INTERNATIONAL MARITIME ORGANIZATION

IMO

E

MARITIME SAFETY COMMITTEE
85th session
Agenda item 17

MSC 85/17/1
21 July 2008
Original: ENGLISH

FORMAL SAFETY ASSESSMENT

FSA – Cruise ships

Submitted by Denmark

SUMMARY

Executive summary:	This document reports on the FSA study on cruise ships carried out within the research project SAFEDOR
Strategic direction:	12.1
High-level action:	12.1.1
Planned output:	12.1.1.1
Action to be taken:	Paragraph 9
Related documents:	MSC 85/INF.2, MSC 72/16, MSC/Circ.1023 – MEPC/Circ.392, MSC 83/INF.2, NAV 51/10 and resolution MSC.194(80)

Introduction

1 The Maritime Safety Committee, at its seventy-fourth session (2001), and the Marine Environment Protection Committee, at its forty-seventh session (2002), approved the Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, as set out in MSC/Circ.1023 – MEPC/Circ.392.

2 The Maritime Safety Committee, at its eighty-first session, and the Marine Environment Protection Committee, at its fifty-fifth session, agreed on draft amendments to MSC/Circ.1023 – MEPC/Circ.392, and the Secretariat prepared a consolidated version of the FSA Guidelines (MSC 83/INF.2).

3 The Maritime Safety Committee, at its eighty-third session, agreed to convene an FSA Experts Group with the purpose of reviewing the FSA studies submitted to the Organization. The FSA Experts Group is expected to meet during MSC 86 under the provisions of the Guidance on the use of human element analysing process (HEAP) and formal safety assessment (FSA) in the IMO rule making process (MSC/Circ.1022 – MEPC/Circ.391).

4 As part of the research project SAFEDOR, a high-level FSA study on crude oil tankers has been performed. The main results of the FSA study are provided in the annex and a more comprehensive report is submitted as document MSC 85/INF.2.

Summary of results from the study

5 The FSA study on cruise ships demonstrated that:

.1 the safety level of cruise ships lies within the ALARP region;

.2 the risk level is dominated by collision and grounding scenarios with low frequencies, but potentially with a large number of fatalities; and

.3 some identified risk-control options were found to be cost effective according to the cost-effectiveness criteria in MSC 83/INF.2 for a specific example cruise ship design used in the study.

Proposal

6 The FSA study indicates that the following area should be further examined with a view to possibly introducing the relevant legislation:

.1 implementation of guidelines for Bridge Resource Management (BRM).

7 In addition, the following risk-control options were shown to be effective in this particular design study and may warrant further investigation:

.1 improved bridge design (above SOLAS);

.2 ECDIS – Electronic Chart Display and Information System;

.3 increased Simulator Training for Navigators; and

.4 improve the damage stability (described in resolution MSC.194(80)).

8 A shortened version of the full FSA report is attached at annex.

Action requested of the Committee

9 The Committee is invited to consider the information provided, and to refer the FSA study to the FSA Experts Group for review, as appropriate.

***

ANNEX

FORMAL SAFETY ASSESSMENT OF CRUISE SHIPS

1 SUMMARY

A full high level Formal Safety Assessment (FSA) has been performed to estimate the risk level and to identify and evaluate possible risk control options (RCOs) for Cruise ships.

The FSA study concluded that both the individual and the societal risk associated with Cruise ships are within the ALARP area. This means that risks should be made ALARP by implementing cost effective risk control options. It was further concluded that collision and grounding accounts for 93% of the risk in terms of fatalities, and that catastrophic accidents with low frequency but with a large number of fatalities account for 85% of the risk.

The basis for the recommendations given in this study is the following:

- An RCO is considered cost-effective if the GCAF (Gross Cost of Averting a Fatality) is less than USD 3M. This is the value used in all decisions made following the FSA studies submitted under Agenda Item 5, Bulk Carrier Safety, at MSC 76, December 2002 and suggested in MSC 72/16, and described in the updated FSA Guidelines (MSC 83/INF.2).

- An RCO is also considered cost effective if the NCAF (Net Cost of Averting a Fatality) is less than USD 3M.

The study demonstrates that the following RCOs are providing considerable risk reduction in a cost-effective manner:

- Implementation of procedures for Bridge Resource Management
- Increase in the required subdivision index for damage stability.

The improved damage stability was shown to be achievable in several cost efficient manners:

- Increased GM
- Increased Freeboard
- Combined Buoyancy addition and increase in GM
- Combined Buoyancy addition and increase in GM and Freeboard.

These two RCOs with significant potential to reduce risk could be considered for inclusion, if cost effective, in specific ship designs.

In addition, the following risk control options are confirmed to be cost effective for Cruise ships, (see also NAV 51/10):

- Improved bridge design (above SOLAS)
- ECDIS – Electronic Chart Display and Information System
- Increased Simulator Training for Navigators.

2 DEFINITION OF THE PROBLEM

New orders for large cruise ships continue for the industry's shipbuilders. The order-book for 2007 now stands at record heights in terms of the levels of investment being made by the industry and with occupancy levels at well over 100 per cent (i.e. increased occupancy in cabins with use of upper berths). Across all the leading operators the industry may already be reaching its capacity limits. This suggests that further investment is probably needed if the industry wishes to continue the momentum that it has experienced over the last two decades and more. Continued globalisation will also assist in this process, with North American sourced tonnage increasingly moving back into Europe and other parts of the world, although home-porting by the industry look set to stay in North America for the foreseeable future. Growth in other markets, including the Far East, is also expected in the near future.

It is also of note that the vast majority of new orders are for the so called Post Panamax ships, with GRT of up to 170,000 carrying up to 5,000 passengers. At the time of this writing, Aker Finnyards, part of the Aker Yards industry group has been awarded the work for a record 220,000 GRT cruise ship from RCCL. The ship, a prototype developed under the project name "Genesis", will be delivered from Aker Finnyards in autumn 2009. The ship will have a capacity of 5,400 passengers. These ships will challenge the industry to ensure and maintain the safety record that it currently has.

Historically, few accidents have occurred with cruise vessels. Zero incidents today however do not necessarily mean that a certain event cannot happen. The result from the modelling is therefore the best estimate on what is the actual risk level for cruise vessels. In order to predict the present and future risk levels it is not enough to look only in the rear mirror. Therefore statistics are used as a supplement to modelling to provide further confidence in the estimated results.

