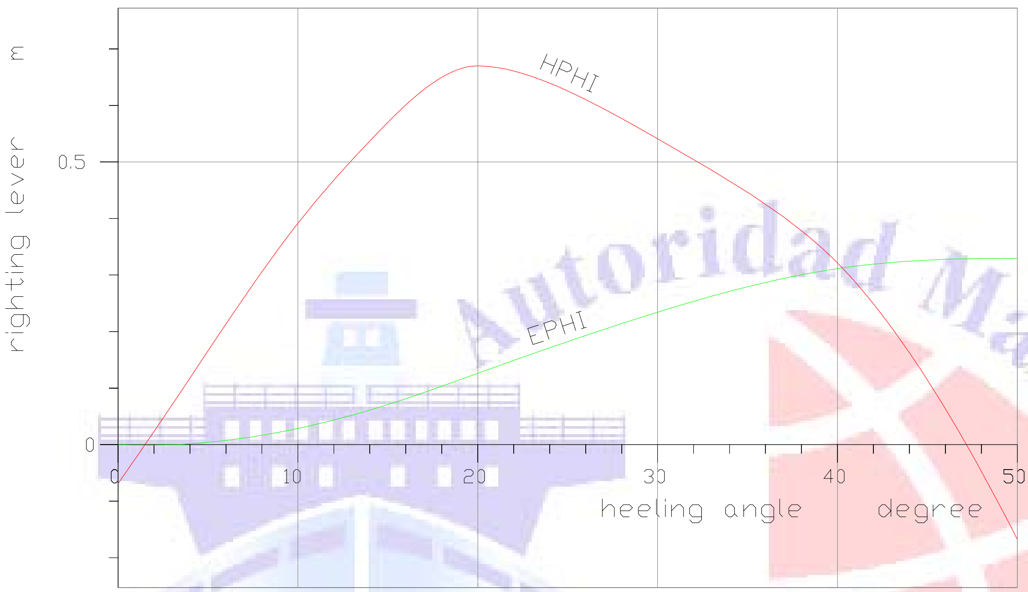


Figure 6 *shows the GZ curves for the ship just before capsize. This shows that at this point, due to the accumulation of water on the garage deck the vessel has very little positive stability and is also in a condition known as Loll.*

Loll is a condition whereby the vessel is not stable when upright; instead it is stable at an angle of heel to either port or starboard. This condition can be caused by either excessive free surfaces of fluids or by too much weight located high up in the ship. The usual cause of loll in a properly loaded ship is free surface. There is no evidence to suggest that the Al Salam Boccaccio 98 was not properly loaded and in this case the loll condition was almost certainly caused by the free surface of the water on the garage deck. In a loll condition if the ship were to roll from side to side then she would 'flop' from one side to the other settling at the stable angle to port or starboard. This would be quite unpleasant for the passengers and quite dangerous for the stability of the ship.

Figure 6

GZ curve of Al Salam Boccaccio 98 with approx 930 tonnes of water on the deck. HPHI is the GZ curve, EPHI is the area under the GZ curve

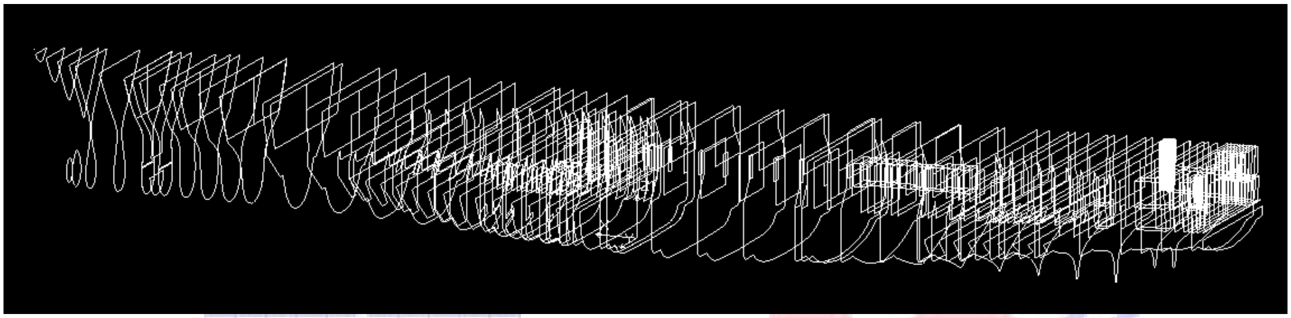
*11.3 **Dynamic Analysis***

Creation of model

A dynamic stability model was built using in-house dynamic stability software PROTEUS. Only the watertight hull was modeled as it is responsible for the entire stability of the vessel. In order to determine how the capsizing occurred, only changes to this part of the hull need be considered. A wind profile which accounts for the superstructure was created to account for the effects of the wind. Loading conditions created in the static stability model in NAPA were recreated in the PROTEUS model.

Figure 7

Plot of dynamic stability model created in PROTEUS



11. 4 **Permeability**

Permeability was assigned to the spaces in accordance with the values specified by SOLAS. The garage was given a permeability of 0.9. This is the values used for Stockholm Agreement analysis of water on deck so was considered to be correct for this analysis.

11.5 **Approach**

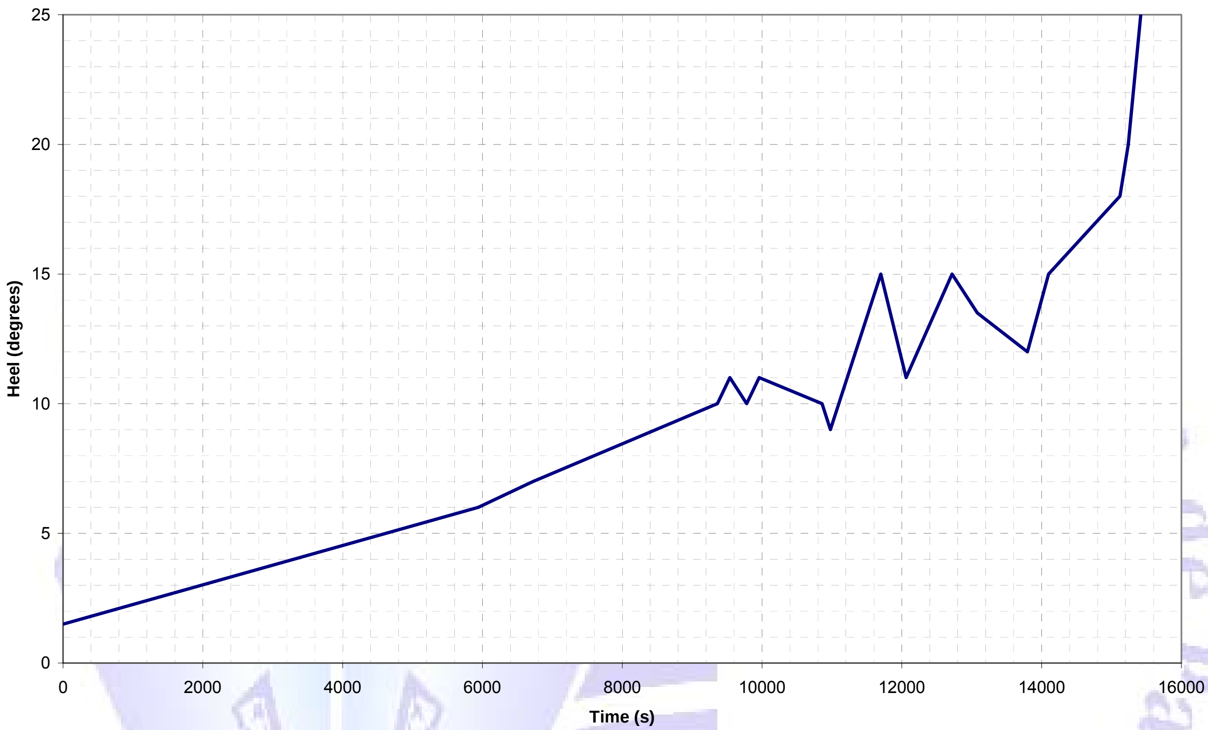
The dynamic analysis focused on the key events found in the VDR data and the witness statements. These were as follows:

- Water from the fixed fire fighting system in the garage accumulated on the garage deck.
- Water down flooded from the garage deck to the crew accommodation.
- It took approximately 4 hours 20 minutes from the fire spray first being activated to the time of capsize.

The following graph shows the heel progression over time from the VDR data.

Figure 8

Graph of heel over time from VDR data



The aim of the dynamic analysis was to try and establish a possible scenario which matched as much of the VDR data as possible and also the capsized in the same time as shown in the VDR data.

12. FIRE FIGHTING WATER

The garage on the Al Salam Boccaccio 98 was equipped with a fixed fire fighting sprinkler system. The pump supplying this system has a capacity of 430m^3/h. A drawing showing the fire fighting system was analyzed to determine that there are 5 different zones making up the whole system. These were shown in the model as 5 separate openings.

A flooding rate was then applied to these openings to give a total flow rate equal to that of the pump.

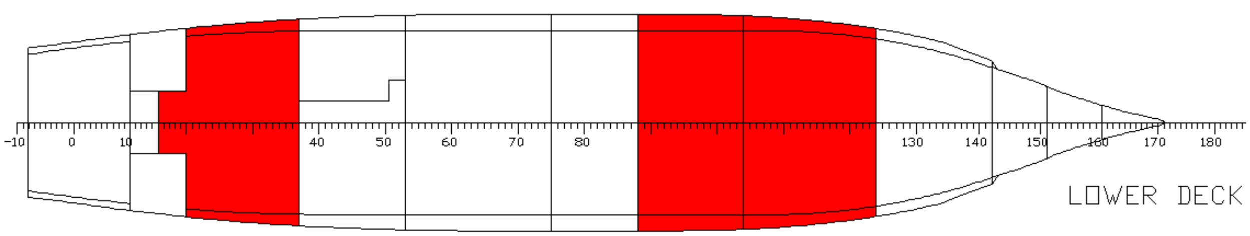
12.1 Down flooding to the crew Accommodation

There is little information regarding this however it was felt that this could affect the scenario so should be considered. One of the crew stated in their statement that at 11pm local time the water in the crew cabins was "knee high". While this is fairly vague and cannot be used to give any sort of accurate analysis it does give an indication of the quantity of water which flooded down to the crew accommodation**.**

Below the car deck there are three areas of crew accommodation, two areas forward and one area aft. This is shown in Figure 9. The two forward accommodation spaces are joined by a watertight door. The crew member however, did not state which crew accommodation it was that flooded. By analyzing the available drawings we were able to identify possible flooding routes for all the crew accommodation areas.

Figure 9

Drawing showing the forward and aft crew accommodation spaces highlighted in red



At this point it should be noted that the arrangement of the centre casing is not clear from the available drawings. Each drawing shows a different arrangement so it is difficult to know which is correct. The drawings and photos of a sister ship were cross checked and a best guess at the arrangement has been used. Different simulations were run using PROTEUS allowing flooding to different crew accommodation spaces and to all spaces to try and identify the most likely scenario.

12.2 Weather Conditions

The weather conditions used in the PROTEUS model are summarized in Table 4 below.

Table 4

Environmental conditions used in simulations

Item	*Description*
Wind Direction	*Southeast*
Wind Speed	*30kts (Davenport spectrum)*
Wave	*3m / 5.5 seconds*
Wave spectrum	*JONSWOP / γ 3.3*

The JONSWOP spectrum was developed from data for the North Sea where the waves are limited fetch due to relatively enclosed nature of the seas. These conditions are very similar to the Red Sea so the JONSWOP spectrum with a γ value of 3.3 was used to predict the wave motions.

12.3 Simulation Runs

From the available information it appears that the flow through the scuppers is a key factor in the capsize scenario. Some initial runs were carried out to determine the effect if there is no flow through the scuppers and if there is full flow through the scuppers i.e. no scuppers blocked. The initial simulation runs are shown in **Table 5** shows the heel over time for run 1 and **Figure 11** for run 3. the heel over time graph obtained from the VDR data which is shown in also included on these graphs for reference purpose. Runs 1 and 3 are en the D1 load case and runs 2 and 4 are in the D2 load case. The results for runs for runs 2 and 4 show similar results and are not shown here.

Table 5

Initial dynamic simulation runs

Run	Load Case	Scuppers	Waves	Wind	Down flooding
1	D1	Closed	3m / 5.5sec	30kts	No
2	D2	Closed	3m / 5.5sec	30kts	No
3	D1	Fully Open	3m / 5.5sec	30kts	No
4	D2	Fully Open	3m / 5.5sec	30kts	No

Figure 10

Heel over time for Run 1. Scuppers not operating, 3m/5.5sec zero crossing period wave, 30kts wind

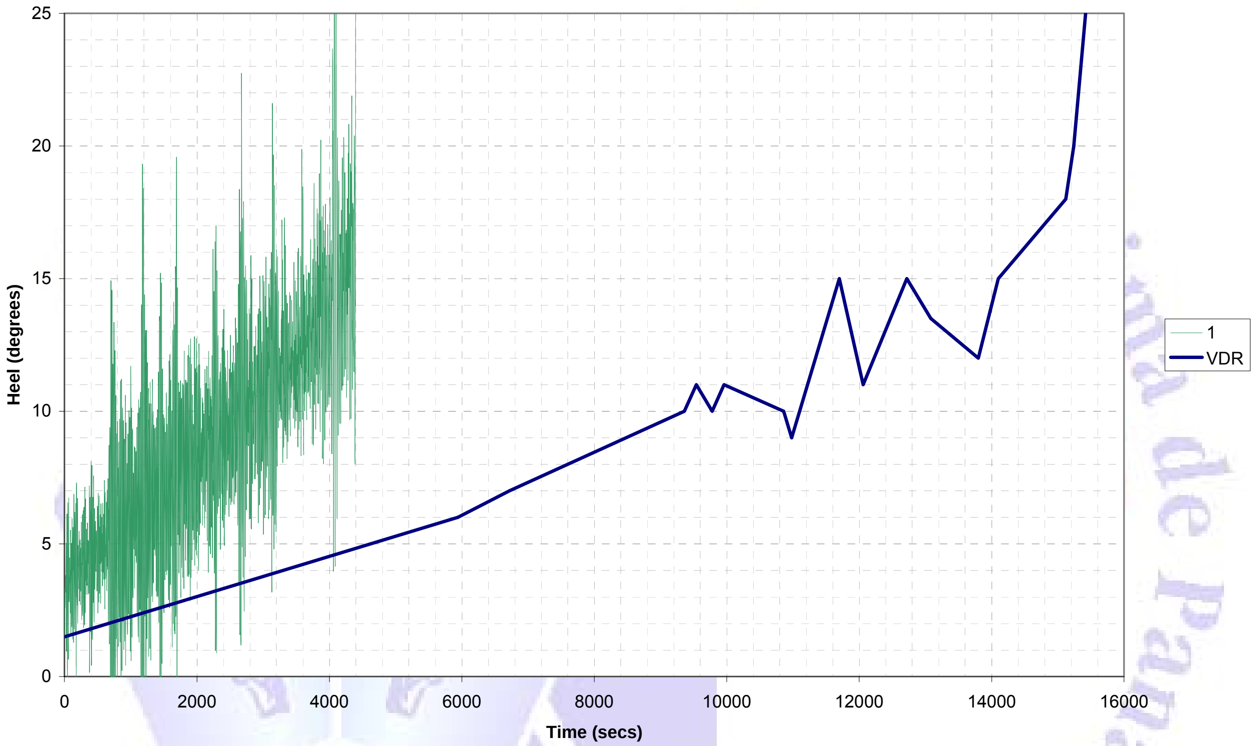
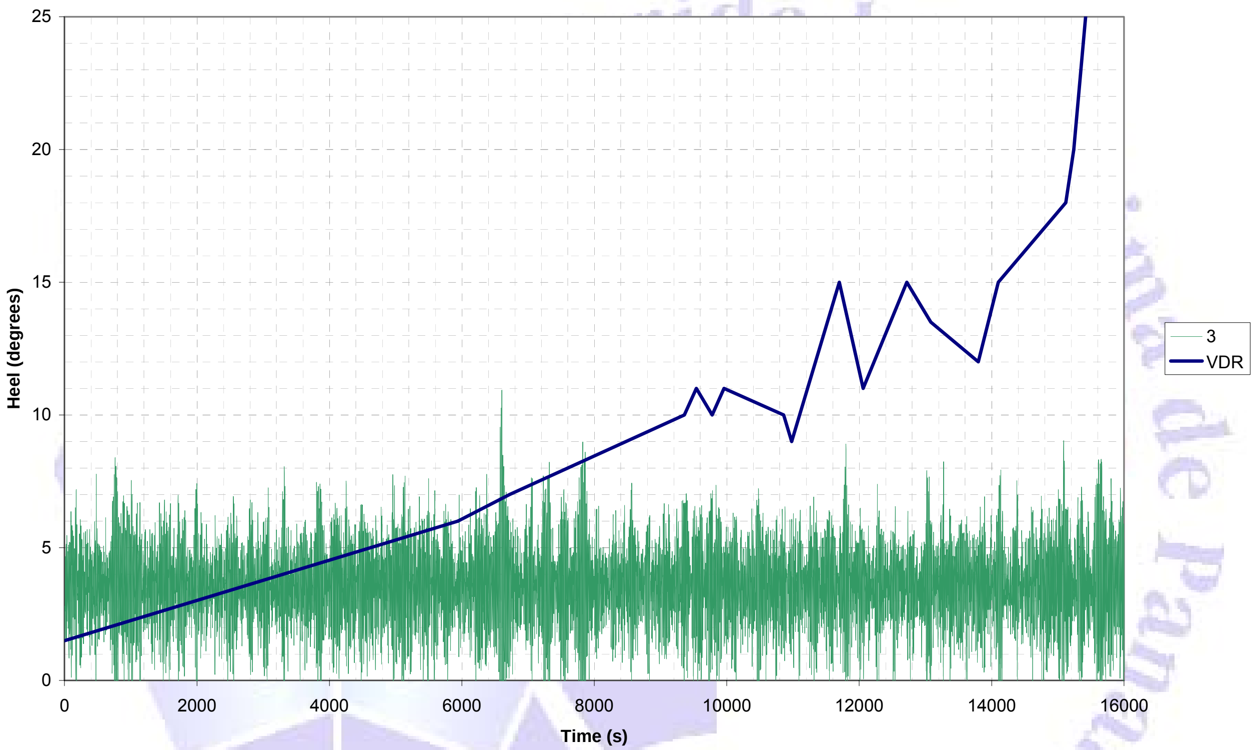


Figure 11

Heel over time for Run 3. Scuppers fully operational, 3m/5.5sec zero crossing period wave, 30kts wind



These results show that with the water flowing through the scuppers in the way they were designed, the vessel would, then the ship would capsize in less than half the time it actually took for the ship to capsize. This suggests that the scuppers may only be partially blocked.

In the VDR data at 21:15 UTC, the officer in the garage stated that 4 scuppers on the starboard side were working. This information was used as a starting point for looking at differing flow rates through the scuppers. Flow rates for the scuppers were set to the equivalent rate of only 4 scuppers flowing on either side. Additional runs were carried out as shown in table 6 with this flow rate.

Table 6

Runs with scupper flow restricted to the equivalent to four scuppers

Run	*Load Case*	*Scuppers*	*Waves*	*Wind*	*Down flooding*
5	*D1*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*No*
6	*D2*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*No*
7	*D1*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*All. Connection closed*
8	*D2*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*All. Connection closed*
9	*D1*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*Aft only*
10	*D2*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*Aft only*
11	*D1*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*Fwd only. Connection closed*
12	*D2*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*Fwd only. Connection closed*
13	*D1*	*Restricted to 4*	*3m / 5.5sec*	*30kts*	*Fwd only. Connection open*
14	*D2*	*Restricted to*	*3m / 5.5sec*	*30kts*	*Fwd only. Connection*

		4			*open*

Runs 5 and 6 were comparable with runs 1 to 4 as the only difference was the flow rate through the scuppers. The graph of heel over time for run 5 is shown in **Figure 12.**

Figure 12

Graph of heel over time for Run 5. Scupper flow equivalent to 4, 3m/5.5sec zero crossing period wave, 30kts wind.

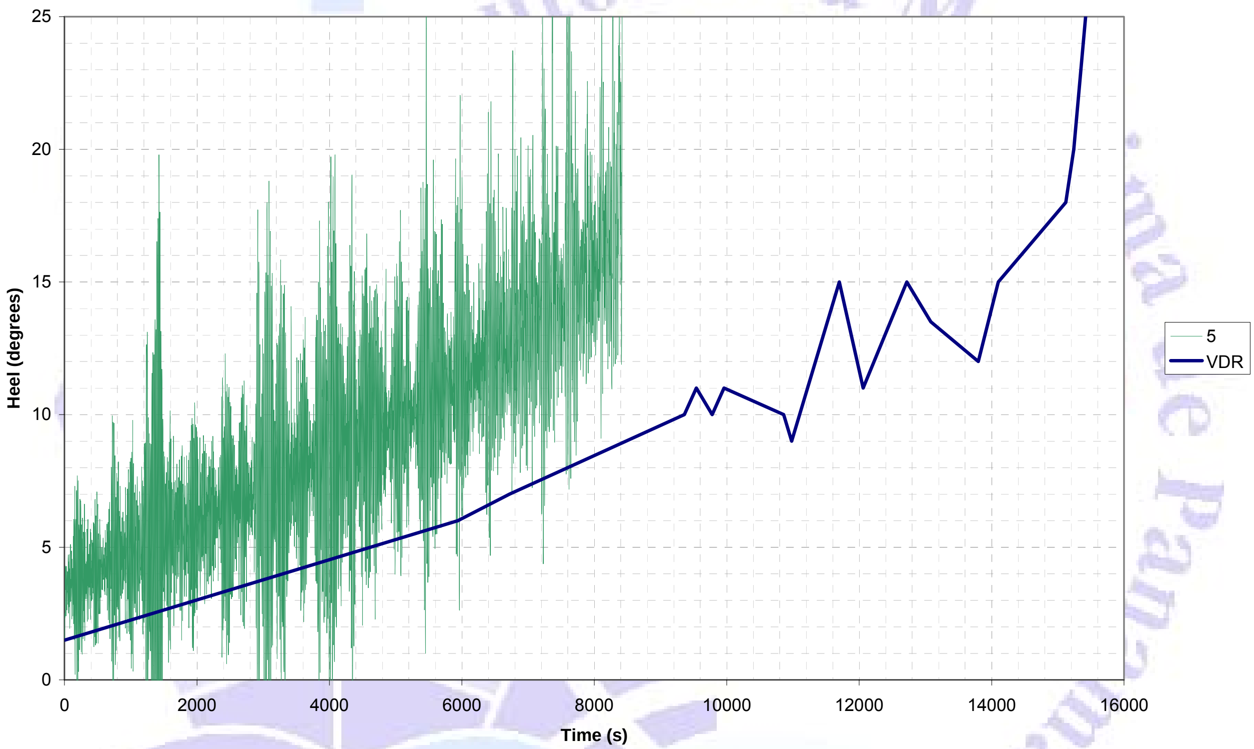
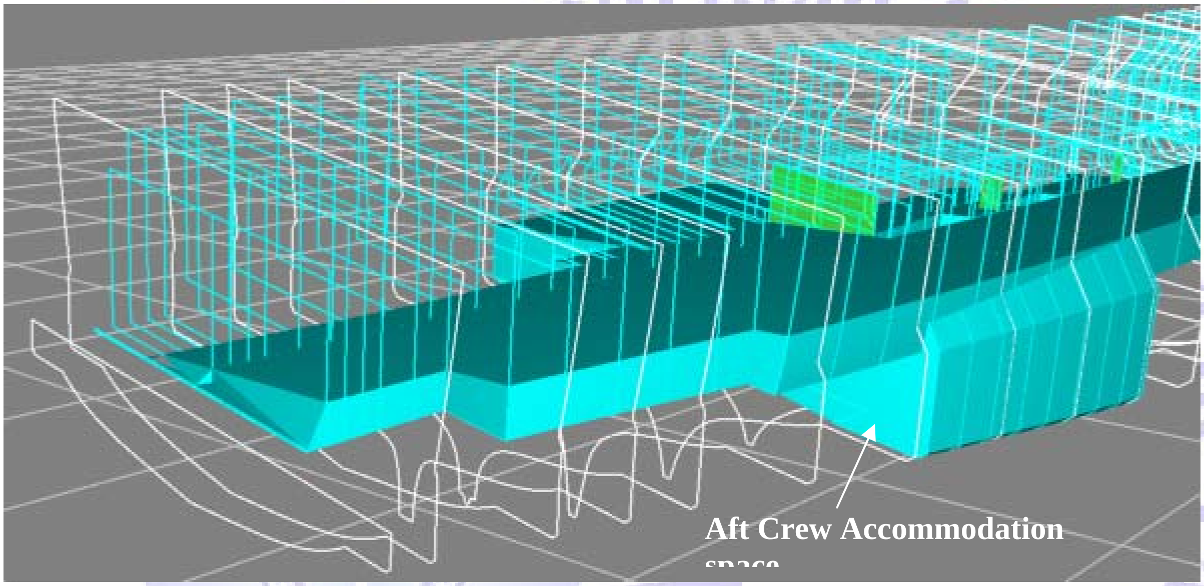


Figure 12 shows that by restricting the flow through the scuppers to the equivalent of 4 scuppers did increase the time taken to capsize. However the time for the ship to capsize is now just over 50% of the actual capsize time. Runs 7-14 were carried out to investigate the different crew accommodation flooding scenarios. Flooding to the aft accommodation (runs 9 & 10) was discounted as this did not agree with enough of the VDR data. Additionally too much water accumulated in the aft accommodation. The witness statement said that the

water level was 'knee high'. In scenarios where the aft accommodation was *allowed to flood, the entire space* filled. This is shown graphically in ***Figure 13**.*

Figure 13

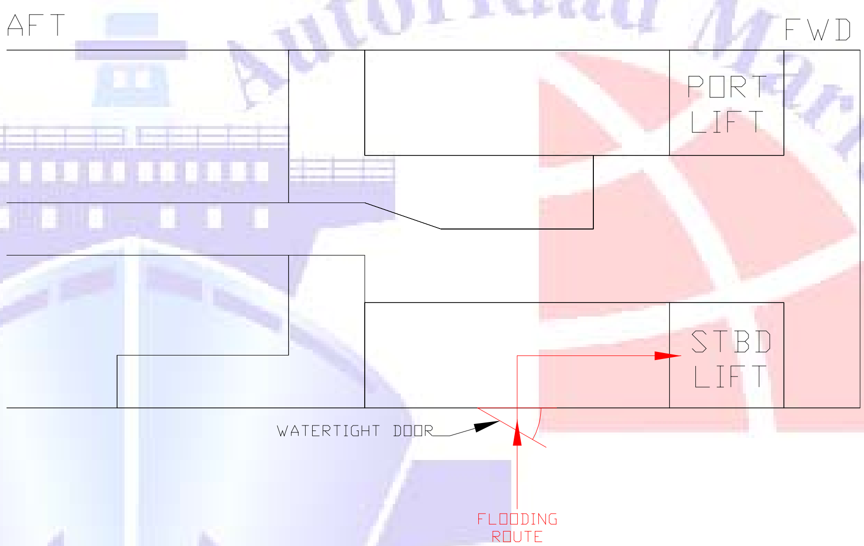
Image showing the flood water accumulation in the aft crew accommodation space



The scenarios where the forward crew accommodation flooded were believed to be the most accurate. There was information in the VDR stating that the door next to the lift was opened with an axe. This is a watertight door so if it was opened, down flooding to the forward crew accommodation via the lift would occur as shown in **Figure 14** the lift connects the centre casing directly to the crew accommodation. As the door between the garage and the centre casing is watertight we have assumend that the lift door were not watertight.

Figure 14

Diagram showing the flooding route on the garage deck through the centre casing down through the starboard lift to the forward crew accommodation.



The graphs of heel over time for runs 11 and 13 are shown in Figure **15** and

Figure 16 respectively.

Figure 15

Graph of heel over time for run 11. Scupper flow equivalent to 4, 3m/5.5sec wave, 30kts wind, down flooding to forward crew accommodation.

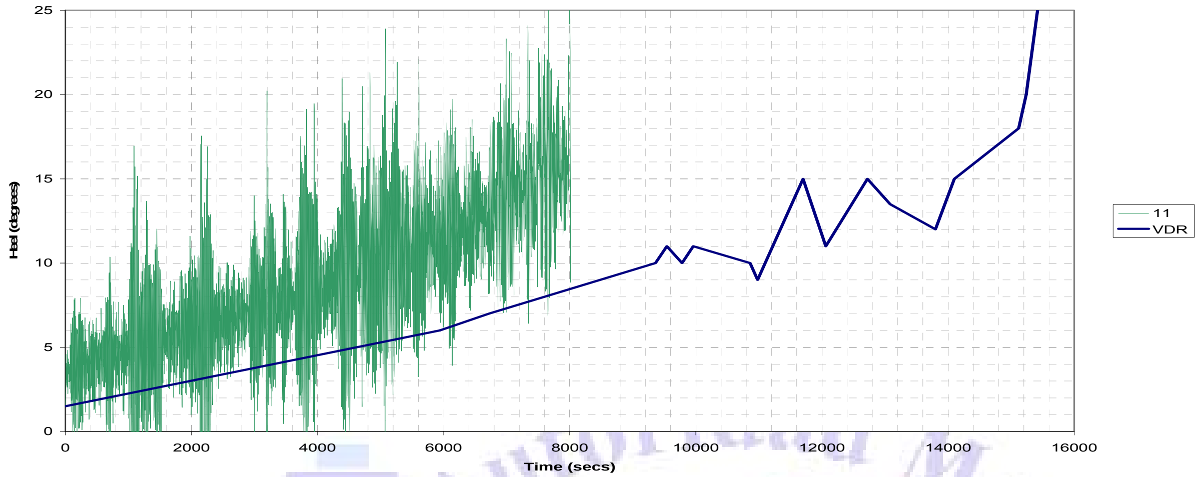
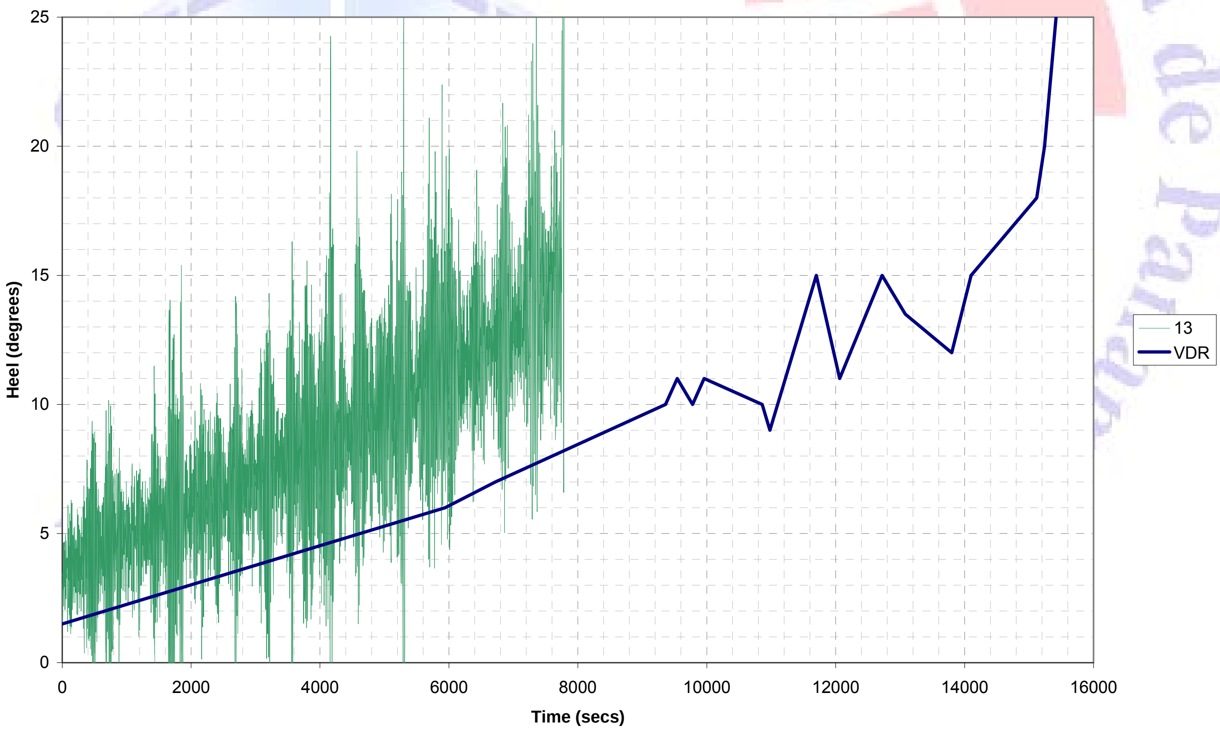


Figure 16

Graph of heel over time for run 13. Scupper flow equivalent to 4, 3m/5.5sec waves, 30ktst wind, down flooding to forward crew accommodation. WT door open.



