S@S WP0

Final Technical Report for Publication

Contract number: G3RD-CT-2001-00331
Period: 2001.07.01 - 2004.06.30
ID no.: S100.00.01.047.006
Date: 2004.08.31

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Approved for release by:

DOCUMENT HISTORY:

Issue:	Date:	Initials:	Revised pages:	Short description of changes: File name:
1.0	2004.08.31	AAD/ HRJ	-	First Issue d:/S@S/reports/047_006

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2 EXECUTIVE SUMMARY

2.1 Contractors

The S@S project was executed by the following group of Institutes, Universities and Companies:

No.	Participant Name	Acronym	Status
01	FORCE Technology - Project Management	FORCE	CO[1]
02	Bureau Veritas	BV	PCR[2]
03	D'Appolonia S.P.A.	DAP	PCR
04	No partner no. 4.	-	-
05	Technical University of Denmark	DTU	PCR
06	ABS Europe Ltd.	ABS	PCR
07	Technical Research Centre of Finland	VTT	PCR
08	Fincantieri Cantieri Navali Italiani S,p.A.	FIN	PCR
09	University of Strathclyde	SSRC	PCR
10	Versuchsanstalt für Binnenschiffbau	VBD	PCR
11	SIREHNA	SIREHNA	PCR
12	Maritime Engineering and Technology for Transport, Logistics, Education	METTLE	PCR
13	University of Newcastle upon Tyne	UNEW	PCR
14	National Technical University of Athens	NTUA	PCR
15	Sea Containers Ltd.	SEA	PCR
16	CETENA S.p.A.	CETENA	PCR

2.2 The project

The Safety-at-Speed project had the ultimate objective to develop an integrated design tool, which would enable the design of advanced high-speed craft (HSC) such that they meet the required safety level at the lowest possible through-life cost, and enable a rational assessment of the cost implications of the variation of safety related parameters.

In present-day design methodologies for advanced HSC there has been no support for the assessment of the balance between the issues of safety and cost. Hence, it has not in practical terms been possible to complete a design at or near the through-life-cost optimum. For current designs, the tendency has so far been to base design decisions on best practice, and while these designs fulfill current safety design requirements, it has been unknown whether the resulting vessels were over-specified in one or more aspects – and hence in reality too expensive to build and operate.

[1] Co-ordinator
[2] Principal contractor

To overcome this situation the goal of the Safety-at-Speed project was to develop a formalized methodology for design for safety of HSC using state-of-the-art techniques and tools. This goal has been successfully achieved and the global deliverable has been produced, which is this methodology, accompanied by supporting tools and information, which will enable the HSC designers to reach an optimal solution with regard to overall safety and through-life cost.

The Safety-at-Speed project had a three-year duration. During the first two years the risk and cost models were developed in the areas of collision and grounding; ship motion hazards; foundering; and containment of damage and fire. During the third and last year the individual models were integrated to a "tool" and this "tool" was demonstrated on a test case. During the first two years models were formulated in all four main areas and data gathering performed through full-scale measurements, model tests and computer analyses. A common format for the models was equally formulated, which facilitated the integration and the implementation of the models.

Dissemination activities have taken place throughout the project and relevant references are given in this report. Exploitation plans for the project have been developed during the project duration.

3 OBJECTIVES OF THE PROJECT

3.1 Project Background

Safety at Speed addresses directly the Key Action 'Land Transport and Marine Technologies': 'Critical Marine Technologies – Efficient, Safe and Environmentally Friendly Ships and Vessels (3.2.1)'. Additionally, Safety at Speed addresses focal points within other key Thematic Priorities: Safety Assessment in Waterborne Transport (2.2.3/3) and Cost-efficient Integration of New Safety Technologies to Improve Quality Shipping (2.2.4/4). In addition to the direct link to 5FP, the project also addresses a number of issues prioritized in the 'The Maritime Industry R&D Master Plan' (MP99), 1999, on the following subjects:

- Area 1.1.2 'Improvements of Competitiveness & Productivity – Design Tools', specifically in the areas of 'Design for Safety';
- Area 1.1.2 'Formal Safety Assessment for Development of Design'.
- Area 2.2.3 'Safety', addressing 'measures to reduce human errors (e.g. through layout optimization, ergonomics, standardization of man-machine interface, etc.)'.

3.2 Objective

The general objective of the project is to develop a formalized methodology for design for safety of HSC using state-of-the-art techniques and tools. The global deliverable is this methodology, accompanied by supporting tools and information, which will enable HSC designers to reach an optimal solution with regard to overall safety and through-life cost. The specific objectives are:

- To analyse the results deriving from the safety assessment of HSC operation;
- To develop an HSC information model describing the risk/cost relationship;
- To use this model to identify safety enhancing design features;
- To analyse the cost-benefits of promising safety enhancing design features;
- To evaluate the effects of safety enhancing design features on ship performance and earning potential, and so develop a design decision support tool;
- To apply the decision support tool in a test case, and
- To utilise the experience from the test case to verify, validate and refine the design for safety methodology.

The scope may be illustrated by the figure shown below, which shows the project overview, and the relation between the different work packages.

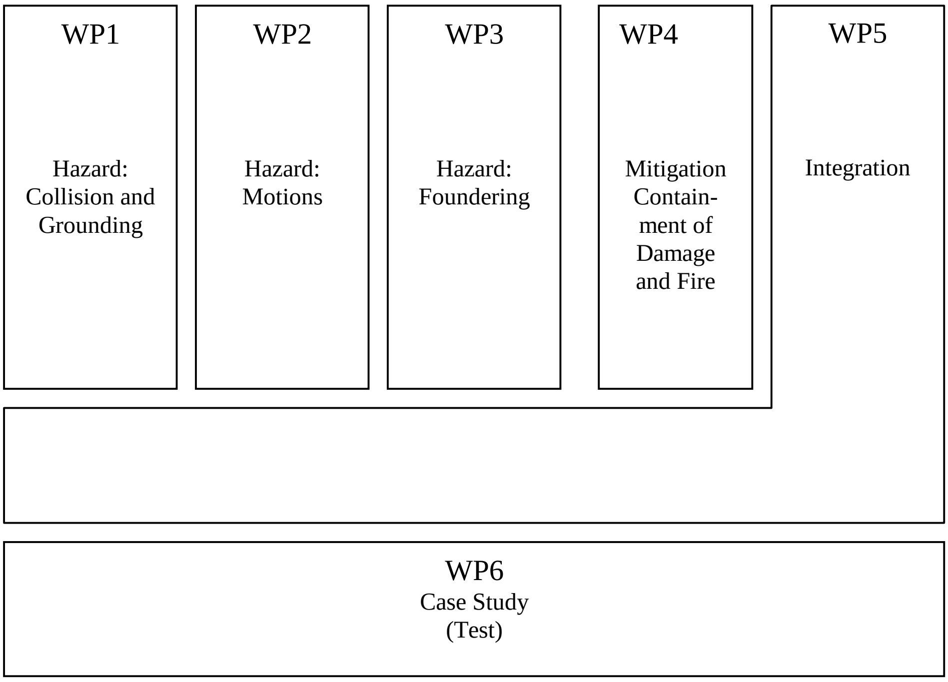

Figure 1: Project Overview

3.3 Objective compared to present practice

Safety considerations are generally relevant for all the different phases of ship design and have an impact on the whole ship level.

The general safety constraints and recommendations result from an assessment of the design specification taking into account dedicated studies, which are mostly related to critical hazards and national laws and regulations. Risk analysis is performed in order to define a risk level associated with the specific design, and if the risk is not acceptable, a new alternative design solution is developed. This procedure is traditionally part of a post process called safety case, which consists of documenting how safety has been considered and incorporated into the design or modification of the equipment, the systems and the whole ship. The safety case must also provide all the information necessary to effectively manage safety of the ship through its in service life, and therefore particularly on the residual risks.

During the design development the safety activities cover different fields starting from the ship requirements to the arrangement of the ship design and the design of equipment/workspace/workplace.
The useful output of a generic safety study is therefore a list of technical options, which could be integrated into the design in accordance with the different status of the ship.

The aim of the safety studies and the safety process can be summarised in the following different steps:

- to conduct a preliminary analysis and assessment of the listed hazards
- to complete analysis according to the most critical hazards
- to identify rules and measures to reduce/suppress hazards
- to define transversal architectural principles which contribute to the general safety of the ship and its crew
- to identify potential discrepancies with the state of design
- to propose alternative common solutions
- to define requirements related to constraints on design of installations on board

The more relevant scope of the present innovative project is therefore to create a dedicated tool which could integrate and organize in a well defined manner the safety studies performed for the more relevant hazards in order to improve the design in a constructive way during all the phases from the feasibility phase to the production phase in order to take the safety of the ship and of the people on board to the highest level.

Moreover, the present tool could be able to complete in a rational manner the safety case, which is a process so relevant for all the innovative high speed crafts.

Especially for military vessels, and for commercial vessels alike, the safety objectives are:

- to give assurance to the customers that the whole ship is compliant with the National laws and regulations and is safe and free from risks to health and safety as far as it is reasonably practicable ;

- to assure that in service support aspects are acceptable for the customers, who will assume responsibility for the safety management of the ship from the point when the ship enters operational service;

- to make appropriate use of standards which shall be international or NATO agreed standards. Where such standards do not exist, then an acceptable cost effective standard is to be contrived, reducing safety risks in compliance with the "As Low As Reasonably Practicable" principle, starting from the least demanding national standard;

- to apply a robust safety management system to ensure that health and safety hazards are identified, assessed and controlled such that the safety risks to the crew, other parties, property and the environment are as low as reasonably practicable.

4 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

4.1 Introduction

The present chapter describes the results of the project. Initially, the final 'Tool' is described and thereafter, the individual models, which form parts of the 'Tool'. Finally, the results of applying the 'Tool' and a test case have been described. This way of describing the results has been found more logical than structuring the description by the work package structure.

4.2 The S@S Project Tool

4.2.1 Theoretical Approach

The challenge of the S@S project is to enable designer of HSC to reach an optimal solution with regard to overall safety and through life cost, i.e. a vessel that meets the required safety level at the lowest cost.

The main outcome of the project is a formalised methodology for design for safety of HSC. This methodology is a practical procedure relying on an integrated design tool, able to compare in terms of risk and cost several alternative preliminary designs of a HSC. The methodology is based on the Formal Safety Assessment approach as per the interim Guideline by IMO (1997/2002).

The Project Tool is organised around a generic safety model and a cost model bound together by the parameters of the proposed design. A parameter is a variable that impacts the safety level and cost of the ship, i.e. a change in the parameter's value causes a change to the safety characteristics and to the cost of the ship. The parameters are basic parameters of naval architecture and other parameters related to operational environment (e.g. intended route) or owner requirements (e.g. ship's availability) for instance.

The risk model materialises under a logical form the various scenarios of accidents that may be encountered by a HSC. The logic of the risk model is based on the risk contribution tree methodology. Fault trees and event trees describe the hazardous situations that may be encountered by the ship.

The following accident categories have been considered:

- collision & grounding,
- dynamic capsizing,
- foundering due to structural failure,
- containment of damage following flooding & fire.

Basically the first three topics cover the chain of events leading to the critical situation, and the last one covers the chain of events following the critical event.

As previously said, the safety model aims to evaluate the risk level of a particular design characterised by a particular set of parameters. The risk model provides users with a simple set of procedures that take as input the values of all relevant main parameters and that can calculate from these the probability of a specific basic event occurring. These procedures are based on simple models, which were developed during the project and which are able to analyse/predict the behaviour of the ship at the early design stage.

These probabilities are then combined according to the fault and event trees to estimate the probability of the end events. The magnitude of accident outcomes is quantified in terms of estimated loss in a given period of time. For instance, when the consequence in question is loss of life, the meaning of risk is the expected number of fatalities in a given period of time. The final level of risk associated with the design is the product of the frequency of the "end event" occurring and of its consequence.

The cost model is a Net Present Value (NPV) model. The NPV is the cumulative discounted cash-flow of the vessel. The formula for this is:

$$\sum_{0 to N} \left(Income - Costs \right) \times (1 + \text{Discount Rate})^{-N}$$

N is the number of Years of life including building and decommissioning.

To calculate the NPV the model is through life. The first part is build cost estimation. The model takes the values supplied by the individual cost models created by work packages 1 - 4 and sums them to form a total cost of the build.

The model now moves on to the operational side of the vessel. To do this the model needs to understand the lifecycle of the vessel. This means how long it spends in operation, how long it spends idle, how long it spends being maintained etc. The percentages of time the vessel spends doing each activity is calculated by the information provided in the lifecycle form.