An analogy from aviation is presented to clarify the need for risk models: Concorde was, according to accident statistics, the safest commercial airplane in the world for over 20 years. Then, following the disastrous Paris accident in July 2000 the ratings dropped from no. 1 to no. 19[1]. Following only one casualty, the new Concorde risk level is estimated to be 12.5 fatal incidents per 1 million flights. Compare this to 0.62 fatal incidents per 1 million flights for the more common Boeing 737. The point is this: Accident statistics can be very deceiving, especially when the statistics are based on small samples, as the case is with Concorde, or for that matter the large cruise vessels. It is essential to develop risk models to estimate the actual risk level of any system.

For the cruise industry, a major catastrophic accident involving large numbers of fatalities would devastate the industry, and a proactive approach to safety is therefore critical, as the tolerance for accidents is very low.

The scope of the study is limited to embrace safety issues and loss of life. Thus, security risks and property risks are regarded as out of scope. Furthermore, the scope is credible accidents of a certain scale, and occupational hazards associated with high frequency and low consequence incidents are defined out of scope. The study only covers the operational phase of a Cruise ships life cycle. Risks associated with vessels at yards or in dock under construction, repair or maintenance or in the decommissioning and scrapping phase are considered out of scope.

---

[1] http://www.airdisaster.com/statistics/

3 BACKGROUND INFORMATION

Risk is defined as the frequency of an event considered together with the associated consequence. In this project the risk is expressed using the estimated number of fatalities per ship year.

The accident statistics are based on the LRFP (Lloyd's Register Fairplay) database. The database is one of the most extensive resources available for merchant ship accident information. The entries are recorded based on accident reports from Lloyd's agents throughout the world. For cruise vessels, the number of entries in the LRFP database is rather low due to the small fleet size. This provides a limited statistical database for defining the current risk level for cruise ships. It is a major point that the recent risk picture is not necessarily representative for the future, and that future accident consequences to some degree will arise in other areas than covered in this study, which has mainly been based on historical events.

4 METHOD OF WORK

The 5 step FSA methodology outlined in the FSA Guidelines has been used in this study. The FSA application has been carried out as a joint effort between Det Norske Veritas AS and Carnival PLC and the project team has comprised risk analysts, naval architects and other experts from the above partners. Technical experts have been extensively consulted throughout the work with the FSA.

Event trees were used to model the risk. In order to develop the event trees, workshops were organized where personnel with industry expertise on cruise ship navigation and collision, fire, and damage stability were gathered. Participants from DNV and Carnival contributed, and to add upon the credibility of work group opinions, results from earlier work on collision, cruise ship fire, and stability has been added when developing the branches in the even trees.

To ensure the quality of the study, the work has been subjected to a review procedure in the SAFEDOR project. The first step in the procedure is a review by a senior expert in DNV, not directly involved in the day to day work on the study. The second step is a review by a project partner not involved in the study, in this case the Danish Maritime Authority (DMA).

5 HAZARD IDENTIFICATION

In the first phase of the FSA the different hazards which define the risk environment for cruise shipping were identified. The methodology used to derive the hazards is described in detail in the main report, but in short:

The identified risk picture was derived from historical statistics and workshops that identified hazards related to operation and design. Twelve (12) hazards were prioritized based upon their frequency of occurrence and severity of consequence which was measured in number of fatalities. Focus was on hazards with high consequences and low frequency rather than low consequences and high frequency.

6 RISK ANALYSIS

The risk is expressed as the expected number of fatalities per ship year for each of the following events: collision, grounding, contact and fire. The main characteristics of the cruise industry's risk exposure can be described in the following (the full analysis is available in the main report):

- Smaller accidents with 2 to 5 fatalities can be expected every year in the current fleet of 172 ships. This corresponds well to historical data from LRFP (1990-2004).
- The risk level is within the ALARP region for crew and for passengers.
- Collision and grounding accounts for 93 % of the risk in terms of fatalities.
- Catastrophic accidents with large number of fatalities account for 85% of the risk despite the low frequency for such events.

The large scale accidents are mainly results from collision and grounding accidents. This is due to the fact that a total loss is more likely to be initiated through a severe collision or grounding accident. These are low frequency, but potentially very high consequence accidents. Although the possibility for a total loss is low the high consequence makes the final risk more significant than any other accidents. Fire is not a high risk scenario although the frequency is relatively high compared with collision and grounding. The consequence of most fires is, by comparison, more limited in terms of loss of life.

It should be noted, that the objective of this project is not only to pursue solutions dealing with high risk areas but to identify solutions with high risk reducing potential. This means that although fire only accounts for 3% of the risk, effective risk reducing measures should not be ignored for this scenario. However, the risks involved in collision and grounding accidents are far greater in absolute terms, and it is likely that these areas also hold the greatest risk reduction potential.

A closer look at the modeled event trees reveals that the bulk of the risk originates from a very specific scenario within the collision and grounding accidents: water ingress leading to a rapid capsize.

Figure 1 illustrates the modeled risk level for cruise ships in an FN diagram. The risk level is calculated as the sum of the four accidents collision, contact, grounding and fire/explosion. The derivation of the limits for societal risks are described in the study. The risk level is within the ALARP region. Table 1summarizes the risk level per hazard type.