Runs 11 to 14 were chosen as the most likely scenarios. In these runs 11 and 13 are in D1 loading condition and 12 and 14 in D2 loading condition. Runs 11 and 12 had the watertight door between the two forward accommodation spaces closed and in Runs 13 and 14 the watertight door is open. Analyzing the above results, it appears that the watertight door between the compartments has very little effect on the outcome. Due to the location of the door very little water if any, would have been able to flow through it. As the door could have been open, this scenario was still considered in further analysis. This scenario matches a lot of the VDR data. The water was flooding through a door we strongly suspect was open. The water accumulated in the accommodation space would seem to be consistent with the witness statements. Further runs were carried out on scenarios 11 – 14 with varying flow rates through the scuppers. The flow rate was increased by the equivalent of 1 scupper for each run. A result was achieved for both loading conditions which had a capsize time close to the actual time it took for Al Salam Boccaccio 98 to capsize. The final runs are summarized in Table 7 below. These runs show that between 6 and 7 scuppers must have been flowing in order for the Al Salam Boccaccio 98 to capsize in the timescale reported in the VDR data

Table 7

Summary of final runs

Run	*Load Case*	*Scuppers*	*Waves*	*Wind*	*Down flooding*
11	*D1*	*Restricted to 6*	*3m / 5.5sec*	*30kts*	*Fwd only. WT door closed*
12	*D2*	*Restricted to 6*	*3m / 5.5sec*	*30kts*	*Fwd only. WT door closed*
13	*D1*	*Restricted to 6*	*3m / 5.5sec*	*30kts*	*Fwd only. Wt door open*
14	*D2*	*Restricted to 6*	*3m / 5.5sec*	*30kts*	*Fwd only. Wt door open*
11	*D1*	*Restricted to 7*	*3m / 5.5sec*	*30kts*	*Fwd only. WT door closed*
12	*D2*	*Restricted to 7*	*3m / 5.5sec*	*30kts*	*Fwd only. WT door closed*
13	*D1*	*Restricted to 7*	*3m / 5.5sec*	*30kts*	*Fwd only. Wt door open*
14	*D2*	*Restricted to 7*	*3m / 5.5sec*	*30kts*	*Fwd only. Wt door open*

The graphs of heel over time for all of the above runs are shown in **Figure 17 to 24.**

Figure 17

Heel over time for Run 11. Scupper flow equivalent to 6, 3m/5.5sec wave, 30kts wind, down flooding to forward crew accommodation.

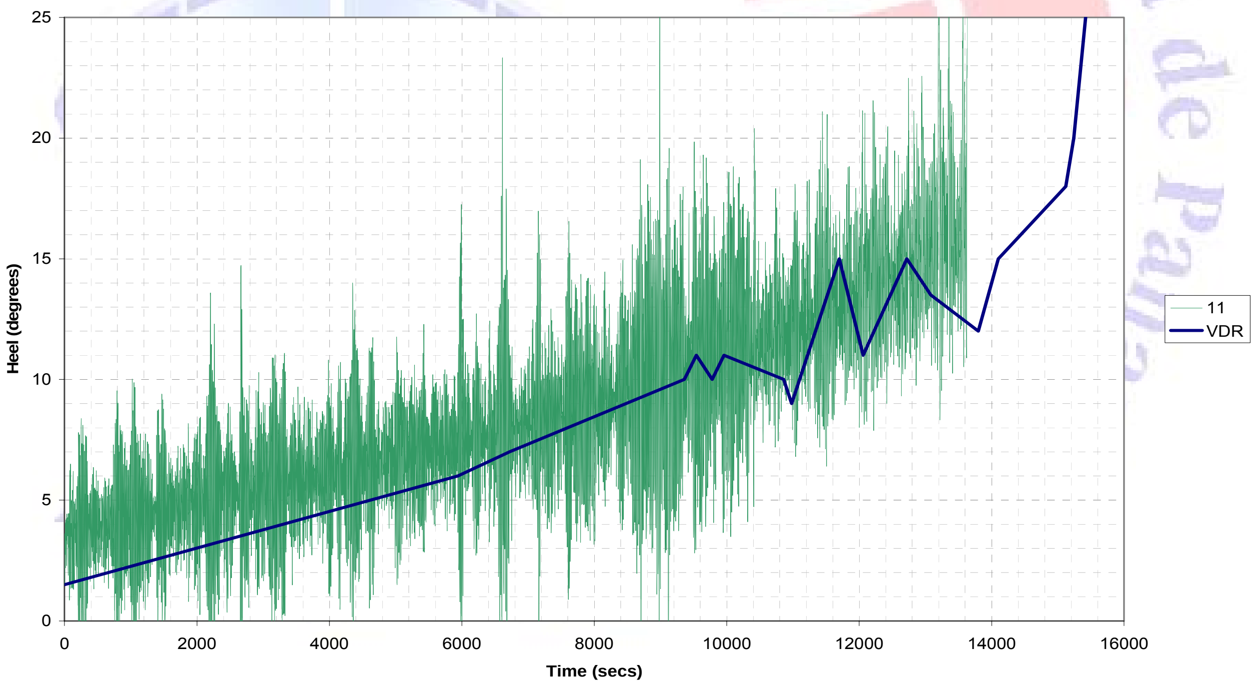


Figure 18

Heel over time for Run 12. Scupper flow equivalent to 6, 3m/5.5sec wave, 30kts wind, down flooding to forward crew accommodation.

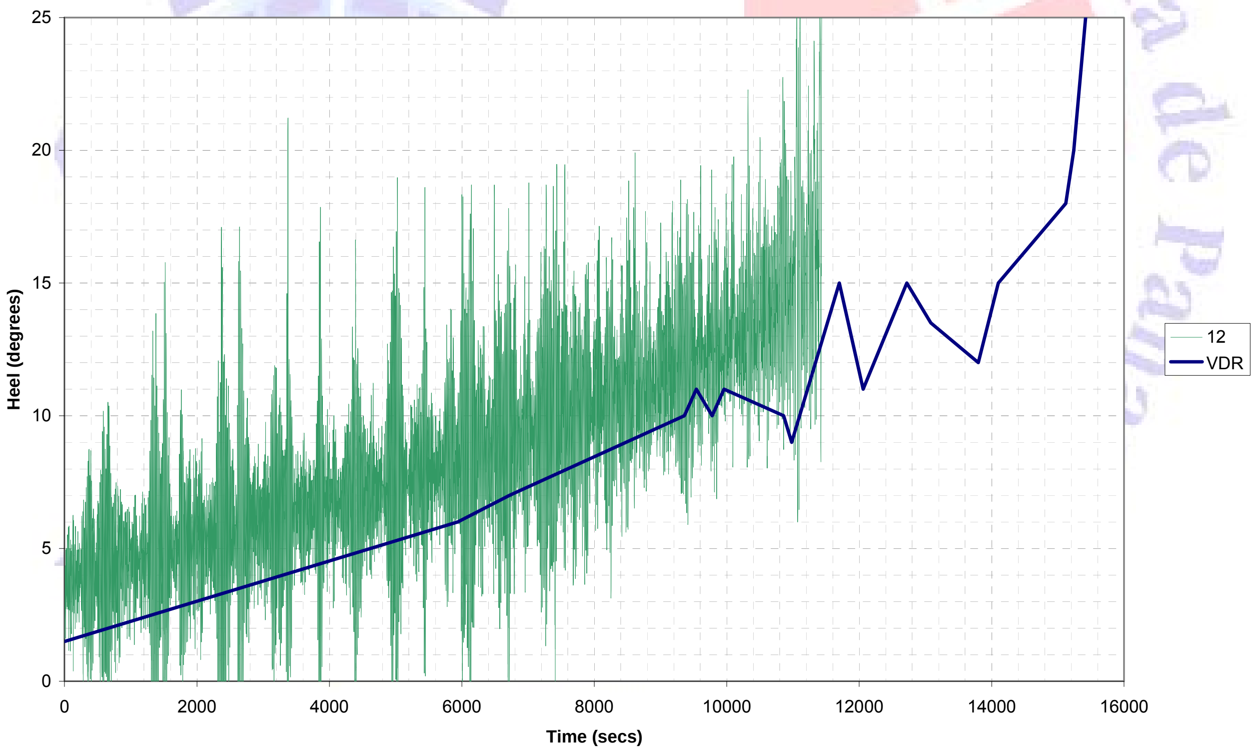


Figure 19

Heel over time for Run 13. Scupper flow equivalent to 6, 3m/5.5sec waves, 30kts wind, down flooding to forward crew accommodation. WT door open.

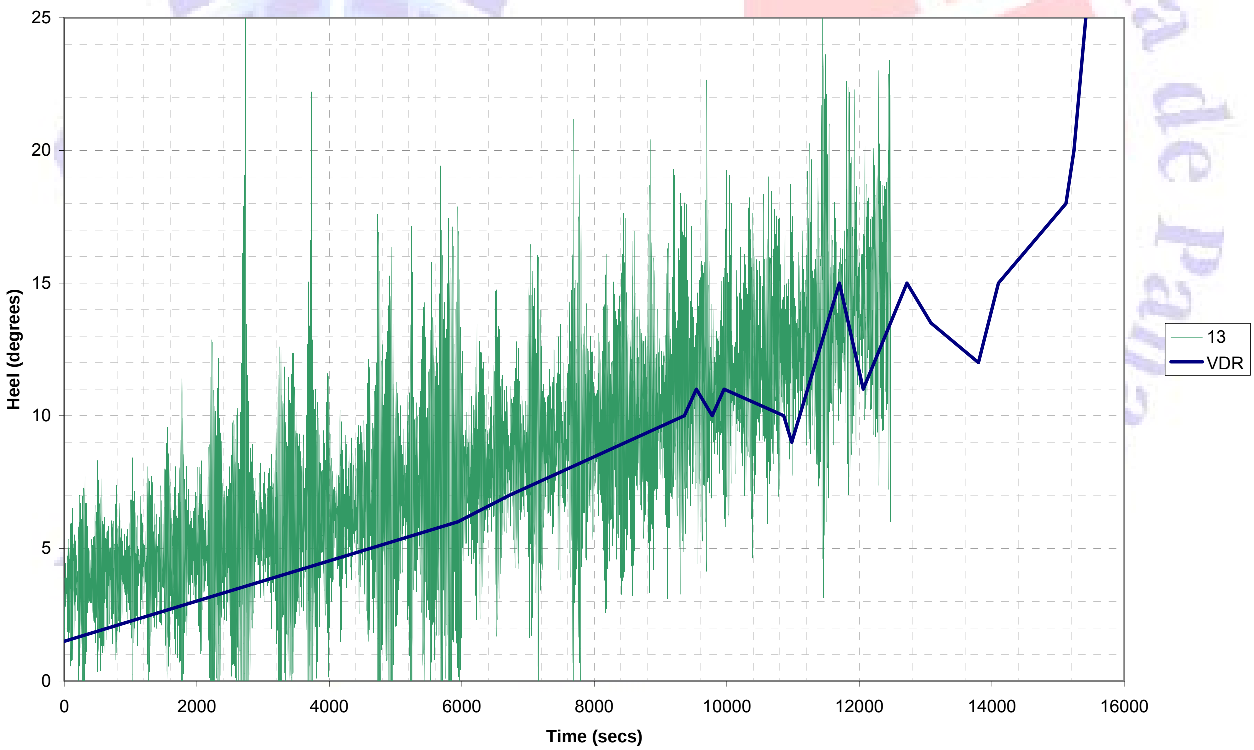


Figure 20

Heel over time for Run 14. Scupper flow equivalent to 6, 3m/5.5sec waves, 30kts wind, down flooding to forward crew accommodation. WT door open.

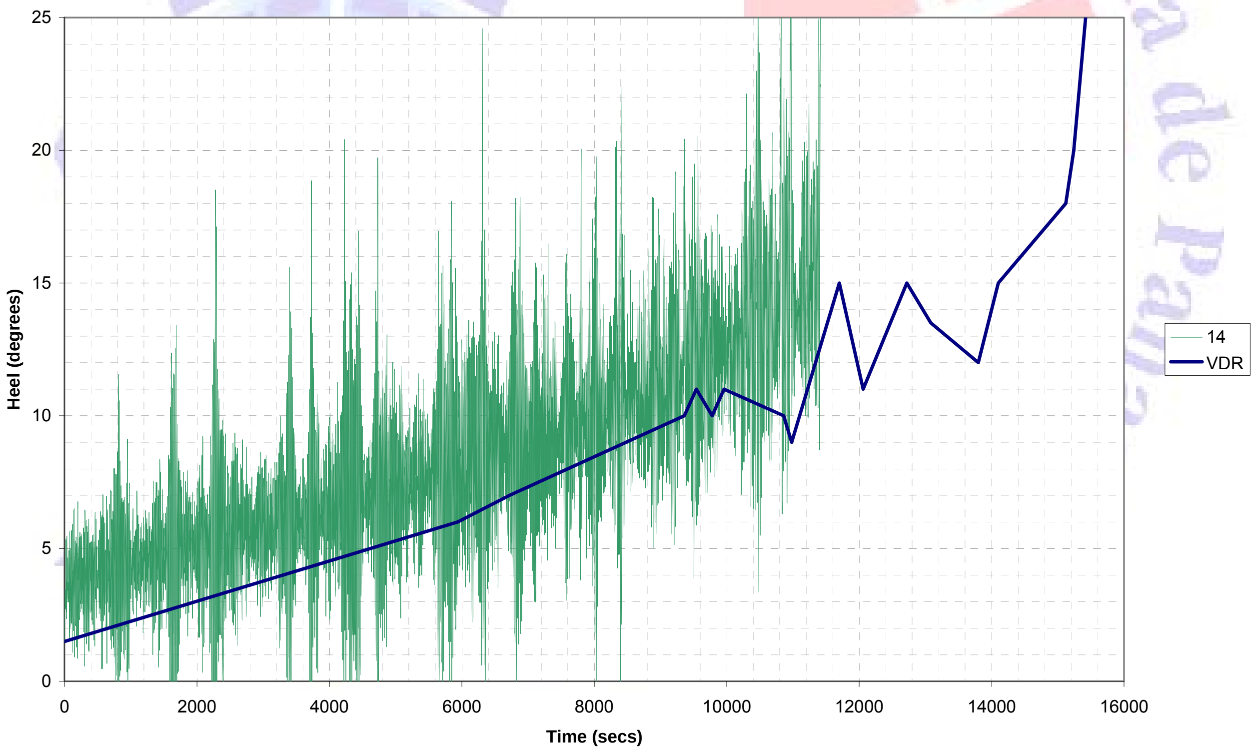


Figure 21

Heel over time for Run 11. Scupper flow equivalent to 7, 3m/5.5sec wave, 30kts wind, down flooding to forward crew accommodation.

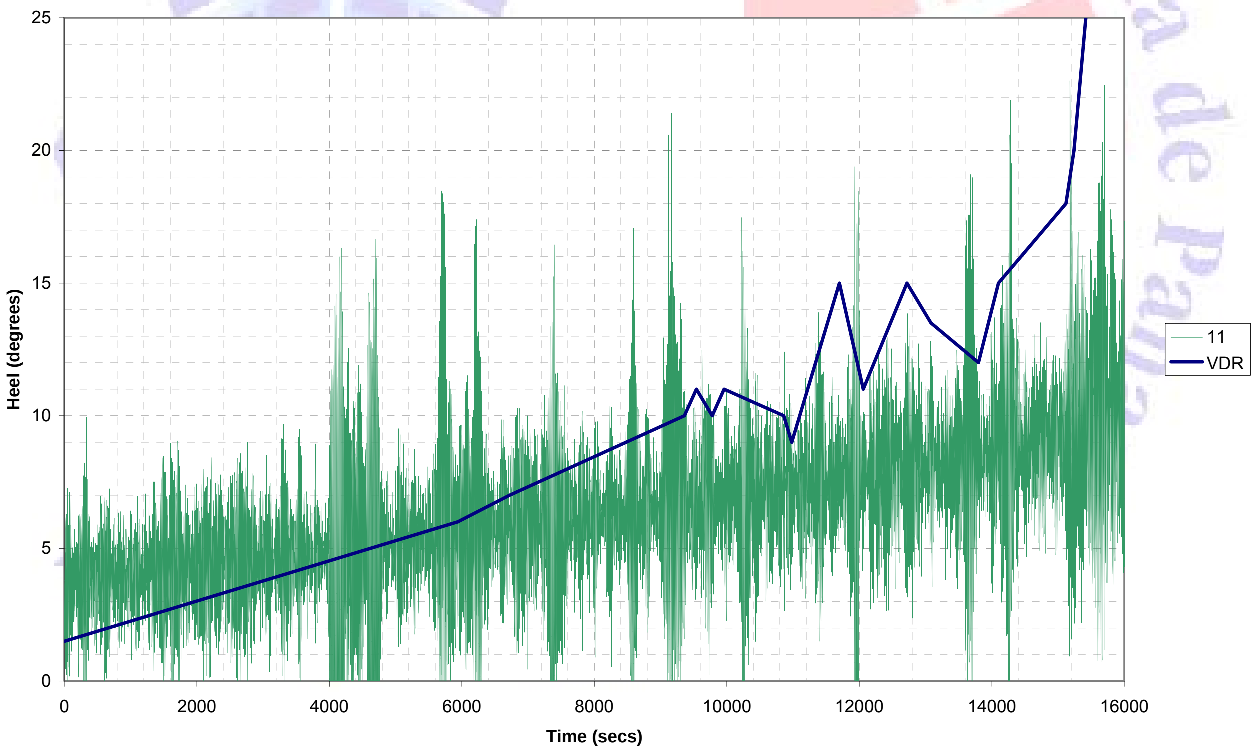


Figure 22

Heel over time for Run 12. Scupper flow equivalent to 7, 3m/5.5sec wave, 30kts wind, down flooding to forward crew accommodation.

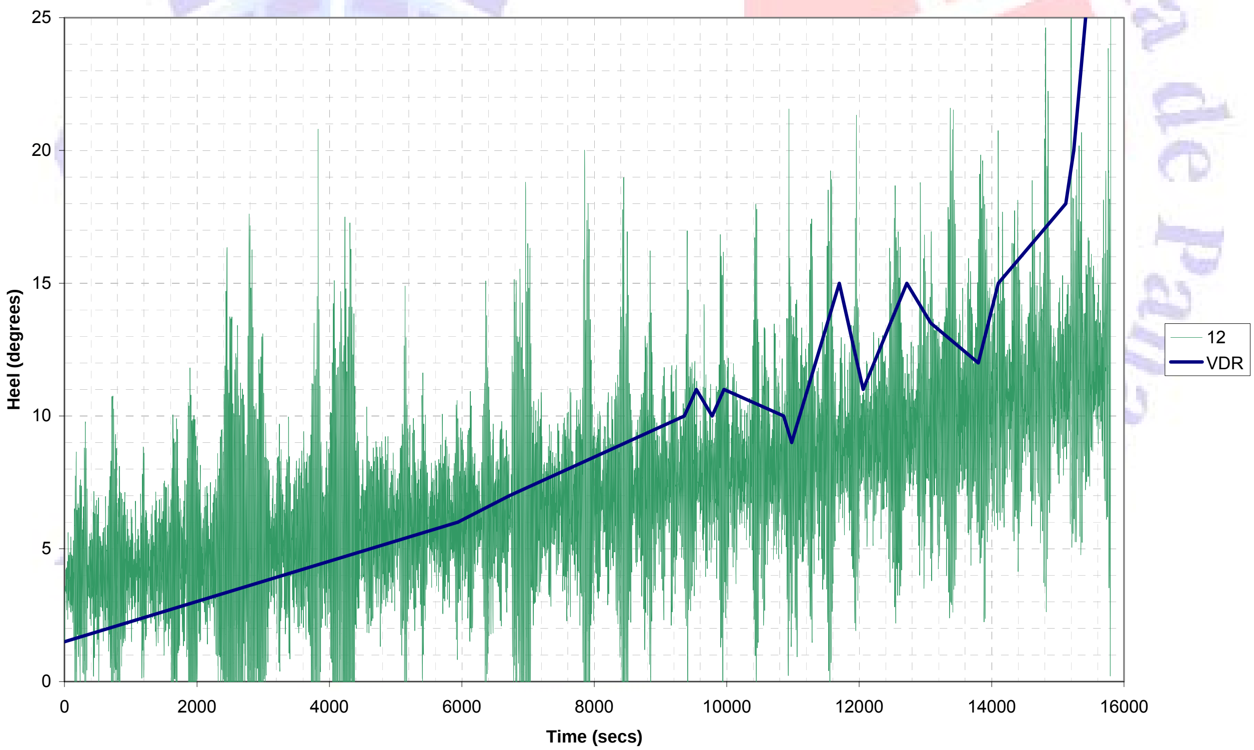


Figure 23

Heel over time for Run 13. Scupper flow equivalent to 7, 3m/5.5sec waves, 30kts wind, down flooding to forward crew accommodation. WT door open.

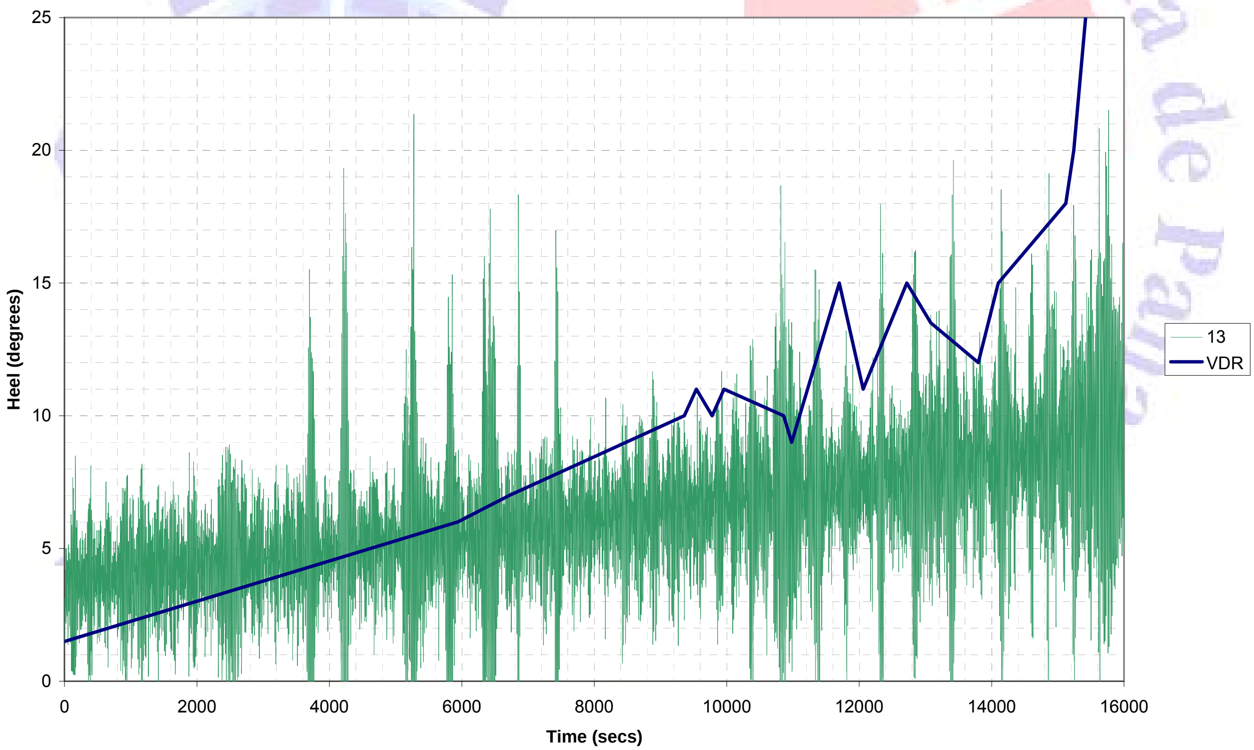
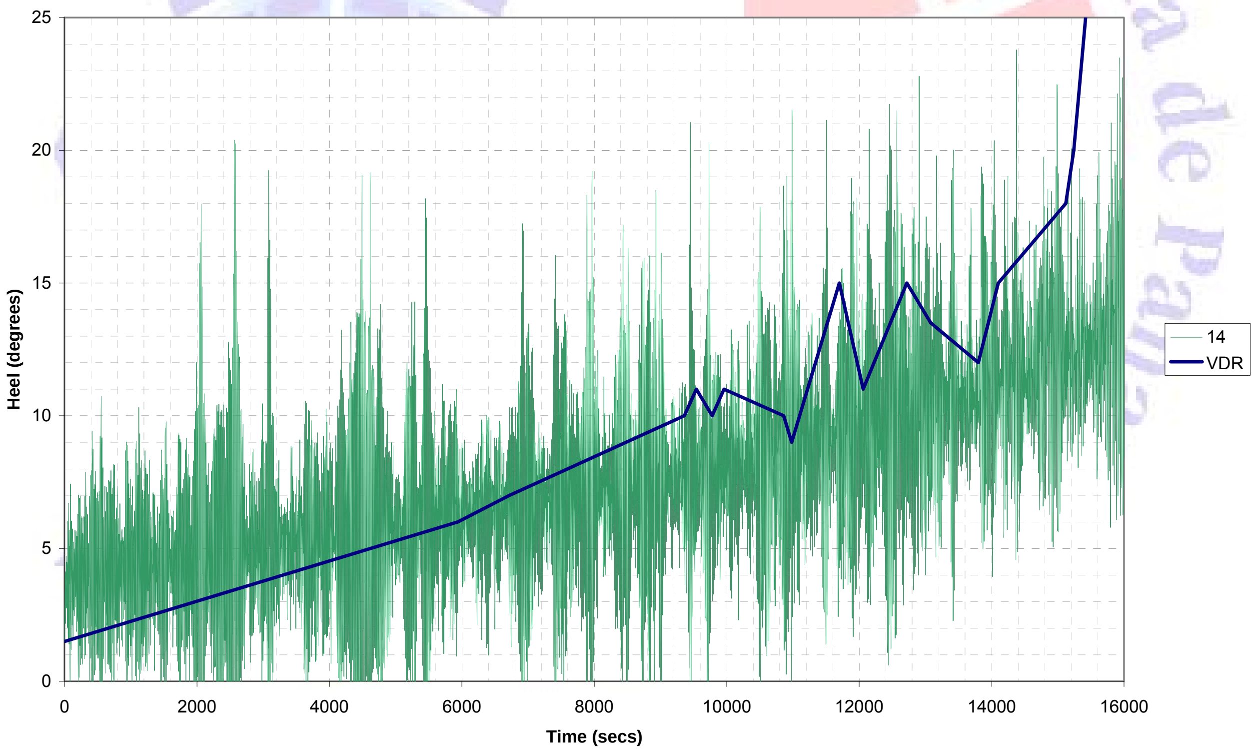


Figure 24

Heel over time for Run 14. Scupper flow equivalent to 7, 3m/5.5sec waves, 30kts wind, down flooding to forward crew accommodation. WT door open.



Runs were also carried out with exactly the same conditions as the above 6 scupper runs (**Figure 17** to **Figure 20)** the only difference was that wind and waves were removed from the simulation. The ship would now effectively be in ideal conditions. The results of these runs are shown in **Figure 26, Figure 27 and Figure 28.**

Figure 25

Run 11 without wind or waves. Scupper flow equivalent to 6, down flooding to forward crew accommodation.

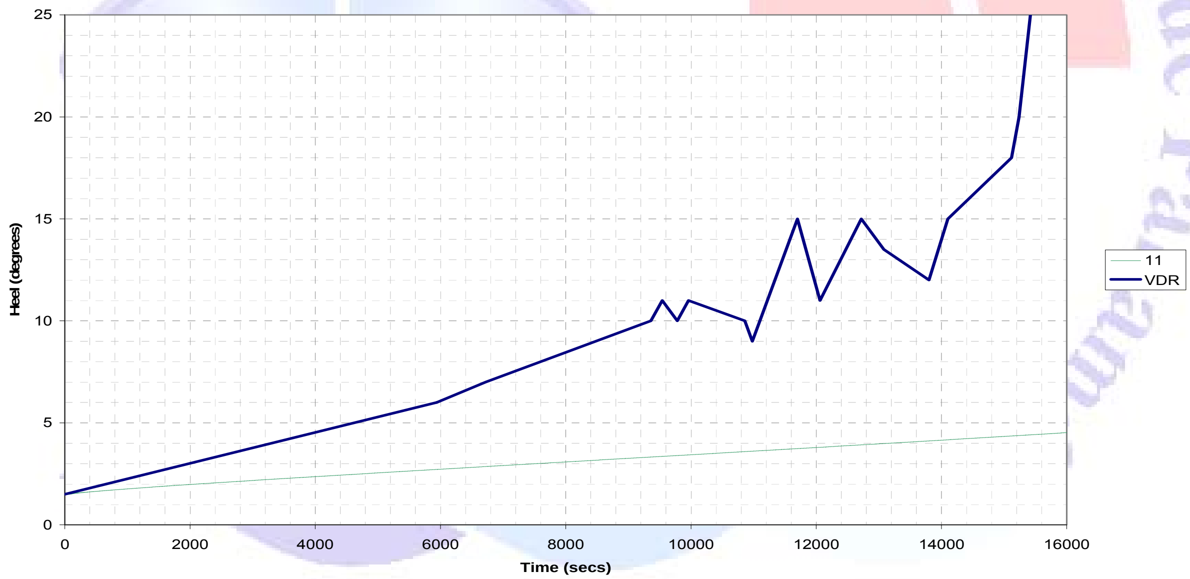


Figure 26

Run 12 without wind or waves. Scupper flow equivalent to 6, down flooding to forward crew accommodation.

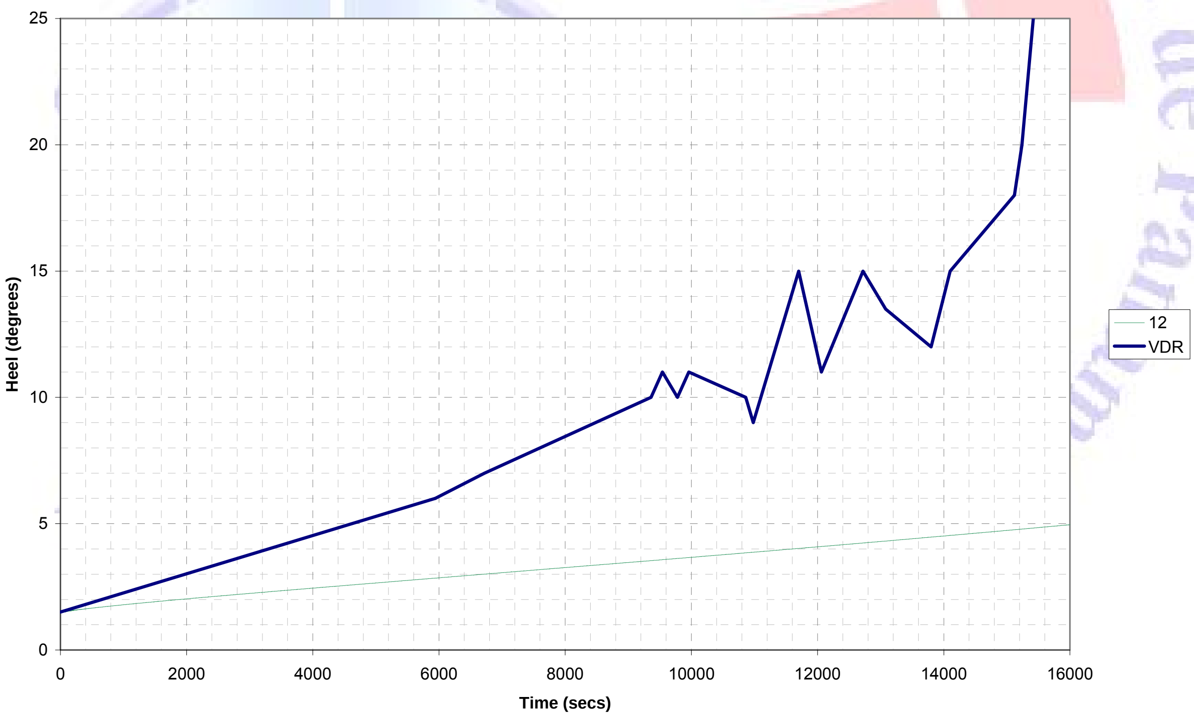


Figure 27

Run 13 without wind or waves. Scupper flow equivalent to 6, down flooding to forward crew accommodation. WT door open.