As NPV calculations require the cash-flow, the model next requires the earnings to be calculated. This calculation has three parts. The first is entering the products to be sold and their prices. These can be standard products such as ticket prices, but some vessels do very well on value added services for example Duty Free. To take this into account additional product places have been added for the user to define.

The second part is calculating the capacity of the vessel. The capacity of the vessel is the product of the physical capacity (a user input) and the availability of the vessel (automatically calculated).

The final part is the demand. This is a user input. Any company considering running a service should do research as to what kind of demand for their services there will be. This information is then entered into the model. There is then a simple comparison calculating how many of each product will be sold limited by either supply or demand which ever is lesser. This gives the earnings.

The next part of the models looks at operating costs. Some of these costs are calculated automatically (for example fuel costs), however there are many different costs and these can be entered independently. There are three types of costs the first is voyage costs like the fuel costs. The second is the maintenance costs. The third is the annual overhead costs like salaries and insurance costs.

Additional bits of information required by the model are, the NPV of the basis vessel, commissioning cost, decommissioning cost and discount rate.

Commissioning and decommissioning cost may vary considerably and therefore may be taken into account if they can be estimated.

The Project tool enables the designer to identify and integrate different Safety Enhancement Features to focus on the areas of high-risk contribution in the risk model, and on the main risk contributors. These measures can either be preventive, i.e. reducing the probability of an event, or mitigating, i.e. reducing the severity of the outcome.

To estimate the cost-effectiveness of these measures in reducing risk, a cost-benefit assessment is carried out by re-evaluating the cost and risk of the alternative design. To compare the different SEF, i.e. to compare the different alternative design solution, the ICAF, which is an indicator of the cost to avert a fatality for each measure, is calculated. Finally, the recommendations and decision-making would be based on the comparison and ranking of the risk control options as a function of associated cost and benefits.

4.2.2 General Steps

The general procedure for using the S@S Project tool consists of several sequential steps, which are listed below.

1. Enter the required information, general information and design and operational parameters for a specific ship design.

2. Calculate the comfort level associated with the proposed design.

3. Calculate the risk level associated with the proposed design.

4. Calculate the cost associated with the proposed design.

5. If the proposed design is not satisfactory, identify areas needing control and potential ‘Safety Enhancement Features’.

6. Implement the Safety Enhancement Features and evaluate the new design with respect to comfort, risk and cost level.

7. Check the cost-effectiveness of the Safety Enhancement Features by calculating the ICAF.

8. Decide which SEF to implement by comparing the related ICAF of the different measures.

4.2.3 Architecture of the Program

The S@S project tool is composed of different applications as summarised on the following graph, which are either part of the risk model (red box) or of the cost model (blue box).

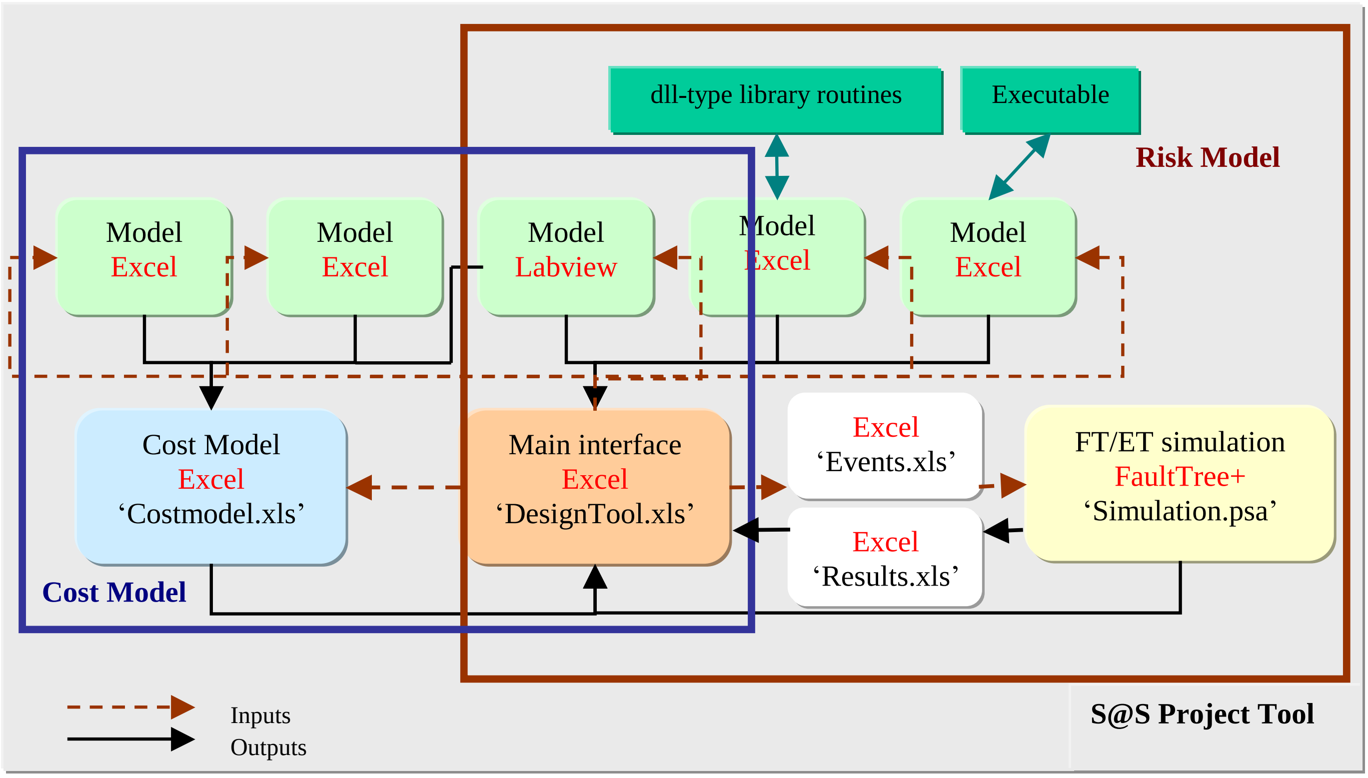

Figure 2: Architecture of the Program

The main interface 'DesignTool.xls' has been implemented in an excel workbook and coded in Visual Basic. The interface stores and displays all the necessary information like a data management system, links all the different applications and contains the outputs.

The file contains ten worksheets, 2 of which are hidden to avoid any data corruption:

- 'Home': home page of the tool displaying the different steps of the procedure
- 'Comfort': evaluation of the comfort level
- 'Collision&Grounding': evaluation of collision & grounding hazard
- 'Capsizing': evaluation of dynamic capsizing hazard
- 'Foundering': evaluation of foundering hazard
- 'Containment of damage – Fire': evaluation of consequences following a fire
- 'Containment of damage Flooding': evaluation of consequences after flooding
- 'Results': display and summary of outputs (risk and cost level)
- 'Current': stores all the current values of the parameters (hidden spreadsheet)
- 'Default': stores the default values of the parameters (hidden spreadsheet)

The cost model 'Cost model.xls' has been implemented in an excel workbook and coded in Visual Basic. The model evaluates the costs and earning ability associated with the proposed design, which is then displayed in the main interface. This is a black box program and there is no need to open it independently.
The file contains 8 worksheets:
- 'Capital Cost': evaluates the build cost
- 'Life Cycle': evaluates the time spent doing actions
- 'Product List': holds the product information
- 'Per Cycle': evaluates cost that come on a per cycle basis
- 'Capacity and demand': evaluates the capacity and demand
- 'Spread': is the detailed results page
- 'Summary': gives a summary of the results
- 'Other inputs': evaluates other costs for instance crew costs

These two workbooks are the general frameworks for the risk and cost evaluation. The core of the project tool is based on a set of modules, which enable the evaluation of intermediate results required for the final risk and cost level calculation. These modules have been implemented in different forms: excel workbook, LABview program, and some of the calculations are done in dll-files compiled with Compaq Visual Fortran programming language or use executable files. They all have been stored in the sub-directory called 'Model' for the safety model:
- S@S_WP2_MSI&MII.xls and S@S_WP2_MSI&MII_Short_Term.xls in folder called S@S_WP2_MSIMII
- collision_striking_grounding.xls in folder called S@SWP1_Manoeuvrability_Model
- Structural_Risk_Cost_Calculator.exe in folder called Structural_Risk_Cost_Model_Comprehensive.
- S@S_WP2_Dynamic_stab.xls
- S@S_WP2_hull_girder_vibration.xls
- S@S_WP2_Indoor_climate.xls
- S@S_WP2_Long_term_loading.xls
- S@S_WP2_Noise_model.xls
- S@SWP1_Human_Factor_model.xls
- S@SWP1_risk_model_controllability.xls
- S@SWP4_Event_Trees_Flooding.xls
- S@SWP4_Fault_Tree_Flooding.xls
- S@SWP4_FireRiskTool.xls

And in the main directory for the cost model:
- power predictionPD_HSC.xls
- power predictionPD_HSCMAX.xls
- S@S_WP2_Availability_v1.01(20031113).xls
- S@SWP1_Cost_model_controllability_v1(20031117).xls
- S@SWP4_Cost_Model_Flooding_v2(20031029).XLS
- S@SWP4_FireCostTool_v1(20031117).xls

The risk evaluation also requires simulating the different scenarios of accidents 'Simulation.psa'. A commercial fault tree / event tree software, called FaultTree+, is hence used to provide the required outputs and analyse the results. Two excel workbooks are designed to ensure the communication between the main interface and the simulation software ('Events.xls' & 'Results.xls').

The communication flows between the different tools are not always automatic, some links require manual operations.

4.2.3.1 Home Page

When launched, the S@S Project Tool first loads the 'Home' page, which displays the main menu and the different steps of the procedure.

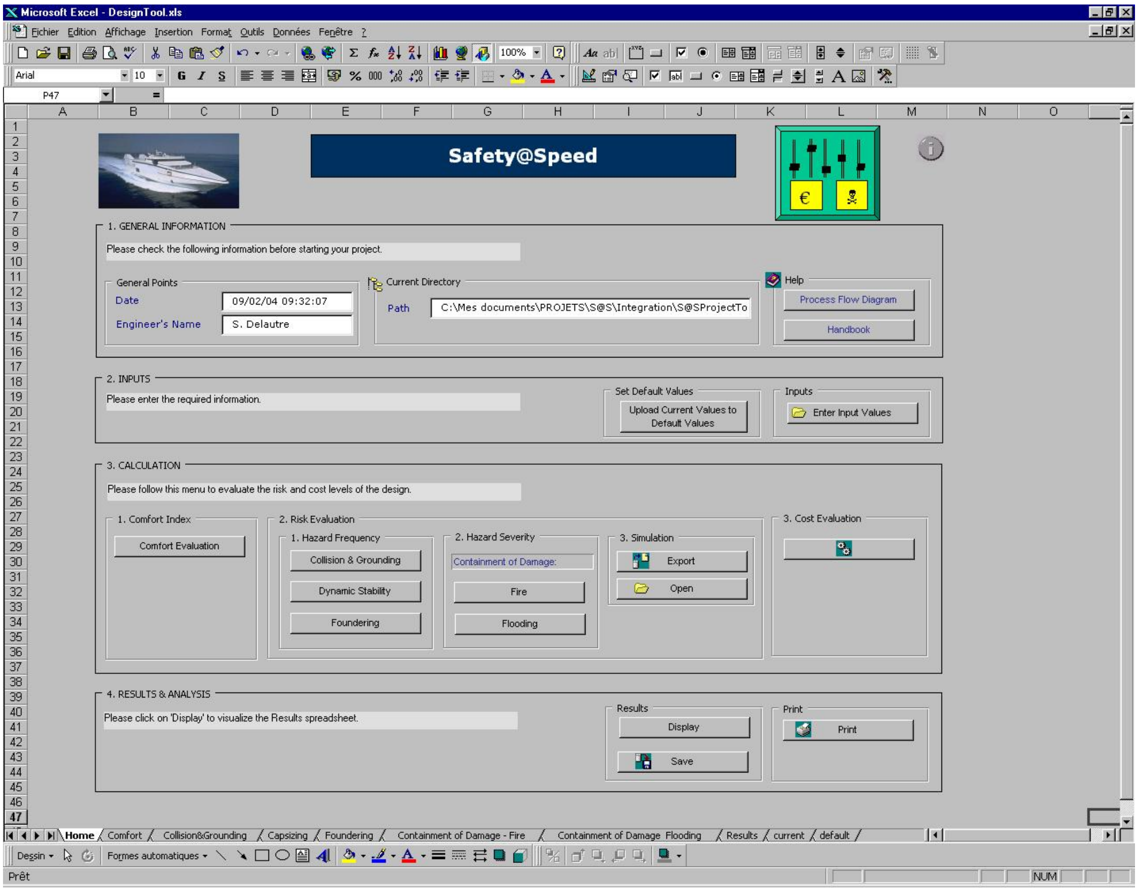

Figure 3: Home Page

General Information

This first paragraph displays the date, the current directory where the file is stored and the name of the Engineer carrying out the analysis, which must be manually entered.