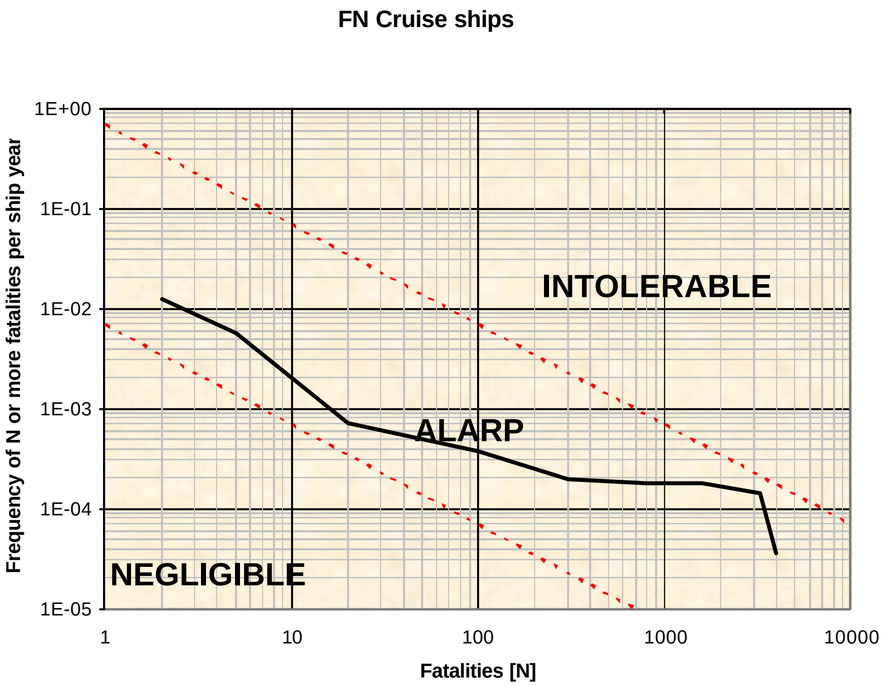

Figure 1: Societal risk

Table 1: Risk Summary – per hazard				
Hazard	**Accident frequency [per ship year]**	**% of all accidents**	**Fatalities [per ship year]**	**% of all Fatalities**
Collision	4.6E-03	10%	2,4E-01	57 %
Contact	1.2E-03	3%	9,2E-03	2 %
Grounding	9.8E-03	22%	1,5E-01	36 %
Fire/Explosion	8.9E-03	20%	1,5E-02	3 %
Others	2.0E-02	44%	6,4E-03	2 %
Sum cruise fleet	**4.4E-02**	**100%**	**4.21E-01**	**100%**

From Table 1, the following conclusions can be derived:

- Almost half (44 %) of the accidents for cruise ships are events other than the four modelled hazards.
- However, the four modelled hazards accounts for 98% of the fatalities.
- Collision and Grounding together amounts to 93% of the fatalities (57% +36%).

7 Risk Control Options

Potential risk control options (RCOs) were identified in a process focusing on two approaches:

1. Review of previously examined RCOs: RCOs which had been evaluated in previous studies, but not found to be recommended for implementation were re-evaluated.

2. Identification of new RCOs. This was done by review of the HAZID, by project member brainstorming sessions, and through interviews of experts in navigation, fire and stability and general industry experience. Experts from class and industry were consulted.

Measures reducing accident consequence and measures reducing accident frequency were sought. From the identification process a long list containing all identified RCOs was generated.

The result of the screening process was a short list of RCOs deemed to be the most promising and RCOs in **Table 2** were selected for further analysis.

There are two reasons why this list was kept short in comparison with other FSA studies, which often consider far more RCOs. Firstly, the cruise industry has a very high focus on safety, and much has been done in the past to secure the vessels. This is clearly reflected in the estimated fire risk, which is very low. This focus has resulted in several previous studies, covering various aspects of cruise industry risk, leaving few areas to be analyzed. Secondly, the risk picture for the cruise industry is so dominated by a few scenarios, which together with the level of previous studies, narrows the focus considerably. In essence, two major considerations dominated the prioritization. Firstly, the clear evidence from the Risk analysis which focuses attention on high consequence collision and grounding accidents. This lead to an active search for RCOs intended for accident avoidance and RCOs for accident mitigation. Secondly, because previous studies (NAV 51/10) have extensively analyzed accident avoidance (aids to navigation), the focused narrowed to accident mitigation RCOs.

Table 2: RCOs selected for Cost – Efficiency Analysis

No	**RCO**
1	Increased GM
2	Increased Freeboard
3	Reserve buoyancy high up and far out
27	Implementation of guidelines for Bridge Resource Management (BRM)
1+3	Combined Buoyancy addition and increase in GM
1+2+3	Combined Buoyancy addition and increase in GM and Freeboard

7.1 Reference ship

Calculations for both economic costs and benefits have been based on the same reference ship as the one used in the Risk analysis. The characteristics of this ship are presented in Table 3. This is a modern “Post Panamax” cruise vessel[2]. This vessel is assumed to represent an average vessel in the future world cruise fleet. A relatively large cruise vessel was selected to represent the future standard cruise ship taking into consideration the growth of the cruise industry. This was done partly to avoid mixing vessels intended for transportation and vessels intended for recreation purposes, and partly to reflect a segment of the fleet in rapid growth.

All proposed RCOs will be evaluated based on an assumed implementation on a vessel as described in Table 3. However, when performing the stability calculations to evaluate the risk reducing effects of damage stability RCOs in this report, a slightly smaller ship was used (Table 4).

[2] A ‘Post-Panamax’ vessel is defined as a vessel where the beam of the hull is greater than 32.5 metres, and hence cannot pass through the Panama Canal.

This was done for convenience as the ship drawings and computerized models were readily available for the smaller vessel. Although smaller by 18% measured in gross tonnes (GT), the geometric dimensions of second vessel are not very different from the first, and it is the opinion of the project team that the stability assessments carried out for the second ship (Table 4) is representative for the first (Table 3).

Table 3: Reference ship parameters

Ship parameters	*Value*
Size	***110,000 GT***
Passengers	***2,800***
Crew	***1,200***
Passengers + Crew	***4,000***
Length	***290 m***
Draft	***8.5 m***
Breadth	***36 m***

Table 4: The specific ship used for stability calculations.

Ship parameters	*Value*
Size	***90,000 GT***
Passengers	***2,500***
Crew	***800***
Passengers + Crew	***3,300***
Length	***290 m***
Draft	***8.5 m***
Breadth	***32.2m***

Table 5: Stability RCOs, alterations to the original ship design

Configuration	Subdiv. Length (m)	Breadth (m)	Freeboard depth (m)	Freeboard (m)	GM (m)	Attained Subdiv. index A	Cost factors	Benefit factors
As is (vessel in Table 4)	285	32.2	10.7	2.2	2.0	**0.80**		
RCO 1: Increased GM 0.5 m	285	**32.7**	10.7	2.2	**2.5**	**0.85**	1)	2)
RCO 2: Increased freeboard0.5 m	285	32.5	11.2	**2.7**	2.0	**0.85**	3)	4)
RCO 3: Reserve buoyancy on bulkhead deck	285	32.2	10.7	2.2	2.0	**0.836**	5)	
RCO 1+3: Reserve buoyancy on bulkhead deck, Increased breadth 1 m Increased GM 0.5 m One additional deck	285	**33.2**	10.7	2.2	**2.5**	**0.875**	6)	7)
RCO 1+2+3: Increased Freeboard 0.5 m, Reserve buoyancy on bulkhead deck, Increased breadth 1m, Increased GM 0.5 m 60% add. Deck	285	**33.2**	11.2	2.7	**2.5**	**0.899**	6)	8)