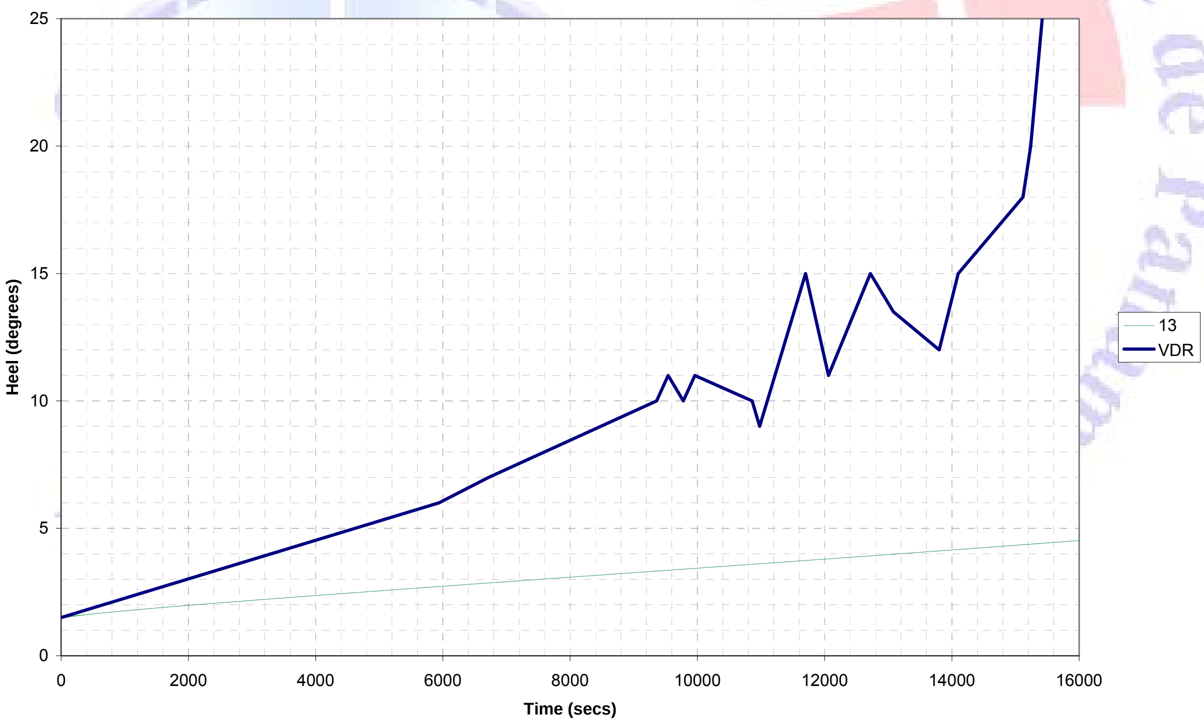
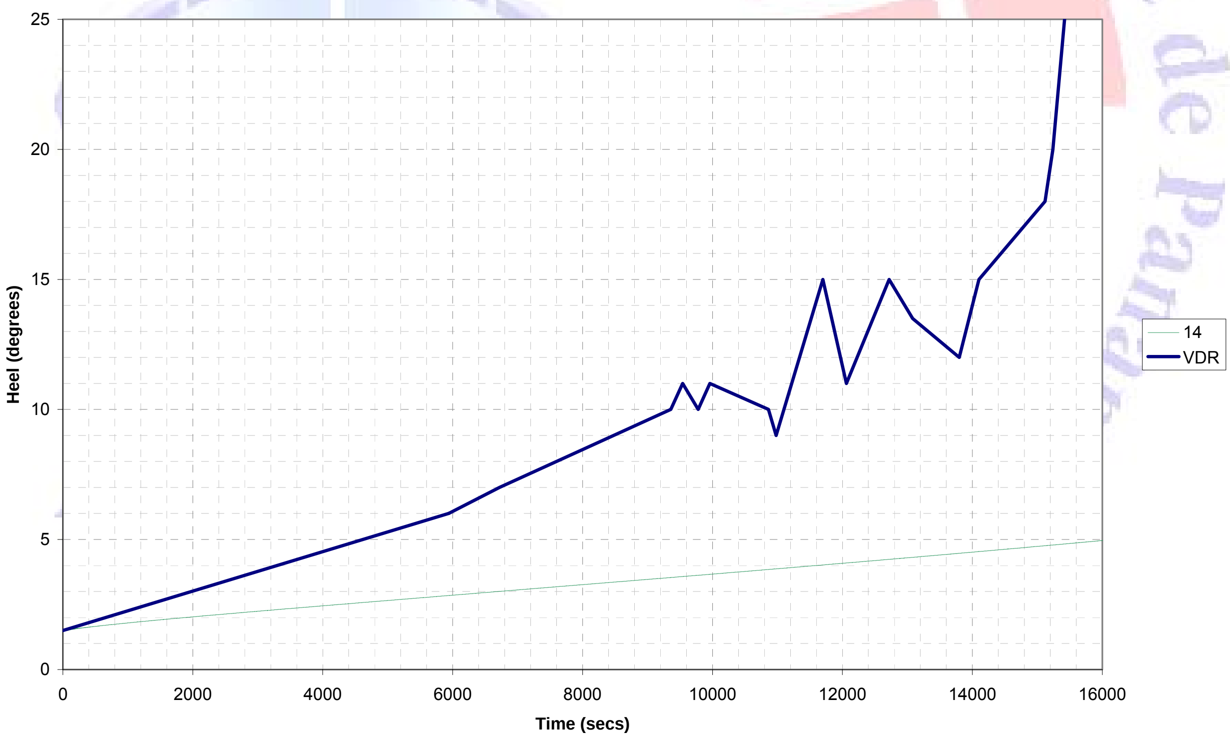


Figure 28

Run 14 without wind or waves. Scupper flow equivalent to 6, down flooding to forward crew accommodation. WT door open.



12. 4 **Fire Pump Sensitivity Study**

Due to the lack of data and as stated in section all of the above runs were carried out ignoring the effects of the fire hoses. The location, number of hoses in use and the duration of use are all unknown. A sensitivity study was however carried out to try and assess the effect that the fire hoses might have.

Method

This study was carried out assuming that the hoses were in operation for the entire duration. Their effect was included as increased flow onto the garage deck. The preliminary report had referenced from the vessel's information that there were 3 fire pumps on the Al Salam Boccaccio 98, each with a rated capacity of 90m^3 per hour. One of these pumps was an emergency fire pump. This study looked at the possibility of 1, 2 or 3 pumps operating. Runs were carried out for the known time from the start of the fire until capsize. The number of scuppers operating was progressively increased to find the point at which the ship capsized. This gives the number of scuppers required to operate in each scenario which caused the ship to capsize in the correct time. As discussed earlier *the watertight door* connecting the forward crew accommodation spaces had little effect on the outcome so for this analysis only runs 11 and 12, where this door is closed, were considered. Runs were carried out for 18000 seconds and the results are shown in Table 8 and Table 9 below.

Results

Table 8

Rrun 11. No of scuppers required to match capsize time

	No. of Fire pumps operating		
	1 pump	***2 pumps***	***3 pumps***
No. of scuppers	*8-9*	*10-11*	*11-12*

Table 9

Run 12. No of scuppers required to match capsize time

	No. of Fire pumps operating

	1 pump	2 pumps	3 pumps
No. of scuppers	8-9	10-11	12-13

The results show that if all 3 fire pumps had been in operation for the entire duration then the equivalent of between 11 and 13 scuppers would have been operational for the capsize time to match the VDR data.Control teams believed that the scuppers were not functioning to full capacity, perhaps obstructed with debris, allowing the water to settle on the deck, provoking a free surface condition that threatened and pushed the ship to an unstable loll. Test runs revealed that if the scuppers were completely blocked, the ship would have capsized in less than half the time it actually took. *This suggests the scuppers were performing to some extent with partial obstruction.* Equipped with 15 scuppers on each side of the garage deck, having them *completely blocked* would speed up the capsizing of the vessel to a period of 1.5 hours based on conditions the night of the accident. In a real emergency, fire fighting conditions at sea and in reduced or enclosed spaces would drag significant debris and residuals significantly to easily block any draining scuppers. In a continuous 4.5 hour period of firefighting activity it is determined that only half of the scuppers were operational and partially blocked particularly during the heel moment.

The dynamic analysis of the effectiveness of the scuppers shows that only 6 scuppers must have been in operation based on conditions reported by the Master for the vessel to collapse at the time frame recorded.

It is Important to underline that after a small angle of heel, all the accumulated water will stay at one side, this means that at an early stage only one side of the ship will have scuppers available to drain the water.

According to the VDR data, the Master made various attempts to try and reduce the heel. In order these were:

- Requesting to stop the fire sprays
- Using a submersible pump to remove the accumulated water

- Filling and emptying tanks

The main attempts involved filling or emptying tanks and the use of a portable pump to remove water from the garage. The pump was supposed to be drawing water from the deck and discharging over the side. However there is evidence in the VDR data to show that this never really worked properly. It is believed that the pump was supposed to be discharging through one of the port scuppers however the connection to the scupper was not good and at one point came completely loose so the pump was just moving water from one side of the car deck to the other. The capacity of this pump was not given, however judging by the fact the heel continued to increase and that it is able to discharge through one scupper we can conclude that it was not of sufficient capacity to overcome the fact that the fixed fire fighting sprays were still on.

The Master requested to fill and empty several different tanks to try and reduce the heel. It would appear that only one of these tanks was actually filled, tank 25 on the port side, and this had little or no effect to reduce the heel. A likely reason for this is because the tank had a capacity of approximately 130t. The tank was filled shortly before the vessel capsized. While this tank was being filled the fire spray was also in operation so as the tank filled the volume of water on the deck also increased cancelling out the effect of filling the tank.

Filling and emptying tanks to try and reduce the heel was a potentially very dangerous strategy and could have made the situation much worse. This is because the ship was in a condition known as "loll". In the condition the ship is not stable when upright but instead will rest at an angle of heel to either side. This was caused by the large free surface of the water accumulated on the car deck. When a ship is in loll the first course of action must be to correct whatever is causing the loll, in this case the water on deck. If this is not corrected and ballast tanks are filled then a potentially very dangerous situation could arise. With a large free surface on the deck and reduced heel the ship is more likely to heel over to port if struck by a large wave or a gust of wind. If this were to happen the ship would roll violently to port to an angle of heel greater than the angle of equilibrium.

From the analysis described in this report, the effect of waves appears to have had a major impact on the ability of the scuppers to clear water from the deck. The analysis carried out and reported here shows that it is extremely unlikely that the scuppers were completely blocked. However any level of blockage would have an effect on the outcome. Further information would be required before a definitive answer could be reached. Many assumptions were made regarding the frictional losses when calculating the full unrestricted flow through the scuppers. This was due to the lack of detailed information.

*12.5 **Dewatering***

The 2/O informed the bridge at 1938 hrs that there was an increasing level of water in the car deck. At 1940 hrs the Master asked t use a potable pump to discharge the water from the car deck. It was noticed that there were complications in the use of the portable pump of not having fixed arrangements to pump the water out from the car deck, and the operation was not satisfactory. Water was being suctioned from one side and pumped to the other side, and then the water returned back to the original side due to the list of the vessel. It was clear that the scuppers were not successfully functional, and concluded to be blocked due to garbage generated during the fire fighting operations and the movement of water containing such residuals.

12.6 **The pilot door as an alternative**

The option of opening a pilot door to drain the water was a viable but risky option, the crew assume that opening the pilot door would aggravate the fire condition. The opening of the pilot door has a destructive effect on the righting arm as the garage space would open to sea. If there was any possibility of water down-flooding from the car deck to spaces below, this could have very serious consequences probably resulting in capsize and eventual sinking of the vessel. It was stated that the water level had reached the sill level in the first 40 minutes, since the door opens inward, it would have been difficult to open it by crew with the weight against it. It would have had to be an earlier determination to have the door opened long before by anticipating the event and this itself would have been a judgment call of risky nature.

The ships heading relative to wind and waves is important when considering the effect of opening the pilot door. Several headings were reported in the VDR transcripts and there exists uncertainty as to what was the correct one when the idea prevailed. Taking in to account the conditions encountered on the night of the incident, opening a pilot door in a very early stage would have removed some accumulated water and may have been beneficial to a stability question.

13. LIFE SAFETY ALTERNATIVES

The best course to limit motions in a 3 to 4m significant sea would be to steer roughly either into or away from the seas and wind. Because of the relatively low sea and low period, such a course would increase pitch motions to a limited extent, but would more likely aid in removing water from the car deck by bringing more scuppers into action. Any intent to clear the clogged scuppers would have improved in an ideal situation.

Progression to a heel angle was a gradual process, so there was sufficient time to muster the passengers and crew to initiate evacuation or abandon ship. From the VDR data there was no evidence to suggest that the master intended to abandon the ship. There is no clear evidence to suggest that the general alarm was ever sounded or that orders were given to abandon ship.

When the fire was detected, 2 hour and 20 minutes after departure, the ship was closer to Duba than Safaga. Early action to report to the port of Duba may have allowed greater assistance to be provided. The crew fought the fire for 4 hours before the ship capsized. A sound decision to return once the fire was discovered would easily yield sufficient time to return to safe grounds.

The reluctance to seek help by either turning the ship around and heading back to Duba or by calling for assistance by radio greatly reduced the amount of assistance available when the vessel capsized and survivors were in the water. This accounts for an increase in the amount of casualties.

14. STABILITY OF RO-RO PASSENGER SHIPS

Effectiveness of car deck drainage systems

The investigation analysis presented in this report centered on the facts relevant to the efficiency of scuppers to drain the vehicle deck of Ro-Ro passenger ships when fire-fighting water is accumulated there. This operational requirement is closely linked to the detrimental effect that free-surfaces have on the stability of a ship. The analysis is based on a critical review of existing regulations for draining arrangements and the quantification of the dynamic ship motion effects on the scupper performance.

An initial review of existing rules and regulations from IMO and its sub-committees and from classification societies and flag administrations provides a global overview of the current regulatory framework regarding the drainage of enclosed spaces on board ships and sets the pace for the following sections.

Before engaging into any numerical calculations (static or dynamic in nature), a collection of 15 Ro-Ro passenger ships of various sizes was created. They were grouped into small (less that 130 m), medium (between 130 and 170 m) and large (over 170 m). They were further grouped according to the layout of their car decks into those with central casing and those with side casing. In this way the conclusions that occur at the end of the investigation are directly linked to actual designs. The selection of the sea states for the dynamic analysis is based on SOLAS' 95 Regulation 14 – Model Test Method.

The analysis of static performance of scuppers is focusing in the comparison of the "Interim Explanatory Notes to SOLAS Chapter II-1, Subdivision and Damage Stability Regulations, Regulation 35-1 – Bilge pumping arrangements" (MSC.1/Circ.1226) and the report of the correspondence group on the "Guidelines for drainage systems in closed vehicle and Ro-Ro spaces and special category spaces" (FP53/7).

The calculations are performed for 0.5^o fore and after trim and 1.0^o and 7.0^o heel. The required water to heel and trim the vessel at the corresponding angles is obtained from the International Code for

Fire Safety Systems (FSS), Resolution MSC.98(73). The analysis is performed on the basis of equilibrium of flow. The dimensions for the scupper piping obtained in this way are smaller than today's standard practice. In addition to that, the outflow margins according to MSC.1/Circ.1226 tend to be positive contrary to the margins calculated with the proposed rule in FP53/7. Such a difference is attributed to the account of trim which occurs as a result of water on deck and which defines the number of scuppers that is active in any case.

The coupling of the scupper performance and the dynamic motion of a ship in waves was performed with an in-house software suite (PROTEUS 3). For this part of the project one "small" and one "large" ship are selected out of the initial 15 as representative examples. The analysis was based on two geometrical versions for garage deck for each ship, one with central casing and one with side casing. The amount of water on the deck and the trim condition were kept the same as for the static case. The scupper performance was based on the variation of pressure distribution in the inlet and the outlet of the scupper piping. In the first case, the ship motions will affect the motion of water on the car deck (sloshing) whereas in the second case the variation of the sea surface will alter the hydrostatic pressure in the outlet of the piping. In total, the variation of the pressure head in combination to the motion of water on the deck will reduce the draining capacity of each ship by up to 70%, with the reduction more pronounced for the smaller ship and the central casing. The PROTEUS 3 results are in general agreement with more dedicated hydrodynamic studies with Computational Fluid

Dynamics (CFD) techniques, which can also account for the sloshing of water in the scupper piping.

The next step in this investigation was to obtain a distribution of scuppers along the deck that would be sufficient to drain any amount of water accumulated there. The approach was based on the premise that if the total scupper cross-sectional area is fixed, then an adequate number of scuppers should be present on either side of the deck. The results of this process favor the idea of maintaining a larger number of scuppers in the bow or the stern (according to the trim condition) contrary to general practice where scuppers are evenly distributed on the deck. This is attributed to the abstract nature of the mathematical modeling used for the calculations and the constraints for the problem variables.

The investigation is concluding with a set of criteria for improving the draining efficiency of garage deck spaces which are based on the significance of the dynamic effects and the importance of taking into consideration both the heel and the trim of the ship when calculating the performance of scuppers. The evident equilibrium of inflow and outflow should be addressed by appropriate safety factors that would take into account any potential blockage of the scupper inlets and water sloshing that would reduce the draining capacity further.

The stability performance of a ship is greatly affected by the presence of free surfaces either in tanks or on decks. In the particular case of accumulated water on a car deck, the deck space will not become deeply-filled for the scenario of interest as, even for comparatively small percentages of filling, the vessel will capsize due to the free-surface effect. For small amounts of water on deck and large vessel motions in roll, the water will tend to move dynamically from side to side with the vessel movement. Larger amounts of water will tend to form a wedge on the heeled side and there will be no significant movement of water across the deck. It is at this stage in particular that the performance of scuppers becomes critically important in ensuring that the volume of water needed for fire fighting can be safely discharged without leading to stability erosion and ultimate capsize, considering the stability reserves of normal Ro-Ro vessels.

The purpose of this investigation is to review the ongoing discussions taking place at IMO level into new requirements for minimum drainage from car decks and special category spaces with the view to contributing to the discussions and, should any short comings of currently proposed rules be identified, suggest alternative criteria. In order to achieve this aim, it is necessary to identify all the relevant regulations (existing and new proposals) and, separately to analyze the dynamic behavior of water in the car deck as a function of the ship motions. Finally, the results are summarized and criteria for the improvement of scupper performance will be presented.

The special feature of this project is the coupling of the scupper efficiency to the dynamic motion of the ship in a wave environment. That is, as the ship rolls, pitches and heaves in rough seas, the water on deck is also in dynamic motion and it affects, in turn, the motion of the ship. Proper location and design of scuppers can assist in fast draining of water on deck and improve the survivability of the ship.

To investigate the possibility of re-occurrence of the above events on Ro-Ro passenger ships, the following need to be addressed:

- The effect of dynamic ship motion on scupper drainage capacity considering the intermittent coverage of the scupper openings on the deck and the varying outside pressure against the hull;
- The effect of car deck layout and size;
- Propose design criteria for scupper capacity to allow workable designs with acceptable level of risk associated with accumulated levels of water.

15. DESCRIPTION OF APPROACH

The first step will be to review existing IMO regulations in order to get in-depth view of all the documents related to the amount of water that can be pumped on the garage deck for fire-fighting and the size of the scuppers for adequately removing it. To this list, the guidelines commonly used by classification societies and flag administrations will also be reviewed in addition to the IMO documents.

Relevant regulations will be analyzed in terms of the provisions they make and the effects they take into account for the definition of the scupper diameter and to asses the performance of the scupper in a static case (without waves) At this stage of the investigation a comparison in terms of requirements will be performed between existing and proposed regulations. The results of this work will set the path for the proposed criterion for dimensioning the scuppers and indicating their location on the car deck.

Ships are seldom operating in calm seas. The implication of this is that when water is accumulated on the vehicle deck of a Ro-Ro ship, depending on environmental conditions, it will be excited by the environment and portray its own dynamic behavior. This sloshing of water in the deck in combination to the constantly varying external water pressure describes a complex combination of pressure variation which substantially affects the outflow velocity and the scupper performance.

In this work, the dynamic analysis that will be performed will focus on

- Flow phenomena related to the oscillatory flow in combination to ship motions, that is, variation of scupper capacity due to dynamic ship motions.
- The effect of the non-linear relationship between pressure across the scupper pipe and the flow velocity;
- Inertia of the water within the scupper;
- Sloshing behavior of the accumulated water on the car deck.

The first point will be addressed by the in-house suite of software PROTEUS 3. The following three points will be analyzed using Computational Fluid Dynamics (CFD) techniques.

Based on the above analysis a set of criteria will be proposed in terms of the operating conditions of the ship and a proper safety factor, to take into account the reduction of the water outflow due to rough seas and any potential blockage of scupper inlets that would deem water drainage impossible.

Finally, an aim to approach the problem of scupper performance from a design, rather than regulatory perspective, where the optimal distribution of scuppers on the car deck will be analyzed to consider how best to maximize the required scupper capacity on the car deck.

16. REVIEW OF CURRENT STANDARDS AND REGULATIONS

Scope

A review of all scupper and drainage related regulations will be made from the point of view of IMO recommendations / requirements, example flag authority interpretations and specific class requirements. The intention is to establish the different approaches either currently implemented or under review and to ensure that the outcome of this project takes into account the current regulatory framework.

The review covers the existing and proposed drainage requirements for car decks. As new proposals for scupper drainage are based on the equilibrium between fire fighting water and scupper drainage, references to rules on fire fighting water are also listed in this section.

Table 10

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
Resolution MSC.194(80) (adopted 20 May 2005) SOLAS II-1 – Construction – Structure, subdivision and stability, machinery and electrical installations Part B – subdivision and stability	When drainage is directly overboard	2.6.1 Where the freeboard to the bulkhead deck or the freeboard deck, respectively, is such that the deck edge is immersed when the ship heels more than 5°, the drainage shall be by means of a sufficient number of scuppers of suitable size discharging directly overboard, fitted in accordance with the requirements of regulation	LRS Part 3 Chapter 12 *4.1.2* Scuppers draining weather decks and spaces within superstructures or deckhouses not fitted with efficient weathertight doors are to be led overboard. BV Part C – Machinery Chapter 1 Section 10 8.5.2 Cases of spaces	SOLAS 15.2.1 Where pipes, scuppers, electric cables, etc. are carried through WT subdivision bulkheads, arrangements shall be made to ensure the WT integrity of the bulkheads.

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
Regulation 35-1 – Bilge pumping arrangements		15 in the case of a passenger ship and the requirements for scuppers, inlets and discharges of the International Convention on Load Lines in force in the case of a cargo ship.	located above the waterline resulting from a 5° heel (a) Scuppers led through the shell from enclosed superstructures used for the carriage of cargo are permitted, provided the spaces drained are located above the waterline resulting from a 5° heel to port or starboard at a draught corresponding to the assigned summer freeboard. Such scuppers are to be fitted i.a.w the requirements stated in [8.7] or [8.8]. (b) In other cases, the drainage is to be led inboard i.a.w. the provisions of [8.5.3]. In addition, it is to be ensured that (Ch 4, Sec 12, 5.1.4) when fixed	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			pressure water-spraying fire-extinguishing systems are provided, in view of the serious loss of stability which could rise due to large quantities of water accumulating on the deck or decks during their operation, the following arrangements shall be provided: (a) in passenger ships: 1. in spaces above the bulkhead deck, scuppers shall be fitted so as to ensure that such water is rapidly discharged directly overboard 2. in Ro-Ro passenger ships, discharge valves for scuppers, fitted with positive means of closing operable from a position above the bulkhead deck i.a.w. the requirements of the ICLL, shall be kept	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			open while the ships are at sea	
	When drainage is to be led inboard, not directly overboard Capacity and arrangement of scuppers Accumulation of water on deck due to fire-fighting	2.6.2 Where the freeboard is such that the edge of the bulkhead deck or the edge of the freeboard deck, respectively, is immersed when the ship heels 5° or less, the drainage of the enclosed cargo spaces on the bulkhead deck or on the freeboard deck, respectively, shall be led to a suitable space, or spaces, of adequate capacity, having a high water level alarm and provided with suitable arrangements for discharge overboard. In addition it shall be ensured that: .1 the number, size and disposition of the scuppers are such as to prevent unreasonable	LR Part 4 Chapter 2 – Ferries, Ro-Ro ships and Passenger ships *11.2.2* Scuppers from vehicle or cargo spaces fitted with an approved fixed pressure water spray fire-extinguishing system are to be led inboard to tanks. Alternatively they may be led overboard provided they comply with Pt 3, Ch 12, 4.1.3 (a) The freeboard is such that the deck edge is not immersed when the ship heels to 5°, and (b) The scuppers are fitted with means of preventing water from passing inboard in accordance with 4.2. *11.2.3* Inboard draining	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
		accumulation of free water; .2 the pumping arrangements required by this regulation for passenger ships or cargo ships, as applicable, take account of the requirements for any fixed pressure water-spraying fire extinguishing system	scuppers do not require valves but are to be led to suitable drain tanks (not engine room or hold bilges) and the capacity of the tanks should be sufficient to hold approximately 10 minutes of drenching water. The arrangements for emptying these tanks are to be approved and suitable high level alarms provided. BV Part C – Machinery Chapter 1 Section 10 8.5.3 Where the freeboard is such that the edge of the bulkhead deck or the edge of the freeboard deck, respectively, is immersed when the ship heels 5° or less, the drainage of the enclosed cargo spaces on the bulkhead deck or on	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			the freeboard deck, respectively, is to be led to a suitable space, or spaces, of appropriate capacity, having a high water level alarm and provided with suitable arrangements for discharge overboard.	
FP 53/7 (30th October 2008) – Report of the correspondence group on "Guidelines for drainage systems in closed vehicle and Ro-Ro spaces and special category spaces	Performance testing and approval standards for fire safety systems	Minimum capacity of drains to be provided by: $A = \frac{1.25Q}{\sqrt{19.62\left(h - \sum h_l\right)}}$ Where: *A* is the total required sectional area of the drains on each side of the deck in m^2; *Q* is the combined water flow from the fixed extinguishing system and the required number of fire hoses in m^3/s; *h* is the elevation head		

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
		difference between the bottom of the scupper well or suction level and the overboard discharge opening or highest approved load line in m; and Σh_l is the summation of equivalent lengths of scupper piping, fittings and valves in m. In no case should the area of each individual drain be less than 0.0078 m^2 or 125 mm diameter piping.		
MSC.1/Circ.1226 approved 15 January 2007 Interim Explanatory Notes to SOLAS Chapter II-1	Scupper capacity	2.6.1 The drainage from enclosed Ro-Ro spaces or special category spaces should be of such capacity that ⅔ of the scuppers, freeing ports etc. on the starboard or port side are	LR Part 3 Chapter 12 Section 4 – Scuppers *4.1.4* In ships where an approved fixed pressure water spray fire-extinguishing system is	Minimum diameter of scuppers and spacing of scuppers are specified by LR and MCA.

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
Subdivision And Damage Stability Regulations Regulation 35-1 – Bilge pumping arrangements		capable of draining off a quantity of water originating from both sprinkler pumps and fire pumps.	fitted in vehicle or cargo spaces, deck scuppers of not less than 150 mm diameter are to be provided port and starboard, spaced about 9.0 m apart. The scupper area will require to be increased if the design capacity of the drencher system exceeds the Rule required capacity by 10 per cent or more. The mouth of the scupper is to be protected by bars.	
			MCA (UK Ship Registry) 2.12.5.2 Normally, scuppers of 152 mm diameter should be fitted on each side of such an enclosed space, and spaced not more than 9.15 m apart when the maximum breadth of the	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			deck in the space is 18.3 m or less. When the maximum breadth is in excess of 18.3 m, the scupper spacing should be decreased in direct proportion to the maximum breadth of 18.3 m.	
	Conditions of heel and trim for drainage	2.6.1 The drainage from enclosed Ro-Ro spaces of the quantity of water specified above should take into account a list of 1° for ships with a breadth of 20.0 m or more and 2° for ships with a breadth below 20.0 m and a trim forward or aft of 0.5°.	MCA (UK) 2.12.5.3 In ships having ramped vehicle decks or unusual sheer on the deck the number and spacing of the scuppers will require to be determined having regard to such features.	
	Protection of scuppers	2.6.1 Scuppers on ro-ro decks should be provided, over the outlet grate, with a removable grill with vertical bars, to prevent large obstacles from blocking the drain. The grill may be placed obliquely against	No specific requirements of removable grill.	MSC 83/3/2 submitted 3 July 2007 jointly by Denmark, Norway and Sweden proposed a grating design to prevent blockage of

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
		the side of the ship. The grill should have a height of at least 1 m above the deck and should have a free flow area of at least 0.4 m^2, while the distance between the individual bars should be not more than 25 mm.		scuppers.
SOLAS 1974/1988 Chapter II-2 - Construction – fire protection, fire detection and fire extinction Part G Regulation 20 - Protection of vehicle, special category and ro-ro spaces	Quantity of water to be removed by drainage system; Provision of bilge wells in each watertight compartment	6.1.4.1.3 In spaces below bulkhead deck in passenger ships, pumping and drainage facilities additional to regulation II-1/21 may if required, be sized to remove no less than 125% of the combined capacity of both the water-spraying system pumps and the required number of fire hose nozzles Bilge wells shall be of sufficient holding capacity and shall be arranged at	LR Part 5 Chapter 13 – Ship Piping Systems *9.1.1* Where arrangements for cooling underdeck cargo spaces, or fire-fighting by means of fixed spraying nozzles or by flooding of the cargo space with water are provided, the following provisions are to apply: (a) The drainage system is to be sized to remove no less than 125 per cent of the combined capacity of both the water spraying	LR same as SOLAS.

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
		the side shell of the ship at a distance from each other of not more than 40 m in each watertight compartment.	system pumps and the required number of fire hose nozzles. (c) Adequately sized bilge wells are to be located at the side shell of the ship at a distance of not more than 40 m in each watertight compartment, *see also* Pt 3, Ch 12, 4.1.4 and Pt 4, Ch 2, 11.2. For cargo ships only, if this is not possible, the free surface effect on the ship's stability is to be determined and submitted to the flag administration for appraisal.	
SOLAS 1974/1988 Chapter II-2 – Construction – fire protection, fire detection and fire extinction Part C – Suppression of fire	Fire pump capacity	*2.2.4.1.1 Total capacity of required fire pumps.* Pumps in passenger ships shall deliver a quantity of water, at the specified pressure of 0.4 N/mm^2, not less than ⅔ of the quantity required to be dealt with by	LR Part 6 Chapter 4 – Fire Protection, Detection and Extinction Requirements *1.1.1* Cargo ships of 500 gross tons or more, all passenger ships and gas and chemical tankers on	LR subscribes to SOLAS requirements for fire pump capacity. ABS requires a higher capacity for fire pumps than

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
Regulation 10 – Fire fighting		the bilge pumps when employed for bilge pumping.	international voyages, where provision is made within International Conventions are to be provided with the fire safety measures required by the *International Convention for the Safety of Life at Sea*, 1974, as amended (SOLAS 74).	SOLAS.
			ABS Chapter 7 Fire Safety Systems Section 3 Fire-extinguishing systems *1.3.1 Total Capacity*. The required fire pumps are to be capable of delivering for fire fighting purposes a quantity of water, at the pressure specified in 4-7-3/1.7 not less than four-thirds (4/3) of the quantity required under 4-6-4/5.3.2 to be dealt with by each of the independent bilge	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			pumps when employed in bilge pumping, using in all cases *L* = length of the vessel, except that the total required capacity of the fire pumps need not exceed 180 m^3/h (792 gpm).	
	Number of fire pumps	2.2.2 Ships shall be provided with independently driven fire pumps as follows: .1 in passenger ships ≥ 4,000 GT, at least three.		
	Capacity of each fire pump	2.2.4.2 Each of the required fire pumps shall have a capacity not less than 80% of the total required capacity divided by the minimum number of required fire pumps, but in any case not less than 25 m^3/h, and each such pump shall in any event be capable of delivering at least the two required jets of water. These fire pumps		

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
		shall be capable of supplying the fire main system under the required conditions.		
	Diameter of fire mains	2.1.3 The diameter of the fire main and water service pipes shall be sufficient for the effective distribution of the maximum required discharge from two fire pumps operating simultaneously, except that in the case of cargo ships the diameter need only be sufficient for the discharge of 140 m^3/h.		
	Number and position of hydrants	2.1.5.1 In any Ro-Ro space or any vehicle space, 2 jets not emanating from the same hydrant shall reach any part of the space, each from a single length of hose.	BV Part C Chapter 4 Section 6 1.2.5 Number and position of hydrants (a) The number and position of hydrants shall be such that at least 2 jets	

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
			of water not emanating from the same hydrant, one of which shall be from a single length of hose, may reach any part of the ship normally accessible to the passengers or crew while the ship is being navigated and any part of any cargo space when empty, any ro-ro space or any vehicle space, in which latter case the 2 jets shall reach any part of the space, each from a single length of hose.	
Fire Safety Code Chapter 8 – Automatic sprinkler, fire detection and fire alarm systems	Sprinkler pump capacity	2.3.3.2 The pump shall provide continuous output of water sufficient for the simultaneous coverage of a minimum area of 280 m^2 at the minimum application rate of 5 litres/min/m^2 over the nominal area covered by the sprinklers.		SOLAS requires sprinkler systems to comply with FSS Code.
	Capacity of	2.3.2.2 A pressure tank		

IMO Resolution/ SOLAS/FSS Code	Scope of regulation	Guidance provided	Specific Class/Flag requirements	Notes
	tank	containing a standing charge of fresh water shall have a volume equal to at least twice the sprinkler pump capacity discharged in 1 min., i.e. 2800 litres.		
	Zoning of sprinklers	2.4.2.1. Sprinklers shall be grouped into separate sections, each of which shall not contain more than 200 sprinklers. In passenger ships, any section of sprinklers shall not serve more than 2 decks and shall not be situated in more than one main vertical zone.		

A review of the various approaches for setting minimum scupper outflow capacity is discussed in Section 8 Proposal of Criteria

17. SCENARIO DEFINITIONS

The investigation that was be performed in the following sections was based on a representative collection of Ro-Ro passenger ships. The necessary environmental input for the analysis of the dynamic performance of the scuppers will be based on referenced standards for the performance assessment of ships.

17.1 **Selection of ship sizes**

For the static analysis, a sample of 15 Ro-Ro passenger ships was analyzed in the following sections. They were grouped according to their size in the following three categories:

- *small* are the vessels less than 130 m LBP (3 ships),
- *medium* are the vessels between 130 and 170 m LBP (10 ships), and
- *large* are defined as vessels greater than 170 m LBP (2 ships).

With respect to the vehicle deck layout arrangement, the 15 ships were grouped according to the location of their casing into:

- "*central casing*" (6 ships) and
- "*side casing*" (9 ships).

For dynamic analysis including CFD analysis, two vessels, one from the small group and one from the large group are considered. Based on these pre-existing hull forms, representative central and side-casing designs were created and used in the analysis to allow a comparison between these alternative deck layouts.

17.2 **Selection of environmental conditions**

The selection of environmental conditions was made according to the sea states that are formally used in SOLAS' 95 Regulation 14 – Model Test Method. As a major part of this work is to consider the effects of dynamics on the scupper performance, these relatively large sea states (4m significant wave height) were considered to act in a beam sea condition to maximise the dynamic effect.

In doing so the investigation detailed in this report, has attempted to consider the maximum dynamic effects to encompass less extreme dynamic scenarios. It should be noted that this work is of limited scope and cannot be considered definitive in this regard.

18. STATIC SIMULATION OF SCUPPER PERFORMANCE

18.1 Scope for static modeling

The following static analysis compares the prescribed requirements for scupper sizing of MSC.1/Circ.1226 and the method proposed in FP 53/7. For both methods the outflow margin is calculated for aft and forward trims of 0.5° and for 1.0° heel (as specified in MSC.1/Circ.1226). The calculations were repeated for 0.5^{o} fore and aft trim and 7° heel angle (maximum equilibrium angle specified for the calculation of the survivability factor in MSC.216 (82), Annex 2).

18.2 Modeling assumptions

The scupper diameter prescribed in the rules for all subject ferries has been calculated by the method specified in MSC.1/Circ.1226 and the method proposed in FP 53/7. The following assumptions have been made in the calculations:

The amount of fire fighting water is taken as the minimum required by the FSS Code;
MSC.1/Circ 1226 has been interpreted as requiring adequate drainage capacity for two-thirds of all submerged scuppers.