A 'Help' menu opens the Project Tool user guide in an electronic format and a schema of the methodology flow chart.

Inputs
This menu enables the designer to enter the parameters associated with the proposed design to study, and also to set the default values.

Calculation
This menu enables the designer to calculate successively the comfort level, the risk level and the cost level of the proposed design.

Results & Analysis
This menu enables to display the result spreadsheet, to print the different pages of the tool and to save the 'DesignTool.xls' file to keep a record of the different design solution in the folder called 'Backup'. This backup only saves the main interface spreadsheet in order to keep the values of the parameters, which define the design solution, and the values of comfort, risk and cost without any other details.

4.2.3.2 Spreadsheet Architecture

All the pages of the project tool are organised in the same way with the same five key points and the same colour code.

Results
The expected result(s) of each model is (are) displayed at the beginning of the page in yellow (automatic calculation). The results are updated automatically at each calculation by the model itself (comprehensive calculation, see below) and must not be entered manually.

Parameters
The list of parameters affecting the calculation is also displayed. If several results are expected from the calculation, the related parameters are listed for each result.

Parameters Values
For information, the values of the parameters involved in the calculation are displayed. These values are those, which are entered at the beginning of the study through the parameter interface. They cannot be changed directly via the spreadsheet.

Calculation Mode
The two buttons of the 'calculation mode' menu are dynamic links to the model performing the calculation. Two ways of using the models were introduced:

- Comprehensive calculation:

The model is used as part of the general risk and cost calculation of the proposed design. The program runs automatically by using the inputs entered in the project tool (the same than those displayed) and updates the results in the main interface spreadsheet. No manual operation is required from the user. To stop the calculation, click 'Echap'.

- Stand-alone Program:

The model can be used separately from the global calculation, as there is no link between the model and the tool. This option was introduced in order to give to the designer the possibility to test the models and to get familiar with the program, before performing a complete risk and cost calculation.
The model must be manually fed with the parameter values and the results are not exported to the main interface. The program needs to be closed before running the comprehensive calculation.

Help
For each model a user guide is available in an electronic format by clicking on 'User Guide'.

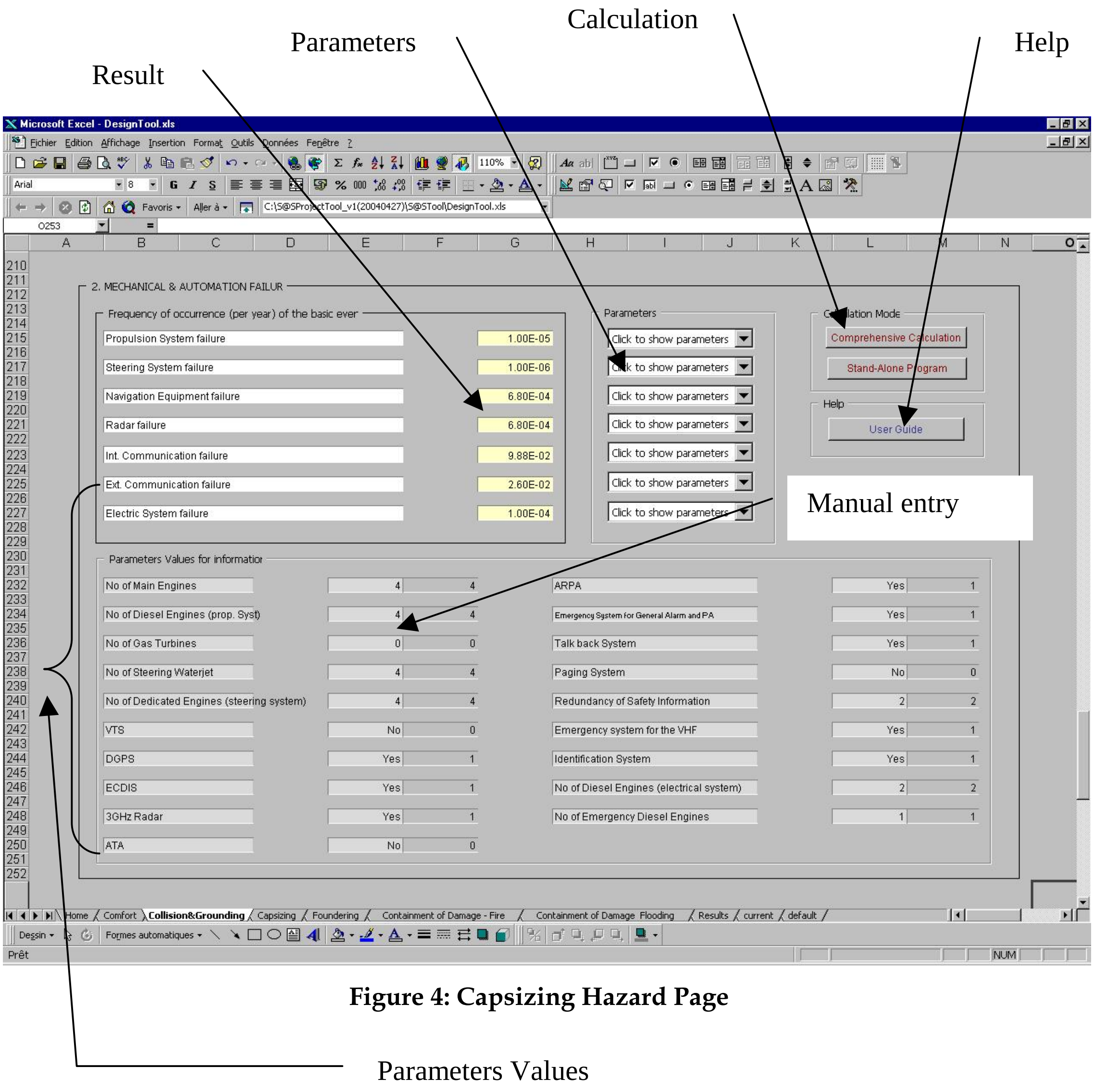

Figure 4: Capsizing Hazard Page

When some data needs to be entered manually, the related cell colour is green (manual entry).

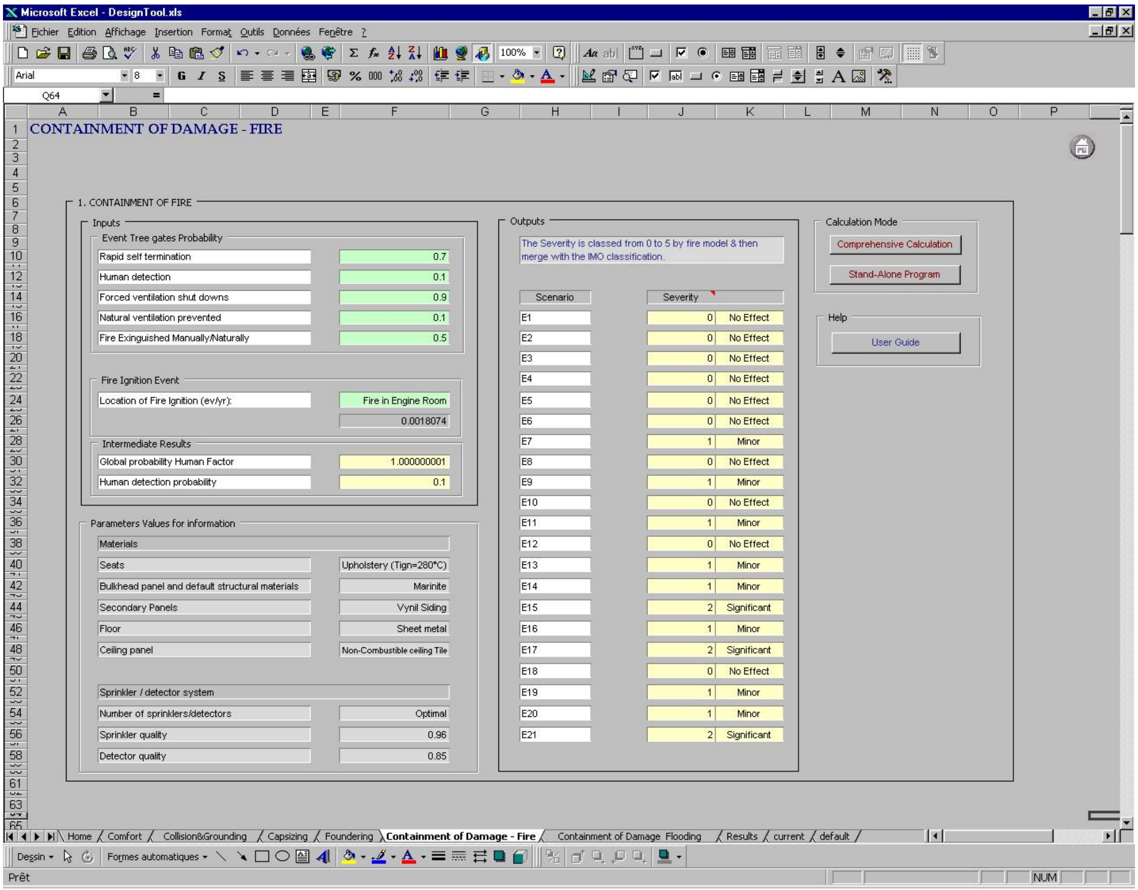

Figure 5: Containment of damage - Fire Page

4.3 Description of Individual models

4.3.1 Short Term Seakeeping Analysis Model

4.3.1.1 Theoretical Approach

The short term seakeeping model calculates the most probable largest value of:

- Heave motion (at the centre of gravity (CG))
- Pitch and roll angles (at the CG)
- Vertical, longitudinal and transverse accelerations (at a user selected location)
- Relative motion and velocity (at a user selected location)
- Vertical bending moment at midship
- Number of slams and water on deck in the reference period.
- Motion Sickness Incidence value (according to the formula presented in 'Seakeeping: ship behavior in rough weather' by A.R. Lloyd)

The most probable largest value corresponds to the largest peak value that it is most probable that the ship will encounter during the reference period in the given sea state.

The necessary inputs are the main dimensions of the ship, the ship speed, the sea state and the reference period, which corresponds to the time the ship is in the specified sea state. A reasonably value is 10000 sec. (approximately 3 hours). The most probable largest value is found by:

$$\text{Peak} = \sigma \times [2\text{Ln}(\text{N})]^{1/2}$$

where N corresponds to the number of waves encountered in the reference period, and is estimated by Reference_period / Tz. Tz is the zero-upcrossing period for the sea state and is an input parameter. σ is the standard deviation, which is calculated by:

$$\sigma^2 = \int_0^\infty \Phi_R^2 S(\omega) d\omega$$

where Φ_R is the response amplitude operator (RAO) for the relevant response (i.e. heave or pitch or...) and $S(\omega)$ is the wave spectrum as function of the wave frequency ω. The wave spectrum can be either the Pierson-Moskowitz or the JONSWAP spectrum. The RAO for the response is determined by the closed form expressions that were developed in WP2. A description of the closed form expressions is found in Jensen et al. (2004) and Mansour et al. (2004). Here are only mentioned the most important assumptions in the models:

- For the heave and pitch motions the ship is modeled as a rectangular box
- For the roll motion the ship is modeled as two connected rectangular boxes
- All three motions (heave, pitch and roll) are decoupled
- Heave and pitch motions are 90° out of phase
- The location of the pitch centre correspond to the ship CG
- The form coefficient δ, used in the roll calculations, is fixed to 0.6

4.3.1.2 General Steps

The model should be used as follows:

- In 'Short_term_stat' worksheet, input of parameters values
- Calculations are automatically updated after each modification input parameters. Calculations can also be launched manually by (F9).

4.3.1.3 Architecture of the Program

The short term seakeeping model has been implemented in the Excel file S@S_WP2_short_term_analysis_v*i.ii*.xls and coded in Visual Basic. The file contains two worksheets:

- Short_term_stat: this worksheet contains the input parameters, which have to be defined by the operator, and displays the main results (most probable peak values).
- RAO: this worksheet contains intermediate calculated parameters and motions, accelerations and VBM RAOs.

References: see Section 9.1

4.3.2 Long Term Motion Sickness and Safety of Footing Model

4.3.2.1 Theoretical Approach

Passenger and crew long term comfort levels with regard to motion sickness and safety of footing are determined and compared with criteria. Relevant parameters are MSI (Motion Sickness Incidence = percentage of passengers feeling sick) and MII (Motion Induced Interruptions per minute = loose of balance per minute). They are utilised in calculating an overall comfort level during one year of operation in a given sea area. As a result the ship's comfort levels are rated as High, Medium or Low. In addition a safety level with regard to maximum horizontal acceleration is determined in the same way.