1) Increased steel weight 50-100 t
2) Increased deck area approx. 100 m2 per deck
3) Increased steel weight 50-100 t
4) Increased deck area approx. 60 m2 per deck
5) Reduced deck area approx. 2500 m2 on bulkhead deck
6) Increased steel weight 1200-1500 t
7) Increased deck area approx. 4500 m2
8) Increased deck area approx. 2500 m2

7.2 Risk reduction of selected RCOs

7.2.1 Increased Freeboard

Freeboard is the distance from the water line to the freeboard deck of a fully loaded vessel; it is measured amidships at the side of the hull. For cruise ships the freeboard deck is normally taken as the bulkhead deck – the deck to which all transverse watertight sub-division is taken. Freeboard represents the safety margin showing to what draft a ship may be loaded under various service conditions. Further description of this RCO is included in the study, and some details are given in Table 5 above.

The risk reduction is achieved through an increased attained damage stability index A. The new requirements (entering into force on January 1st 2009) call for a required stability index R = 0.8 for a ship as described in Table 4 (based on the calculation procedure of MSC 194(80), using the values of Table 4). This will be used as the base case performance.

Increasing the Freeboard by 0.5 meters will raise the index A from 0.8 to 0.85. These calculations are based on the work done in the HARDER project[3], and implemented in MSC 194(80). Using the event tree developed in the Risk analysis it is found that for the collision scenario this translates to a risk reduction of 0.07 lives per ship year, or 2.1 lives per ship lifetime. Put in another way, this RCO is expected to save one life per ship every 14.3 years. Perhaps more important than focusing on the specific value for the estimated number of lives saved, is to realize the relative decrease in risk brought on by the increased value of A, and thus increased stability. Increasing the index A by 0.05 corresponds to increasing the probability of staying afloat by 5 percentage points. This is the same as reducing the probability of sinking after water ingress from collision by 25% (sinking in 20 out of 100 cases vs. sinking in 15 out of 100 cases). This scenario is in turn the dominant risk driver for large cruise ships, meaning the risk level on cruise ships is sensitive to changes in R.

As the subdivision index A does not directly relate to any other scenario than collision, the risk reducing effects of the selected RCO with regard to grounding and contact are more difficult to identify. In the current report no attempt to do so is made. While it is the firm belief of the project team that the current RCO will impact on the grounding scenario in particular, this effect is ignored in the current risk evaluation. This means that the estimated risk reducing effect of 2.1 lives per ship lifetime should be considered to be conservative.

7.2.2 Increased GM

GM is an expression for the relation between the height of a vessels centre of gravity, and its centre of buoyancy. Further description of this RCO is included in the main report, and some details given in Table 5. Increasing the GM by 0.5 meters will raise the attained damage stability index A from 0.8 to 0.85. Using the event tree developed in the Risk analysis it is found that for the collision scenario this translates to a risk reduction of 0.07 lives per ship year, or 2.1 lives per ship lifetime.

This estimate should be considered to be conservative, as only the collision scenario is considered (see section 0).

---

3 http://www.safereuroro.org/SEII_Newsletter_Issue_2_June_2004_RE1.pdf

7.2.3 Added buoyancy, high up and far out

A description of this RCO is included in the main report, and some details given in Table 5. Figure 2 and Figure 3 illustrate the implementation of the RCO. Adding buoyancy on the bulkhead deck will raise the index A from 0.8 to 0.836. Using the event tree developed in the Risk analysis it is found that for the collision scenario this translates to a risk reduction of 0.045 lives per ship year, or 1.35 lives per ship lifetime.

As only the collision scenario is considered (see section 0), this estimate should be considered to be conservative. However, it should be noted that that this RCO has only been examined for its effectiveness related to an increase in the A value. The implications on layout and other potential economic or safety hazards/risks have not been evaluated. For instance, the lack of outboard space on deck 4 may potentially lead to a collection of other risks – e.g., Machinery that is required to be put closer to passenger spaces, lack of management capability due to offices placed away from control stations, etc. This has not been evaluated in this report.

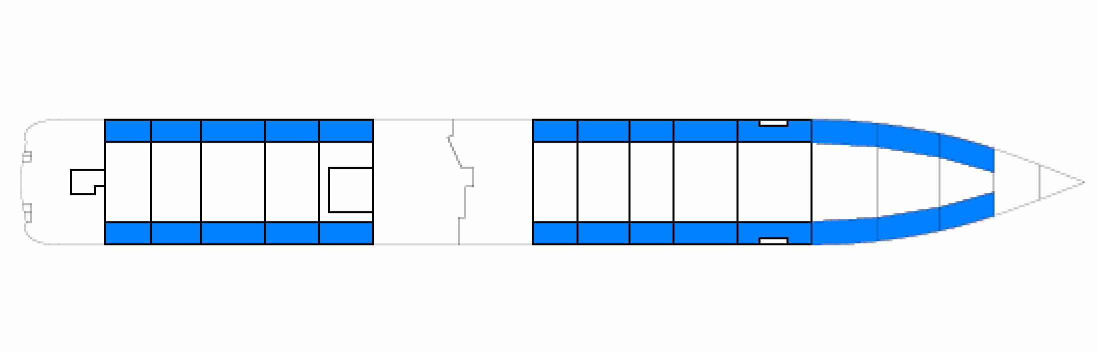

Figure 2: Simplified bulkhead deck plan, illustrating the position of the added buoyancy compartments.

Figure 3: Approximate position of added buoyancy compartments. For illustration purposes only.

7.2.4 Implementation of guidelines for Bridge Resource Management (BRM)

The RCO is described in detail in the main report. The effect of implementing enhanced Bridge Resource Management procedures is a reduction in accidents related to navigational errors. The risk models developed in the Risk analysis are not well suited to evaluate such an effect, as the models were not developed to evaluate the processes leading up to accidents such as grounding or collision. The reason for this is found in the objective statement of the Risk analysis:

"The risk modelling has been performed at high level in order to produce an overall risk picture for a generic cruise ship and the current world cruise fleet. However, in order for the FSA to provide value for an operator or designer as a practical tool for decision making in the design phase, more detailed risk models will be necessary".