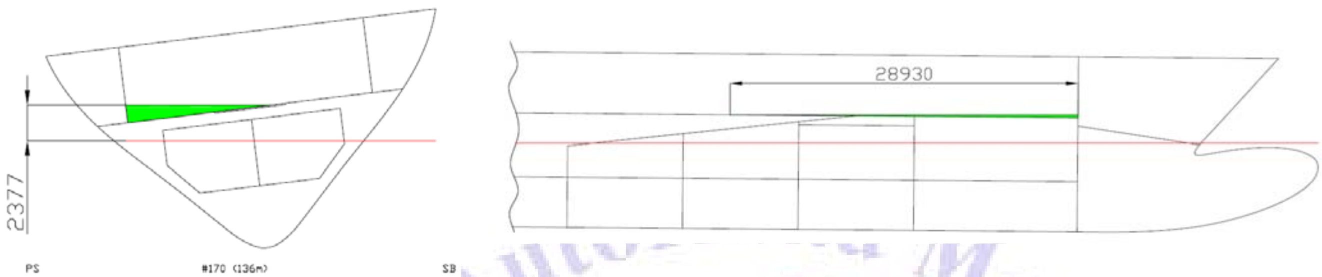
In calculations for MSC.1/Circ.1226, 9.0 m spacing (as required by some class societies and flag administrations) has been used. For FP 53/7 the number of scuppers is kept to the specified minimum of 4.

In the calculations based on MSC.1/Circ.1226, the head of water required to heel the vessel to 1.0^{o} was considered in dimensioning the scuppers.

In all calculations it was assumed that fire hoses contribute a total of 360 litre/minute additional water to the sprinkler capacity. The discharge coefficient was taken as 0.6 throughout. The depth of the scupper well (required in the calculation of scupper diameter by the method specified in FP53/7) is taken conservatively as 0.5m.

Figure 29

Example – measurement of head of water and length of water wedge (for "active scuppers")



18.3 **Static modeling**

The static simulation of scupper performance has been carried out for the 15 existing designs using general naval architecture software NAPA software. In each case a certain amount of water was loaded on the vehicle deck in order to induce heel and the required degree of trim (forward or aft). The subsequent step was to measure the head of water from the top surface of the wedge up to the sea level, and the length of the deck where the wedge of water was formed in each condition (

Figure **29**). This information was used to define the ratio of "active scuppers":

$$\frac{\text{Wedge length}}{\text{Car deck length}} \%$$

The summary of the subject vessels particulars and the measurements taken for 1° and 7^{o} heel for aft and forward trims of 0.5° can be found in **Table 11.**

Table 11
Various measurements for the subject vessels

		1.0deg heel			7.0deg heel		
ID	Trim (+/- 0.5deg)	Water on deck	Head of Water for Scuppers	Active Scuppers	Water on deck	Head of Water for Scuppers	Active Scuppers
		[tonne]	[m]		[tonne]	[m]	
1	Stern	70	1.359	50%	420	1.445	96%
	Bow	120	1.378	58%	465	1.445	94%
2	Stern	100	2.426	27%	215	1.917	90%
	Bow	50	2.426	25%	120	1.716	64%
3	Stern	40	3.469	11%	273	2.833	83%
	Bow	30	2.909	32%	210	2.467	70%
4	Stern	100	2.909	35%	375	2.106	83%
	Bow	55	2.551	31%	315	1.963	79%
5	Stern	160	2.163	42%	645	1.835	91%
	Bow	90	2.046	37%	450	1.666	100%
6	Stern	120	2.437	21%	380	2.053	98%
	Bow	55	2.066	15%	245	1.673	61%
7	Stern	60	2.075	8%	325	1.724	66%
	Bow	120	2.336	15%	376	2.092	99%
8	Stern	25	1.854	8%	155	1.604	85%
	Bow	15	1.947	4%	123	1.592	56%
9	Stern	235	2.356	29%	670	2.151	88%
	Bow	170	2.554	52%	570	2.376	100%
10	Stern	18	1.478	26%	50	0.706	65%
	Bow	5	1.514	14%	44	0.814	61%
11	Stern	70	1.674	37%	200	0.914	77%
	Bow	30	1.894	30%	82	1.034	70%
12	Stern	10	1.794	17%	79	1.000	54%
	Bow	4	1.215	20%	20	0.460	43%
13	Stern	8	1.126	16%	56	0.585	46%
	Bow	9	1.197	20%	89	0.767	51%
14	Stern	220	2.36	19%	810	1.872	88%
	Bow	140	2.456	45%	525	1.885	89%
15	Stern	20	2.391	23%	122	1.674	73%
	Bow	47	2.48	29%	126	1.803	82%

The following charts illustrate the “active scuppers” under 1^{o} and 7^{o} heel conditions with 0.5° bow and stern trim.

Figure 30
Active scuppers at 1°heel

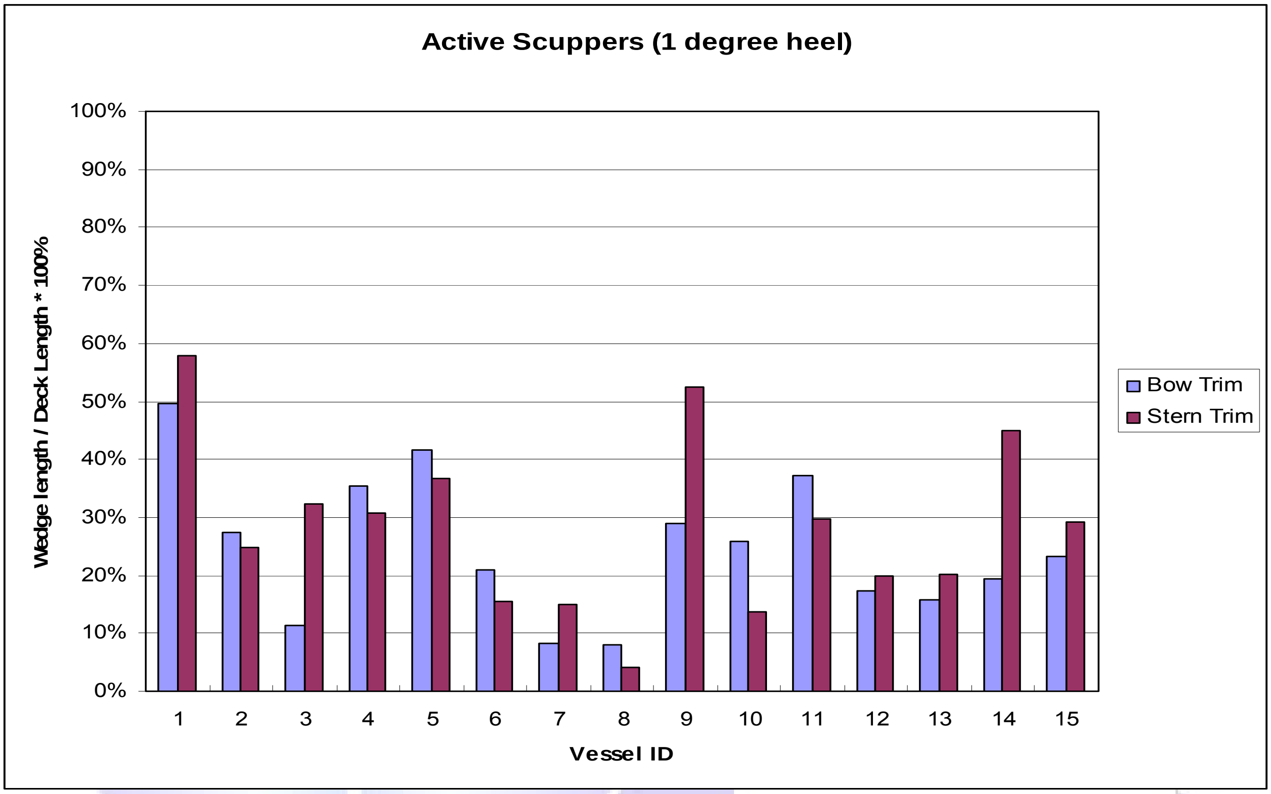
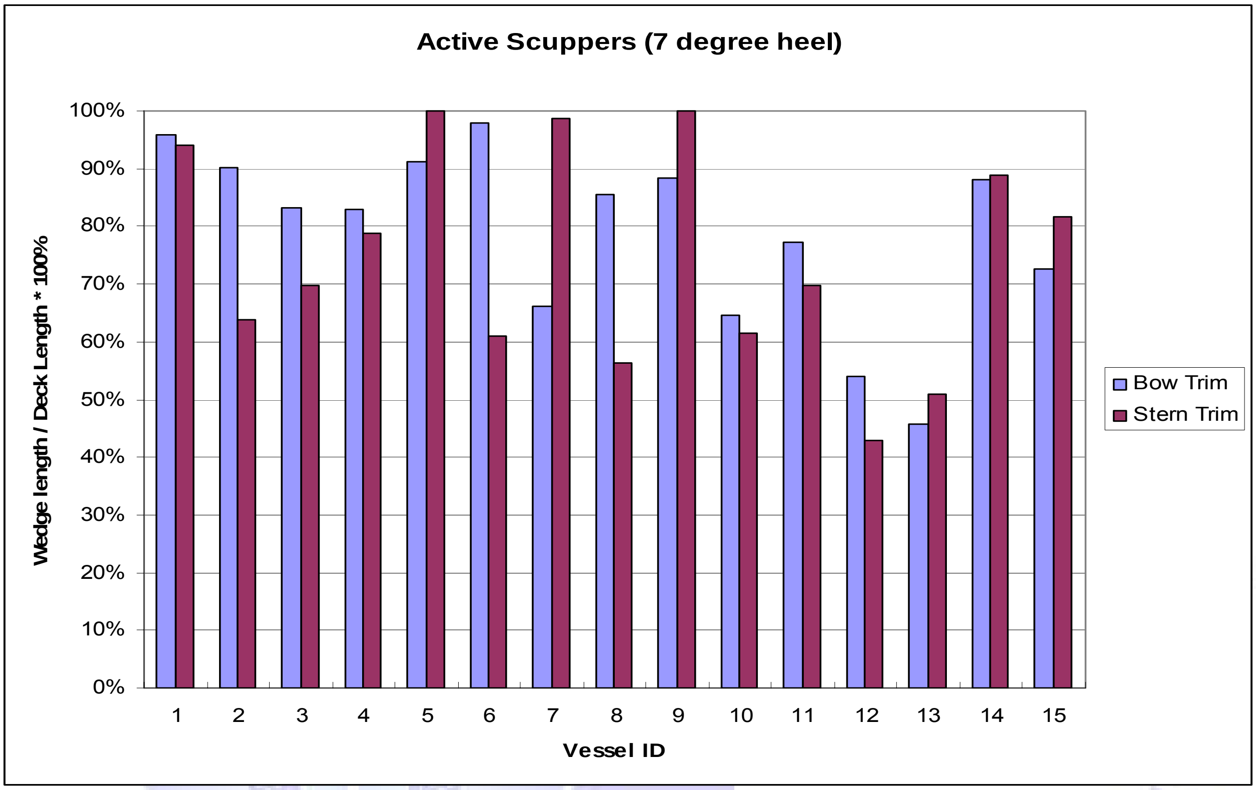


Figure 31
Active scuppers at 7°heel



Panamá Maritime Authority
Directorate General of Merchant Marine
Marine Accidents Investigation Department
Panama, Republic of Panama

18.4 Outflow margin for Compliance with FSS Code

The number of scuppers is calculated by the ratio of garage deck length by the assumed distance of 9.0 m for either side of the ship as specified in LR, Part 3 Chapter 12 Section 4. All figures required for the below calculations are included in Table 11.

The outflow margin is defined as the percentage of the volume ratio of water flowing out through scuppers to the water provided by fire-fighting.

margin = [(drained water / fire-fighting water) – 1] %

In case of "minimum fire-fighting" the fire-fighting water was assumed according to FSS as the pump output for simultaneous coverage of a minimum area of 280 m^2 at the minimum application rate of 5 litres/min/m^2 over the nominal area covered by the sprinklers (280 * 5 =1400 litres/min)

Table 12
Number of scuppers for minimum fire-fighting capacity

Vessel ID	Sprinkler Capacity (Minimum Fire-Fighting)	Required no. of scuppers on ONE side
1	1400	14
2	1400	22
3	1400	17
4	1400	20
5	1400	17
6	1400	17
7	1400	17
8	1400	13
9	1400	19
10	1400	14
11	1400	17
12	1400	18
13	1400	13
14	1400	18
15	1400	18

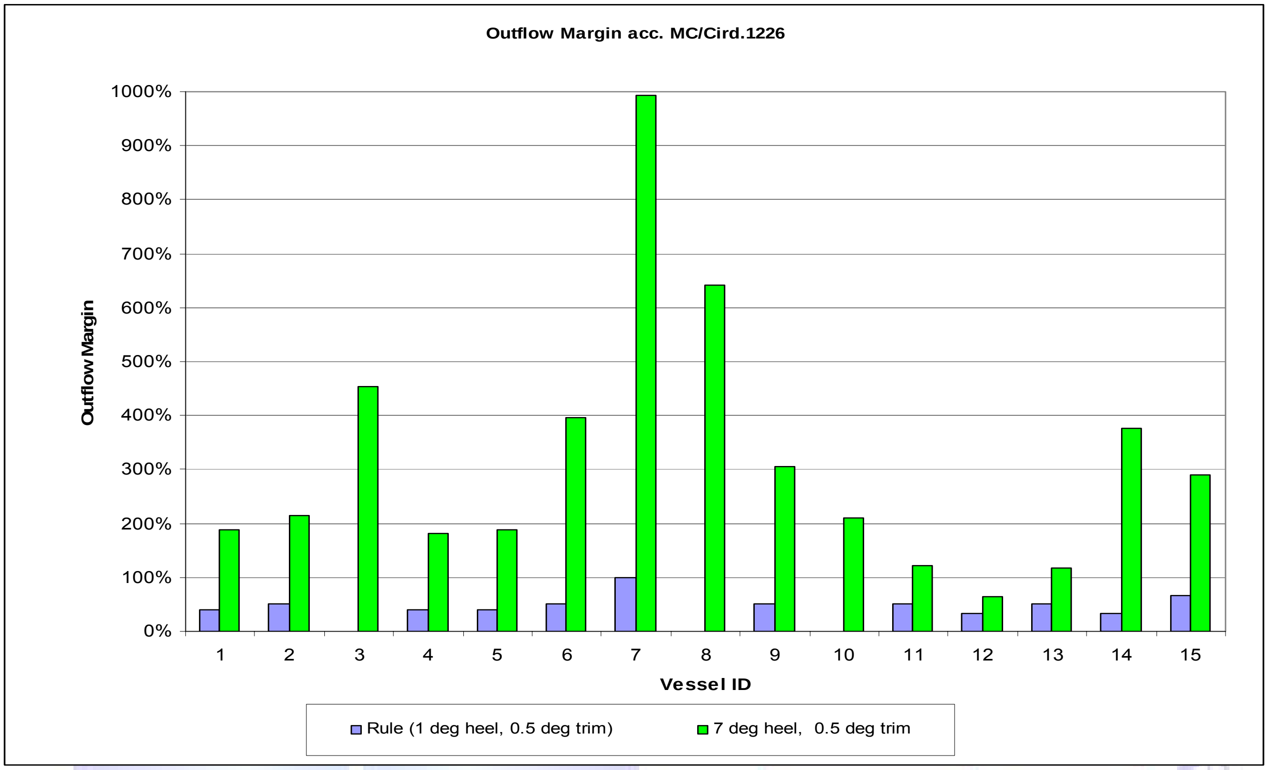
Considering that similar results for bow and stern trim had been observed, the outflow of submerged (active) scuppers was calculated for:

- 1.0^{o} heel with 0.5^{o} bow trim
- 7.0^{o} heel with 0.5^{o} bow trim.

All outflows were calculated for minimum fire-fighting capacity.**¡Error! No se encuentra el origen de la referencia.**) and they are presented as a percentage margin of the volume of the available fire fighting water on chart in table 14, table 13 Scupper sizing according to MSC. 1/Circ.1226

Vessel ID	Rule Number of Scuppers Active	Rule Flow per scupper [l/min]	Required Scupper Area [m²]	Required Scupper Diameter [mm]	Outflow Capacity Margin	
					Rule (1 deg heel, 0.5 deg trim)	7 deg heel, 0.5 deg trim
1	5	352	0.002	50	40%	189%
2	4	440	0.002	48	50%	215%
3	2	880	0.003	65	0%	453%
4	5	352	0.001	42	40%	181%
5	5	352	0.002	45	40%	189%
6	2	880	0.004	70	50%	395%
7	1	1760	0.008	99	100%	994%
8	1	1760	0.008	102	0%	641%
9	4	440	0.002	48	50%	306%
10	2	880	0.005	77	0%	211%
11	4	440	0.002	53	50%	122%
12	3	587	0.003	66	33%	64%
13	2	880	0.005	82	50%	116%
14	3	587	0.002	56	33%	375%
15	3	587	0.002	56	67%	290%

Figure 32
Diagram depicting the outflow capacity margin according to MSC .1/Circ. 1226



Ps 3, 8 and 10 have 0 % outflow margin for 1.0 ° heel which implies that the scupper outflow capacity matches the scupper flow onto the car-deck. This is due to the very small amount of water required to heel these vessels (as it can be seen in **Table 11**, The scupper spacing is 9.0 m so there are only a few scuppers covering the area of localized water wedge. Therefore there is no outflow margin for small heel, however a margin can be observed for the same vessels at 7° heel.

In the case of FP 53/7, the results are calculated according to the following equation with and without the specified lower limit of 125 mm of drainage pipe diameter.

$$A = \frac{1.25Q}{\sqrt{19.62\left(h - \sum h_i\right)}} \quad (1)$$

Where

Q: combined water flow from the fixed extinguishing system and the required number of fire hoses measured in m^3/s

h: elevation head difference between the bottom of the scupper well or suction level and the overboard discharge opening or highest approved load line measured in m;

$\sum h_i$: *summation of the equivalent lengths of scupper piping, fittings and valves measure in m.*

Figure 33
Two variations of scupper arrangement for minimum 4 scuppers according to F 53/7

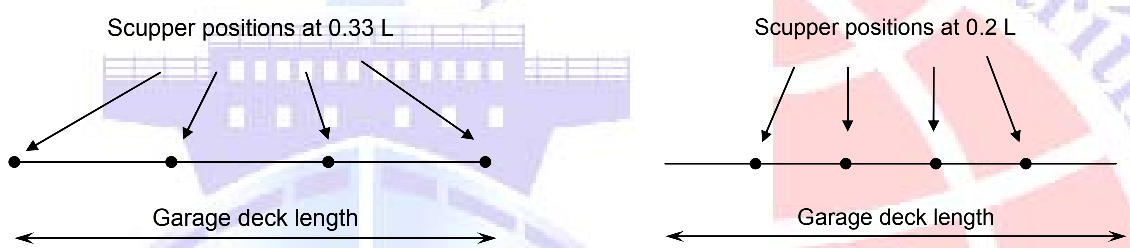


Table 13
Scupper sizing according to FP 53/7 for 1°heel and 0.5°aft and forward trim

scupper well depth	0.5
Min. No. of Scuppers	4
Drainage Cap. Factor	1.25

				Active Scuppers		Outflow Margin (without 125mm diameter limit)			Outflow Margin (with 125mm diameter limit)		
Vessel ID	Rule Flow per scupper [l/min]	Required Scupper Area [m]	Required Scupper Diameter [mm]	No. of scuppers (0.2L spacing)	No. of scuppers (0.33L spacing)	Flow per scupper [l/min]	Margin (0.2 L spacing)	Margin (0.33 L spacing)	Flow per scupper	Margin (0.2 L spacing)	Margin (0.33 L spacing)
1	550	0.004	67	3	2	651	11%	-26%	2281	289%	159%
2	550	0.002	53	2	1	531	-40%	-70%	3048	246%	73%
3	550	0.002	50	1	1	533	-70%	-70%	3338	90%	90%
4	550	0.002	53	2	1	556	-37%	-68%	3125	255%	78%
5	550	0.003	63	2	2	706	-20%	-20%	2799	218%	218%
6	550	0.004	73	1	1	945	-46%	-46%	2813	60%	60%
7	550	0.002	55	1	1	538	-69%	-69%	2819	60%	60%
8	550	0.003	59	1	1	592	-66%	-66%	2665	51%	51%
9	550	0.002	54	2	1	557	-37%	-68%	3004	241%	71%
10	550	0.003	63	1	1	586	-67%	-67%	2379	35%	35%
11	550	0.003	58	2	1	530	-40%	-70%	2532	188%	44%
12	550	0.003	63	1	1	532	-70%	-70%	2157	23%	23%
13	550	0.004	73	1	1	698	-60%	-60%	2076	18%	18%
14	550	0.002	54	1	1	560	-68%	-68%	3006	71%	71%
15	550	0.002	52	2	1	518	-41%	-71%	3026	244%	72%

Figure 34
Outflow Margin according to FP 53/7 for 1°heel and 0.5°aft and forward trim

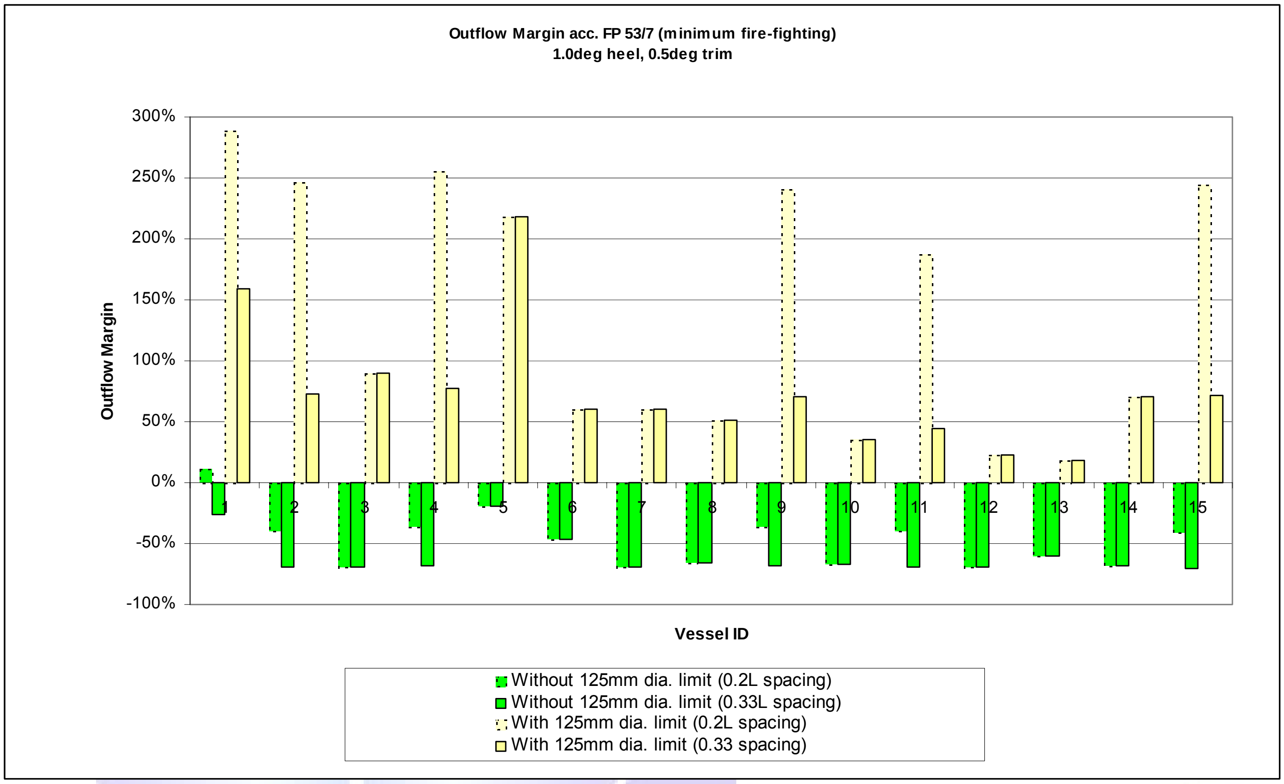


Table 14
Scupper sizing according to FP 53/7 for 7°heel and 0.5°aft and forward trim

scupper well depth 0.5
Min. No. of Scuppers 4
Drainage Cap. Factor 1.25

						Outflow Margin					
				Active Scuppers		(without 125mm diameter limit)			(with 125mm diameter limit)		
Vessel ID	Rule Flow per scupper [l/min]	Required Scupper Area [m]	Required Scupper Diameter [mm]	No. of scuppers (0.2L spacing)	No. of scuppers (0.33L spacing)	Flow per scupper [l/min]	Margin (0.2 L spacing)	Margin (0.33 L spacing)	Flow per scupper	Margin (0.2 L spacing)	Margin (0.33 L spacing)
1	550	0.004	67	4	3	671	53%	14%	2352	435%	301%
2	550	0.002	53	4	2	447	2%	-49%	2563	483%	191%
3	550	0.002	50	4	3	491	12%	-16%	3074	599%	424%
4	550	0.002	53	4	3	487	11%	-17%	2742	523%	367%
5	550	0.003	63	4	3	638	45%	9%	2526	474%	331%
6	550	0.004	73	4	2	850	93%	-3%	2531	475%	188%
7	550	0.002	55	4	3	491	12%	-16%	2569	484%	338%
8	550	0.003	59	3	2	549	-6%	-38%	2469	321%	181%
9	550	0.002	54	4	3	532	21%	-9%	2870	552%	389%
10	550	0.003	63	4	2	405	-8%	-54%	1644	274%	87%
11	550	0.003	58	4	3	392	-11%	-33%	1871	325%	219%
12	550	0.003	63	3	2	327	-44%	-63%	1327	126%	51%
13	550	0.004	73	3	2	503	-14%	-43%	1497	155%	70%
14	550	0.002	54	4	3	498	13%	-15%	2677	509%	356%
15	550	0.002	52	4	3	433	-2%	-26%	2532	475%	332%

Figure 35
Outflow Margin according to FP 53/7 for 7°heel and 0.5°aft and forward trim

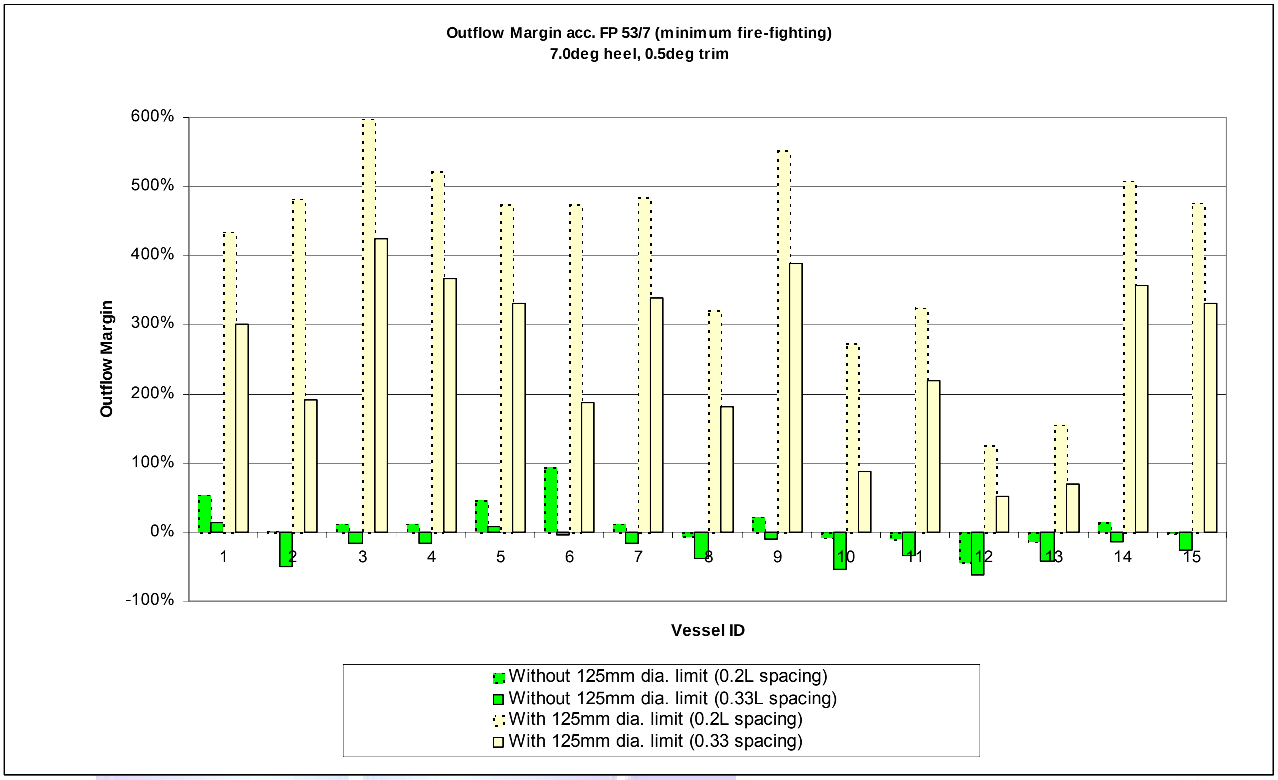
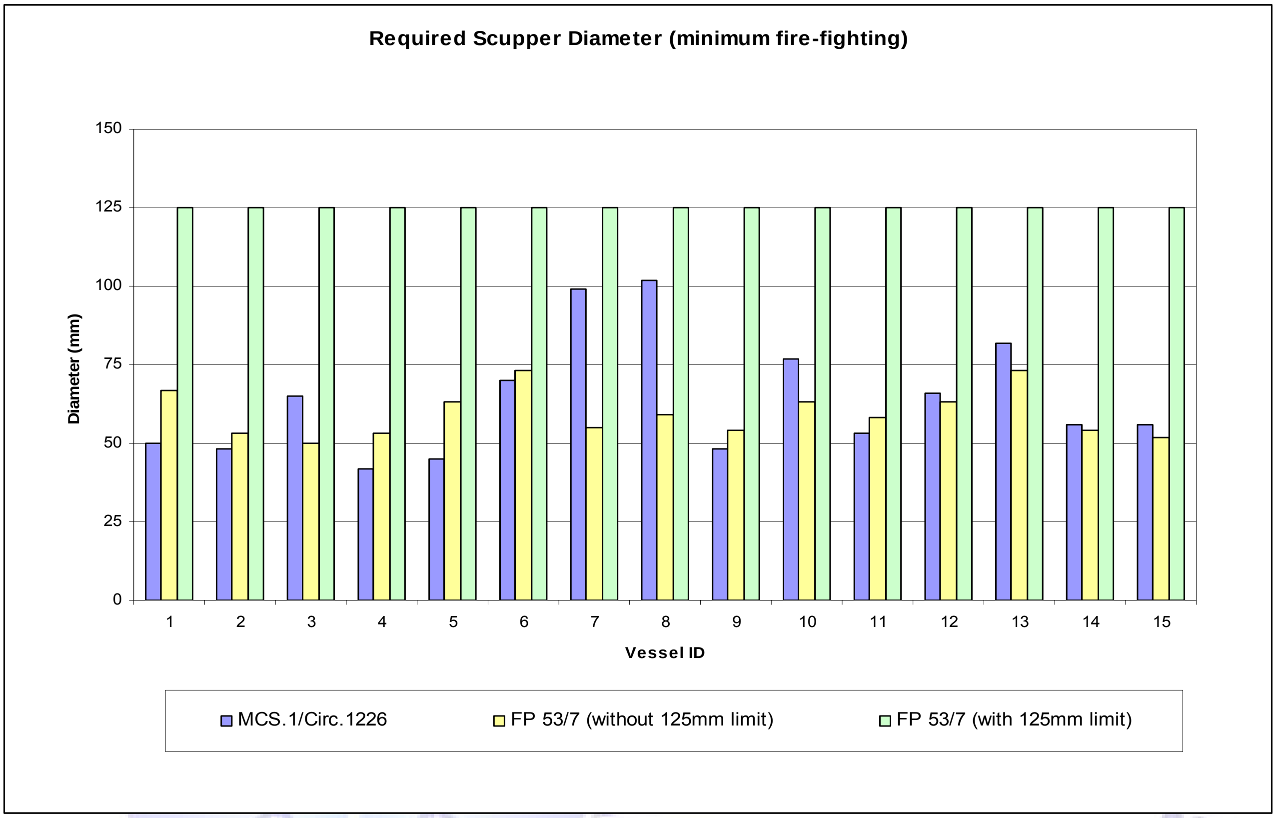


Figure 36
Required scupper diameter for MSC.1/Circ. 1226 and FP53/7 with 125 mm minimum diameter requirement and without.



18.5 **Outflow margin for enhanced fire fighting capacity**

The calculations detailed above were repeated for enhanced fire-fighting capacity (Table 15), under the assumption that the minimum sprinkler coverage (5 l/min/m^2) is capable of being delivered over the entire vehicle deck area. The deck area for every ship is presented in **Table 11.**

Table 15

Required number of scuppers and sprinkler capacity for enhanced fire-fighting (application rate the same as for minimum fire-fighting)

Vessel ID	Sprinkler Capacity (Enhanced Fire-Fighting)	Required no. of scuppers on ONE side
1	7640	14
2	24165	22
3	16140	17
4	19695	20
5	12755	17
6	14715	17
7	14985	17
8	8575	13
9	16730	19
10	12000	14
11	17960	17
12	16930	18
13	11445	13
14	20730	18
15	18495	18

Table 16
Scupper sizing acc. MSC.1/Circ.1226 – enhanced fire-fighting capacity

					Outflow Capacity Margin	
Vessel ID	Rule Number of Scuppers Active	Rule Flow per scupper [l/min]	Required Scupper Area [m²]	Required Scupper Diameter [mm]	Rule (1 deg heel, 0.5 deg trim)	7 deg heel, 0.5 deg trim
1	5	1600	0.009	105	40%	189%
2	4	6131	0.025	178	50%	215%
3	2	8250	0.030	197	0%	453%
4	5	4011	0.016	142	40%	181%
5	5	2623	0.011	122	40%	189%
6	2	7538	0.033	205	50%	395%
7	1	15345	0.067	292	100%	994%
8	1	8935	0.041	229	0%	641%
9	4	4273	0.017	150	50%	306%
10	2	6180	0.032	202	0%	211%
11	4	4580	0.022	169	50%	122%
12	3	5763	0.033	205	33%	64%
13	2	5903	0.035	211	50%	116%
14	3	7030	0.029	192	33%	375%
15	3	6285	0.025	181	67%	290%

Note:
The Outflow Capacity Margin is the same as for the minimum fire-fighting. According to MSC.1/Circ.1226 the required scupper area is increased consequently to drain enhanced fire-fighting water volume.