In the developed models, the operating and sea state conditions that will be encountered by the ship are defined as a probability distribution of wave incidences with respect to the ship and by a wave scatter diagram (probability distribution of (Tz, Hs), Tz – zero up-crossing period, Hs – significant wave height). The ship speed is considered constant for all these conditions (ship speed input by operator). Wave incidence and sea state (Tz, Hs) are considered to be independent variables.

Then, for each combination of wave_incidence(i), and wave characteristics Tz(j), Hs(k) conditions, the MSI and MII values are calculated using motion sickness [1], safety of footing [1] and simplified seakeeping models [2,3] also developed in WP2. The most probable maximum horizontal acceleration value a_{hPeak} is derived from the variance σ_{ah}^2 as:

$$a_{hPeak} = \sigma_{ah}\sqrt{2\ln(N)}$$

where N corresponds to the number of waves encountered and is estimated by Reference_period / Tz for each considered sea state. The reference period is 300 s according to guidelines of IMO HSC Code. The variance of horizontal acceleration σ_{ah}^2 is calculated as the sum of the variances of longitudinal and transverse accelerations.

These calculations are performed separately for passenger and crew area locations. Therefore the user may supply different criteria for passenger and crew areas if necessary but the default values are the same.

For each condition the MSI rating $\Gamma_{MSI}(i,j,k)$ equals 3 if calculated MSI value is less than the upper limit for high comfort level (representing high comfort level), 2 if MSI is between upper limits for high and medium comfort levels (medium comfort level), and equals 1 otherwise (low comfort level). The overall MSI comfort rating is calculated by summing all ratings which have been weighted by the probability of occurrence of each condition. The overall MSI comfort rating $\Gamma_{MSI,Tot}$ is then given by:

$$\Gamma_{MSI,Tot} = \sum_i \sum_j \sum_k P(wave\_incidence(i)) \times P(Tz(j), Hs(k)) \times \Gamma_{MSI}(i, j, k)$$

Identical calculations are performed for each MII rating $\Gamma_{MII}(i,j,k)$ and maximum horizontal acceleration rating $\Gamma_{ah}(i,j,k)$ using the corresponding criteria for passengers and crew. The overall ratings for MII $\Gamma_{MII,Tot}$ and maximum horizontal acceleration $\Gamma_{ah,Tot}$ are then:

$$\Gamma_{MII,Tot} = \sum_i \sum_j \sum_k P(wave\_incidence(i)) \times P(Tz(j), Hs(k)) \times \Gamma_{MII}(i, j, k)$$
$$\Gamma_{ah,Tot} = \sum_i \sum_j \sum_k P(wave\_incidence(i)) \times P(Tz(j), Hs(k)) \times \Gamma_{ah}(i, j, k)$$

MSI and MII comfort ratings and maximum horizontal acceleration safety ratings can be calculated in several user defined locations (defined by their co-ordinates X, Y, Z in meters with respect to the ship aft perpendicular, centreline and baseline), corresponding to passenger and crew locations. Then the maximum values of MSI, MII and maximum horizontal acceleration ratings obtained over all selected locations of passenger (resp. crew) areas are compared to the limit values.

After the overall comfort ratings with respect to motion sickness and safety of footing and safety rating for maximum horizontal accelerations have been calculated the corresponding comfort levels (or safety levels in the case of horizontal acceleration) can be set:

- Overall comfort (safety) rating is higher or equal to 2.5: comfort level is set to "High".
- Overall comfort (safety) rating between 1.5 and 2.5: comfort level is set to "Medium"
- Overall comfort (safety) rating below 1.5: comfort level is set to "Low".

The seakeeping models used are closed form expressions. They have been developed within WP2 for the calculation of heave, pitch, roll, vertical acceleration, longitudinal acceleration, transverse acceleration and vertical bending moment RAOs and variance. Since MSI, MII and maximum horizontal acceleration models are based on roll motion and acceleration levels, only formulas for predicting the variance of roll motion, vertical, longitudinal and transverse accelerations are used. These accelerations result from heave, roll and pitch motions and the lever arms between the calculation locations and the ship CG.

Basic assumptions used by the simplified seakeeping model are:

- For the heave and pitch motions the ship is modelled as a rectangular box
- For the roll motion the ship is modelled as two connected rectangular boxes
- All three motions (heave, pitch and roll) are de-coupled
- Heave and pitch motions are 90° out of phase
- The location of the pitch centre corresponds to the ship CG
- The form coefficient δ is fixed to 0.6

4.3.2.2 General Steps

The model should be used as follows:

- In 'Main' worksheet input the design parameter values and ship speed and select whether active stabilisation is used or not.
- Check/modify the locations for MSI and MII calculations ('Locations' worksheet), wave scatter diagram ('Scatter diagram.' worksheet), wave incidence probability distribution ('Incidence distrib.' worksheet) and criteria ('MSI&MII criteria' worksheet).
- In 'Main' worksheet, press 'Calculate MSI&MII :' button. Old comfort and safety levels shown in yellow cells are erased at the same time. Once the calculation is finished, new comfort and safety levels are displayed in the yellow cells.

4.3.2.3 Architecture of the Program

The long term motion sickness, safety of footing and maximum horizontal acceleration model has been implemented in the Excel file S@S_WP2_MSI&MII_v*i.ii(yyyymmdd)*.xls and two dll-files.
The Excel file consists of five worksheets containing all the user input and output needed in the calculations of MSI, MII and maximum horizontal acceleration. The actual calculation of these models is done in a dll-file compiled with Compaq Visual Fortran programming language. Visual Basic code has been used for reading the input data, passing all the necessary input and output parameters to and from the external dll-subroutine and displaying the output results.

The Excel file contains five worksheets:

- Main: where the design parameters and speed are input by the operator, the MSI, MII and maximum horizontal acceleration calculation is activated and the results displayed.
- Locations: where the co-ordinates of the locations of passenger and crew areas are given. The locations are defined separately for passenger and crew areas.
- Scatter diag.: where the wave scatter diagram is given.
- Incidence distrib.: where the wave incidence distribution with respect to the ship is given.
- MSI&MII criteria: where criteria for MSI and MII comfort levels as well as maximum horizontal acceleration safety levels are given. The criteria for passengers and crew areas can be different though the default values are the same.

The actual calculation is done in dll-type library routine file MSI_MII_Program_v*i_ii*.dll. A Fortran run-time file Dforrt.dll contains no calculation code but it is necessarily needed during the execution.

4.3.3 Hull Girder Vibration Model

4.3.3.1 Theoretical Approach

The model calculates the free hull girder vibrations of the ship, for modes up to 5 (6-noded mode). It can be used for the prediction of the lower modes of free vibration in vertical or horizontal bending. The obtained values are compared against the frequencies of the major excitation sources aboard the ship (like main engine unbalanced forces-moments, propeller excitation, etc) or the encounter wave frequencies. This is the first step in the prediction of the vibration levels at the early design stages of the ship design.

The program assumes that the hull girder vibrates like an one-dimensional beam. This is a common assumption, made when dealing with the lower modes of the hull girder vibration [1,2,3]. The corresponding mathematical model takes into account the longitudinal variation of the elastic and dynamic properties of the ship. The analysis starts with the splitting of the hull girder into a sufficient number of beam (line) elements and the Bernoulli-Euler formulation is followed for the establishment of the elastic and inertial matrices of the system.

The elastic and inertial properties are assumed constant inside each element/hull segment. For each of them the user must provide the values for the total (structural and cargo) mass and the equivalent hydrodynamic mass of the surrounded water. The later can be derived from the output of 2-D hydrodynamic codes, through the application of the well known 'strip theory'. The frequency-independent upper limits of the hydrodynamic added masses in vertical or horizontal directions should be included in the data.

Based on the above values, the program forms the total mass matrix of the system following a 'consistent mass matrix formulation' approach. During this, two additional corrections are applied on the hydrodynamic added mass. The first one corresponds to a correction of the 2-D added masses for 3-D flow effects, which is mode depended [1]. The second is an application of a local correction, depended on the vicinity of each beam to the hull girder ends [1]. Both correction factors are computed and applied internally by the program.

The values of the sectional 2nd moment of inertia representing the bending stiffness of the beam in vertical or horizontal direction are used for the construction of the stiffness matrix for each beam finite element. The total system stiffness matrix is then composed and the associated eigenvalue problem is solved by the 'subspace iteration' numerical method [4] in order to obtain the natural frequencies. The Sturm sequence check [4] is also applied at each stage of the subspace iterations, to check the results of the computations.
The hull girder vibration model was verified against theoretical results and experimental data, as presented in the pertinent user guide.

4.3.3.2 General Steps

The model should be used as follows:

- In 'Main' worksheet, input the data for the properties of each beam element, the basic ship data and the frequencies of the major excitation sources.
- In 'Risk_of_resonance' worksheet, press the 'Click to update values' button. The resonance percentages for each source are presented in the table of the results and the overall risk of resonance is characterized.

4.3.3.3 Architecture of the Program

The hull girder vibration model has been implemented in the Excel file S@S_WP2_hull_girder_vibration_v*1_00*.xls and coded in Visual Basic. The file contains two worksheets:

- Main: where the analysis data are input by the user
- Risc_of_resonance: where the results of the calculations are presented.

In addition to the aforementioned excel file, two other executable files are called internally by the program, through the macro 'Calculate_hull_vibrations' each time the button 'Click to update values' in the worksheet 'Risc_of_resonance' is pressed:

- Program predata.exe: This program is called for the preparation of the appropriate ASCII intermediate data file, which stores the analysis input data
- Program sasvb.exe: this is the main computing module for solving the eigenvalue problem for the frequencies of the hull girder vibrations. The results are stored in an intermediate file in the directory 'C:\sascomf' and are read automatically by the calling macro of the excel workbook.

4.3.4 Indoor Climate Model

4.3.4.1 Theoretical Approach

The model calculates the required power and air flow of the HVAC systems of a ship, given the requirements for the indoor climate and a description of the internal spaces of the ship.

The adopted approach for the calculation of the thermal loads follows the specifications presented in ISO 7547 [5]. The accommodation spaces of the ship are divided into groups, which are served by individual HVAC systems. For each system the user gives the required indoor temperature and humidity for winter and summer conditions, which must be in accordance to the comfort criteria, (see, for example, [8]), the required ventilation, the estimated infiltration and exhaust air flows, as well as the supplied air temperature and air flow.

Given the heat transfer coefficients for each space, the calculation of the thermal loads is then straightforward, following the simplified formulas and psychrometric calculations presented in [6] and [7]. The required power of the units is then computed and compared against the user supplied values.

4.3.4.2 General Steps

The model should be used as follows:

- In 'System Data' worksheet, give the general parameters for the design of the HVAC system and the properties of the individual HVAC systems.
- In the 'Room data', input the values for the heat transfer coefficients and the room parameters for each individual accommodation space.
- After this, go back to the worksheet 'System Data', press the 'Compute system loads' button and then watch the results in the last worksheet 'System Loads'.
- Change the design values of each HVAC system in worksheet 'System Data', if the results are not satisfactory.

4.3.4.3 Architecture of the Program

The indoor climate model has been implemented in the Excel file S@S_WP2_indoor_climate_model_v*1_00*.xls and coded in Visual Basic. The file contains three worksheets:

- System Data: where the analysis parameters and the data for each HVAC system are given
- Room Data: where the specific parameters describing each accommodation space are given by the user
- System Loads: where the capacities of the HVAC systems described in worksheet 'System Data', necessary to serve the spaces described in worksheet 'Room Data' are presented, based on the calculations of the program.

The values in the last worksheet are updated each time the button 'Compute System Loads' pressed: the appropriate macro is called, which reads the data of the analysis in the first two worksheets and writes the results in the third one.

4.3.5 Noise Model

4.3.5.1 Theoretical Approach

The theoretical approach followed for the prediction of the noise levels aboard the ship has been originally developed by SNAME, as presented in detail in [9]. A simplified version of this approach was developed in NTUA [10], which forms the basis of the noise prediction model developed in the framework of the S@S project.

In general, the noise prediction requires the determination of the acoustic and vibration characteristics of three elements: the noise source, the transmission path and the receiver.

The noise prediction procedure includes two basic interacting paths inherent to the noise transmission aboard the ship: the airborne and the structureborne one. Following the airborne path, noise is transmitted to the receiver via the air and the common boundaries of adjusted spaces. Usually airborne path is a significant factor only within noise source spaces or spaces adjacent to them.

On the other hand, structure borne paths usually carry noise away from the source, as well as to the spaces adjacent to the source areas.