However, extensive modelling of the events leading to grounding and collision was done in the FSA Large Passenger Ship Navigation study (NAV 51/10). The focus of the two FSAs was different. For the FSA Large Passenger Ship Navigation study (NAV 51/10) it was stated that:

"The most valuable output from a risk model is not the overall risk levels that are predicted by the model, but the structure itself and all the contributing factors that enables an understanding of the failure mechanisms and gives a quantified result whenever one of the input parameters is altered".

And

"The most important learning from the project is the understanding of the relation between the factors that contribute to grounding and collision. The most important use of the models will be as a tool to evaluate the effect of risk control options for new regulations".

Thus, the absolute level of risk was not of great importance in the FSA Large Passenger Ship Navigation study (NAV 51/10), compared to the ability to asses the risk reducing effects of RCOs. Based on this it is believed that the risk reduction (in percent) estimated in NAV 51/10 study is accurate and applicable to the current study. While the risk reducing potential of the proposed RCOs will be calculated using the percentage of accidents avoided from NAV 51/10, the risk levels from this study will not be used. As the focus of the two studies is different, the initial risk level (which is to be reduced) is believed to be most updated. Comparing the risk of fatalities, measured in terms of per ship year, it is seen that the risk estimated for is 6.6 times higher for collision and 1.7 times higher for grounding. As for the sum of the risks, this study is a factor 3.7 higher than NAV 51/10. In conclusion, the potential risk reducing effect of the BRM RCO is estimated to be 0.954 lives per ship year, combining the results of the risk assessment and NAV 51/10.

Note also that the risk reducing effects of the BRM option under evaluation is limited to reducing the frequency of accidents, not the consequence. Although it may be argued that a well organized and efficient bridge crew could contribute to the safety in i.e. fire and evacuation scenarios it is evident from the Risk Analysis that the bulk of the risk is associated with hull damage and rapid capsize, under which circumstances the bridge crew is unable to assist.

7.2.5 Combined Buoyancy addition and increase in GM

A solution combining *RCO 1: Increased GM* and *RCO 3: Added buoyancy high up and far out* is analyzed. This solution involves adding reserve buoyancy on the bulkhead deck, as in RCO 3, as well as increasing the GM by 0.5 m as in RCO 1, by widening the ship. However, as adding buoyancy results in loss of cabin space, it would be very beneficial to be able to fit an additional deck to the ship to compensate for this. In the proposed solution this is achieved by increasing the breadth of the ship by 1 m (rather than 0.5 m as in RCO 1) to achieve a 0.5 m increase in GM when an additional deck is added (which in itself lowers the GM).

Adding buoyancy on the bulkhead deck and at the same time increasing GM by 0.5 m will raise the index A from 0.8 to 0.875. Using the event tree developed in the Risk analysis it is found that for the collision scenario this translates to a risk reduction of 0.095 lives per ship year, or 2.85 lives per ship lifetime. This estimate should be considered to be conservative, as only the collision scenario is considered. However, without an increase in length, there is an issue with fitting extra LSA (lifeboats), which are needed to serve the added passengers from the extra deck. This issue is not considered further in the current report.

7.2.6 Combined Buoyancy addition and increase in GM and Freeboard

A solution combining *RCO 1: Increased GM, RCO 3: Added buoyancy high up and far out* and also *RCO 2: Increased Freeboard* is analyzed. This solution is similar to the other combination, only adding the increase of freeboard as in RCO 2. However, because increasing the freeboard will lower the GM, the additional deck can only be 60% of what it would be without increased freeboard (because the 1 m increase in ship breadth is implemented to compensate for both the freeboard and the extra deck).

Adding buoyancy on the bulkhead deck, increasing the freeboard and at the same time increasing GM by 0.5 m will raise the index A from 0.8 to 0.899. Using the event tree developed in the Risk analysis it is found that for the collision scenario this translates to a risk reduction of 0.125 lives per ship year, or 3.75 lives per ship lifetime. This estimate should be considered to be conservative, as only the collision scenario is considered. However, without an increase in length, there is an issue with fitting extra LSA (lifeboats), which are needed to serve the added passengers from the extra deck. This issue is not considered further in the current report.

8 Cost –Efficiency Assessment

The RCOs presented above are analyzed in this chapter using the methods and criteria set out by IMO MSC 83/INF.2. Table 5 presents details on the proposed damage stability RCOs and the alterations made for each RCO. The information in Table 5 is used in the following subsections to evaluate risk reduction, costs and benefits.

The cost and benefit of the RCOs will be spread over the lifetime of the vessel. Some RCOs might involve costs every year while others only involve costs at given intervals. In order to be able to compare the costs and benefits and calculate the NetCAF and GrossCAF, Net Present Value (NPV) calculations have been performed using the formulae as given below:

$$NPV = A + \frac{X}{(1+r)} + \frac{X}{(1+r)^2} + \frac{X}{(1+r)^3} + \ldots + \frac{X}{(1+r)^T}$$
$$= A + \sum_{t=1}^{T} \frac{X}{(1+r)^t}$$

Where ‘X’ is the cost or benefit of RCO any given year, ‘A’ is the amount spent initially for implementation of RCO, and ‘r’ is the interest rate. Henceforth, in all calculations for cost-efficiency, an average ship lifetime of 30 years will be assumed.

8.1 Cost of implementing RCOs

The direct costs of the measures have been divided into two parts: Initial costs and yearly costs over the lifetime of the vessel. The initial costs include all costs of implementing the measure, e.g., acquiring and installing equipment, additional construction costs and training of crew. During the lifetime of the vessel there might be additional costs at regular intervals in order to maintain the effect of the measure, e.g., equipment service and refreshment courses. The additional cost might occur annually, but in some cases every two or five years.

8.1.1 Increased Freeboard

The cost of increasing the freeboard by 0.5 meters comes from adding more steel to the ship, with the associated added labor, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight is estimated as a minimum of 50 tonnes, and a maximum of 100 tonnes. The cost of the steel, including labor is estimated at $ 6,000 per. This gives a high estimate of $ 600,000 and a low estimate of $300,000. The high estimate of $600,000 is used in the calculations.