Table 17

Scupper sizing acc. FP 53/7 for 1°heel and 0.5°aft and forward – enhanced fire-fighting capacity

scupper well depth	0.5
Min. No. of Scuppers	4
Drainage Cap. Factor	1.25

				Active Scuppers		Outflow Margin (without 125mm diameter limit)			Outflow Margin (with 125mm diameter limit)		
Vessel ID	Rule Flow per scupper [l/min]	Required Scupper Area [m]	Required Scupper Diameter [mm]	No. of scuppers (0.2L spacing)	No. of scuppers (0.33L spacing)	Flow per scupper [l/min]	Margin (0.2 L spacing)	Margin (0.33 L spacing)	Flow per scupper	Margin (0.2 L spacing)	Margin (0.33 L spacing)
1	2000	0.013	128	3	2	2367	-11%	-41%	2367	-11%	-41%
2	6131	0.024	175	2	1	5923	-52%	-76%	5923	-52%	-76%
3	4125	0.015	137	1	1	3996	-76%	-76%	3996	-76%	-76%
4	5014	0.020	160	2	1	5065	-49%	-75%	5065	-49%	-75%
5	3279	0.018	154	2	2	4212	-36%	-36%	4212	-36%	-36%
6	3769	0.028	190	1	1	6475	-57%	-57%	6475	-57%	-57%
7	3836	0.016	145	1	1	3756	-76%	-76%	3756	-76%	-76%
8	2234	0.011	119	1	1	2405	-73%	-73%	2665	-70%	-70%
9	4273	0.018	150	2	1	4324	-49%	-75%	4324	-49%	-75%
10	3090	0.017	148	1	1	3295	-73%	-73%	3295	-73%	-73%
11	4580	0.021	166	2	1	4417	-52%	-76%	4417	-52%	-76%
12	4323	0.024	174	1	1	4179	-76%	-76%	4179	-76%	-76%
13	2951	0.022	168	1	1	3743	-68%	-68%	3743	-68%	-68%
14	5273	0.022	167	1	1	5364	-75%	-75%	5364	-75%	-75%
15	4714	0.018	152	2	1	4436	-53%	-76%	4436	-53%	-76%

Figure 37
Outflow Margin according to FP 53/7 for 1°heel and 0.5°aft and forward trim

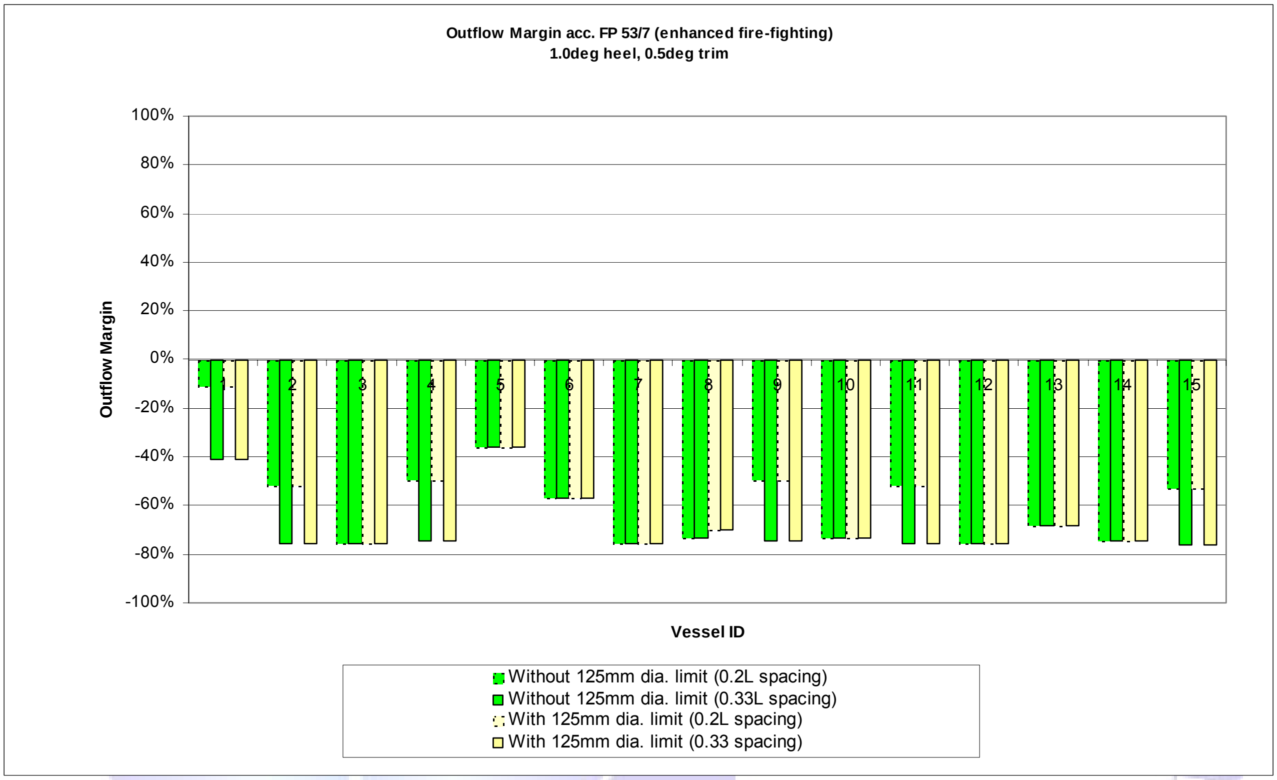


Table 18
Scupper sizing acc. FP 53/7 for 7°heel and 0.5°aft and forward – enhanced fire-fighting capacity

scupper well depth	0.5
Min. No. of Scuppers	4
Drainage Cap. Factor	1.25

				Active Scuppers		Outflow Margin (without 125mm diameter limit)			Outflow Margin (with 125mm diameter limit)		
Vessel ID	Rule Flow per scupper [l/min]	Required Scupper Area [m]	Required Scupper Diameter [mm]	No. of scuppers (0.2L spacing)	No. of scuppers (0.33L spacing)	Flow per scupper [l/min]	Margin (0.2 L spacing)	Margin (0.33 L spacing)	Flow per scupper	Margin (0.2 L spacing)	Margin (0.33 L spacing)
1	2000	0.013	128	4	3	2441	22%	-8%	2441	22%	-8%
2	6131	0.024	175	4	2	4981	-19%	-59%	4981	-19%	-59%
3	4125	0.015	137	4	3	3680	-11%	-33%	3680	-11%	-33%
4	5014	0.020	160	4	3	4443	-11%	-34%	4443	-11%	-34%
5	3279	0.018	154	4	3	3800	16%	-13%	3800	16%	-13%
6	3769	0.028	190	4	2	5826	55%	-23%	5826	55%	-23%
7	3836	0.016	145	4	3	3423	-11%	-33%	3423	-11%	-33%
8	2234	0.011	119	3	2	2228	-25%	-50%	2469	-17%	-45%
9	4273	0.018	150	4	3	4132	-3%	-27%	4132	-3%	-27%
10	3090	0.017	148	4	2	2277	-26%	-63%	2277	-26%	-63%
11	4580	0.021	166	4	3	3264	-29%	-47%	3264	-29%	-47%
12	4323	0.024	174	3	2	2571	-55%	-70%	2571	-55%	-70%
13	2951	0.022	168	3	2	2698	-31%	-54%	2698	-31%	-54%
14	5273	0.022	167	4	3	4778	-9%	-32%	4778	-9%	-32%
15	4714	0.018	152	4	3	3712	-21%	-41%	3712	-21%	-41%

Figure 38
Outflow Margin according to FP 53/7 for 7° heel and 0.5°aft and forward trim

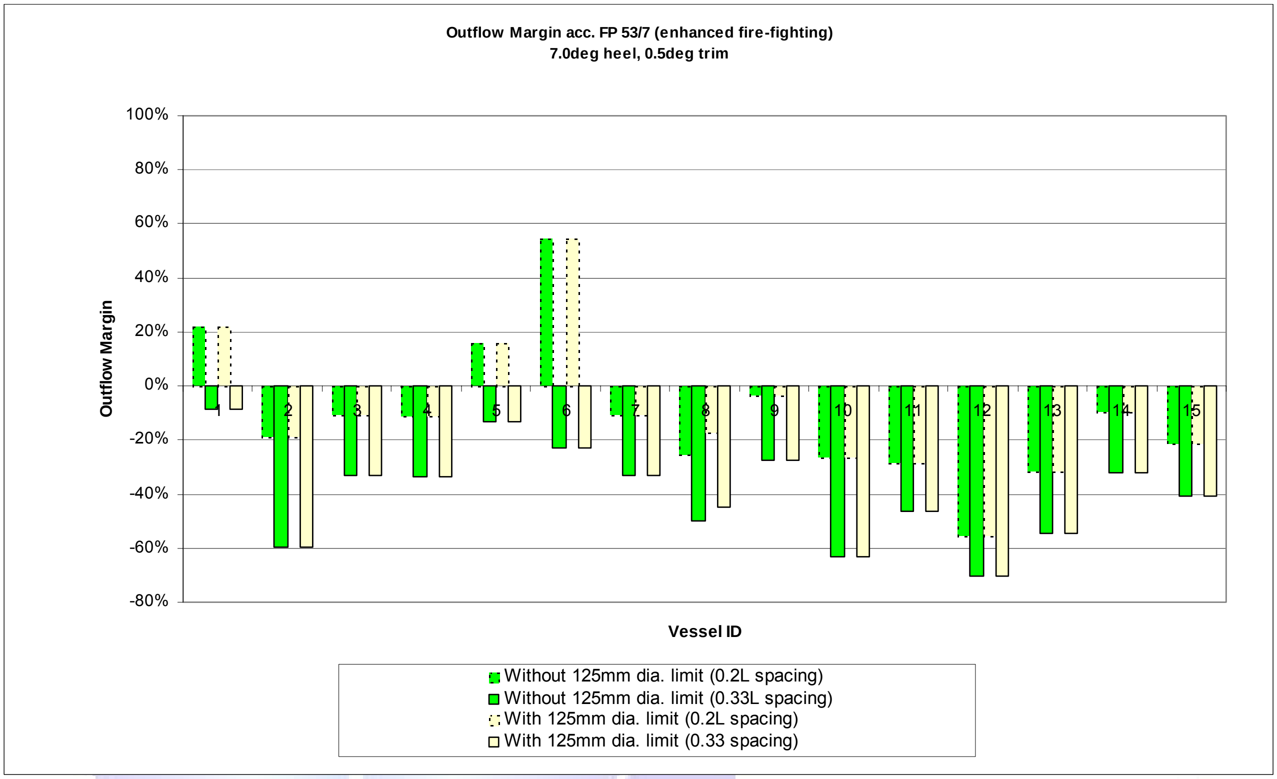
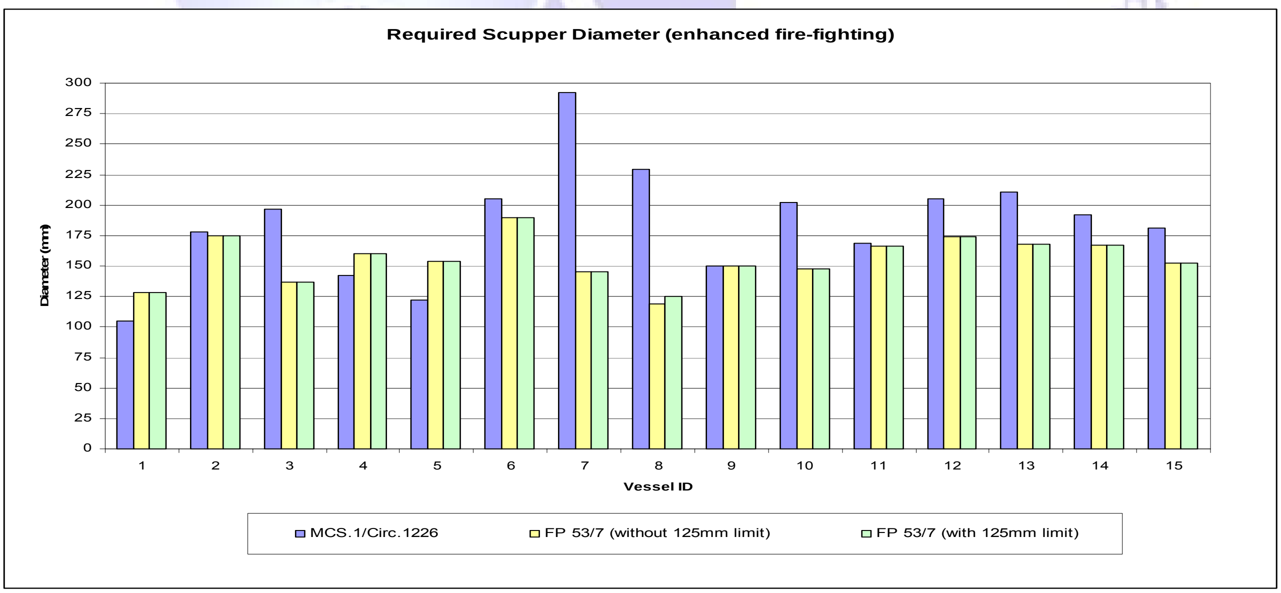


Figure 39
Required scupper diameter for MSC.1/Circ. 1226 and FP53/7 with 125 mm minimum diameter requirement and without.



19. DISCUSSION

Calculations carried out on the basis of equilibrium of flow (with additional margins as specified in MSC.1/Circ.1226 and FP 53/7) for the minimum required fire fighting capacity will produce scupper diameters between 50 -100 mm. This is considerably smaller than today's standard practice and the requirements given by some class societies and flag administrations.

The outflow margins according to MSC.1/Circ.1226 tend to be positive (showing adequate scupper drainage capacity) for the 1^o heel / 0.5^o trim case as heel and trim are taken into consideration when dimensioning the scuppers. The margin tends to increase for larger angles of heel showing additional outflow capacity in the system.

In the case of FP 53/7, the margins of outflow calculated according to equation (1) on the basis of small volumes of water (inducing only 1^o of heel) are negative, showing insufficient outflow capacity. This is primarily a result of a small amount of water being required to heel the vessel to 1^o when combined with a significant trim value, which results in a small proportion of scuppers being covered for this condition. The negative margin is maintained for larger angles of heel showing that scuppers sized according to this equation could result in angles of heel larger than the 7^o maximum equilibrium angle specified in SOLAS II-1 Regulation 8.6 or potential capsize if fire fighting water is maintained for longer periods of time. This is due to the absence of any trim consideration for the dimensioning of the scupper cross-section area, which is in contrast with the consideration of trim in the calculation of outflow margins.

20. DYNAMIC SIMULATION OF SCUPPER PERFORMANCE

20. 1 **Scope**

This chapter will focus on the dynamic effects of ship motion on the scupper drainage capacity. The investigation of these effects will focus on the pressure variation in the inlet and outlet of the scuppers, the inertia of the water in the piping arrangement and the sloshing of the water on the vehicle deck.

The analysis will be performed using in-house flooded-vessel simulation software Proteus 3. This software uses a sea keeping formulation to solve the vessel motion problem and models the internal movement of water by simplified approaches. Flow between internal compartments or the sea is computed by Bernoulli's laws. The software as been developed for over 30 years at the university of Strathclyde and Safety at Sea and has been validated in over a hundred commercial and research projects.

Despite a large amount of attention paid to the movement of water on an open car deck applied by researchers in the field of dynamic stability, the modeling of the dynamics of water on deck by simplified approaches should be approached with caution. To this end a large CFD study was undertaken to verify the results from Proteus and to quantify the dynamic effects by an independent means. This work is detailed in Appendix 1.

20.2 **Model Setup**

The sampled ships, Ships 1 (small) and Ships 2 (large) from Figure 40 were used in the dynamic analysis described in this section. This was to allow the assessment and comparison of the ability of ships of different size to drain water from their garage deck.

For each of the vessels given above two vehicle deck configurations side and central casings were tested. The side casing deck was assumed to span 2.0 m along each side of the hull. The centre casing deck was assumed to span 2.0 m along the centerline for 70% of the deck length.

Figure 40
Diagram of the deck layout used for the centre casing condition for Ship 1

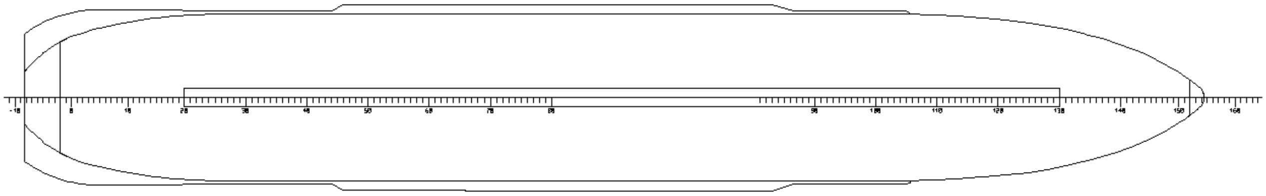


Diagram of the deck layout used for the side casings condition for Ship 1

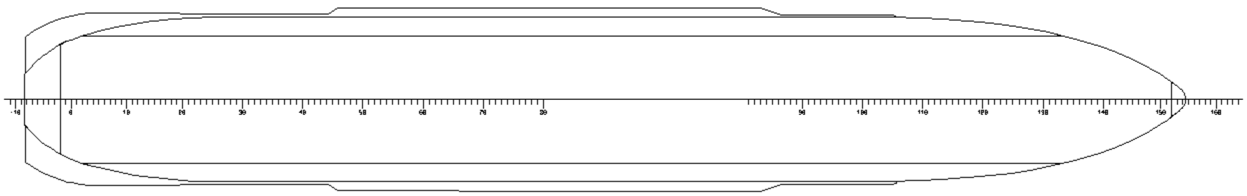


Diagram of the deck layout used for the centre casing condition for Ship 2

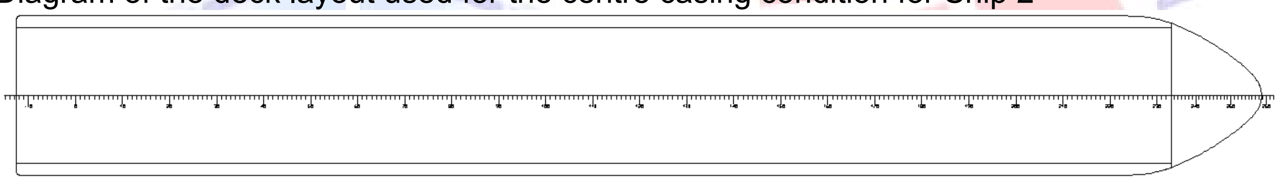
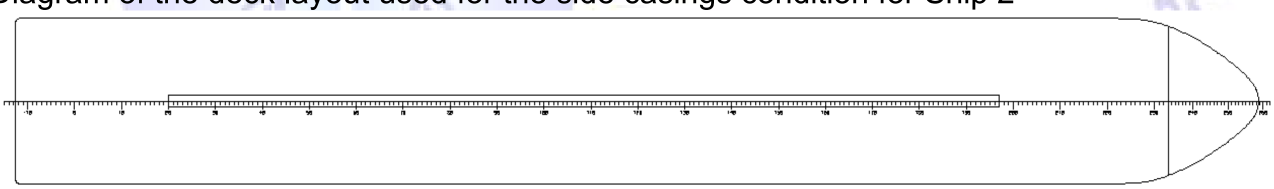
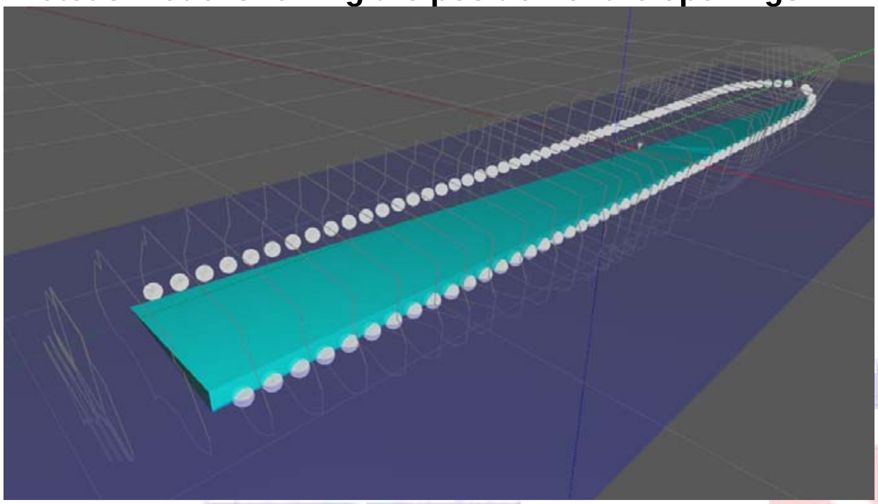


Diagram of the deck layout used for the side casings condition for Ship 2



A series of scuppers (at 2.0 m intervals) were modeled on both sides of the deck. Their functionality is similar to the real scupper arrangements, i.e. they register flow every time water is occupying the space directly above them. The intention of high density of the artificial scuppers on the deck is to provide with detailed view of the movement of water due to ship motions.

Figure 41
Proteus model showing the position of the openings



20.2 **Method**

Analysis of the water motion on the deck of the vessel was undertaken for each combination of vessel size and deck arrangement. The vessel will typically experience the most severe roll conditions in a beam sea environment and so the effectiveness of the scupper drains in a beam seas for a JONSWAP 4.0 m, 8.0 s and 12.0 s irregular waves was calculated (these sea states are formally used in SOLAS' 95 Regulation 14 – Model Test Method). The amount of water to heel the ship to 7^o was maintained for the whole analysis.

The vessels chosen for the analysis were given appropriate loading conditions in NAPA, in which the amount of water required to heel the vessel to 7^o was calculated. This input was then introduced to PROTEUS 3 for simulation for 300s.

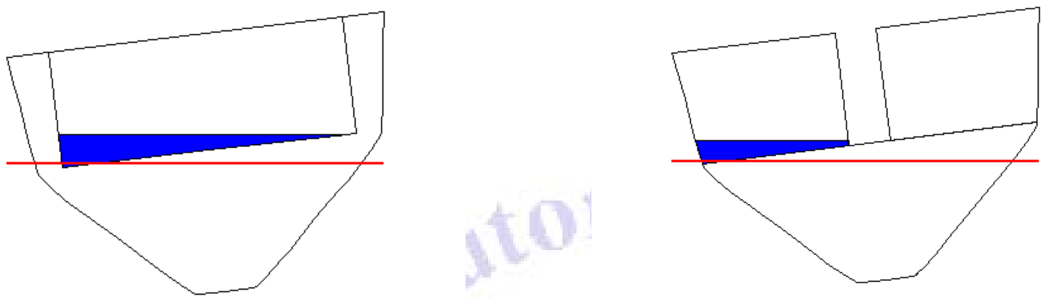
Using the outputs available, two factors of the scupper effectiveness were assessed. Firstly, the total outflow of the scuppers in comparison to the static or still water condition was calculated for all scenarios. In addition, the number of scuppers draining at any given moment was also noted for each run.

The total outflow of water from the car deck allows the assessment of the outflow of water with varying wave heights and lengths. The movement of water will reduce/increase the head at different points and expose/cover different scuppers leading to varying total outflows. As scupper capacity at the moment is designed to still water conditions any deviation from this condition is important to the ability of the vessel to survive. To ensure a conservative result which as far as possible bounds the general problem to give maximum reduction factors, the increase in head due to the length of scupper pipe was not included in the calculations for both the static and dynamic drainage rates.

Although the total outflow with waves is the ultimate goal of this analysis, the number of scuppers draining at any given moment in comparison to the static condition gives further useful information on the ability of the ship to deal with water on deck in waves. This helps to show the effect of waves on the position of the water on deck and therefore how the position of scuppers on deck can affect the outflow. The total number of scuppers flowing was noted while the number for both Port and Starboard were also noted to allow comparison with the effects of heel. The percentage of time each scupper was draining also gave an indication of the water position on deck.

Figure 42

Section through the hull showing the (i) side casing and (ii) the central casing and the water on deck



20.4 **Results**

20.4.1. **Total outflow comparisons**

Table 19 and

Table 20 contain the results of the percentage total outflow reduction with respect to the equilibrium results for their respective vessels.

Table 19
Total outflow reduction as a percentage of equilibrium total outflow from the vehicle deck of Ship 1 (Small hull)

	Trim	8s 4m % of Equilibrium	12s 4m % of Equilibrium
Centre Casing	Bow	67%	62%
	Even	72%	72%
	Stern	75%	72%
Side Casing	Bow	61%	50%
	Even	64%	47%
	Stern	63%	52%

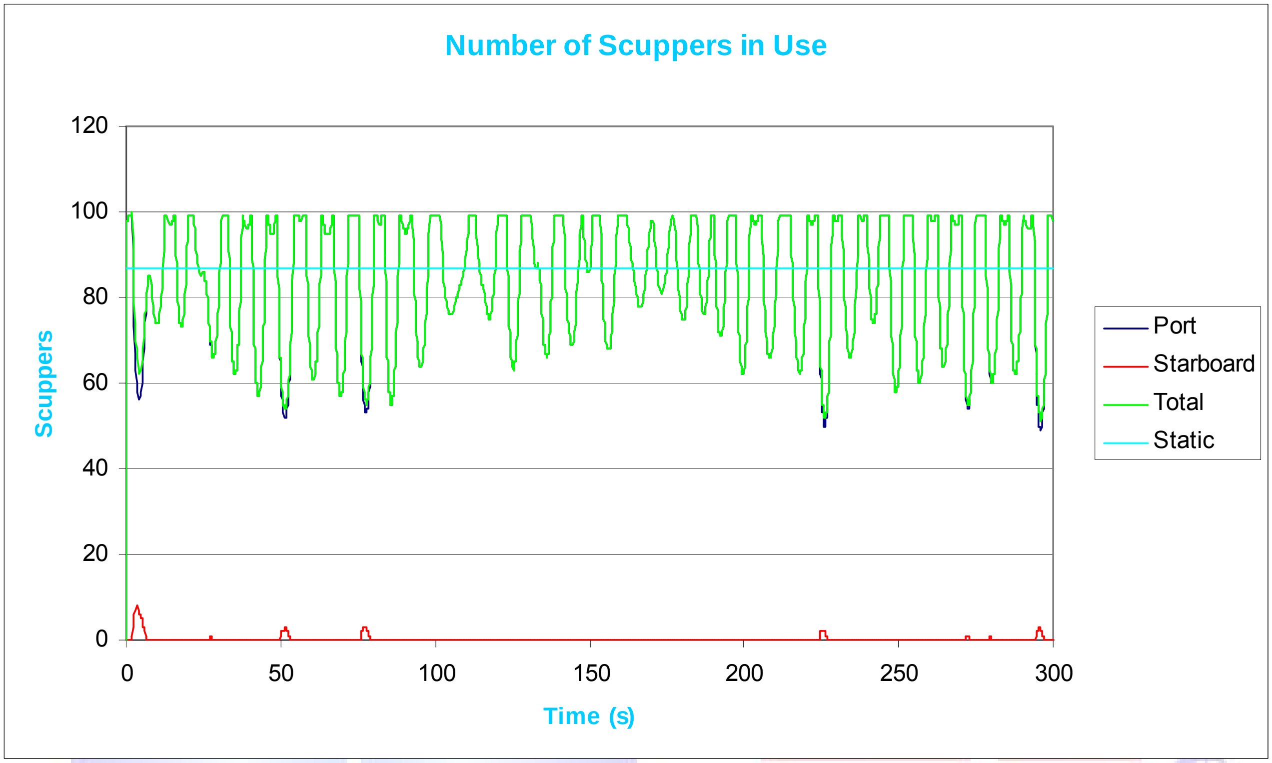
Table 20
Total outflow reduction as a percentage of equilibrium total outflow from the vehicle deck of Ship 2 (Large hull)

	Trim	8s 4m % of Equilibrium	12s 4m % of Equilibrium
Centre Casing	Bow	47%	48%
	Even	44%	42%
	Stern	54%	53%
Side Casing	Bow	47%	55%
	Even	42%	41%
	Stern	44%	45%

20.4.2. **Scupper Coverage Study**

The results show that the movement of water on the deck will reduce the effectiveness of the scuppers and the total outflow (Figure 43) and partially show the range of movement of water on deck. **Figure 43** shows the number of scuppers draining on each side of the vessel plus the total compared to the static. Table 22 shows the percentage of time each scupper was draining water from the deck.

FIGURE 43



The number of active scuppers during the simulation for Ship 2 in bow trim to wave action at any given moment**. Table 21** and **Table 22** give the number of scuppers draining on average for the 300s simulation for the Port and Starboard sides and the Total average. These are compared to the number of scuppers which were draining during static calculations to give a reduction or increase in the number of scuppers draining on average.

Table 21
Results for Ship 1 showing the total numbers of scuppers draining on average during dynamic simulations

	Trim	Hs=4.0 m	Average number of active scuppers			Static Total	Dynamic Reduction/Increase
			Port	Starboard	Total		
Centre Casing	Bow	8s	41.6	0.1	41.7	42	1% (Reduction)
		12s	34.4	2.1	36.5	42	13% (Reduction)
	Even	8s	43.9	0.1	44.0	54	19% (Reduction)
		12s	35.2	1.5	36.6	54	32% (Reduction)
	Stern	8s	27.5	1.1	28.6	44	35% (Reduction)
		12s	13.1	11.6	24.7	44	44% (Reduction)
Side Casing	Bow	8s	43.5	19.7	63.2	71	11% (Reduction)
		12s	33.0	33.9	66.9	71	6% (Reduction)
	Even	8s	41.2	26.0	67.1	59	-14% (Increase)
		12s	34.0	30.1	64.1	59	-9% (Increase)
	Stern	8s	45.8	16.2	62.0	57	-9% (Increase)
		12s	35.8	26.7	62.5	57	-10% (Increase)

Table 22
Results for Ship 2 showing the total numbers of scuppers draining on average during dynamic simulations

	Trim	Hs=4m	Average number of active scuppers			Static Total	Dynamic Reduction/Increase
			Port	Starboard	Total		
Centre Casing	Bow	8s	85.6	0.0	85.6	84.0	-2% (Increase)
		12s	65.9	4.0	69.9	84.0	17% (Reduction)
	Even	8s	92.0	0.0	92.0	91.0	-1% (Increase)
		12s	84.8	9.8	94.6	91.0	-4% (Increase)
	Stern	8s	81.2	0.0	81.2	82.0	1% (Reduction)
		12s	73.7	22.4	96.1	82.0	-17% (Increase)
Side Casing	Bow	8s	82.9	0.1	83.0	87.0	5% (Reduction)
		12s	55.8	26.4	82.2	87.0	5% (Reduction)
	Even	8s	94.9	0.0	94.9	94.0	-1% (Increase)
		12s	73.7	22.4	96.1	94.0	-2% (Increase)
	Stern	8s	87.1	0.0	87.1	87.0	0%
		12s	67.2	17.8	85.0	87.0	2% (Reduction)

20.5 **Discussion**

The results for the percentage outflow show that for both vessel sizes studied, reductions in outflow capacity due to dynamics are up to 70%. This should be taken into consideration when applying rules based on static considerations.

Reduction factors for the smaller vessel tend to be more significant than for the larger vessel. This is as expected as dynamics tend to be more significant for smaller vessels due to their tendency to roll through larger angles for the same sea-states.

There are small differences in wave period with the only significant difference for the small vessels side casing. Here the reduction in the short wave period is more significant than the long wave period. This appears to be due to more activity of the scuppers on the starboard (high) side for this case.

Differences between central and side casing results were not very large apart from the small vessel long period waves. Here the side casing results showed less reduction than the centre casing configuration due to the reasons outlined above.

One significant difference between the side and central casing was noticed in the CFD study reported in Appendix 1, here the side casing results had a much larger peak pressure on the scupper inlet. The reason for this is that the absence of the central casing allows for a diagonal shallow water wave (or bore) to wash across the deck. On impact with the low side wall, the pressure is raised significantly at this instance. This effect results in higher outflow but the effect is moderated by the dynamics of flow within the scupper pipe.

the CFD work reported in Appendix 1, a comparable reduction factor was noted for the CFD and Proteus approach. For the small vessel in the short period waves, a reduction factor for dynamic effects of 44% for side casings and 53% for central casing configurations to compare with 61% and 67% respectively from the Proteus work. The agreement for both configurations is reasonable but it is noted that the side casing reduction is over predicted by Proteus by a larger amount. This is due to the presence of a shallow wave (or bore) for the side casing result which significantly increased outflows in for the CFD. It is thought that this is a peculiarity of the case chosen and would not necessarily be seen in all side casing configurations. As a result it is believed that the Proteus results (as more conservative) are more suitable to make general conclusions on. The CFD work showed that for the sea states water dynamics on the deck can be quite significant, resulting in reasonably high pressure, however as noted above, the inertia of the water within the pipe reduces the outflow that otherwise would have been seen had nos cupper existed

21. SCUPPER ARRANGEMENT STUDY

21.1 Scope

The main factor affecting the rate of flow from the scuppers is the head of water driving the flow. For a scupper with the outlet positioned below the waterline, the driving head is constant for all submerged scuppers. For scuppers positioned above the waterline, the height of water on the car deck (in addition to the scupper height) determines the driving head.

21.2 Model set-up.

An arrangement optimization should try to determine the scupper distribution that maximizes the available scupper outflow. This will be done by maximizing the area within the deeply filled regions which for a scupper outlet above the water line ensures the largest flow. For scuppers exiting above and below the waterline, the higher the depth above the scupper is, the greater the percentage time the scupper will be covered and draining from the car deck.