Practical procedures for the control and minimization of the noise levels aboard ships can be found in literature (e.g. [9],[11])

The noise prediction procedure follows the basic path-receiver approach. The basic steps of the procedure are as follows:

- Calculation of the sound power for each noise source and the corresponding source free vibration levels
- Calculation of the airborne and structureborne transmission losses
- Calculation of the sound pressure levels in each receiver space, taking into account the airborne and structureborne transmissions, the contribution of any noise sources inside each space and the acoustic properties of the surfaces.
- Comparisons of the obtained values against the criteria [8].

The first step in the procedure is the determination of the sound power and free vibration levels for the various shipboard equipment, using an estimating technique based on empirical values. The amount of airborne and structureborne noise that will be transmitted is depended mainly on the acoustic and vibratory power generated by the source. A measure of the acoustic power of the source is given by the sound power level Lw, in decibels, referenced to a power of 10^{-12} Watts. Empirical formulae, presented in [9], for the determination of Lw for each type of the shipboard equipment are used by the model, in order to obtain the sound power level analysed in the standard octave bands.

The structureborne noise source level of each source is measured by the 'free' vibration acceleration level, which is given in dB referenced to 10^{-3} cm/sec^2. After the calculation of the above levels the model computes the acoustic absorption properties of each room, calculate the transmission losses for the airborne and structureborne paths and combine the individual results, in order to obtain the total noise level in the receiver space.

It should be noted that the noise prediction problem is, in general, very complicated and requires the detailed description of the acoustic properties of the complex ship structure. So, in order to derive a simple model, several simplifications had to be made. The most important of them are the simplification for the transmission losses due to the ship structure (only deck to bulkhead connections were considered for the structureborne noise transmission and a standard value, taken from [9], was used for the loss per meter of ship structure) and the consideration of only the direct acoustic field at the middle of each room.

4.3.5.2 General Steps

The model should be used as follows:

- The user should give the main dimensions and the noise limits (from [8]) of each room entered in the analysis in the worksheet Room Data .
- In the worksheet 'Room Param.' the acoustic parameters for each space must be supplied.
- the specific parameters of each noise source aboard the ship and taken into account in the analysis, should be defined in the worksheet 'Noise Sources'.

- In the worksheet Prop. Data the specific parameters of the propellers relevant to the noise estimation should be entered.
- the description for the airborne noise transmission paths should be specified in the worksheet 'Airborne Paths'
- In worksheet Bhd_TL the user should describe the transmission losses in the structural vibrations, due to the bulkhead to deck intersections.
- The main dimensions of the typical panels of each room/space should be given in worksheet 'Typical Panels'.
- After completed the input phase the user returns to the first worksheet and presses the 'Compute ' button. The program performs the calculations and the predicted noise levels are presented in the last column of the worksheet. The comparison against the noise limits given by the user in the previous column of the worksheet can be easily done. Intermediate results of the program are stored in worksheets Room const., Source Levels, Str_borne levels, Prop. Noise, Source Rooms, Airborne noise, Str_borne Noise and Total Levels.

4.3.5.3 Architecture of the Program

The indoor climate model has been implemented in the Excel file S@S_WP2_noise_model_v*1_00*.xls and coded in Visual Basic. The Excel file contains the VB functions for the implementation of the predictive algorithm and the following eighteen worksheets:

- Room Data : Where the main dimensions of the rooms/spaces of the ship, which enter in the noise prediction analysis, either because they have noise sources or because they are acoustic receiver spaces, are given. The corresponding noise limits are also given here.
- Room Param. : In this worksheet the acoustic parameters for each space are given (i.e. surface noise absorption coefficients and correction factors)
- Noise Sources : where the specific parameters of each noise source are defined.
- Prop. Data : In this worksheet the specific parameters of the propellers relevant to the noise estimation are given.
- Sabine Values : It stores a data base for the sabine absorption coefficients for various materials, commonly used in shipbuilding. The user may alter the values, add elements to the list, based on his experience, or use the values as they are given.
- Source Adjustments : Where a data base for the noise source adjustments of various types of shipboard equipment is given, together with the corresponding values for the acceleration levels and the transmission losses due to the source mounting systems
- Transm. Losses : It is another database storing typical values for the transmission losses of typical panels used in the shipbuilding.
- BHD_TL : The transmission losses in the structural accelerations due to the deck to bulkhead intersections are given.

- Typical Panels : The main dimensions of typical panels of each room/space are given here.
- Room const. : It is an output worksheet. The calculated values for the room acoustic constants of each space are presented.
- Source Levels : The noise and acceleration levels coming from each noise source are given here, as computed by the model.
- Str_borne levels : The computed structureborne acceleration levels for each space are presented here
- Prop. Noise : In this worksheet the noise transmitted from the propeller to each space is given.
- Source Rooms : Where the computed noise levels in the spaces containing noise sources are presented
- Airborne Paths : The user enters here the description for the airborne noise transmission paths.
- Airborne Noise : The calculated values for the airborne noise transmitted to each space are calculated here.
- Str_borne Noise : The noise levels due to the structureborne noise transmitted to each space are calculated in this worksheet.
- Total Levels : The results for the total noise levels at each compartment are given in this worksheet.

4.3.6 Human Factor Model

4.3.6.1 Theoretical Approach

The deliverable D131 describes the formulation of a model for calculation of probabilities of human factors related basic events. The model is based on a list of *human factors related parameters*, which can be adjusted individually and independently of each other. These parameters have to be set in this final tool by the end user.

The setting of the human factors related parameters will have an influence on the probability of the *human factors related basic events*. A *human factors quotient (HFQ)* will therefore be calculated as a single value expression of the setting of the parameters. The human factors quotient is in the range between 0 and 1 where 0 represents the worst possible setting of all human factors related parameters and 1 is the best possible setting of the parameters. We would expect, that the worst possible setting (0) would generate an increased probability of human error compared to a value while the best possible setting (1) would generate a decreased probability of human error compared to the value. A set of *coefficients* is needed for calculation of the human factors quotient. These coefficients are obtained by expert judgement (skilled high speed navigators) of the importance of each parameter with respect to the probability of human error in general. The method used in this expert judgement is a "*pair wise comparison*" method, and the data is collected by means of a distributed questionnaires.

4.3.6.2 General Steps

The model for calculation of probabilities of human factors related basic events can be summarized in the following way:

Preparation of model (already done, prior to delivery of the model):

1. Coefficients for each parameter have been calculated by expert judgment (pair wise comparison). Additional information is available in the report D1.3.1., ID S101.31.01.052.002.
2. Probabilities for each combination of basic event and human factors quotient level have been calculated by expert estimation. Additional information are available in the report D1.3.1., ID S101.31.01.052.002.
3. The end user has the possibility of adjusting the model by using own values.

Application of model:

1. Parameters can be adjusted by the end user
2. Human factors quotient (HFQ) are calculated on basis of the setting of parameters (by placing the "flag" in the selected value column) and the HFQ level should be identified on the basis of this calculation
3. Probabilities from the column in the basic event / HFQ level matrix corresponding to the HFQ level calculated in step 2 should be used in the fault trees.

Step 1 and 2 in the preparation of the model has been fulfilled by the use of questionnaires. Additional information is available in the report D1.3.1. ID S101.31.01.052.002.

4.3.6.3 Architecture of the Program

The program is implemented to a ordinary Excel spreadsheet:

- S@SWP1_Human_Factor_model_v3.1(20031008).xls

The file contains two worksheets:

- Parameters: this worksheet contains the input parameters, which have to be defined by the operator, and displays also some of the main results: The HFQ-factor and total cost.

- Probability factors: this worksheet contains the BE values calculated by using the input parameters. All BE used in the fault tree (to be found in the D1.3.4) and which are related to the Human Factor are displayed.

4.3.7 Mechanical and Automation Failures' Model

4.3.7.1 Theoretical Approach

The present document represents the user's guide for the tool that D'APPOLONIA has developed within T132 "Implementation of Models for Mechanical and Automation failure" with the support of CETENA and METTLE. The tool has been conceived for the preliminary design phase of High Speed Crafts. It can evaluate the influence on specific hazards (i.e., collision, grounding and striking) of different parameter configurations related to systems whose failure may lead to these hazards [1]. The tool allows the calculation of failure rates of systems for multiple parameter configurations and the costs associated to each configuration.

This tool has to be used in conjunction with the software "Fault Tree Plus" (Isograph®); the failure rates have to be used as input data in order to calculate the occurrence probability of hazards such as collision, grounding and striking.

4.3.7.2 Main Assumptions Risk Model

Because of the vastness of parameters that may characterise systems onboard ships, it was very difficult to identify first the most critical ones with respect to the hazards mentioned above and, secondly, to establish hierarchies of importance between them. Moreover, data related to the reliability of systems components are difficult to find. Nevertheless, on the base of a literature review, it turned out that the failures of those systems that had been considered critical for the hazards under analysis (e.g., detection equipment, propulsion system, steering system etc.) were extremely low. Though it is clear that the total loss of some systems onboard cannot be excluded a priori, it is practically impossible to provide the quantification of such failures.

Consequently it was decided of using the REDUNDANCY concept as criterion to matching different configurations of parameters.

Moreover, the influence of the human factor was not considered, in the sense that it is supposed that failures are only generated by the system itself and neither by incorrect maintenance nor incorrect use.

4.3.7.3 Main Assumptions Cost Model

Because of the lack of data relative to the labour and maintenance costs, it was decided to consider them as percentage of the component cost.

4.3.8 Manoeuvring Errors' Model

4.3.8.1 Theoretical Approach

Fault Trees (FTs) for Collision, Striking and Grounding were developed within work package 1 of S@S project on the basis of results of previous projects and WP1 brainstorming sessions. The objective of developing these FTs was the identification of Basic Events (BEs) leading to Collision, Striking and Grounding Top Events.

According to the FTs developed, the BEs related to manoeuvring errors are:

- BE1: Last minute avoidance too late: failed to turn in time to avoid collision, for encountered ship sea state, with actual ship speed, and accounting for manoeuvrability performance in open sea.

- BE2: Remaining distance too short for crash stop for encountered environment condition.

These BEs are the only ones that are exclusively related to the manoeuvring capabilities of the design vessel in normal conditions of operation (no human error or mechanical failure). Nevertheless, the position of these BEs in the various Top Events FTs should be taken into account in the modelling of these Basic Events. Therefore, scenarios have been defined for every Basic Events in order to determine the associated parameters and the collision avoidance trajectories.

These scenarios of last minute collision avoidance have been defined with respect to the rules of navigation when sailing (COLREGS rules).

A complete description of the manoeuvring error model can be found in S@S deliverable No. D1.3.3, ID S101.33.11.052.001B

For each Top Event, one or two Basic Events are related to manoeuvring errors. The Basic Events for two different Top Events can have the same name but to build an accurate model, a definition of scenarios specific to each Basic Event has been necessary. Moreover, the capabilities of the manoeuvring model and the outputs of this model have also been taken into account in the formulation of the scenarios. The manoeuvring model allows determining the conventional IMO manoeuvrability criteria for a given design (Length, Breadth, Draft, and Displacement) in a sailing configuration (Depth, Speed).

4.3.8.2 Top Event N°1: Striking with a floating object

The corresponding Basic Event to model is BE1.

Two scenarios were defined:

- When the floating object is on the vessel course and has a drift speed with the same direction as the vessel speed.
- When the floating object has course perpendicular to the vessel course.

The parameters that are taken into account are:

- For the design vessel: initial speed, length between perpendicular, breadth, draft and displacement. A radius of safety is defined from the ship length and breadth.
- For the floating object: a cargo container is considered L=6.1m, B=2.4m
- Distance d_0 at which the collision avoidance manoeuvre is launched. It depends on the efficiency to detect the floating object.

The drift speed of the floating object V is neglected.

4.3.8.3 Top Event N°2: Striking with a fixed object in open sea

The corresponding Basic Event to model is BE1.

According to what is described in the previous paragraph, the model and the parameters for fixed object avoidance in open sea are the same as for a floating object. The only difference consists in the choice of typical fixed object. Two types were chosen: a fixed object the safety area radius of which was defined as R_1=50m and a large object such as an offshore platform, the safety radius of which was defined as R_1=500m.

As previously, the distance at which the manoeuvre is launched depends on visibility, level of automation etc. But as the fixed object is different from the floating object (larger), d_0 should also be larger.

4.3.8.4 Top Event N°3: Striking with a fixed object in restricted water

The corresponding Basic Event to model is BE2.

The only action necessary for avoiding striking is a crash stop manoeuvre characterized by the stopping distance Ds.