There are two main drivers for a vessel's resistance in water. Resistance due to the friction between hull and water, and resistance due to energy lost in wave generation from water being displaced as the hull passes through it. It can roughly be stated that frictional resistance is depending on wetted surface and speed. The wave resistance is depending on hull shape and speed. An increase in beam will result in an increased GM value and some additional wetted surface due to more steel weight. Due to the increased beam, the hull will to some degree increase its wetted surface. However this is countered by the reduction of its draft. It is thus assumed that the changes in displacement and wetted surface are insignificant. Using Guldhammer/Harvalds method gives a rough figure of the increase in resistance when holding all dimensions constant but the beam/draft ratio. It also gives a rough figure of resistance based on experience data from an extensive towing tank database. The method was however developed in the 1960's and the new hull design has a lower resistance than this method gives. However, since it is the difference between two different designs and not the full resistance that is of relevance to this analysis, the method can still be used. This gives a contribution to the wave resistance which results in 1% increase in total resistance. The relation between drag and fuel consumption is linear for small changes in drag, giving a 1% increase in fuel consumption due to the 1% increase in drag.

The annual total fuel consumption of the vessel is estimated at $ 17.1. The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 1% of $ 11.4 million or $ 114,000. At 5% interest, over 30 years, the net present value of this cost is $ 1,752,000.

In total, the estimated cost (steel and fuel) of increasing the freeboard by 0.5 meters is $ 2,352,000.

8.1.2 Increase GM

The cost of increasing the GM by 0.5 meters comes from adding more steel to the ship, with the associated added labor, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight is estimated as a minimum of 50 tonnes, and a maximum of 100 tonnes. The cost of the steel, including labor is estimated at $ 6,000 per. This gives a high estimate of $ 600,000 and a low estimate of $300,000. The high estimate of $600,000 is used in the calculations.

The increase in fuel consumption for this RCO is the same as for the RCO with the increase in Freeboard, both increasing the breadth of the ship by 0.5 meters. Net present value of this cost is $ 1,752,000.

In total, the estimated cost of increasing the GM by 0.5 meters is $ 2,352,000. It is also worth noticing that increasing the GM will make the vessel stiffer and experience higher accelerations in roll, which may require increased lifting capacity of the stabilizers to maintain the level of comfort for passengers. This aspect is not considered further.

8.1.3 Added Buoyancy

The cost of adding buoyancy is associated solely with a reduction in available cabin space, assuming that the cost of any added steel needed to seal off buoyancy compartments is countered by the savings from not outfitting the same compartments with cabin interior. The proposed solution requires a loss of cabin space of 2,500 m^2. While there are no passenger cabins on the bulkhead deck as such, the loss of space on this deck will be transferred to other decks where cabin space will be reduced. The typical revenue of a cabin is $ 130,000 annually. Given a typical size of such a cabin at 15.6 m^2, this yields a typical revenue of $ 8,400 per m^2. (As argued in the main report, bulkhead deck space should be valued higher than ordinary cabin space. However, lacking a structured approach to the valuation of this space, the value of $ 8,400 per m^2 is used in the calculations). Thus 2,500 m^2 of lost deck space translate to a reduction in annual revenue of $ 20,750,000 (8,400·2,500).

Over 30 years, at 5% interest, this amounts to a net present value of $ 320 million. Note that the uncertainty in pricing the lost space implies that the actual cost of adding the Added Buoyancy is likely to be higher than the presented estimate.

8.1.4 Implementations of guidelines for BRM

The cost of implementing enhanced BRM is related solely to the costs of training and educating officers. For each officer a course fee of $3,700 is estimated. Added to this is a cost of subsistence of $ 800 and travel expenses of $ 1,500. Also, the officer's salary is added estimated at $ 1,000 for the 5 day course.

Currently most cruise operators man their bridge's with two officers working a four hour shift. Therefore (6) six officers are used to continuously man the bridge. It is believed that the captain and staff captain should also attend the course. This brings the total to (8) eight persons. This number needs to be doubled to take into consideration the officers' leave plan. As an approximation, navigational deck officers are onboard for about half the year in total (3 months on, 3 months off).

The course has to be repeated every 5 years. It is assumed that not all officers take the course at the same time, and so the cost of 16 courses is thus spread evenly over 5 years. In all, this gives an annual cost of 22,400 US $. At an interest rate of 5% over 30 years, the net present value (NPV) of the costs is 344,343 US $.

8.1.5 Combined Buoyancy addition and increase in GM

The cost of combining RCO 1 and RCO 3, i.e. increasing the GM by 0.5 meters as well as adding buoyancy on the bulkhead deck, comes from adding more steel to the ship, with the associated added labor, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The added steel weight comes from widening the ship as well as from adding an additional deck, and is estimated as a minimum of 1,200 tonnes, and a maximum of 1,500 tonnes. The cost of the steel, including labor is estimated at $ 6,000 per tonnes. This gives a high estimate of $ 9,000,000 and a low estimate of $ 7,200,000. The high estimate of $ 9,000,000 is used in the calculations.

The increase in vessel breadth is estimated to cause a 2% increase in fuel consumption (by the same approach as described in the previous sections). The annual total fuel consumption of the vessel is estimated at $ 17.1 million. The fraction of this used for propulsion is 2/3 (the remainder is for power generation), meaning that the increase in fuel consumption amounts to 2% of $ 11.4million or $ 228,000. At 5% interest, over 30 years, the net present value of this cost is $ 3,500,000.

In total, the estimated cost of increasing the GM by 0.5 meters and adding buoyancy on the bulkhead deck is $ 12,500,000. This includes adding an extra deck to the vessel. It is also worth noticing that increasing the GM will make the vessel stiffer and experience higher accelerations in roll, which may require increased lifting capacity of the stabilizers to maintain the level of comfort for passengers. This aspect is not considered further. Note also that there are other cost implications to adding a further deck with increased weight and increased passenger complement, e.g., increased capacity requirements in Restaurant, toilets, cinemas, public spaces. It is also possible that taxation, docking costs, insurance and other cost factors are affected. These issues are not considered further in the current report.

8.1.6 Combined Buoyancy addition and increase in GM and Freeboard

The cost of combining RCO 1, RCO 2 and RCO 3, i.e. increasing the GM by 0.5 meters as well as adding buoyancy on the bulkhead deck and increasing the freeboard, comes from adding more steel to the ship, with the associated added labor, and from an increase in the fuel consumption of the vessel as a result of increasing the breadth of the ship and thereby the water drag.