21.3 Method

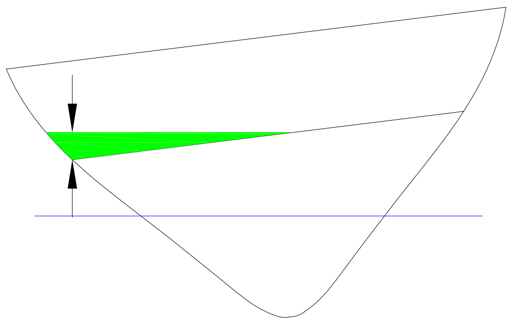
One generic hull form was selected and given two different vehicle deck configurations; one flat, the other sheared. Six scuppers were then distributed along the length of the vehicle deck.

For three trimmed initial conditions (stern, even keel and bow) water was placed on the vehicle deck of sufficient quantity to almost eliminate all positive GZ from the stability curve for that trim condition. This quantity of water was considered to be the critical amount of fluid for that trim, were any additional water accumulation would result in capsize.

For each trim, with the associated critical quantity of water on the vehicle deck, the resulting height of water at each scupper location was measured at equilibrium. This gave 18 water height values (3 trims x 1 height per scupper x 6 scuppers)

Figure 43

Example of water height



21.3 Results

The optimizer was setup to optimize the distribution of scupper area that ensures the largest average submergence over the three trim values. The total cross-sectional area was constrained to be constant, to ensure it was the *distribution* of scupper area that would be optimized.

The trims are associated with the initial condition of the vessel before any water is added to the vehicle deck. It can therefore be reasoned that once water is added to the vehicle deck:

Stern trim will tend to trim more by the stern, though even keel is a remote possibility depending on the amount of trim verses the amount of sheer (i.e. deck geometry)
Even keel will tend to trim either by the stern, even keel (sinkage) or bow depending on the geometry of the deck
Bow trim will tend to trim more by the bow, though even keel is a remote possibility depending on the amount of trim verses the amount of sheer (i.e. deck geometry)

Therefore, depending on the geometry of the deck it is highly likely that either bow trim or stern trim will dominate the resulting scupper distribution by requiring greater scupper area in the region of greater water heights.

The graphs below clearly show that, for the chosen hull form and vehicle deck geometries, bow trim dominates for both sheered and flat deck configurations. The maximum water height for each curve is circled to highlight this point.

Figure 44

Normalized water height for a sheered deck

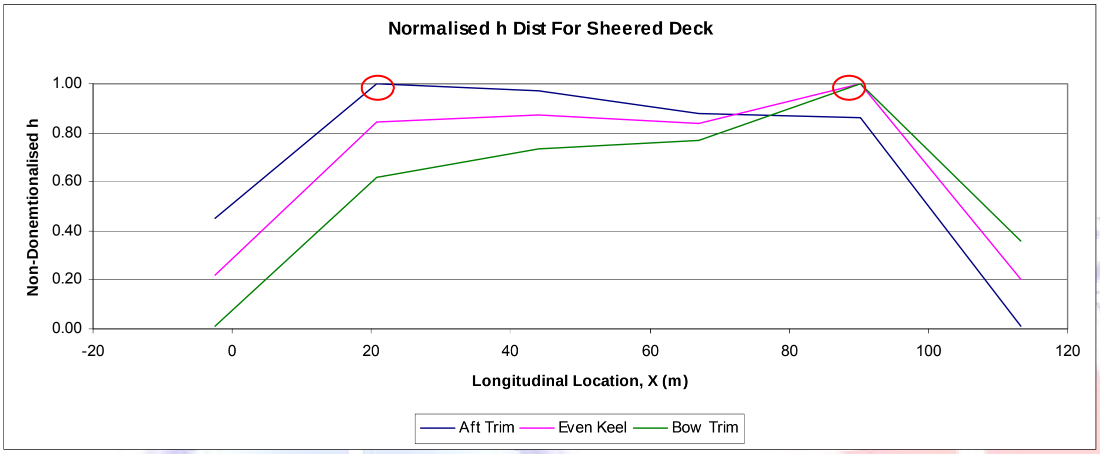
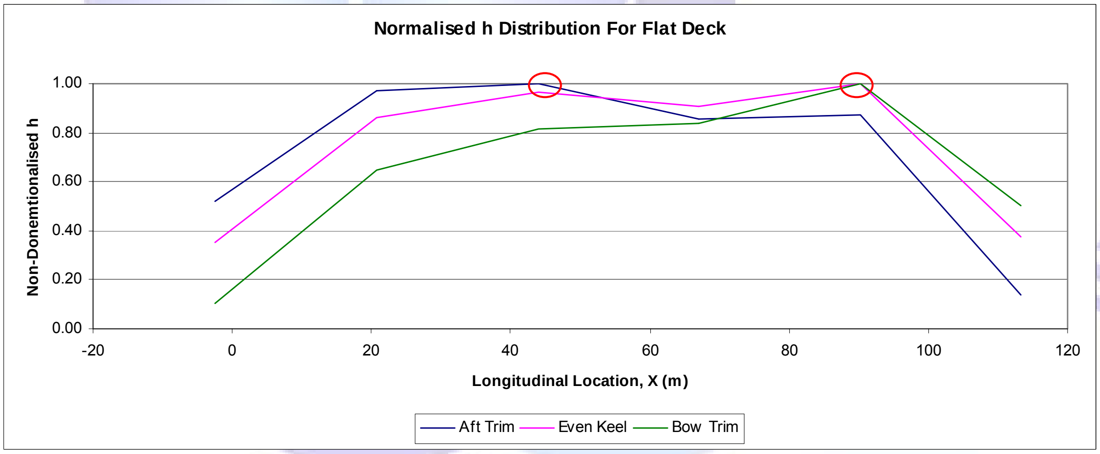


Figure 45
Normalized water height distribution for a flat deck



The resulting optimized scupper distributions can be seen below.

Figure 46
Optimized solution for scupper distribution on a sheered deck

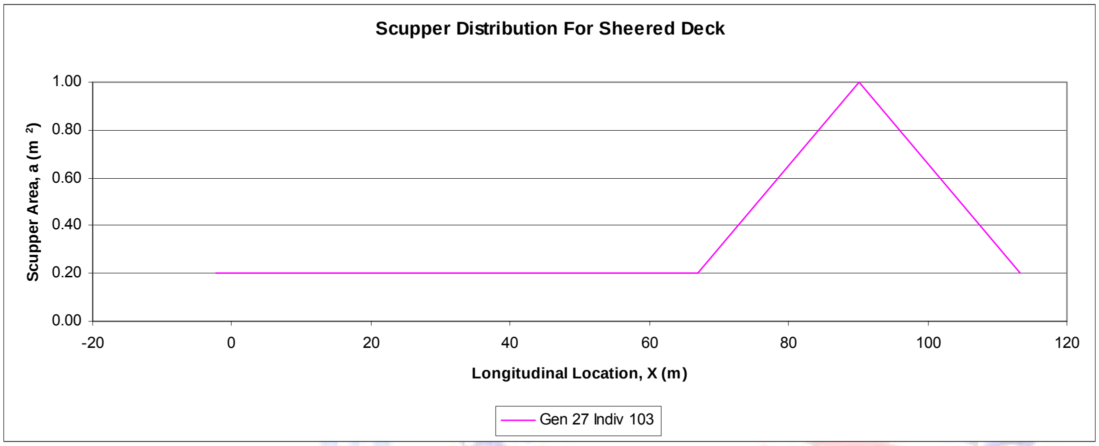
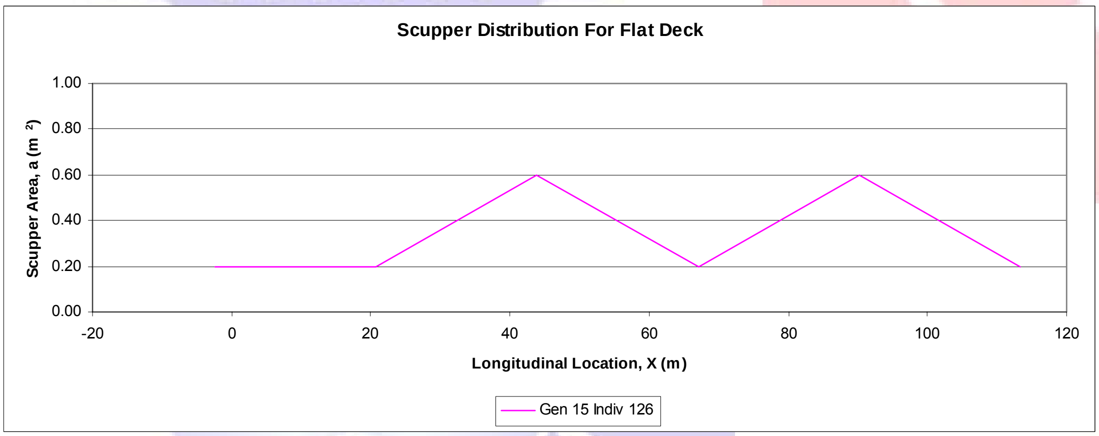


Figure 47
Optimized solution for scupper distribution on a flat deck



21.5 **Discussion**

The optimization study tends to produce scupper area distributions that maximize the area positioned in the bow of the vessel due to the large build up of water within this region in bow and even keel cases.

The limitations of this approach actually did not find any benefit in including additional scupper density in the stern region which is due to the combined objective function which favored the bow trim cases.

To generalize the principle what is apparent from this study is that any optimization study will always favor the placement of scuppers in a forward or aft extreme of the car deck, even when deck shear is included in the model. From a simple reading of this result, it would appear that advice to designers should be to concentrate scupper area in these locations which is against the current practice of evenly distributing scuppers.

As the study reported here is of a limited scope, this would appear to be a step too far without a much more extensive study however, some guidance taken in that the scuppers placed at extreme ends are of critical importance and care should be taken that these are in place, maintained properly and of at least similar capacity to those positioned centrally.

22. PROPOSAL OF CRITERIA

The review detailed in section 3, shows that there are two forms of rules for the prescription of minimum scupper sizes. The first approach has is specified by Lloyds registers sets the minimum size of scupper pipe diameter and spacing. The MCA sets a similar requirement on scupper size. While relatively unsophisticated as a rule it has the advantage of being simple to understand and apply. The disadvantage of this rule is that it does not take into consideration the multitude of determining factors on scupper outflow (losses, head differences, volume of fire fighting water onto the deck)

The minimum 150 mm diameter combined with a maximum spacing of 9m defined by LR and the MCA, will tend to set a requirement for scuppers outflow which exceed the minimum requirements for fire-fighting requirements on all of the vessels studied by a significant margin. Nether-the-less for a vessel fitted with an enhanced level of fire fighting capacity, or following a design with adverse effects on scupper outflows (e.g. low car-deck height), these minimum requirements may have a small or negative margin on scupper outflow leading to a dangerous situation in terms of stability while fire fighting.

The alternative approach advocated in MSC.1/Circ.1226 and FP53/7 is based on the equilibrium between fire fighting capacity on the car deck and the scupper outflow capacity. The approaches include additional margins on scupper capacity of 50% and 25% respectively to allow for the effects of dynamics, blocked scuppers or calculation error. Note that the reason for the safety margin is not outlined in either of these documents. The work detailed in section 6 show that a factor of at least 70% should be applied to account for the effects of dynamics which is higher than the allowance required by both of these rules.
The major difference between these rules is the way in which trim and heel are handled. In MSC.1/Circ.1226 there is a requirement to consider the outflow capacity with a 1 deg heel combined with a 0.5 deg trim value. How this trim and heel should be used in the calculations of minimum scupper capacity is not clear however we have taken this to mean the following.

The amount of water on the car deck is taken as the volume required to heel the vessel to 1 deg.

The head of water is taken as the vessel with the volume of water on the car deck (stated above) combined with 1 deg heel and 0.5 deg trim
The number of scuppers actively draining water, is taken as those covered with the calculation volume of water combined with the specified heel and trim.

In FP53/7 the trim and heel are not required to be considered and head values are specified as the upright vertical separation between the bottom of the scupper well and the outside water level (for a submerged scupper outlet). As a consequence of the inclusion of trim and heel in MSC.1/Circ.1226 it was found in section 5 that

The minimum rule diameter for MSC.1/Circ.1226 are larger than for FP53/7
A positive margin of outflow is maintained for low trim and heel conditions

Another difference between the two approaches given in MSC.1/Circ.1226 and FP53/7 is the specification of the number of scuppers. While MSC.1/Circ.1226 does not propose any minimum number of scuppers of spacing, FP53/7 requires a minimum of 4 scuppers. Note that this falls short of the maximum 9.0m spacing specified by Lloyds Register and the MCA. In the review detailed in section 5 on FP53/7, it was found that the requirement of only 4 scuppers on the car deck resulted in only one scupper being active for many cases when volumes of water on the car deck are small. Although for larger angles of heel and trim, more scuppers become active, this corresponds to larger volumes of water on the car deck and at a greater danger to the vessel.

To summarize an ideal rule for the requirement of scupper capacity should include the following features.

The minimum scupper capacity should be based on an equilibrium of fire fighting water and scupper outflow capacity. A sufficient margin should be included to allow for dynamic effects. Based on the dynamic results, we would propose that the margin be at least 100%
Trim and heel should be required to be included in the calculation to allow for a reduction in scupper coverage.

A minimum number of scuppers should be specified. We would propose that the maximum spacing requirement of 9m be used to ensure a number of scuppers are covered for small amounts of water on the car deck.

Based on the above requirements the proposed criteria from this research work are listed in the following.

Rule Volume of water on car deck is to be calculated as that required to achieve 1 deg heel for the minimum KG value for 0.5 deg trim aft/forward of even keel at the highest approved water line, whichever is the lesser.
The minimum, total scupper area is to be no less than

$$A = \frac{2.0Q}{\sqrt{19.62\left(h - \sum h_l\right)}}$$

Q: combined water flow from the fixed extinguishing system and the required number of fire hoses measured in m^3/s
h: elevation head difference between the surface of the water on the car deck for the Rule Volume and the overboard discharge or highest approved load line whichever is the lesser (in m)
$\sum h_l$: *summation of the equivalent lengths of scupper piping, fittings and valves measure in m.*
Scupper spacing to be no greater than 9.0

23. CONCLUSIONS AND RECOMMENDATIONS

23.1 Conclusions

Recent proposals for requirements on scupper dimensioning based on the static balance between fire-fighting water on the car deck and the scupper capacity appear to be a logical approach provided maximum trim is taken into account in determining the scupper dimension. If trim is not considered, it is possible for the scuppers to be undersized and may result in large heel angles in incidents where fire fighting water is used for a sustained period of time.

Scupper dimensions derived by the recent proposals to IMO result in lower scupper capacity than the minimum requirements set by some class societies and national administrations in the case of minimum fire fighting capacity on the car deck.

The simple static calculation is over predicting the total outflow from scuppers arranged on a car deck. Recent proposals for scupper rules allow for margins of 25-50% however a margin of at least 72% should be allowed for according to this study.

Differences between deck configurations were not found to be very significant apart for the small vessel in long period waves. This was due to the coverage of starboard scuppers noticed in this analysis which was not seen in other configurations.

The CFD analysis showed a similar level of scupper reduction as the Proteus (simplified) approach. Although for the sea states analysed the motions of water on deck were computed to be quite large with high peak pressures, in particular for the side casing analysis, the dynamic effects were significantly reduced by the inertia of the water within the scupper pipe.

The scupper arrangement study showed that for scuppers exiting above the waterline, a concentration of scupper area at the bow and the stern aids more effective scupper drainage. This is because for a vessel with large volume of water on deck, the vessel will tend to trim aft or forward but rarely on even keel. Consequentially, the deepest scupper coverage is found at these locations and therefore the most effective use of scupper area.

For scuppers exiting below the waterline, the effect is not as marked as the driving head is equal for all scuppers however, the placement of scuppers in this area will result in scuppers being covered more frequently.

23.2 **Recommendations**

It is recommended that the coverage of scuppers in trim and heel scenarios be considered in the application of any new rule. The failure to do this may result in the sizing of scuppers which are insufficient to adequately drain the car deck.

Although the conclusion of this work concluded that the most efficient scuppers tend to be positioned at the fore and aft locations, in particular for vessels (as is the modern trend) without shear, it does not necessarily follow that scuppers should be oversized in these locations at the expense of centrally located scuppers. We would recommend that scupper area should never be reduced or absent from the extreme ends of the car deck.

A criteria based on static equilibrium of fire fighting water and scupper outflow was proposed based on discussions included in recent IMO documents. Shortcomings of both rules regarding specification on minimum numbers of scuppers, margin to account for dynamic effects and the inclusion of heel and trim were remedied in this proposal.

24. REFERENCES

International Convention on the Safety of Life at Sea 1974 as amended.

Lloyds Register, Rules and Regulations for the Classification of Ships, July 2007

American Bureau of Shipping, Rules for Building and Classing Steel Vessels 2009

Maritime Coastguard Agency (UK)

BV Rules for the Classification of Steel Ships – November 2008 Edition

Fire Safety Code

Maritime Safety Committee

International Association of Classification Societies – Uniform Interpretation on Load Line

"Fundamentals of Thermal-Fluid Sciences", Y. A. Cengel and R. H. Turner, 2001 (ISBN 0-07-118152-0)

24.1. Appendix 1. Computational Fluid Dynamics (CFD)

Despite the versatility and modeling efficiency of CFD method, the computational power and time required for a complex simulation as this is prohibitive. Thus it is necessary to decompose the problem into several components, study each one in term and assemble the results at the end. The components affecting the flow of water through the scuppers can be identified as:

- The variation of water pressure at the scupper outlet due to the motion of ship induced by the waves,
- The variation of pressure (due to variation of water level) at the scupper inlet in the vehicle deck space due to sloshing (induced by ship motions);
- The inertia of the water in the scupper is affecting the instantaneous flow of water through the pipes (i.e. the variation of momentum of water).

The rest of this section is organized as follows:

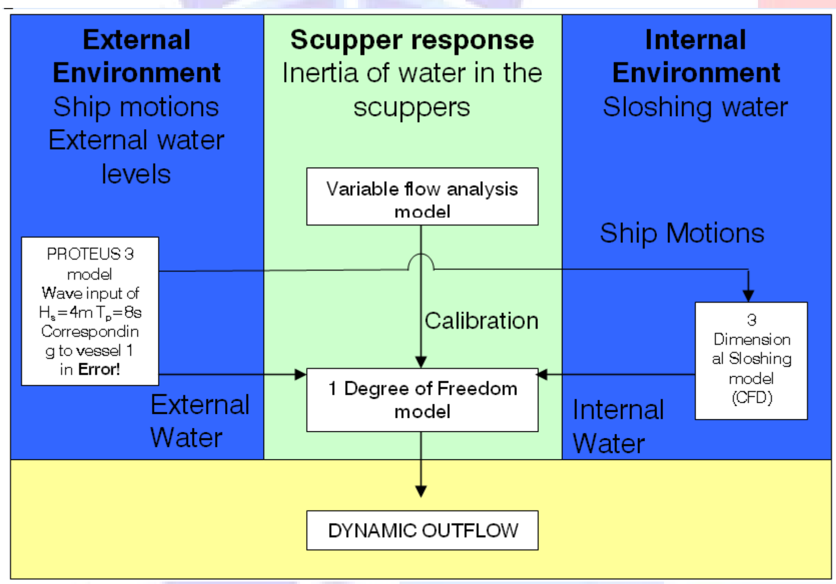
Effects of variable pressure head on the flow rate

Representation of the dynamic system of a scupper arrangement with a 1-degree-of-freedom parametric model.

This model allows general assessment of the effects of the inertia of the water in a scupper pipe as a function of its geometrical configuration and the pressure differential causing the flow through the pipe.

Prediction of the sloshing of water around the car deck by a 3-dimensional model, and deduction of the water pressure variation at the inlet of each scupper.

The various methods and flow of data is shown in the following schematic.



The ship motions for certain sea conditions and the associated pressure variation at the scupper outlet are predicted using PROTEUS 3. The process involved is described in section 6.3.

Flow rates through a scupper with varying pressure

The model that will be used in this study is based on the following set of assumptions:

- The flow is calculated for one scupper based on arrangements of existing ships.
- A 90^{o} miter bend in the pipe is included.
- The system will have two pressure components:
- The constant pressure differential from a difference in height between the mean water line and the height of water on the deck;
- The varying pressure differential due to wave and ship motion effects.
- The static system for verification is modeled with an arbitrary pressure differential equivalent to 2.0 m of water.

For the purposes of this investigation the pressure variation has the form of a sinusoidal wave.

Each scupper has no effect on adjacent scuppers.

The flow of water in the scupper system is achieved due to pressure differential. The pressure equals to gh, where is the density of water, g is the gravitational acceleration and h the pressure head.

The surface roughness factor of the pipe is taken from the literature and it is assumed equal to 0.045 mm.

The effect of a grating in the scupper inlet is not considered.

The losses of the static system are described in Table 24.

The fluid properties are obtained from the FLUENT 6.3 database, and are listed in Table 25.

Scupper arrangements have a non-return valve in the outlet to control water backflow. This effect is not considered here, and no backflow through the scupper is ensured by maintaining a positive pressure in the inlet.

Figure 48
Simple diagram of model

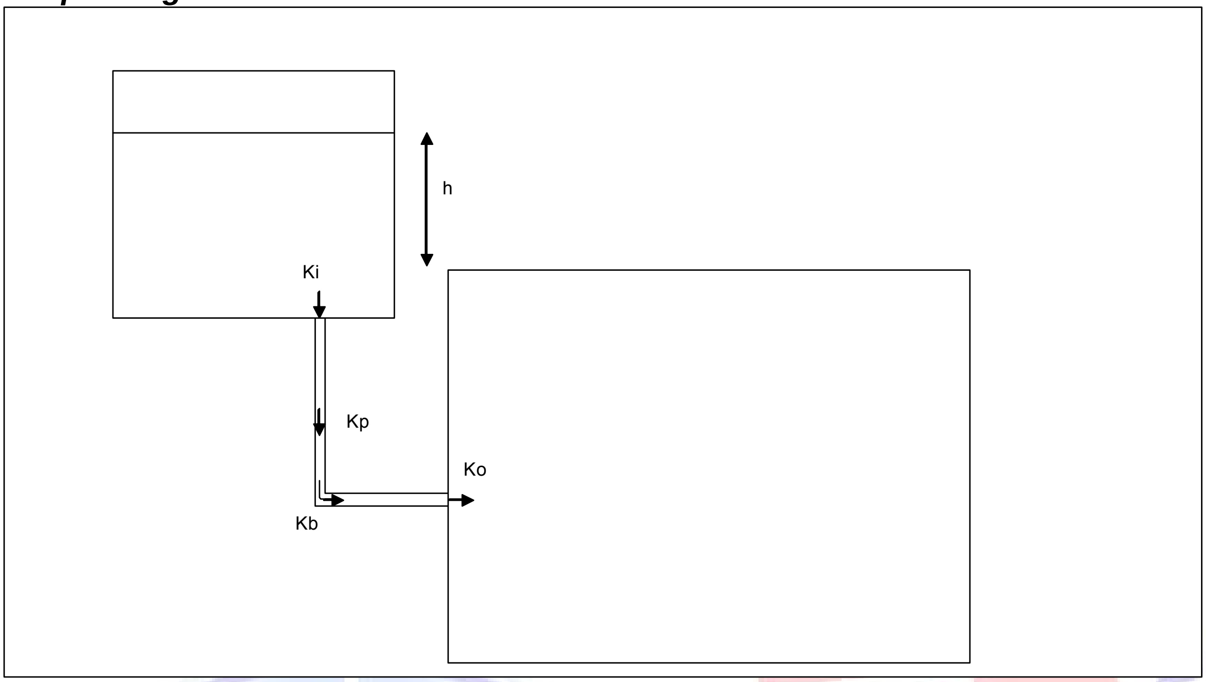


Figure 49 depicts the CFD model. The parts colored orange are walls, the purple component is the pipe, the green component is the pressure inlet, and the blue component is the pressure outlet. Only half the ship section is modeled due to symmetry and the hidden side is the symmetry plane.

Figure 49
Scupper pipe CFD model

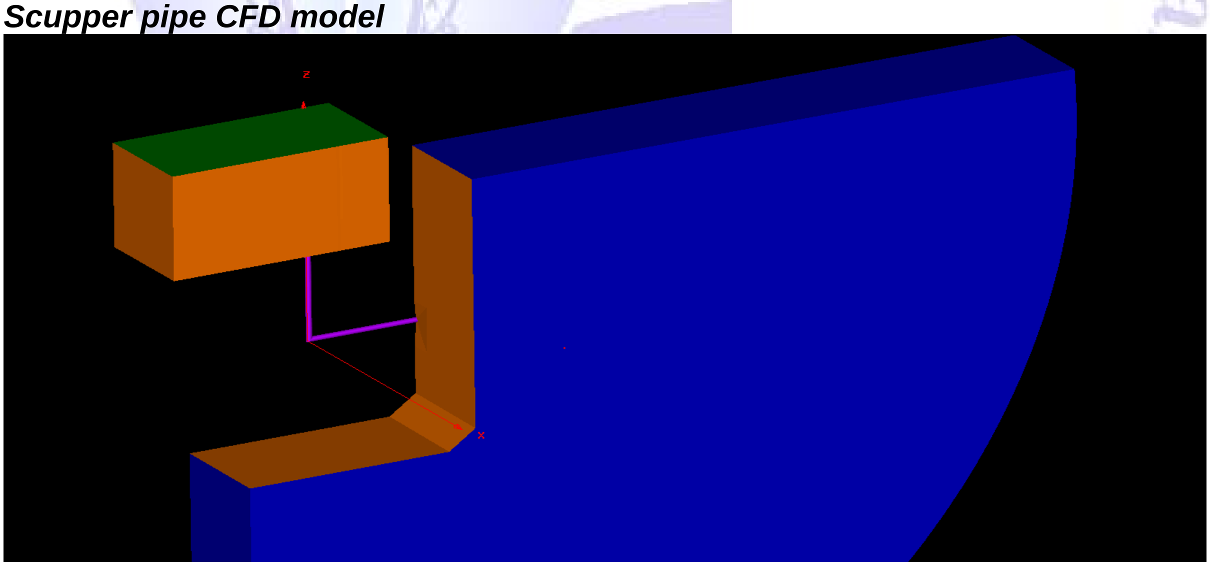


Table 23
Dimensions of Pipes

Component	Dimension
Legnth of pipe	5.3 m
Diameter, D	0.125 m
Roughness factor □	0.000045 m

Table 24
Losses in the system

Area of loss	Value	Description
Pipe losses Kp	0.739	f*L/D
Inlet losses Ki	0.020	(well rounded edge)
outlet losses Ko	1.000	(sharp edges)
Bend losses Kb	1.100	(mitred 90 degree in the model)

The pipe losses are calculated from the Colebrook equation, 0.

Table 25
Fluid Properties

Density, □	998	Kg/m^3
Kinematic Viscosity, ν	$1.004 * 10^{-6}$	m^2/s

A series of simulations will be completed, with a wave period of 7s and differing variable pressures. There will be an extra simulation performed with a 5s period to check the sensitivity to period.

A comparison between the 0.0 m equivalent variable water height case and a static calculation by hand will be used for verification of the computed results.

Validation of CFD results

The static model gives a coefficient of discharge from the modified Torricelli law, 0:

$$C_d = \frac{V}{\sqrt{2gh}} \tag{2}$$

Where h is equivalent to the static water head of 2.0 m, and V is the calculated velocity at the pipe inlet and outlet. Gravitational acceleration, g, is assumed to be 9.81 m/s^2.

A hand calculation was performed in order to obtain the outflow velocity using static fluid mechanics methods. The loss coefficients and fluid properties are described in Table 24 and Table 25. The losses in pressure head in the system were calculated using equations (3) – (7). The results are summarised in

Table 26.

$$h_{lt} = K_T \frac{V^2}{2g} \tag{3}$$

$$K_T = K_i + K_o + K_b + K_p \tag{4}$$

$$K_p = f \frac{L}{D} \tag{5}$$

$$\frac{1}{\sqrt{f}} = -2\log\left[\left(\frac{\varepsilon}{3.7D}\right) + \left(\frac{2.51}{Re\sqrt{f}}\right)\right] \tag{6}$$

$$C_{dhand} = \frac{V}{\sqrt{2g(h - h_{lt})}} \tag{7}$$

Where:

h: head loss, m
K: loss factor, given for the various components as described in Table 24
f: frictional factor for the pipe calculated using the Colebrook equation (6)
Re: Reynolds number V×L/ν, where ν is the kinematic viscosity
L: pipe length, m

D: pipe diameter, m

Table 26
Results from static calculation

Technique	Flow velocity (m/s)	Coefficient of discharge
CFD	3.68	0.587
Static hand calculation	3.19	0.509

In static conditions, the CFD approach predicts higher flow velocity than the static calculation, however the difference in calculated values is not significant and not unusual for comparisons of this type.

Inlet pressure variation

The calculations were repeated for the same CFD model as before but with the additional element of a time-dependent inlet pressure in the form of a sinusoidal wave. This approach is used for approximating the motion-induced fluctuations in the height difference between the internal and external (sea waves) water levels. The roughness factor of the scupper pipe was not included in the CFD model due to its minor contribution.

The velocity calculated through the pipe was compared to the velocity that would be achieved using an equivalent water height to the applied pressure, along with the coefficient of discharge from the static CFD calculation (Table 26) This is also compared to the velocities calculated using the coefficient of discharge from the hand calculation. The velocity is calculated using equation (2).

The resulting velocity traces can be seen in for 1.0 m head variation and 7.0 s period between peaks. The Quasi static velocities are calculated according to Equation 2, using the CFD calculated coefficient of discharge (C_d).