The parameters of the model are:

- For the design vessel: same as for top event No 1. The stopping distance Ds is derived from the RSM manoeuvring model.
- For the fixed object: as for open sea, two types of fixed objects are considered: a fixed object (safety area radius R_1 = 50m) and a large object such as an offshore platform (R_1 = 500m).
- Distance d0 of launching of the striking avoidance manoeuvre

4.3.8.5 Top Event N°4: Collision in open sea

The corresponding Basic Event to model is BE1.

The scenarios associated with this Basic Event are very similar to the ones related to striking with a floating object. Indeed, three scenarios were defined:

- When the vessel encountered is on the vessel course and has a speed with the same direction as the vessel speed.
- When the vessel encountered has a course perpendicular to the vessel course.
- When the design vessel is overtaking the encountered vessel.

The parameters of the model are:

- For the design vessel: same as for top event No 1.

- For the encountered vessel: 6 different types of vessels with associated service speeds are defined: oil tanker, bulk carrier, container vessel, passenger vessel, Ro-Ro vessel, small vessel. A circular safety radius is defined from L and B.
  The percentage of vessel of various type encountered is depending on a parameter TD called: "Traffic Distribution". To simplify the choice of traffic description, 3 configurations of traffic are defined with the probability of encountering each of the 6 vessel types.
- Distance d_0 at which the collision avoidance manoeuvre is launched.

4.3.8.6 Top Event N°5: Collision in restricted water:

The corresponding Basic Event to model is BE2.

The scenarios associated with this Basic Event are very specific as we assume that the design vessel is on a collision course with an encountered vessel and has no other alternative than launching a crash stop manoeuvre to avoid collision. Two cases are considered:

- When the vessel encountered has course perpendicular to the vessel course.
- When the design vessel is overtaking the encountered vessel.

The parameters of the model are the same as for top event No 4.

4.3.8.7 Top Event N°6: Powered Grounding:

For this top Event, the two Basic Events (BE1 and BE2) are to be modelled.

The parameters of the model are:

- For the design vessel: same as for top event No 1.
- The ground safety radius is constant and chosen as R_1=500m.
- Distance d_0 at which is launched the collision avoidance manoeuvre

4.3.8.8 Modelling of manoeuvring criteria and of time dependent trajectory:

The simplified manoeuvring model was undertaken using Response Surface Methodology.

The first step in the development of the RSM model was to obtain a training set allowing developing response surfaces. This training set consists in a set of IMO manoeuvring criteria for various fast vessel designs. These data can be derived from sea trial results or simulations. Due to the lack of material in literature on manoeuvring sea trial results of fast vessels, it has been decided to perform numerical manoeuvring simulations.

From simulations carried out by DMI with the software DENMARK, a database of IMO manoeuvring criteria of similar fast vessels has been developed.

The turning avoidance trajectory is the derived from the turning circle trajectory, modelled by a straight line followed by an ellipse and the speed of the vessel on the trajectory was derived by regression from the results of the simulations carried out by DMI.

In order to obtain the position of the vessel on the trajectory at a given instant t, the trajectory should be time dependent. Therefore the speed of the vessel on the trajectory was derived from the results of the simulations carried out by DMI.

The modelling of the crash stop manoeuvre is based on the knowledge of the stopping distance Ds. Again, the speed of the vessel has been derived from regression.

4.3.8.9 Calculation of Collision Probability

According to the description of the manoeuvring model, the position of the design vessel with regard to the obstacle can be known for each instant t. By a time simulation the occurrence of collision can be derived from the model. The collision probability is then combined for all the scenarios:

$$Pcollision = \sum_{i=1}^{3}\sum_{j=1}^{5} Freq\_scenario(i) \times Freq\_ship\_type(j) \times Pcollision(i, j)$$

The values of probability depend on some fixed values predefined in the model such as the percentage of various ship types according to the traffic distribution or the size of the encountered vessel. Such values have been derived from literature or estimated by model developers. They are not specific to a sailing zone or derived from specific databases. Nevertheless, these values are not fixed definitively and could be adapted to specific cases by end user.

4.3.8.10 General Steps

The procedure consists in:

First Step:
Calculating the manoeuvring criteria of the design vessel once the design and operational parameters are tuned.

Second Step:
Tuning the specific parameters of each Basic Event scenario according to other Basic Event scenarios.

Third Step:
Launching the Probability Calculations.

4.3.8.11 Architecture of the Program

The manoeuvring errors model has been implemented in the Excel file S@S_WP1_collision_striking_grounding_v*i.ii*.xls and coded in Visual Basic. The file contains nine worksheets.

- 'Manoeuvring criteria': for the input of the designed ship parameters and for the calculation of corresponding ship manoeuvring criteria.
- Six worksheets defining the scenarios for the six top events considered:
  - 'Collision in open sea'
  - 'Collision in restricted water'
  - 'Striking with a floating object'
  - 'Striking with a fixed object in open sea'
  - 'Striking with a fixed object in restricted water'
  - 'Powered grounding'
- 'Probabilities': for the input of one parameter (distance d0), the calculation and display of probabilities of each basic event.
- 'Encountered vessel': for the definition of the type, dimensions of possible encountered vessels, and the definition of traffic distributions of these vessels.

4.3.9 Long Term Dynamic Stability Risk Model

4.3.9.1 Theoretical Approach

In order to deliver a probability of effects on humans and on the ship due to dynamic stability failure, the IMO guidance rules have been implemented in a long term analysis, in the same way as implemented for the availability model (see §4.3.15).

Thus, the operating and sea state conditions that will be encountered by the ship are defined as a probability distribution of wave incidences with respect to the ship and by a wave scatter diagram (probability distribution of (Tz, Hs), Tz – zero up-crossing period, Hs – significant wave height). The ship speed is considered constant for all these conditions (ship speed input by operator). Wave incidence and sea state (Tz, Hs) are considered to be independent variables.

The probability of being in dangerous surf-riding/broaching, marginal surf-riding/broaching, dangerous successive waves attack, dangerous synchronous rolling and dangerous parametric rolling zones is determined separately for each phenomenon by applying the IMO procedure for each condition wave_incidence(i), and wave characteristics Tz(j), Hs(i). For each phenomenon, and each condition, the occurrence Γ(i,j) is either 0 (safe) or 1 (dangerous or marginal). Then, the global probability of occurrence of each phenomenon is given by:

$$\sum_i \sum_j P(wave\_incidence(i)) \times P(Tz(j), Hs(j)) \times \Gamma(i, j)$$

Then these probabilities are weighted with factors giving the occurrence per year of each phenomenon with respectively:

- No, Minor, Major, Severe and Catastrophic effects on ship,
- No, Minor, Significant, Severe and Catastrophic effects on humans.

These weighting factors include in fact two levels: the probability of encountering the phenomenon when the ship is in the IMO dangerous / marginal zone, and the probability of having one of the five effects when the phenomenon occurs.

The above occurrences are also summed up over each phenomenon to give the total occurrence per year of each effect.

The weighting factors have been defined by expert judgment. They are presented as a matrix in the 'Matrix' worksheet.

		Broaching / Surf-riding		Successive waves	Synchronous roll	Parametric roll
		Dangerous	Marginal	Dangerous	Dangerous	Dangerous
Effect on ship	No	0.839	0.920	0.839	0.839	0.839
	Minor	0.100	0.050	0.100	0.100	0.100
	Major	0.050	0.025	0.050	0.050	0.050
	Severe	0.010	0.005	0.010	0.010	0.010
	Catastrophic	0.001	0.001	0.001	0.001	0.001
Effect on humans	No	0.678	0.839	0.678	0.678	0.678
	Minor	0.200	0.100	0.200	0.200	0.200
	Significant	0.100	0.050	0.100	0.100	0.100
	Severe	0.020	0.010	0.020	0.020	0.020
	catastrophic	0.002	0.001	0.002	0.002	0.002

Figure 6: Matrix of weighting factors

The above matrix is defined for a ship equipped with steering water jet. Such a steering device is favorable to reduce the risk of dynamic instability for following seas. Consequently, if the ship is not equipped with steering water jets then the above probabilities for broaching / surf-riding and successive waves attack are multiplied by a factor of 2, given in the 'Matrix' worksheet.

The above matrix is also defined for active roll stabilization in operation. The risk of synchronous or parametric roll will be reduced if active roll stabilization is operating. Consequently, if no active roll stabilization is operating then the above probabilities for synchronous and parametric roll are multiplied by a factor of 10, also given in the 'Matrix' worksheet.

Finally, the risk of being in a dangerous or marginal dynamic stability zone will be null if the crew follows the IMO guidance. Consequently, the probability of each effect is weighted by the factor (1-HFQ), where HFQ is the Human Factor Quotient calculated in WP1 and demonstrating the crew performance. For a very performing crew, HFQ=1 and the weighting factor is zero. For a poor performing crew, HFQ=0 and the weighting factor is 1, which means that the dangerous or marginal situations will not be avoided.

Following the IMO procedure, dangerous or marginal surf-riding/broaching and dangerous successive waves attack situations are investigated only if:

- The wave length is larger than 0.8 x ship length between perpendiculars
- The significant wave height is larger than 0.04 x ship length between perpendiculars
- The wave direction is 0° to 45° from the stern

It is not clear from the IMO guidance whether the constraints applied for broaching should be applied also on synchronous and parametric rolling. Since this does not seem physically relevant, it has been decided to search the occurrence of synchronous rolling and of parametric rolling whatever the wave length, height and direction with respect to the ship.

The IMO guidance indicates that synchronous (resp. parametric) rolling occurs when the wave encounter period is close to the roll natural period (resp. half the roll natural period). This has been implemented as synchronous (resp. parametric) rolling occurs when the difference between the wave encounter period and the roll natural period (resp. half the roll natural period) is lower or equal than 20% of the roll natural period (resp. of half the roll natural period).

For successive waves attack, a difference has been detected on the dangerous zone boundaries given in the text (encounter wave period/mean wave period between 1.5 and 2.8) and the ones represented on figure 3 of the guidance (encounter wave period/mean wave period between 1.36 and 3.08). The latter have been assumed to be correct.

4.3.9.2 General Steps

The model should be used as follows:

- In 'Main' worksheet, input of design parameters values, of ship speed and of the HFQ value to be used.
- Check/modifications of wave scatter diagram ('Scatter diagram.' worksheet), wave incidence probability distribution ('Incidence distrib.' worksheet).
- In 'Main' worksheet, press 'DYNAMIC STABILITY CALCULATION' button. The number of conditions (wave incidence, Tz, Hs) to be calculated and the progress (in %) of the calculation is displayed. Once the calculation is finished, 'Completed' appears for progress and the probability values for each effect are displayed in the yellow cells.

4.3.9.3 Architecture of the Program

The dynamic stability model has been implemented in the Excel file S@S_WP2_Dynamic_stab_v*i.ii*.xls and coded in Visual Basic. The file contains four worksheets:

- Main: where the design parameters, speed and HFQ value are operator input, the capsizing calculation is run and the results displayed.
- Scatter diag.: where the wave scatter diagram is input.
- Incidence distrib.: where the wave incidence distribution with respect to the ship is input.
- Matrix: were the weighting factors corresponding to the various effects on ship and humans for each phenomenon, and where additional weighting factors accounting for the absence of steering water jet and of active roll stabilization are given.

4.3.10 Long Term Wave Loading Model

4.3.10.1 Theoretical Approach

The long term loading model calculates the most probable maximum largest long term vertical bending moment (VBM) at midship for the Mediterranean scatter diagram with given weather routing factors and an operational profile. This is done both with a linear and a non-linear analysis. The non-linearity is only included in the sagging VBM. In the non-linear analysis whipping can also be included.

The probability that the individual peak values in the linear long term analysis will exceed a given value is taken as a weighted sum over all the sea states and the operational profile in the usual manner:

$$P\left(R^{peak} > r\right) = \int\int\int\int \exp\left(-\frac{1}{2}\left(\frac{r}{\sigma_R}\right)^2\right) Wp(H_S, T_Z, V, \beta) dH_S dT_Z dV d\beta$$

where H_S is the significant wave height, T_Z is the zero up-crossing period, V is the ship speed, β is the ship heading, and σ_R is the standard deviation for the VBM. This is calculated with a closed form expression which uses the main dimensions as input, see Jensen and Mansour (2002), Jensen and Mansour (2003) and Jensen (2004) for details.

The sea state and the operational parameters are assumed to be statistically independent so that

$$p\left(H_S, T_Z, V, \beta\right) = p\left(H_S, T_Z\right) p\left(V, \beta\right)$$

The Mediterranean Sea scatter diagram is used together with an operational profile in which three zones are defined:

$$1 \le H_S \le 3;\ 4 \le H_S \le 6;\ 7 \le H_S \le 11$$

In each zone fractions of time with a given combination of V, β are specified. These fractions can, however, vary from zone to zone making it possible to introduce speed reduction and change of course in heavy sea. Other sea states can be defined, possibly taking into account weather routing, see Olsen et al. (2004).