The costs associated with these modifications are the same as for the other combinatory solution, totaling $ 12,500,000. Also, the same reservations apply.

8.2 Economic benefit of implementing RCOs

The implementation of a RCO might have other benefits than reducing number of fatalities. These benefits could be reduced maintenance cost, reduced expected annual accident cost and reduced wet/dry dockings resulting in increased revenue. The reduced expected accident cost for each RCO has been found by accessing the potential risk reduction for each case, using the risk models presented.

8.2.1 Increase Freeboard

The economic benefit of increasing the freeboard by 0.5 meters is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The increase in freeboard is associated with an increase in ship breadth. This modest increase of 0.3 meters gives an increase in deck space of 60 m^2 on each affected deck. The typical revenue of a cabin is $130,000. Given a typical size of such a cabin at 15.6 m^2, this yields typical revenue of $8,400 per m^2. Assessing the value of these extra square meters depends on how the space can be utilized. Naturally, 60 m^2 of added deck space does not translate to four added cabins of 15 m^2 each. It is therefore assumed pessimistically that only 10% of the added deck space is utilized. Furthermore it is assumed that the increase will affect 10 decks. In total, this gives an added annual revenue of $ 498,000 (8,400·60·0.10·10).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased freeboard reduces the frequency of this event from 2.3 10^{-4} per ship year to 1.7 10^{-4} per ship year. As each such event involves the total loss of a $450 million vessel (Source: Carnival and ShipPax database 3.0, cd version 2005.3), the annual savings amount to $ 27,000.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 8.16 million.

8.2.2 Increase GM

The economic benefit of increasing the GM by 0.5 meters is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The increase in GM is associated with an increase in ship breath. This modest increase of 0.5 meters gives an increase in deck space of 100 m^2 on each affected deck. The same assumptions are applied as for the Increase Freeboard option. In total, this gives an added annual revenue of $ 830,000 (8,400·100·0.10·10).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from 2.3 10^{-4} per ship year to 1.6 10^{-4} per ship year. As each such event involves the total loss of a $ 450 million vessel, the annual savings amounts to $ 31,500.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 13.4 million.

8.2.3 Added buoyancy

Reduced accident costs are the only economic benefit from this RCO. The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased buoyancy reduces the frequency of this event from 2.3 10^{-4} per ship year to 1.89 10^{-4} per ship year. As each such event involves the total loss of a $ 450 million vessel, the annual savings amounts to $ 18,600.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is \$ 286,000.

8.2.4 Implementations of guidelines for BRM

The benefit associated with implementing BRM is due to a reduction in all types of collision, contact and grounding accidents (not only total losses). This benefit was estimated in the FSA Large Passenger Ship Navigation study (NAV 51/10), based on an average cost of collision, contact and grounding accidents. This benefit is assumed to be the same in the current study.

The benefits of implementing the navigation RCOs are thought to be adequately presented in NAV 51/10. The calculations are based on average accident costs for accidents of all consequences. It may be that the number of total losses due to capsizing is underestimated (the fatality risk level indicates this), and consequently the benefits are underestimated. However, the benefits are not as sensitive as the number of expected total loss accidents and the risks to human life. The bulk of the benefit stems from avoiding more frequent accidents.

It is therefore decided to keep the benefit figures used in NAV 51/10, i.e. a net present value of \$ 540,000.

8.2.5 Combined Buoyancy addition and increase in GM

The economic benefit of increasing the GM by 0.5 meters and adding buoyancy on the bulkhead deck is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The proposed solution involves adding an extra deck to the ship, which adds more space than the buoyancy elements subtracts. In sum, the solution gives 4,500 m^2 of added space. Assessing the value of these extra square meters depends on how the space can be utilized. The typical revenue of a cabin is \$ 130,000. Given a typical size of such a cabin at 15.6 m^2, this yields typical revenue of \$ 8,400 per m^2. It is not obvious how 4,500 m^2 of added deck space translate to a corresponding number of added cabins of 15 m^2 each. It is therefore assumed that only 50% of the added deck space is utilized. In total, this gives an added annual revenue of \$ 18,900,000 (8,400·4,500·0.50).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from $2.3\ 10^{-4}$ per ship year to $1.44\ 10^{-4}$ per ship year. As each such event involves the total loss of a \$ 450 million vessel, the annual savings amounts to \$38 700.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is \$ 291 million.

8.2.6 Combined Buoyancy addition and increase in GM and Freeboard

The economic benefit of increasing the GM by 0.5 meters, increasing the freeboard by 0.5 meters and adding buoyancy on the bulkhead deck is achieved through a reduction in accident costs (not including the economic benefit of saving lives) and through an increase in deck space, generating added revenue.

The proposed solution involves adding an extra deck to the ship, although this deck is only 60% of what it could be without the increase in freeboard, which adds more space than the buoyancy elements subtracts. In sum, the solution gives 2,500 m^2 of added space. The same assumptions as for the other combinatory option are applied. In total, this gives an added annual revenue of $ 10,500,000 (8,400·2,500·0.50).

The reduction of accident costs stems from a reduction of total loss accidents due to sinking of the vessel in accidents where the vessel is rammed by another ship. The increased GM reduces the frequency of this event from 2.3 10^{-4} per ship year to 1.13 10^{-4} per ship year. As each such event involves the total loss of a $ 450 million vessel, the annual savings amounts to $ 53 000.

Over 30 years, at 5% interest, the net present value of both reduced accident costs and increased deck space is $ 162 million.

9 Results & Uncertainties

Table 6: Results

	Risk reduction ? R	**Cost[2)] ? C**	**Benefit[2)] ? B**	**GrossCAF**	**NetCAF**
	# of saved lives[1)]	$	$	$	$
RCO 1: Increased GM	2.10	2 350 000	13 400 000	1 120 000	- 5 260 000
RCO 2: Increased Freeboard	2.10	2 350 000	8 160 000	1 120 000	- 2 770 000
RCO 3: Added buoyancy	1.35	322 800 000	286 000	239 100 000	238 900 000
RCO 27: BRM	0.95	344 000	540 000	361 000	- 205 000
RCO 1+3: Combined Buoyancy & GM	2.85	12 500 000	291 000 000	4 390 000	- 97 800 000
RCO 1+2+3: Combined Buoyancy, GM and Freeboard	3.75	12 500 000	162 000 000	3 340 000	-39 900 000

1) Per ship per lifetime, assumed 30 years
2) Net present value, 5% interest rate, 30 years

Note that the value of the risk reductions from each measure are not additive, i.e. implementing RCO 1 and RCO 27 simultaneously will not yield a risk reduction of equal to the sum of the two: 2.1+0.95=3.05. This is because the introduction of one RCO will lead to lower risk reductions for all preceding RCOs as the remaining risk reducing potential is reduced.