Figure 50
Velocity Trace; Water Head Variation = 1.0 m, Period= 7.0 s

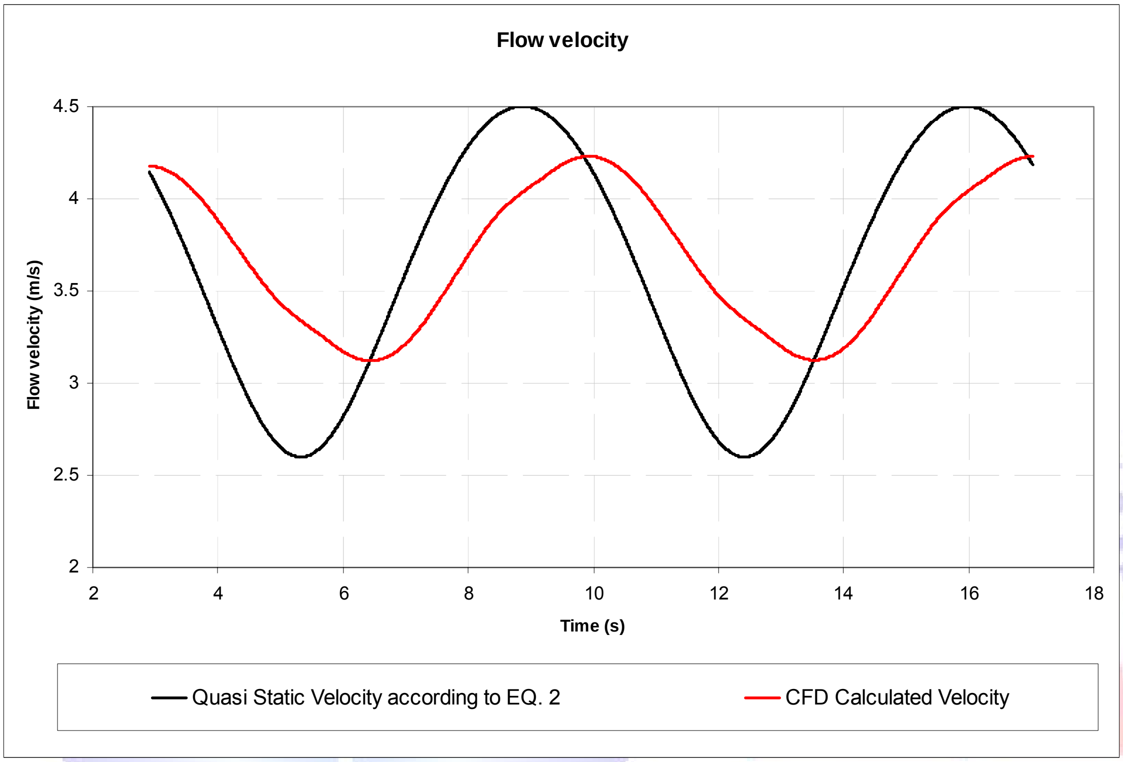


Figure 51
Velocity Trace; Water Head Variation = 0.75 m, Period= 7.0 s

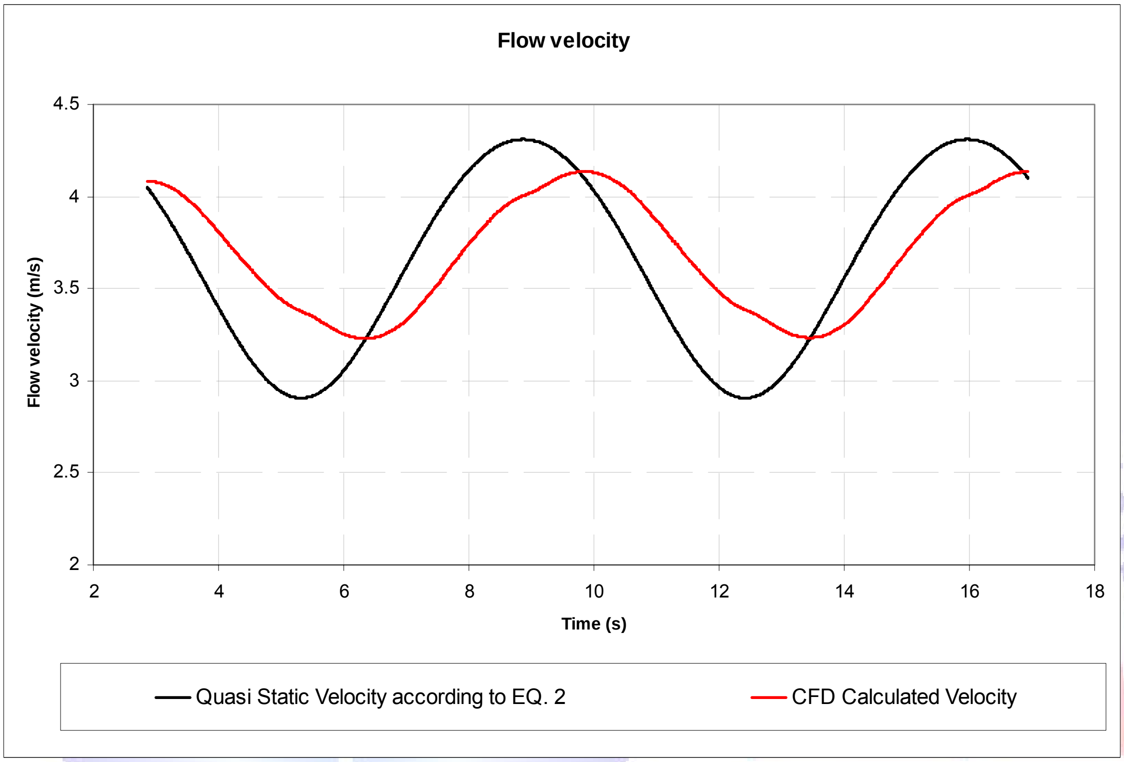


Figure 52
Velocity Trace; Water head Variation = 0.5 m, Period = 7.0 s

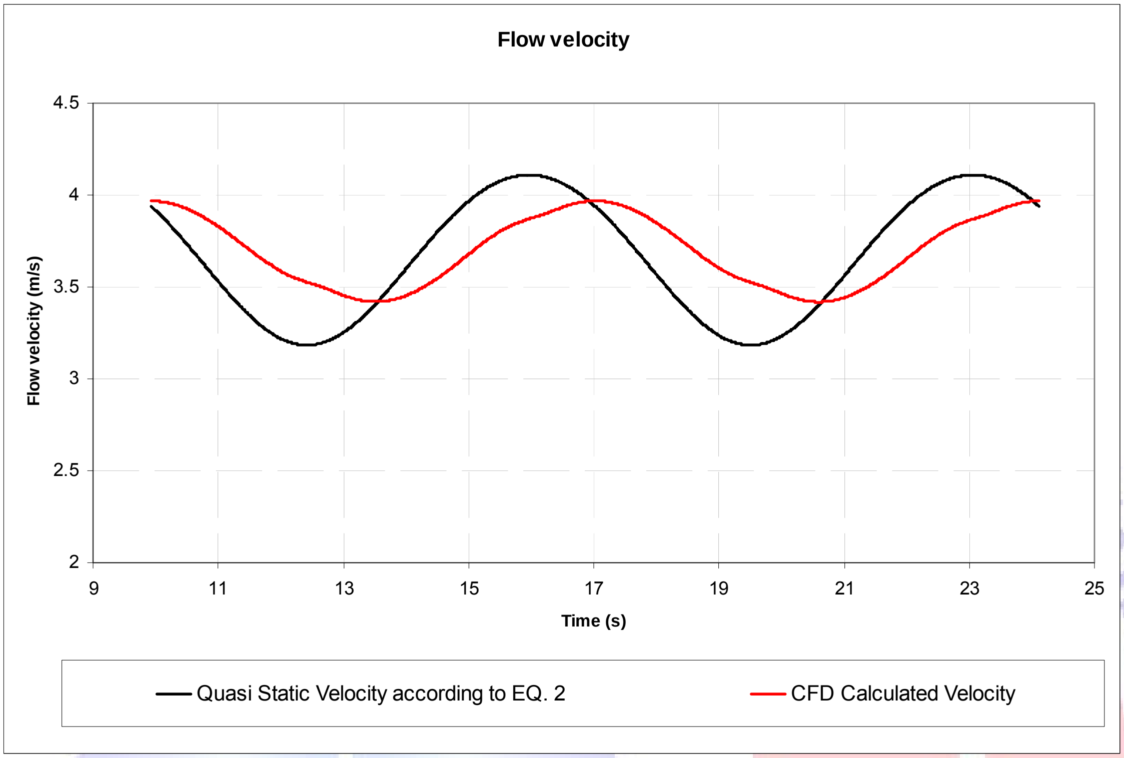
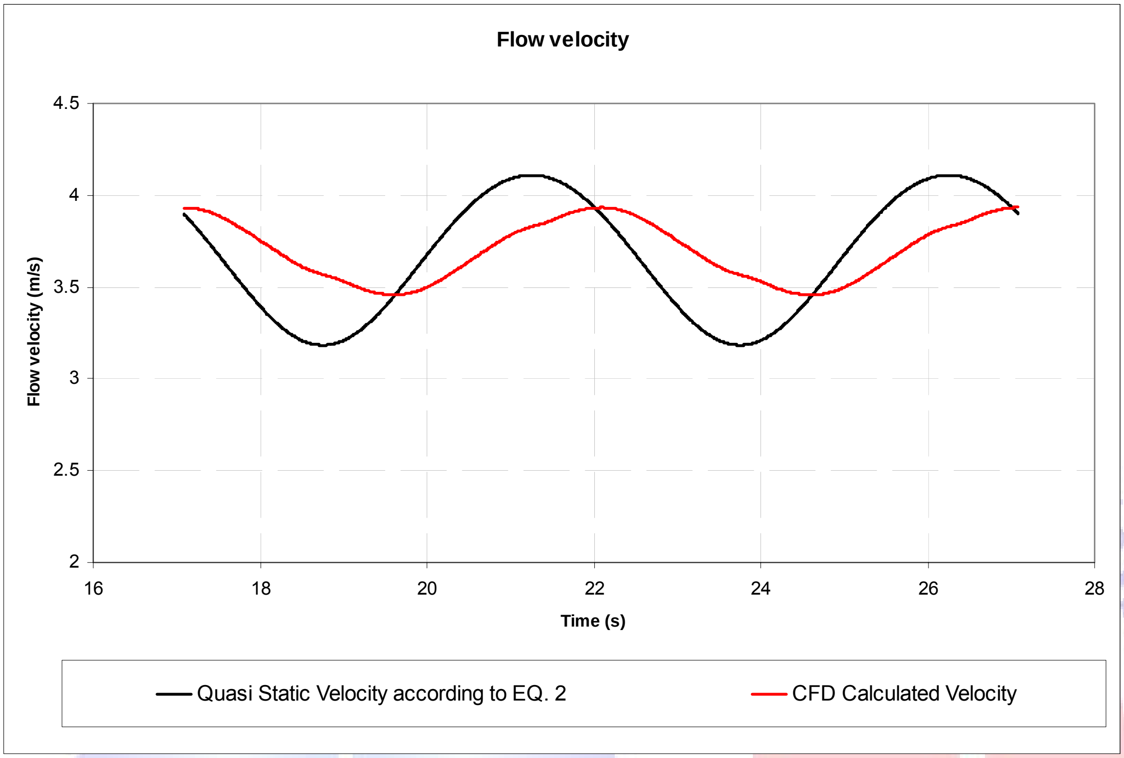


Figure 53
Velocity Trace; Water Head Variation = 0.5 m, Period = 5.0 s



It can be seen from through **Figure 43** that the flow velocity calculated from the quasi-static calculation (black line) has a similar mean value though amplitude of oscillation is higher than that calculated by the CFD. Furthermore, there is a sizable phase shift between the two results. Both these observations lead to the conclusion that the behavior of the flow within the pipe is affected by the system dynamics.

Table 27 through **Table 29** show the amplitudes of the various calculations, and the percentage difference between the CFD calculations. Results are based on the instantaneous pressure head and the $C_{d.}$ from the static CFD calculation, and the velocities predicted using CFD.

Table 29 shows the comparison of the dynamic flow predicted from CFD to the static flow velocities.

Table 27
Comparison of Dynamic Results

Velocity Amplitudes	Hs= 1.00 m, Period= 7 s	Hs= 0.75 m, Period= 7 s	Hs= 0.50 m, Period= 7 s	Hs= 0.50 m, Period= 5 s
Predicted From CFD	1.11	0.92	0.55	0.47
Quasi Static Velocity According to Equation 2	1.90	1.71	0.93	0.93
Percentage Difference	41.5 %	46.2 %	40.8 %	49.4 %

Table 28
Static and Dynamic results, Velocity predicted by CFD

	Hs= 1.00 m, Period= 7 s	Hs= 0.75 m, Period= 7 s	Hs= 0.50 m, Period= 7 s	Hs= 0.50 m, Period= 5 s
Static	3.68	3.68	3.68	3.68
Average Dynamic	3.68	3.67	3.69	3.70
Percentage Difference	0.00 %	-0.27 %	0.27 %	0.54 %

Table 29
Static and Dynamic results, Quasi Static Velocities as in Equation 2

	Hs= 1.00 m, Period= 7 s	Hs= 0.75 m, Period= 7 s	Hs= 0.50 m, Period= 7 s	Hs= 0.50 m, Period= 5 s
Static	3.68	3.68	3.68	3.68
Average Dynamic	3.61	3.60	3.63	3.66
Percentage Difference	-1.90 %	-2.17 %	-1.35 %	0.54 %

These results show that the amplitude of the quasi-static results could be reduced by approximately 40%., reflecting a non-linear behavior over the sample pressure variations. The average velocities could be increased by approximately 1-2 %.

Degree-of-Freedom Model

The analysis performed in the previous paragraph demonstrated that the maximum flow rates through a scupper with varying pressure head are over predicted.

This behaviour is attributed to the fact that the momentum of the water in the scupper piping arrangement is not taken into consideration.

In order to account for this error, a 1-Degree-of-Freedom (1DOF) model was developed in order to replicate the effects of the variation of the water momentum. This is a computationally more advantageous technique which allows fast prediction of the outflow velocity for a series of scuppers, contrary to the CFD technique which takes many hours for one scupper only.

It is assumed that the viscous forces (F_v) are proportional to the average velocity $(\bar{v})$ within the pipe.

$$F_v = K_v \bar{v}^2$$

Where K_v is a constant.

When in static equilibrium the applied pressure to the column of water in the scuppers is equal to the total losses within the pipe.

$$\Delta PA = F_v = K_v \bar{v}^2$$

According to Torricelli's law

$\bar{v} = C_d \sqrt{2g\Delta h}$ gives $\Delta P = \rho g \Delta h$

$$A\rho g\Delta h = K_v {C_d}^2 2g\Delta h$$

$$A\rho = 2K_v {C_d}^2$$

$$K_v = \frac{\rho A}{2{C_d}^2}$$

$$\Rightarrow F_v = \frac{A\rho}{{C_d}^2}\frac{\bar{v}^2}{2}$$

For an oscillating column of water

$$Force = M\dot{v}(t)$$

M is mass of fluid within column $(\rho AL)(1+k)$

Where k is a factor to account for added mass (other inertia effects).
Force is applied pressure force and viscous force.

$$\rho g \Delta h(t) A - \frac{A \rho \bar{v}^2}{2{C_d}^2} = \rho A L (1+k) \dot{v}(t)$$

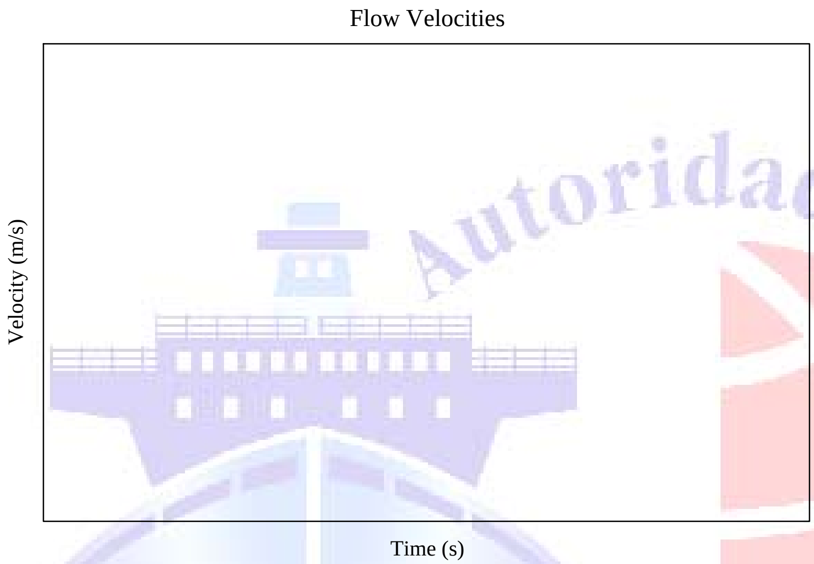
$$\Rightarrow g \Delta h(t) - \frac{\bar{v}^2}{2{C_d}^2} = L(1+k)\dot{v}(t)$$

$\Delta h(t)$ is the time varying head difference between inlet and outlet.

The calibration of the 1DOF model was made with the varying flow analysis from above with 2.0 m constant head and 1.0 m varying head overlaid on the input pressure. The period of variation was 7.0 s. Figure 54 shown the calibration of the model.

Figure 54

Flow Velocities from 1DOFmodel compared to a CFD model of actual flow, and a model of flow using hand calculations.



Sloshing Analysis – 3D

The following step of the investigation was to analyze the flow of water in an empty, three-dimensional (3D) vehicle deck. The analysis of water sloshing is based on a garage deck model with (i) side casing (**- Figure 55**) and (ii) central casing (
Figure 56). These models are based on Ship 1 in **Figure 40 - Figure 55.**

3D Model of the open vehicle deck showing areas used for pressure measurement

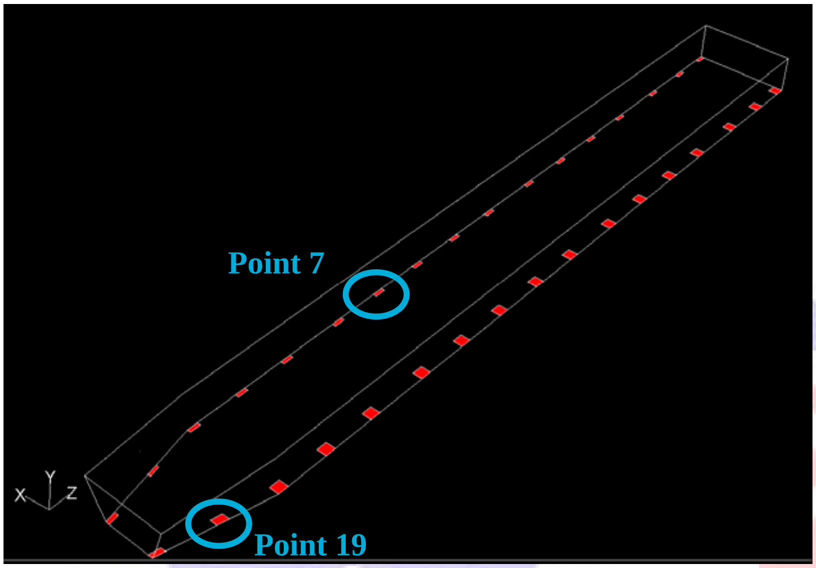
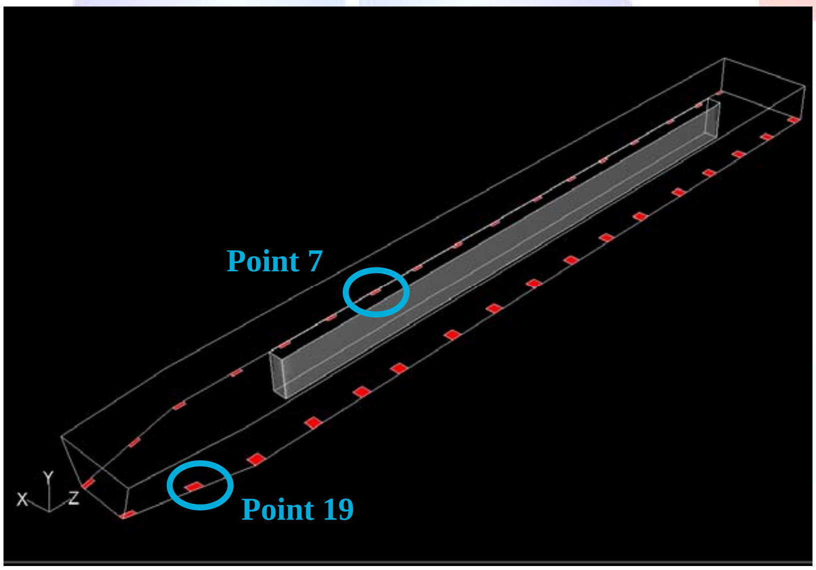


Figure 56
3D Model of the car deck with centre casing showing areas used for gauging pressure



A VOF[2] model was calculated using the commercially available CFD solver FLUENT (ver. 6.3) to measure the pressures on 34 points (highlighted in red in the diagrams) in the perimeter of the car deck given the conditions and motions of the case with bow trim and

[2] VOF stands for Volume of Fluid. 'The VOF model can model two or more immiscible fluids by solving a single set of momentum equations and tracking the volume fraction of each of the fluids throughout the domain. Typical applications include the prediction of jet breakup, the motion of large bubbles in a liquid, the motion of liquid after a dam break, and the steady or transient tracking of any liquid-gas interface'. – Fluent 6.3 users guide

water on deck. The volume of water in the CFD model was estimated by the height of the water above the deck at 105.0 m from the stern. This is the location at which the deepest water depth was recorded in the NAPA model for Ship 1.

The simulation of the water sloshing entails the following modeling components for the effect of gravity:

The harmonic motion of the gravity vectors is represented by a sinusoidal wave for accelerations in the vertical and horizontal directions.

PROTEUS 3 was used to predict motions for roll, heave, sway and pitch. The gravitational acceleration vector components for the 3D analysis were derived from the respective motions of the vessel.

The gravitational accelerations for the spatial movement of water are added to the system as momentum source terms, applied to the centroid of each discretized volume by multiplying the accelerations due to the motion of the ship by the density of the fluid in the particular volume,

The output of the calculation was the pressure variation at the selected locations highlighted in red in **- Figure 55** and

Figure 56. The pressures at each area were then converted to an equivalent height of water above the vehicle deck for every instance of time, according to:

$$h_{CFD} = \frac{Pressure}{\rho g} \quad (9)$$

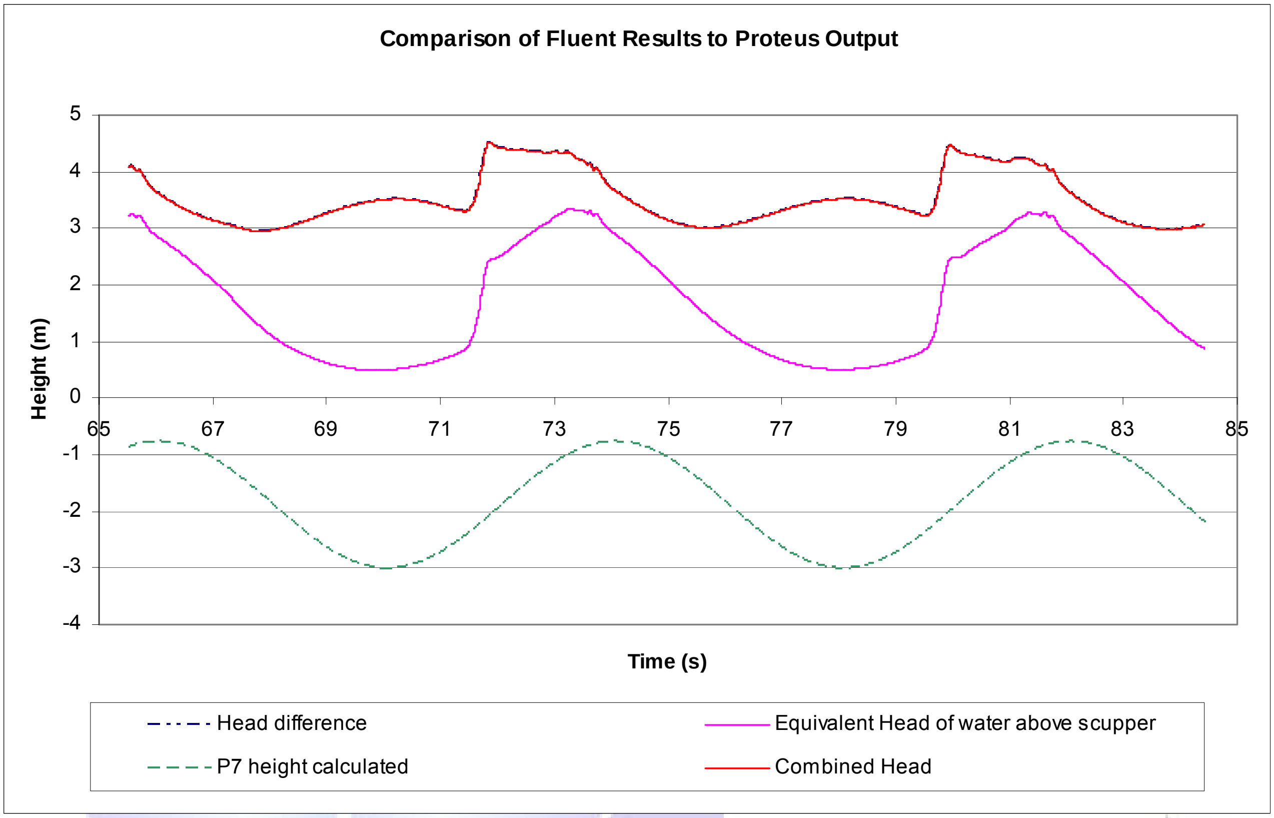
The height of water above the deck, combined with the assumed height of the relative points above the sea water (which were also approximated using sinusoidal terms), gives the total difference in water head for each individual scupper at any time instance.

All the combined head values for Point 7 are large and positive (Figure 57, which signifies that the non-return valves of the scupper system are not taken into consideration. For a situation where the combined head in way of a scupper is zero or negative (i.e. the water level outside the car deck is above the water level inside the car deck at that scupper inlet, or there is no water above that scupper) the equivalent head value is taken as zero, and no outflow occurs through that scupper for the particular time step.

To reduce numerical errors, the minimum threshold water head above a scupper calculated from the CFD results was taken as 0.05m.

Figure **58** shows these effects for a scupper where the water flow is not constant (Point 19). Frames showing the water surface inside the car deck in its various states are shown in **Figure 59** through, **Figure 61** The times corresponding to these diagrams are also marked on **Figure 58.**

Figure 57
Time history of pressure head and roll for Point 7in the Side Casing case



Point A in

Figure **58** shows the flow through the scupper when the head difference is positive (this generally occurs when the internal water level is above the external water level) but the internal water head is zero. Point B in

Figure **58** represents the case where the internal water head is positive, but the external water head is higher than the internal water head, thus the flow is still zero.

Figure 58
Time history of point 19 in the Side Casing case, where the water does not always flow out

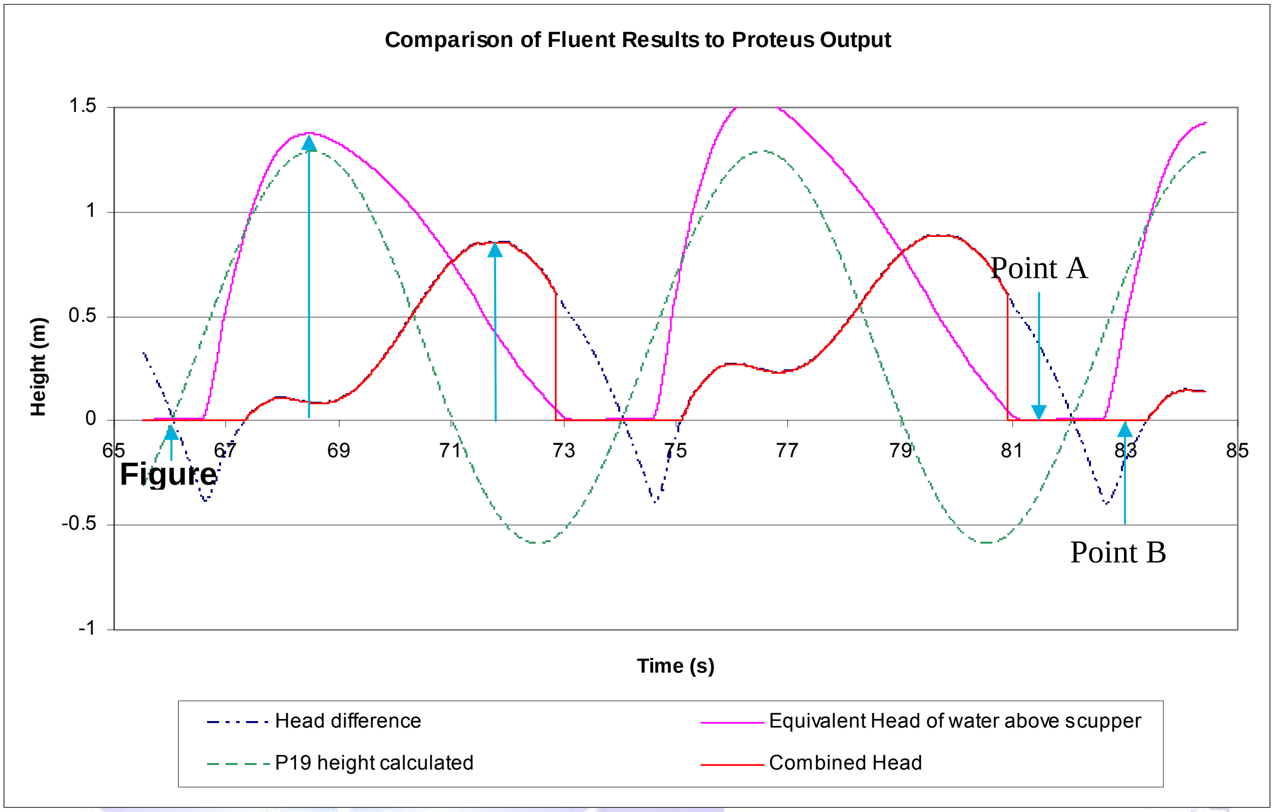


Figure 59

Free surface of water in the vehicle deck when flow at point 19 is predicted to be near its maximum value

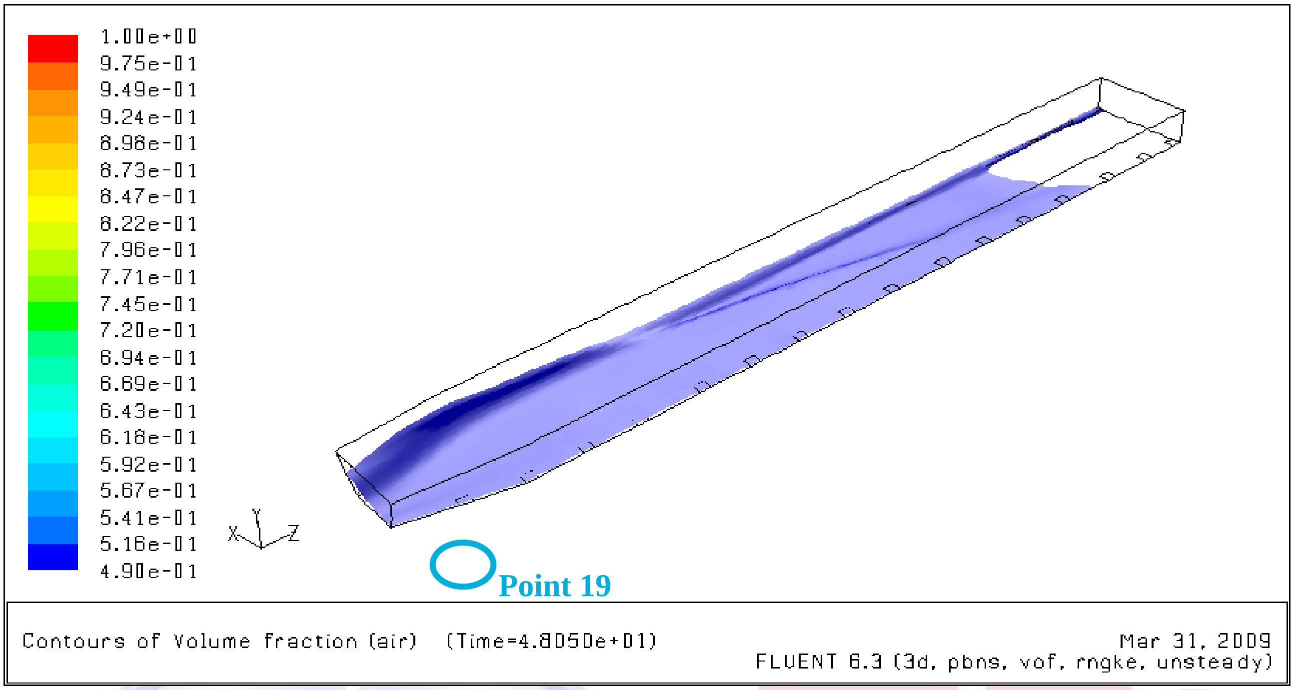


Figure 60

Free surface in the vehicle deck when water above point 19 is at 0.0 m

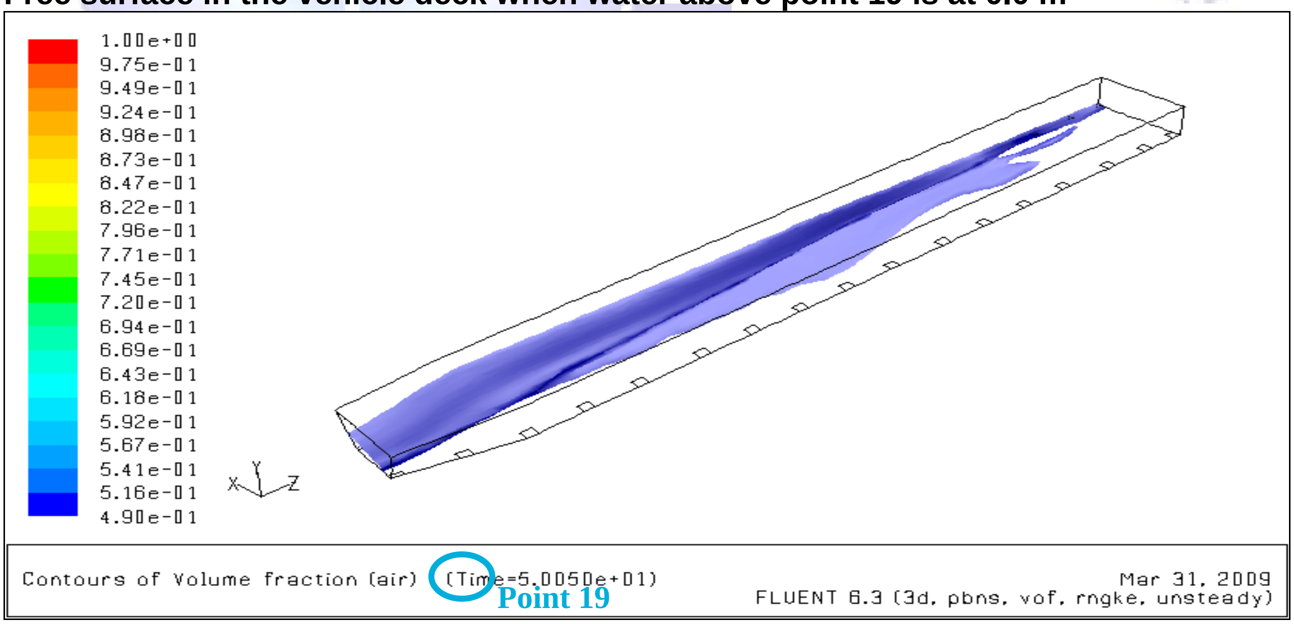


Figure 61
Free surface in the vehicle deck when equivalent water head is near maximum value for point 19

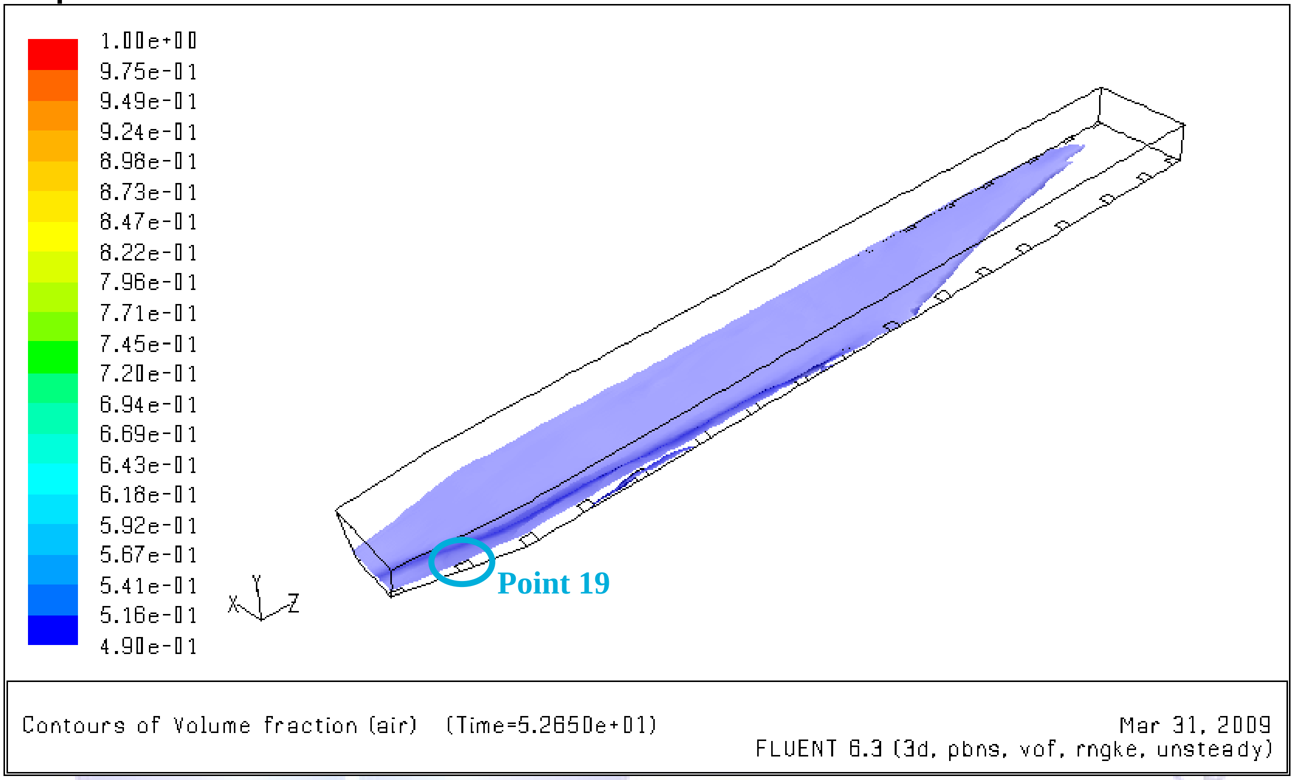


Figure 62 to **Figure 64** show the water surface on the deck for the centre casing condition. It can be seen on these figures that areas of the deck once more do no flow continuously.