The weight factor W represents the average number of peaks per unit time in a sea state:

$$W = W\left(T_Z\right) = \frac{T_Z^a}{T_Z}$$

where

$$\frac{1}{T_Z^a} = \iint \frac{1}{T_Z}\ p\left(H_S, T_Z\right) dH_S\ dT_Z$$

The probability that the individual peak values will exceed a given value ($P(R^{peak}>r)$) is calculated for a given range of r and a Weibull distribution is fitted to the results. From the Weibull distribution the most probable largest peak value can be found from:

$$\text{Peak} = \alpha\left(\ln N\right)^{1/\beta}$$

where α is the scale factor and β is the exponent for the Weibull distribution.

4.3.10.2 General Steps

The model should be used as follows:

- In 'Long term VBM' worksheet, input of parameters values
- After modification of the input parameters, calculations must be launched manually by pressing 'shift+ctrl+a' to update the results.

4.3.10.3 Architecture of the Program

The long term analysis of the VBM model has been implemented in the Excel file S@S_WP2_long_term_loading_v*i.ii*.xls and coded in Visual Basic. The file contains one worksheet:

- Long term VBM: this worksheet contains the input parameters, the auxiliary results and the main results. With the spreadsheet it is possible to get the most probable largest VBM both in a linear and non-linear formulation, and the whipping bending moment can be included.

4.3.11 Structural Foundering Risk Cost Model

4.3.11.1 General

As part of the integrated risk-cost approach, Workpackage Three has created a LabVIEW software tool, which investigates the reliability and cost of a proposed high-speed craft midship section. This software automates the calculation of many of the required parameters for the overall risk and cost model, and also provides feedback to the designer about the reliability of a proposed structural design. This section gives an overview of the software program, and the calculations and assumptions inherent in the tool. Information on how this piece of software integrates into the overall S@S approach is discussed in the previous sections of this deliverable. At the current time, two versions of the tool are available. One version allows all of the input information to be entered through a graphical user interface (GUI version). The other version loads the input information directly from text files, including automatically transferring the input parameters from the Excel-based project tool (text version). The project tool user's guide for more information on creating the input text files automatically. Currently, the text version is the version integrated into the overall S@S tool.

4.3.11.2 Theoretical Approach

The software is designed to investigate the reliability and cost of a proposed high-speed craft midship section, using the loadings and parameter list available within the S@S project tool. It is envisioned that this tool will work in conjunction with the classification society rules spreadsheet produced by ABS in Task 3.2, which is described in D3.2.3. For the purposes of this discussion, it is suffice to say that the rule spreadsheet can be used to generate the preliminary scantlings of several alternative midship sections, which meet the minimum classification society requirements. These midship sections can be entered into the software, which will evaluate the risk and cost associated with each of them, allowing the designer to pick the optimum scantlings to use in the design.

The software is designed to operate within the S@S project tool, thus it is limited to using the inputs on the S@S parameter list and that available from other Workpackages. The loading available within the project consists of global vertical bending moments, limiting the structural analysis to longitudinally effective members in the midship section. These structures are entered as un-stiffened plates, stiffened plates, or extruded sections. Three types of structural performance are considered, local collapse of members under compressive loads, overall collapse of the hull girder, and fatigue failures in structural details. The collapse stress of each panel is calculated through an empirical formulation. Miner's sum fatigue formulations are applied at structural details in the midship section. Each stiffened panel is assumed to have stiffener end connections, which should be checked for fatigue with an user-specified stress concentration factor, and the user can specify additional details such as expansion joints or other cut-outs by providing their location in the midship cross-section and their stress concentration factor. The structural risk associated with these calculations is determined by using reliability formulations to estimate the probability of failure, as discussed in Deliverable 3.3. Cost is calculated on a weight basis, specific material and labour costs are assigned to each form of each aluminium alloy, i.e., 5083 plating or 6082 extrusions. The amount of each material and form in the midship section are summed up and multiplied by these specific costs yielding the build costs. Overheads are treated as a percentage of the labour costs. Maintenance costs are also considered and are adjusted for the level of structural risk, using the *SuperSeaCats* as reference vessels.

Because of effort and time limitations, certain factors are not yet included in the model. This includes local pressure loadings and the associated structural response, transverse structures, and panels welded at locations other than their boundaries.

4.3.11.3 General Steps

The general procedure for using the software tool depends on which version(GUI or text) of the tool is used, however, the general steps for each analysis are as follows:

1. Enter the basic vessel and run information

2. Enter the long-term loading from Workpackage Two's long-term loading spreadsheet.

3. Divide the midship section into un-stiffened panels, stiffened panels, and extruded panels with homogenous properties. Enter these into the software.

4. Enter any additional structural details to be checked for fatigue.

5. Confirm that the reliability constants and fatigue S-N curves enter as defaults are appropriate for the proposed vessel.

6. Confirm that the costing constants are appropriate for the proposed vessel.

7. Check the entered data by plotting the midship section.

8. Run the model.

9. Review the output to ensure that the data is correct and that the model ran without any errors.

The same general sequence is also followed when using the text file version of the program with the overall S@S tool, however the data input required in steps 2-6 is automatically transferred from the S@S tool to the program by means of text files.

4.3.11.4 Architecture of the Program

Both versions of the program consist of stand-alone LabVIEW applications, which in turn rely on several dynamic link libraries to operate. Both versions of the program run automatically, the input data is loaded, the program executes without further user intervention, and then an output file is produced. Two different types of input information are used in the program. The first is the S@S parameters related to structural foundering, these parameters come from the user input forms in the S@S project tool and the output of other workpackages. It is these parameters, which the user should vary to develop a safer or more cost-effective design. The second type of data considered is constants. These address issues such as material properties for fatigue, cost data, and uncertainties in the input information. These constants should not be varied as a design evolves, but may be updated from time to time to keep the program current with changing cost data or improved material properties.

4.3.12 Fire Risk and Cost Model

4.3.12.1 Theoretical Approach

The objective of Task 4.3 in S@S is primarily to develop a systematic approach, which enables the evaluation of risks and costs associated to Risk Control Options (RCOs) for the containment of fire onboard high speed craft.

Following the identification of the main means for containment of fire (Task 4.1) and the analysis of parameters related to fire containment (Task 4.2), the work performed in Task 4.3 has focused on the development and implementation of a model suitable for applications during the early design stages.

4.3.12.2 Main Assumption Cost Model

The risk model was developed through the following main steps:

1. Development of a simplified Event Tree taking into account both active and passive RCOs, and human factors elements;
2. Quantification of the Event Tree gates. Data needed to perform this step have been retrieved from literature;
3. CFD simulations for parametric analyses of fire propagation according to different RCOs parameters configurations;
4. Analysis of the simulation outcome based on a original approach developed by D'Appolonia;
5. Evaluation of the consequences through the definition of class severity;
6. Identification of the level of risk for each design options.

For each fire scenario defined through the Event Tree Analyses and for each selected design alternatives, CFD simulations were performed by using the Fire Dynamics Simulator (FDS) model.

Computational fluid dynamics (CFD) analyses have been carried out (reproducing the scenarios as depicted in the event tree analysis) for estimating the consequences of a fire event occurring on a HSC.

4.3.12.3 Main Assumption Risk Model

The cost model is developed evaluating the costs variations of RCOs (in terms of through life costs and maintenance costs) with respect to the different configuration of the design parameters. The cost of each parameter has been evaluated in terms of material, labour and maintenance costs in order to produce a model suitable for integration into WP5.

4.3.12.4 General Steps

In order to use the tool it's necessary a personal computer with Microsoft® Windows Operating System; Microsoft® Excel 97 or above; minimum 486 processor; minimum 640Kb RAM; 12Mb of hard disk space (for installation).

4.3.12.5 Architecture of the Program

Two different Excel workbooks have been prepared for fire risk and cost model:
- FireRisk Tool_v2(111103).xls
- FireCostTool_v1(20031117).xls

The fire risk model comprises several worksheets but the user will have only to deal with the "Fire Risk Tool" worksheet; the others will be hidden and used to perform the calculations.

The fire cost model comprises only the "Cost Model-WP4" worksheet.

4.3.13 Risk/Cost Model for Flooding Containment

4.3.13.1 Theoretical Approach

The risk/cost model for flooding, developed as part of the activities of Work Package 4 of the project, has been implemented in three separate Excel workbooks, for use within the project-wide Project Tool, as follows:

- Event trees for outcomes of collision, grounding and striking (including methods for the estimation of branch probabilities within the event trees).

- Differential cost model for different vehicle deck arrangements and for variations in the number of bulkheads and position of main deck.

- Fault and event trees for flooding from evolved from causes other than collision, grounding or striking.

These excel workbooks are outlined in the following.

Event Trees for Flooding
This workbook comprises four spreadsheets. The first spreadsheet includes estimation methods for the calculation of the branch probabilities of the event trees for collision, grounding and striking. These event trees are the following three spreadsheets of the workbook.

Assuming all collision, grounding and striking incidents that can potentially happen, classification of incidents is done in the following way:

- Struck or striking ship. (*Classification made for collision incidents only*) This classification was considered necessary due to the different extent of damages (damage to the side when the vessel is the struck ship or damage to the bow when the vessel is the striking ship) and the potentially different flooding consequences. The branch probabilities for this classification were considered as 50%-50%, which reflects a view that it is largely a matter of chance which is the striking and which is the struck ship.

- Minor and non-flooding incidents. Within this category, minor incidents that do not result in flooding and have minor effects to people are considered. There is no further classification of these incidents in the current analysis.

- Flooding incidents. These are incidents were the hull is punctured below or close to the waterline, resulting in entry of water to one or more compartments.

- The branch probabilities for an incident being a minor and non-flooding or being a flooding incident are calculated based on the time the vessel travels on various speed ranges during a trip. The association made is that for lower speeds there is a higher possibility the incident to be minor and non-flooding, whilst for higher speeds it is almost certain that the incident would result in flooding.

- Flooding incidents are further classified as resulting in the vessel remaining afloat, sinking or capsizing. The method to calculate the branch probabilities for these events is outlined in the following.

- Fire incidents. (*Classification made for collision incidents only*) These are incidents were the collision results in a fire, due to a punctured oil cargo tank (in case where the colliding vessel is a tanker). It has been included in the analysis for reasons of completeness of the method. The branch probability however is expected to be extremely low, which is reflected in the set value chosen for these events.

The predictive method for the outcomes of collision, grounding or striking when flooding occurs (i.e. remains afloat, sinks or capsizes), have been developed using results of damage survivability calculations carried out for the S@S basis vessel and a second high speed monohull, as well as, for reason of completeness of the approach, by using research results derived for conventional passenger Ro-Ro vessels (for a limited percentage of potential damage scenarios). In summary, calculations performed and data used include the following:

- Damage survivability results of the S@S basis vessel for two-, three- and four-compartment damage cases.
- Attained Subdivision Index calculations for the three alternative bulkhead arrangements considered for the S@S basis vessel with GM varying from 0.5 to 5.3 metres.
- Results of damage stability calculations of a second high speed monohull (122 metres in length).
- Damage survivability results obtained for conventional passenger Ro-Ro vessels (used for a limited percentage of potential damage scenarios only).

In calculating the branch probabilities for flooding incidents (remains afloat, sinks or capsizes), distribution density functions for non-dimensional extents of damage have been used, modified accordingly to reflect the design and operational profile of high speed monohulls.

The model uses the following as input parameters:

- Service speed
- Length of the vessel
- Route distance
- Time to enter and exit ports
- Variations on bulkhead deck arrangement
- Number of transverse watertight bulkheads
- Vertical location of bulkhead deck

Finally, an association is made with the severity scale for effects to human life and property contained in IMO's FSA Guidelines within the event trees for outcomes of collisions, grounding and striking developed.

Cost Model for Flooding
The model requires the following input:

- Main particulars (length, clearance of the bulkhead deck, draught, beam, block and midship coefficients, wetted surface area

- The number of transverse watertight bulkheads, the bulkhead deck depth and the arrangement on the bulkhead deck for the variant designs considered (basis vessel and alternative under consideration)

- Material, labour and overhead unit cost (per square metre) for construction

The model outputs an overall figure for the cost difference as well as the cost differences for all the variations considered separately.