The results in Table 6 show that *RCO 1: Increased Freeboard*, *RCO 2: Increased GM* and *RCO27: Implementation of procedures for Bridge Resource Management* has low values for both GrossCAF and NetCAF compared to *RCO 3: Added buoyancy high up and far out*. The GrossCAF values are below $ 1M and the NetCAF values are negative. A negative NetCAF indicates that the RCO is beneficial in itself, i.e. the costs of implementing the RCO is less than the economical benefit of implementing it, regardless of how many lives that are saved. A GrossCAF value below $ 3M also indicates that the RCO should be implemented, according to the IMO criteria MSC 83/INF.2. The combinatory solution of RCO 1 and RCO 3 is also extremely cost efficient, due to the huge economic benefits involved. The combinatory solution of RCO 1, RCO 2 and RCO 3 is also highly cost efficient due to economic benefits, but is also close to meeting the 3 m $ GrossCAF criteria due to very high risk reducing effect.

A sensitivity analysis (given in detail in the main report) shows that the results are not sensitive to fuel cost or steel weight. The conclusions rely on the most conservative estimates (using high fuel costs and high steel weights). The results are more sensitive to the degree of utilization for added space. However, the conclusions are based on the assumption of 10% utilization (50% for the combined solutions), and the analysis demonstrates that the degree of utilization must be well below 4% for the NetCAF values to be positive. This means that the RCOs would be cost effective even if the extremely conservative space utilization percentage of only 4% was assumed.

For the stability RCOs evaluated in this study, the results are conservative in the sense that none of the proposed designs have been optimized. The results demonstrate that even without a refinement of the design proposal the proposed measures are cost effective according to the IMO criteria. Furthermore, no estimation of risk reduction in relation to grounding accidents has been made. The actual risk reduction is thus likely to be higher than the figures used in the current calculations. This consolidates the robustness of the results.

10 RECOMMENDATIONS

This study demonstrates that the RCOs listed in the upper part of Table 7 are cost-effective according to the IMO criteria. Furthermore, the project team finds good reason to reiterate the recommendations made in the FSA study on large passenger ship navigation (NAV 51/10), and these are included in the bottom part of Table 7.

Table 7: RCOs recommended for further consideration at IMO

Based on current FSA:	
No	**RCO**
1	Increased GM
2	Increased Freeboard
27	Implementation of guidelines for BRM
1+3	Combined Buoyancy addition and increase in GM
1+2+3	Combined Buoyancy addition and increase in GM and Freeboard
Based on NAV 51/10:	
39	Improved bridge design (above SOLAS)
30	ECDIS – Electronic Chart Display and Information System
33	Increased Simulator Training for Navigators

These RCOs with significant potential to reduce loss of lives are recommended for further detailed consideration as potential IMO requirements. Some of these RCOs are already implemented on most cruise vessels (such as ECDIS). The measures are not, however, currently required by IMO.

The results clearly indicate that the implementation of BRM procedures is cost effective according to the IMO methods and criteria. This measure has a negative NetCAF value and a GrossCAF value close to one tenth of the recommended upper limit.

Also, the analysis shows that, for the particular example ship anaylised both *RCO 1: Increased GM* and *RCO 2: Increased Freeboard* are cost effective, with GrossCAF at about one third of the IMO recommended upper limit, and with negative NetCAF which are shown to be robust. Although RCO 3: Added buoyancy high up and far out is not cost efficient in itself, a combination of this RCO 3 and RCO 1 as well as a combination of RCO 3, RCO 2 and RCO 1 proved to have potential. These combined solutions give the highest risk reduction for the example ship, giving a large negative Net CAF value. These solutions are thus also recommended, despite GrossCAF values above the IMO recommended limit. This analysis indicates that for the example ship the required subdivision index R could be raised from 0.8 to at least 0.90 in a cost efficient manner. However, the suggested solutions for increased damage stability are only indicative of what could be achieved. It should be left to the designer to find a suitable way of conforming to the rules. This means that if further detailed studies on a specific ship designs showed it justified then the subdivision index R could be raided cost effectively. The implementation of any specified measure, such as the RCOs evaluated in this report, should be left to the design; the current report merely indicates ways in which a higher R could be provided.

A further consideration is the effect on cruise ship operation of a reduction in space on the bulkhead deck. This may have severe operating implications for cruise ships as this deck is used for many essential operational functions including passenger embarkation and disembarkation, security screening, loading of stores and baggage, storage of hotel stores (particularly food and beverages) and preliminary food preparation. The detailed effects of changes to the bulkhead deck layout on cruise ship operations have not been assessed in this study and need to be addressed in detail to calculate the full cost and truly assess the benefit of the proposed changes.

It is highly recommended to continue research in the area of damage stability along the lines suggested in this report, to firmly establish the highest level for R which is consistent with the current cost efficiency criteria used at IMO and consistent with the practical operation of cruise ships. In this connection it is also recommended for future work to investigate the use of lightweight structural materials for use in the superstructure of a cruise ship. This option has occurred to the project team very late in the work on this report, and is thus not included in the list of potential RCOs. Reducing the weight of the superstructure may be beneficial for the vessels stability. In future studies it is also recommended to analyse any effects the proposed RCOs may have on grounding accidents as this has been omitted in the current study.

With the introduction of the new probabilistic damage stability rules /8/ an increase in GM, and in some cases freeboard, is already being seen when compared to ships designed to the current regulatory regime.

In conclusion this study shows that for the particular design examined it appeared, within the constraints of the study, that there is potential for cost effective risk control options to reduce risk, according to IMO criteria. These include both operational and design changes to reduce the frequency of incidents and design changes to reduce their consequences. Before such design changes can be incorporated in individual ships more detailed studies related to the specific design, operation and costs of that ship would be needed. Continued research in this area is highly recommended.

With the introduction of the new probabilistic damage stability rules (MSC 194(80)) an increase in GM, and in some cases freeboard, is already being seen when compared to ships designed to the current regulatory regime.

___