Figure 62
Free surface in the vehicle deck in the centre casing condition

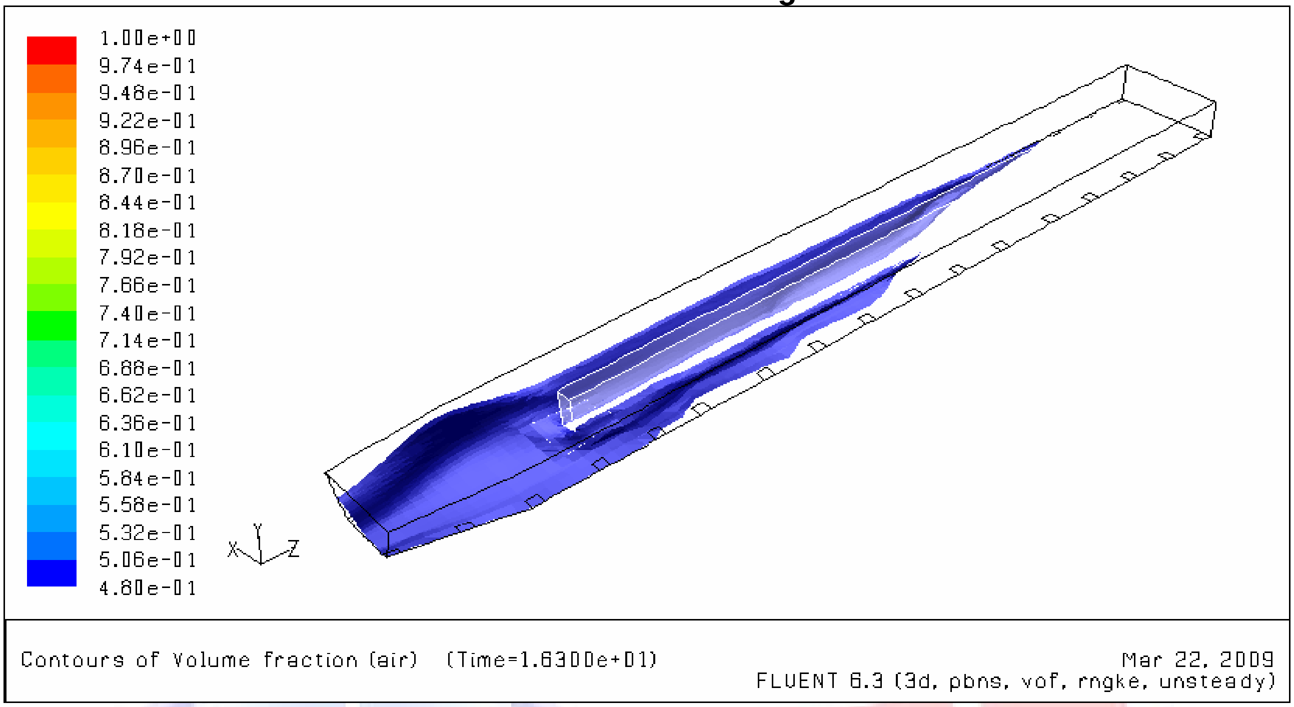


Figure 63
Free surface in the vehicle deck in the centre casing condition

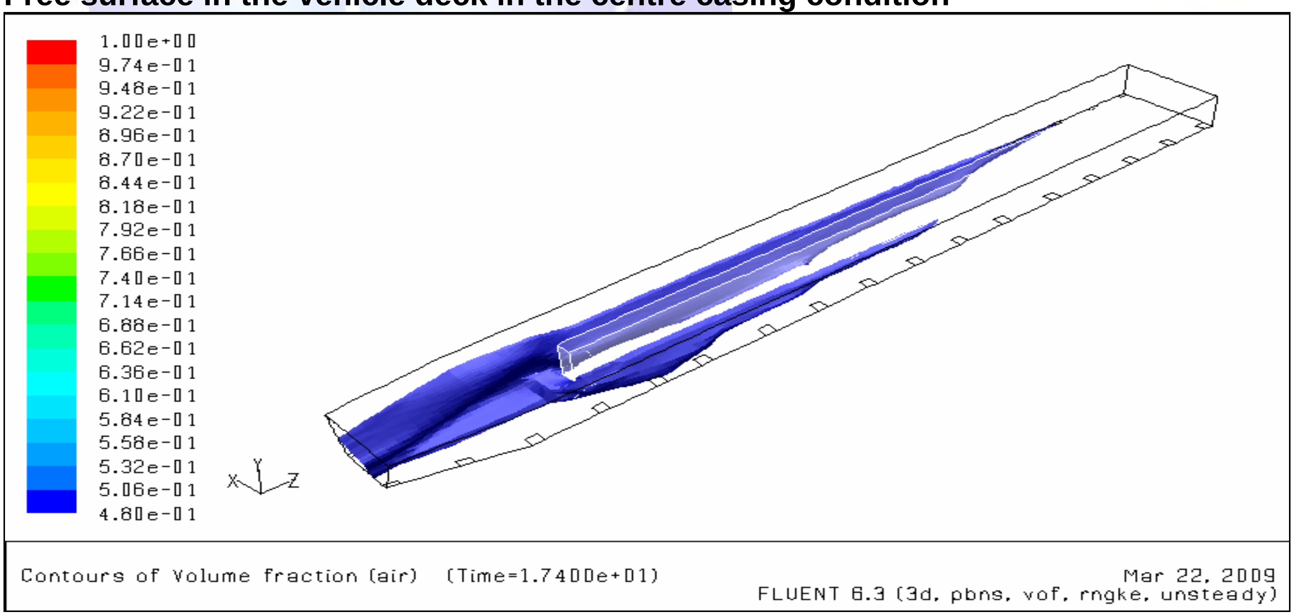
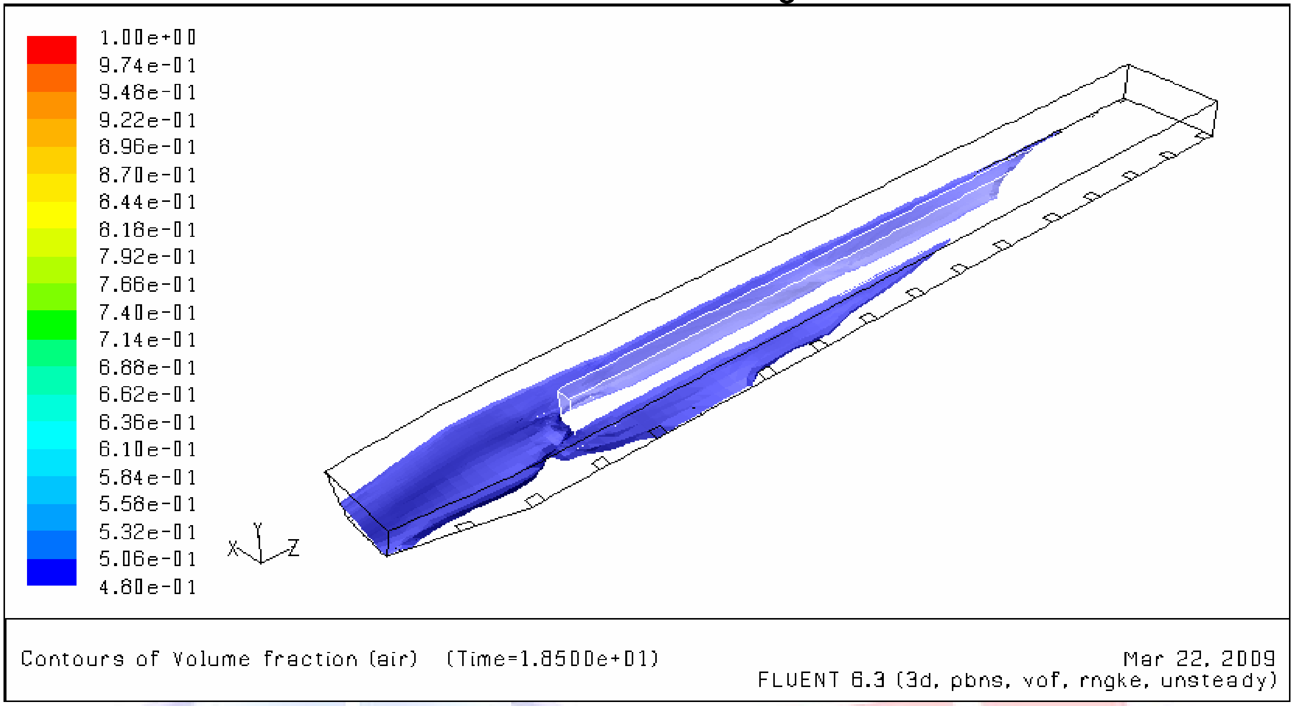


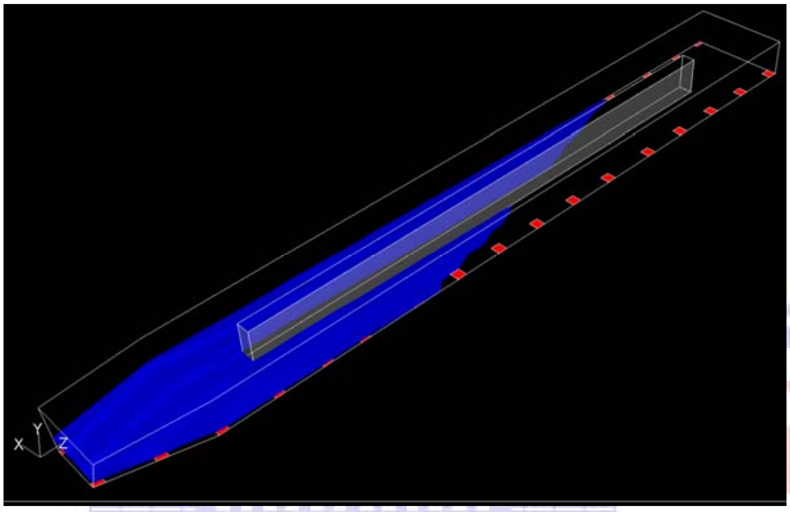
Figure 64
Free surface in the vehicle deck in the centre casing condition



These combined water heads were converted into an instantaneous velocity for each scupper using the coefficient of discharge as presented in **Table 26** for the 3D oscillating flow model. The time averaged velocity was obtained for each scupper. The total time averaged velocity is the sum of all the time averaged velocities, both for the central and the side casing models.

In order to compare the time averaged to the total static outflow velocity, a calculation with zero ship motions was performed. The method of obtaining the static water head was similar to that used to calculate the dynamic water head. The centre casing model was set up at the desired heel and trim angles by altering the gravity vectors, and the height of the water above each scupper was calculated as described for the dynamic process. The vessel was also set to the same heel and trim values in the PROTEUS 3 model in calm sea and the heights of the points above the water level were measured. The average static head of water for active scuppers was calculated to be 2.45 m. The water rests in the static condition as shown in Figure 65.

Figure 65
Water position in the static case



In order to take into account the momentum variation in the scupper piping, the 1DOF model was used to calculate the outflow velocities. The effect of the 1DOF model is to smooth abrupt velocity changes and alter the average velocity over the duration of the simulation. Two examples of this can be seen in **Figure 66** and **Figure 67** for points 7 and 19 respectively, for the deck with the side casing.

Figure 66
Flow properties for Point 7 in the 1 Degree of Freedom Side Casing model

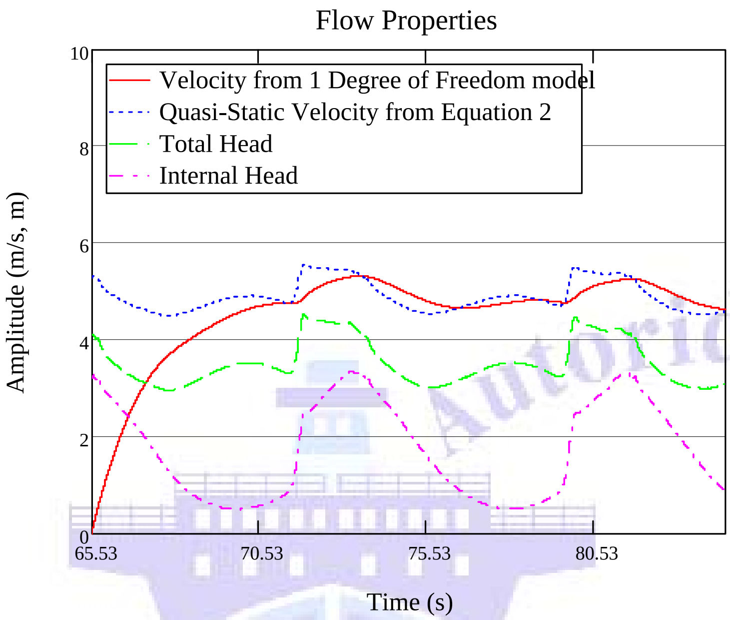
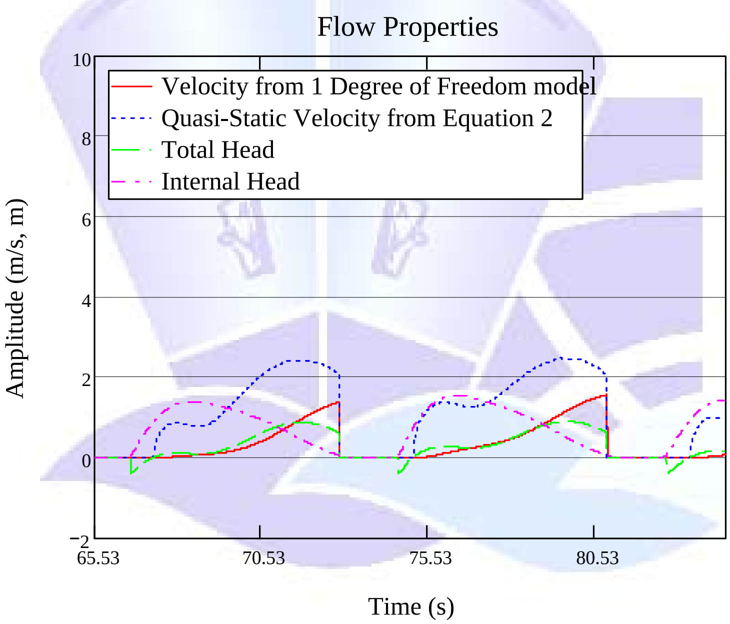


Figure 67
Flow properties for Point 19 in the 1 Degree of Freedom Side Casing model



The average out flow for the side and central casing analysis is compared to the results given in Section 6 and are summarised in the following Table.

Table 30
Comparison of percentage reductions in outflow by two methods

Configuration	**Proteus**	**CFD**
Side Casing	61%	44%
Central Casing	67%	53%

Discussion

From the CFD results on the single scupper pipe it can be concluded that the effects of dynamics in the simplified case of a sinusoidally varying inlet pressure, the effect of the dynamics of fluid flow within the scupper results in a reduction of average flow of approximately 1-2 %. Although this reduction is not very significant, the peak values can be reduced by as much as 20% (judging by half the amplitude) for the cases investigated, showing the importance of pipe dynamics in intermittent flows.

The analysis of the flow on the open deck shows that for the environmental conditions studied in this work, the pressures on the scupper inlet can be very large and will assist in the flushing of flow from the scupper. This is particularly evident in the case of the side casing where a shallow water wave (or bore) was observed to transverse across the deck for every wave pass. The effect of scupper pipe inertia is to moderate this pressure pulse and reduce the resulting flow from the scupper by a significant margin.

The comparison between the Proteus and CFD methods is reasonable and particularly close in the case of the central casing configuration. In the case of the side casing configuration, the CFD method predicts a lower reduction due to dynamics than Proteus due to the transverse bore described in the above. This phenomenon is a fluid resonance phenomenon and cannot be relied upon to be consistent in all cases for side casing designs particularly for alternative deck arrangements, widths or excitation frequencies. The more conservative Proteus analysis is of benefit in this case as this effect is removed from the results.

CHAPTER B-1 CONCLUSION

1. CONCLUSIONS

On the night of the accident, with all watertight doors were closed, the Al Salam Boccaccio 98 complied with both intact and damage stability regulations applicable to this vessel.

The Assessment of Intact and Damage Stability Research details that the vessel was in compliance at departure from the load port with applicable stability requirements. The report details the calculations of loading conditions for the time of the incident and the compliance check with relevant stability requirements. The RINA stability rules were found to meet the vessels loading condition at the time of the incident.

Both tests conditions created to prove that the loading conditions were accurate at the time of the Al Salam Boccaccio 98 departure gave a positive margin to the maximum allowable KG compared to the compliance margins listed in the Stability Booklet, to include the relaxation in GZmax position by RINA. RINA rules allow the GZmax position to occur at an angle lower than the recommended angle of 25 degrees provided the stability curve demonstrates additional area up to an angle of 30 degrees. Though the intact requirements differ from those recommended by IMO for passenger vessels (Section A.749.(18), both loading conditions were found to in compliance with the relevant stability standards. The conclusion of the work was that the loading condition at the time of the incident complied with RINA Stability Rules and the vessel's draught was within the maximum draught, therefore complying with the Loadline Convention.

Progression to a heel angle was a gradual process, so there was sufficient time to muster the passengers and crew to initiate evacuation or abandon ship. From the VDR data there was no evidence to suggest that the master intended to abandon the ship. There is no clear evidence to suggest that the general alarm was ever sounded or that orders were given to abandon ship. The order to abandon ship at any time and even considering all sequence of events would had been the only way to save more lives.

The relevant stability requirements for the vessel are according to the RINA rules in place at the time of their approval of the stability book. These requirements were confirmed in an email from RINA dated 21st June 2007. The intact requirements differ from those recommended by IMO for passenger vessels A.749(18). The RINA rules allow the GZmax position to occur at an angle lower than the recommended angle of 25 deg provided the stability curve demonstrates additional area (than is required by the recommended IMO rules) up to an angle of 30 degrees. This rule is commonly applied by other regulatory authorities for vessels with large beam to draught ratios.

1. If the scuppers were completely blocked the ship would capsize in just less than 1.5 hours in conditions on the night of the accident.

2. With the scuppers unblocked and flowing freely fire fighting water will not accumulate sufficiently to cause the vessel to capsize. It should be noted that only half the scuppers were considered to be operational at any one time due to the heel.

3. The most possible scenario is the partial blockage of the scuppers by debris from the fire fighting operations.

4. The dynamic analysis shows that if the vessel loading condition was as reported by the Master then there must be the equivalent of 6 scuppers flowing on each side for the vessel to capsize in the correct timescale. If the loading condition was more similar to our modified load case, which had higher weights for the cargo and therefore a higher centre of gravity, then there would have to be the equivalent of between 6 and 7 scuppers operational in order for the time to capsize to follow the available testimony. It should be noted however that there are uncertainties in the way the flow through the scuppers has been calculated due to a lack of information.

5. The fire sensitivity study shows that if all 3 fire pumps had been in operation for the duration of the fire fighting activities then for the loading condition as reported by the

Master, between 11 and 12 scuppers would need to be flowing for the ship to capsize in the correct time. For our modified loading condition the required number of scuppers is similar.

6. The analysis has shown that the weather in the night of the capsize had a detrimental effect on the ability of the scuppers to remove the accumulated fire fighting water. In ideal conditions, without any wind or waves, the Al Salam Boccaccio 98 would have taken longer to capsize.

7. There is evidence in the VDR data that at the time of the incident the scuppers were partially blocked by debris and residues. The analysis carried out shows that it is extremely unlikely that the scuppers were completely blocked, however any degree of blockage would have impacted on the vessel's ability to stay upright during fire-fighting activities.

8. Al Salam Boccaccio 98 had normal steering qualities similar to other ships of her size provided that her steering devices were functioning normally.

9. A Steering problem was reported at the start of the fire and followed by frequent malfunctions of the steering pump.

10. If the steering gear was functioning normally and there was no navigational errors the ship would likely have sunk about 34.4 NM from Safaga Port at position 26^{o} 55 N, 034^{o} 34.8 E. Due to the possible failure of the steering gear and possible rudder jam or due to confusion and operational mistakes by the crew, the ship lost significant distance on her intended travel route. If the ship stayed on her route she would had been sank closer to the Port of Safaga.

11. Regardless of the position of the sinking if the MRCC of the area had launched in a timely manner the SAR operation at the time when they had received the EPIRB signal, it would had much more probabilities to save lives

12. Opening of the pilot door on the leeward side could have helped to remove the accumulated water however this decision would have to have been taken in the first hour after discovering the fire. Given the risks of opening a side-shell door discussed above, and remembering that at this time the vessels condition could not have been described as critical, we believe this action would not represent good seamanship, additionally after some time it was very difficult to open the pilot door considering the list of the ship and the amount of water accumulated in the car deck.

13. Failure and refusing to seek help by either turning the ship around heading back to Duba or by calling for assistance by radio greatly reduced the amount of assistance available when the vessel capsized and when survivors were in the water. Failure to carry out either of these actions by the Master is likely to have increased the number of casualties.

14. The VDR shows that the passengers and crew received no instruction to abandon ship. When the heel angle increased to a point where there was a real danger of capsizing, abandoning ship would likely have reduced the number of casualties.

15. The reconstruction only considered the events leading to thecapsize as there was insufficient evidence to continue a reconstruction of events after this point. The most relevant information relating to the sequence of events was included in the reconstruction based on findings from the review of the witness settlements and the VDR data. The time line of the incident was followed as far as possible so that decisions and actions that were taken or omitted can be analyzed. All technical and analytical conclusions were drawn from this information and subject to field testing, parallel testing and reconstruction.

16. The investigation analysis has shown that the weather in the night of the incident had a detrimental effect on the ability of the scuppers to remove the accumulated firefighting water and has shown that on balance probabilities, the technical cause of the capsize

was due to a combination of factors including the weather conditions on the night of the incident and accumulation of firefighting water due to partially blocked scuppers. It would appear that the flow through the scuppers was a key factor in the capsize scenario.

17. The stability performance of a ship is greatly affected by the presence of free surfaces either in tanks or on decks.

18. The reconstruction of the events looked solely at the technical factors ultimately the vessel was lost through degradation of its stability, but the primary cause was a failure to extinguish a cargo fire. There was no evidence to suggest that the general alarm was ever sounded or that orders were given to abandon ship, hence a catastrophic loss of lives.

19. It is recommended that the coverage of scuppers in trim and heel scenarios be considered in the application of any new rule. The failure to do this may result in the sizing of scuppers which are insufficient to adequately drain the car deck. A criteria based on static equilibrium of fire fighting water and scupper outflow was proposed based on discussions included in recent IMO documents. Shortcomings of both rules regarding specification on minimum numbers of scuppers, margin to account for dynamic effects and the inclusion of heel and trim were remedied in this proposa

CHAPTER "C"

CONCLUSION

1. CONCLUSIONS

It is difficult to understand how, given all the efforts made to improve aspects of safety of life at sea, coupled with the developing of new regulations, this still cannot be fully integrated into a plan of action when an emergency situation like this arises, especially considering the human factor complexities during emergency situations.

At this stage of the investigation, we drew the following conclusions:

The vessel was certified and equipped with sufficient safety equipment for the number of passengers on board.
The vessels was designed, constructed and certified for unrestricted navigation.
The vessel was holding a certificate of exemptions for which she was equipped with alternative means, according to the International Conventions.
The master and crew members all held certificates and training, as required by the STCW 78 Convention, as amended; however, emergency procedures were not followed through accordingly.

The vessel had previously been inspected by the local authorities, the Flag State and the ROs; however, none of them were able to identify the possible cause of this accident.

The ISM audit filed to identify any possible misinformation between ROs.
The last annual safety inspection by the Flag State was not carried out in a timely manner; therefore, it was unable to identify possible documentation incongruence.
The vessel suffered a fire which, apparently, began in the car-deck; however, the origin of the fire could not be properly located at an early stage.
During the course of the investigation, it was determined that the fire may have started in one of the following locations: a passenger's luggage loaded at the Port of Duba, Saudi Arabia.

The fire alarm detected at the panel was reset before the response teams were in place, perhaps because the crew members on watch in the bridge assumed it was part of the trouble stemming from auto-pilot dysfunction, or perhaps to avoid sounding the alarm. The alarm of the fire control panel is designed to automatically sound the general alarm after 2 minutes, unless it receives an acknowledgement from someone.

We cannot ascertain the origin of the fire; however, all evidence leads to a location at, in or near a trailer stowed in the port forward on the car-deck level.

The passenger's luggage was not subject to any rigid screening or inspection to avoid flammable or combustible materials being improperly carried on board.

The trailers on which the luggage was stowed did not offer any protection as to a fire resistance barrier or to protect the cargo enclosed until extinguished.

The accumulation of smoke due to the combustible material in the passengers' luggage, the cars, and other elements, may have caused a reduction on the visibility, as well as an obstacle in trying to locate the source, and contributed to difficulties in fighting the fire.

The number of cars and other elements in the cargo area prevented easy access to maneuver the fire hose lines in the area of the fire.

As a result of the fire-fighting operations, the water that was delivered on board created a critical increase in the level of water on the car-deck, which was impossible to discharge in a timely manner by the crew, thus generating an unsafe and unstable list condition.

As a result of the fire-fighting operation, the large volume of water delivered may have also contributed to the accumulation of debris, trash, and residue around the car-deck, and perhaps clogging the scuppers, and thus impeding the water from being freely discharged overboard.

Emergency response procedures were not properly followed by the master and consequently followed by the crew, as established in the Safety Management Manual of the vessel.

According to the stability book approved by RINA, the ship complied with SOLAS 90 standards as one compartment ship carrying a considerable amount of cargo with respect to the passengers, as per SOLAS, Chapter II/1/5.6.2, and ensured the compliance with SOLAS, Chapter II-1, Regulation 8-1, as well as compliance with the mandatory sections of the Intact Stability Code.

It was noted from the VDR and crew statements that there was confusion of the master in understanding, accepting and giving orders to the crew and passengers, particularly asking for external help and preparing the passengers to abandon the ship.

Weather conditions present at the time, such as current and wind, may have contributed to the increase on the list of the vessel.

The general concern about the fire-fighting operation may have generated a lack of attention paid to the navigation of the vessel and the actual courses being navigated, which may have contributed to the shifting of the cargo, thus resulting in an additional factor that contributed to the increase of the list.

The crew began following the emergency procedures on their own, with no guidance or direct orders from the master.

There was uncertainty regarding the type of ballast operations required to correct the list.

The unclear instructions given to conduct the ballast operation may have actually generated the increase on the list of up to 25 degrees to starboard.

The master did not accept the recommendations of his officers to contact vessels in the vicinity, the company, or the authorities. Moreover, he ignored the recommendations to abandon ship.

The master also refused to be seen by other vessels in the vicinity, and instead ordered the lights on his vessel to be turned off.

The abandon ship operation was neither ordered nor carried out at any stage.

The ingress of sea water due to the excessive list of the vessel eventually caused the sinking of the ship.

The ISM system onboard did not work effectively mainly due to the fact that the master as the over right authority did not followed the established procedures.

It is a matter of concern whether a great deal of the paperwork required by the ISM Code is being followed just as a matter routine compliance on many of the ships, without actually putting these procedures into practice onboard.

The SAR operations were considerably delayed in arriving at the site of the sinking.

2. MAIN CAUSES OF THE ACCIDENT

At this stage, we have identified the following main causes that contributed to this accident, which lead to a massive loss of lives:

An uncontrolled fire that grew out of proportion.

An excessive list on the vessel caused by the water utilized during the fire-fighting efforts, which subsequently led to a progressive loss of stability on the vessel.

The failure of the master to notify, in a timely manner, the company, the vessels in the vicinity, or the authorities of the ongoing situation and to request help or assistance.

Orders to evacuate the vessel were never given or carried out, as per established procedures.

The significant delay by the appropriate authorities in starting search and rescue operations.

PMA is convinced, at this time, that had the above-mentioned procedures been conducted in a proper and timely fashion, following established procedures, this accident could have been prevented.

CHAPTER “D”

RECOMENDATIOS

1. RECOMMENDATIONS AT THIS STAGE OF THE INVESTIGATION

To The IMO:

The ISM:

- It is of utmost importance to embark, as a matter of urgency, in a study to review the parameters contained in the ISM Code, as well as the procedures established by each individual system onboard vessels and their application during real life situations, the ISM code shall take into consideration the response by the crew members in order to ensure that the code include more practical verification approach to the real emergencies on board.

- The implementation of the ISM Code onboard should consider addressing normal daily safe working practices, including real emergency situations, through a practicable and user friendly system tailored to the type and trade of the vessel, as well as the culture of the crew members on board.

- The implemented ISM system should clearly identify, in a concise manner, the scope of the implementation audit for a newly established company, as well as for the initial audit.

Communications amongst the crew:

- It is recommended to review the parameters for communications between the master and his crew members during emergency procedures and preparedness in order to avoid misunderstanding of orders, as well as discussing the effects of the actions to be taken during real emergency situations.

Fire-Extinguishing systems:

- It is of great importance to conduct a review, as a matter of urgency, of the type and performance of fixed fire extinguishing systems, in particular, the water type systems installed in the car-decks of Ro-Ro passenger ships, in order to avoid the effects caused by the excessive use of water during a fire-fighting operation.

Fire detection systems:

- The requirements established in SOLAS 74, Chapter II-2, as well as the FSS Code, with regard to fire detection systems within the car-decks of RO-RO passenger ships, should be reviewed, in order to include smoke detectors.
- Despite the fact that heat detectors are devices used for fire detection, it has been noted that, in this case, a smoke detector may have been able to detect the fire at an earlier stage than a heat detector, especially when dealing with car- decks.

Scuppers and water drainage in the car-decks on RO-RO Passenger ships:

- The design and performance of the scuppers on car-decks of RO-RO passenger vessels, as well as their capacity to drain water effectively, should be reviewed, as a matter or urgency, in order to clearly specify the characteristics and design, especially taking into account the large amounts of water needed to be drained, and considering that the flow of water from the fire extinguishing system shall never be higher than, or equal to, the drainage capacity of the scuppers.

- To include in the design and performance of the scuppers, arrangements to avoid the obstruction or clogging of the scuppers caused by residue generated during normal operations or while under an emergency situation.

- To review the installation of alternative means to drain water whenever the drainage system of the scuppers fails to drain the accumulated water in car-decks of RO-RO passenger ships.

- The design of the scuppers should be reviewed as explained previously in this report in chapter B1 (stability of RO/RO ships) 23.2 recommendations.

Standardized distance between cars stowed in car-decks:

- A standardized distance between cars while stowed in the car-decks of RO-RO passenger ships should be established in order to allow easy movement of crew members within the car-deck during emergency situations.

Human Error:

- It is important to review the role of the human element in emergency situation response and crisis management behavior.

GMDSS and SAR:

- The uniformity of the GMDSS system worldwide, and its implementation by each member state, should be reviewed, in order to guarantee reception of emergency signals by the appropriate SAR centers in a timely manner so that search and rescue operations may be initiated as soon as possible.

- Assistance with regard to search and rescue operations should be implemented for countries with considerable passenger ship traffic conducting short international voyages.

VDR:

- A CCTV system could be incorporated as part of the integral interface of the VDR, to provide a clear view of the entire car-deck area by the officer on watch on the bridge. This may also be useful for recreating all possible scenarios on RO-RO passenger ships.

Intact Stability Code:

- A uniform Damage and Intact Stability Criteria must be established for all Flag States and ROs, as we recommend that the Intact Stability Code be made mandatory in its entirety.

IMO Code for the Investigation of Marine Casualties and Incidents:

- It is recommended that a review of the Code be conducted in the areas covering the procedure for carrying out investigations, and the availability of information by both parties, as well as cooperation problems where two States are involved in the investigation, covering ways to solve any controversy.

To the Flag State of the ship:

- Create a uniform standard for qualification and approval of inspectors acting on behalf of the Flag State, in order to verify the performance of the RO and the ship being certified.
- Implement more rigid procedures to control and monitor the RO through the establishment of a systematic inspection regime to be followed by qualified surveyors.

- To review the established procedures for communication and exchange of information between the Flag State and ROs, in order to avoid wrong cross-references, especially when two ROs are acting in the same vessel, and safety requirements may cause confusion in the applicability of the regulations, and may also affect certificates issued by another RO.

- To urgently carry out an assessment and to develop a rigorous inspection program for all RO-RO passenger ships registered under the Panamanian Flag, and to evaluate the existing compliance measures required by the Flag States and Classification Society Rules.

Port Authorities:

- The inspection of checked luggage when embarking at a port must be strictly enforced by the Port Authorities to avoid the loading of prohibited, hazardous, flammable, explosive, or toxic items within the luggage without the proper stowage and transportation procedures.

RO-RO Companies:

- It is strongly recommended that the stowage of luggage or cargo in open-type trailers in the car-decks of RO-RO passenger ships be avoided, and serious consideration given to the stowage of these items in enclosed areas designated for this purpose, where detection and fire-fighting measures may be implemented.

- It is strongly recommended to reiterate to all masters, watch standing officers, and crew members, that any emergency situation shall be immediately reported to the company, the authorities, and if practicable, to ships in the vicinity.

2. FUTURE ACTIONS TAKEN AFTER THE PRELIMINARY REPORT

In order to fully accomplish the objective of this investigation, the Panama Maritime Authority hired an independent party of professionals to conduct technical studies and calculation of the possible scenarios, as well as the probable causes for the sinking, utilizing a computerized model of the ship.

Eng. Reynaldo Garibaldi
Primary Investigator