Fault Trees for Flooding
The fault and event trees for flooding from causes other than collision, grounding or striking, calculate the probability of occurrence and estimate the severity of their outcomes for the following events:

- Flooding due to wave damage
  - Through bow or stern doors, hull, into bridge
- Flooding due to open door on bulkhead deck
  - Bow, stern or side doors
- Flooding via down-flooding openings
- Flooding below the bulkhead deck

The following basic events have been considered as contributing to these causes of flooding:

- Wave damage to outer bow door
- Failure of outer and inner bow door
- Flooding through stern doors, hull, into bridge due to wave damage
- Bow, stern, side doors not closed when going to sea
- Bow, stern, side doors opened in port
- Flooding when bow, stern, side door open
- Flooding via down-flooding openings and below bulkhead deck

The model relates to the following parameters (the user of the workbook can alter the input values for these parameters):

- Area of operation
- Rules and bow door configuration
- ISM Compliance
- Turn around time in port
- Sheltered water routes
- Freeboard
- Number of trips per year

Finally, an association is made with the severity scale for effects to human life and property contained in IMO's FSA Guidelines within the event trees for outcomes of flooding from other causes.

The results of this workbook are considered to be consistent with historical data (deriving from general statistical analyses of relevant accidents). The overall order of magnitude of this type of incidents is calculated as 1 in 1,000 years, whilst for serious associated casualties this figure is down to 1 in 10,000 years and above. This analysis has been included for reasons of completeness of the overall model for consequences of flooding.

4.3.13.2 General Steps and Architecture of the Program

No particular general steps need to be followed. Inputs should be entered in the first spreadsheet of each workbook only.

Event Trees for Flooding

- Spreadsheet (**Branch Probabilities**):
  - Input values for service speed, length of the vessel, route distance and time to enter/exit ports should be entered in boxes E3, E5, E7 and E9 respectively of this spreadsheet (input parameters 1 to 4).
  - The four drop-down menus (input parameters 5 to 8) should be used to determine the subdivision characteristics of the alternative under consideration.
    - As variations of the arrangement of the bulkhead deck, the following have been considered:
      - Short centre casing (40% of vessel's length), no side casings
      - Short centre casing (40% of vessel's length), long side casings (80% of vessel's length)
      - Long side casings (80% of vessel's length), no centre casing
      - Short centre casing (40% of vessel's length), part side casings (40% of vessel's length)
      - Long centre casing (80% of vessel's length), no side casings
    - As nominal number of transverse watertight bulkheads, the integer closer to the result of division of the length of the vessel by 10 should be considered.
    - As nominal vertical location of the bulkhead deck, the 70% of the ratio of draught above the bulkhead deck height (the deck up to which watertight transverse subdivision extends) should be considered. However, the variation refers to the draught of the vessel only (for example, for a vessel with a draft of 2.5 metres, if we lower the vertical location of the vehicle deck by 10 cm, the figure is - 0.04).
  - Output branch probabilities are automatically calculated in Cells D29 to D33, J29 to J32, I68 to I70, I87 and I88. These automatically update the branch probabilities in the event trees for collision, grounding and striking.
- Spreadsheets (**Collision Event Tree**), (**Grounding Event Tree**), (**Striking Event Tree**). No inputs to be provided in these spreadsheets and no alternation should be made.

Cost Model for Flooding

This workbook consists of one spreadsheet only (called **Design Changes**), which contains both inputs and outputs.

- Inputs to this spreadsheet are the following:
  - Length of the vessel, bulkhead deck clearance, breadth, draught, block and midship coefficient, wetted surface area. The values for these parameters are inputted in Cells E7, E9, E11, E13, E15, E17, E21, respectively.

- o Variations of the midship coefficient and wetted surface area are inputted in Cells E18 and E22 respectively.
- o The number of transverse watertight bulkheads and the vertical location of the bulkhead deck for the basis ship are inputted in Cells M11 and M13, whilst the arrangement on the bulkhead deck is determined through the use of the associated drop-down menu.
- o The number of transverse watertight bulkheads and the vertical location of the bulkhead deck for the alternative under consideration are inputted in Cells U11 and U13, whilst the arrangement on the bulkhead deck is determined through the use of the associated drop-down menu.

Fault Tree for Flooding

Macros should be enabled to run this workbook.

- Spreadsheet (**Input Characteristics**): Input values should be entered in this spreadsheet, by selected the appropriate option in the drop-down menus or by entering operational values (input parameters 1 to 16).
- Spreadsheet (**Base Events Frequencies**): No alternation should be made on this spreadsheet. These are the basic assumptions made within the model.
- Spreadsheet (**Fault Tree 1**): No alteration should be made. The output of the spreadsheet is contained in Cell F10.
- Spreadsheet (**Fault Tree 2**): No alteration should be made.
- Spreadsheet (**Figure of Contributions**): Graphical representation of contributions.
- Spreadsheet (**Contributions of Scenarios**): No alteration should be made. Automatic calculation of the branch probabilities of the event tree, using the results of the fault tree analysis.
- Spreadsheet (**Event Tree**): No alteration should be made.

4.3.14 Model for Power Prediction and Weight and Cost of Machinery

4.3.14.1 Theoretical Approach

For the determination of the construction and the operation cost of a HSC (High Speed Craft) the calculation of the propulsive power is a basic demand. Without knowing the power needed for a certain speed it is not possible to estimate neither the cost for the machinery in the manufacturing phase nor the fuel costs for the ship in service.

As it is the intention of the tool to calculate the costs with a variation of different parameters, a power prediction algorithm had to be developed which is able to follow the change of the most important main parameters reasonably.

Available data from model tests with fast vessels (high Froude numbers on deep and shallow water) has been collected and analysed. The target was to generate a formula, which is describing the characteristics of a power curve in none dimensional way. This has been achieved bay introducing a basic (deep water) curve and a shallow water addition. The deepwater curve is not based on physical assumptions but on the best fit to the none dimensionalised measurements for the power. The shallow water hump is modeled as a bump in the region of the Froude depth number 1, dependant in its size on the water depth. The sum of the deep and the shallow water component is recalculated in the full scale using the power 2.3 for the speed and the power 0.75 for the displacement. These values have also been found by the best fit of prediction to the measurements.

Within the limits of the data available it was not possible to include variations of the ratios L/B (length by breadth) or B/T (breadth by draught) – the only parameters of the main dimensions used have been the length (for the Froude number) and the displacement (for the general dependency of the power from the size).

The special details of the hull shape and characteristics of the propulsion system are also not regarded by the algorithm and variation of all these details have no influence on the power calculated.

4.3.14.2 General Steps

The tool can be used on a personal computer with Microsoft® Windows Operating System and Microsoft® Excel 97 or above running. All computers, where Excel can be executed should be able to run the spreadsheet. It can be assumed, that any processor of the Pentium class is sufficient for the tool.

4.3.14.3 Architecture of the Program

The tool consists of a single Excel workbook called:

- PD_HSC.xls

It contains only one spreadsheet titled "Propulsion, Weight and Cost". For the execution of the tool Visual Basic code is linked to this spreadsheet. The main formula to calculate the power is situated in a separate Basic module. It can be used as a user defined function within Excel.

4.3.15 Ship Availability and Active Stabilisation System Costs Model

4.3.15.1 Theoretical Approach

Ship availability refers to the period during which the encountered sea state allows the ship to operate. An availability of 1 means the ship can sail under all sea state conditions.
The HSC code, Annexes 3 and 9, define limits for normal operation and for worst intended conditions, as maximum horizontal and vertical peak accelerations expected for a given period (5 minutes).

In the developed model, the operating and sea state conditions that will be encountered by the ship are defined as a probability distribution of wave incidences with respect to the ship and by a wave scatter diagram (probability distribution of (Tz, Hs), Tz – zero up-crossing period, Hs – significant wave height). The ship speed is considered constant for all these conditions (ship speed input by operator). Wave incidence and sea state (Tz, Hs) are considered to be independent variables.

Then, for each condition wave_incidence(i), and wave characteristics Tz(j), Hs(i), the maximum horizontal and vertical acceleration expected in the selected reference period are calculated using simplified seakeeping models also developed in WP2. For each condition, the availability Γ(i) equals 1 if maximum horizontal and vertical accelerations are lower or equal to the limit (HSC) ones, and equals 0 otherwise. The total availability is then given by:

$$\sum_i \sum_j P(wave\_incidence(i)) \times P(Tz(j), Hs(j)) \times \Gamma(i, j)$$

Accelerations can be calculated in several user defined locations (defined by their coordinates X, Y, Z in meters with respect to the ship aft perpendicular, centerline and baseline), corresponding to passenger and crew locations for instance. Different locations can be defined for horizontal accelerations calculation and for vertical ones. Then the maximum horizontal (resp. vertical) accelerations obtained over the selected locations are compared to the limit values.

The seakeeping models used are closed form expressions. They have been developed within WP2 for the calculation of heave, pitch, roll, vertical acceleration, longitudinal acceleration, transverse acceleration and vertical bending moment RAOs and variance. Since availability criteria are based on acceleration levels, only models for predicting the variance of vertical, longitudinal and transverse accelerations are used in the availability model. These accelerations result from heave, roll and pitch motions and the lever arms between the calculation locations and the ship CG.

The variance of horizontal acceleration is calculated as the sum of the variances of longitudinal and transverse accelerations.

The peak values are derived from the variance σ^2 by: Peak = σ x $[2Ln(N)]^{1/2}$, where N corresponds to the number of waves encountered, and is estimated by Reference_period / Tz for each considered sea state.

The other basic assumptions are the ones used by the simplified seakeeping model, that is:

- For the heave and pitch motions the ship is modeled as a rectangular box
- For the roll motion the ship is modeled as two connected rectangular boxes
- All three motions (heave, pitch and roll) are decoupled
- Heave and pitch motions are 90° out of phase
- The location of the pitch centre corresponds to the ship CG
- The form coefficient δ is fixed to 0.6

4.3.15.2 General Steps

The model should be used as follows:

- In 'Main' worksheet, input of design parameters values, of ship speed and of the class criteria to be used. The list available for the class criteria definition refers to the chart on 'Class criteria' worksheet.
- Check/modifications of locations for acceleration calculations ('Locations' worksheet), wave scatter diagram ('Scatter diagram.' worksheet), wave incidence probability distribution ('Incidence distrib.' worksheet).

- In 'Main' worksheet, press 'AVAILABILITY & ACTIVE STAB. COSTS:' button. The number of conditions (wave incidence, Tz, Hs) to be calculated and the progress (in %) of the calculation is displayed. Once the calculation is finished, 'Completed' appears for progress and the availability value is displayed in the yellow cell.

4.3.15.3 Architecture of the Program

The availability model has been implemented in the Excel file S@S_WP2_availability_v*i.ii*.xls and coded in Visual Basic. The file contains six worksheets:

- Main: where the design parameters and speed are input by the operator, the availability calculation is run and the results displayed.
- Locations: where the co-ordinates of the locations where horizontal and vertical accelerations have to be calculated. The locations are defined separately for horizontal and vertical accelerations.
- Scatter diagram: where the wave scatter diagram is input.
- Incidence distribution: where the wave incidence distribution with respect to the ship is input.
- Class criteria: where criteria for defining availability are defined. The criteria correspond to a reference period of peak value occurrence, limit horizontal acceleration and limit vertical acceleration. Several values can be defined, corresponding to different Classification Societies for instance.
- Cost Data in which equipment, labor, overheads and maintenance cost information for active stabilization are given.

4.4 The S@S Project Tool Application Studies by Fincantieri

The main objective of Work Package 6 case study was to test in a real-life HSC design process the majority of methods and tools developed in WP1 to WP4 of S@S project and integrated in a unique tool by WP5.

The method used for this Work Package 6 was to start using the integrated tool with a baseline existing High Speed Craft, assessing its overall safety level. The second step was to generate an enhanced vessel, considering both safety and cost effectiveness and the third step was to compare the two designs and the use of the integrated tool during the two different processes.

The chosen baseline ship was the Superseacat III, a monohull Ro-Ro Fast ferry, designed and built by Fincantieri.

During the first step (task 6.1) the Project Tool has been used from a user point of view.
The values of the ship "SuperSeaCat 3" or all the necessary technical assumptions have been used as input parameters and a calculation was performed by means of the Project Tool and the software FaultTree+. In that way the safety level of the ship was assessed.

During the first part of the task, corrections were made to the models and to the integrated tool, both in the details of input process and in the code itself. After these corrections the Tool was entirely running and the input parameters were closer to a real design frame-work.

Some other comments have been pointed and were discussed during a specific workshop with other Work Packages leaders.

During the task 6.2 a definite run of simulation for the basic vessel was proposed considering also the conclusions and the proposed changes requested since the first step of work.

The results found were judged realistic and the run of few calculations allowed underlining the most important critical parameters. Among them, the speed, the draft and the frame spacing.

The results were analysed and several calculations were run in order to find the main critical parameters and subsequently the alternative design configurations to be tested.

The final scope of WP6 included in task 6.3 was to compare the results obtained from the tool, when the alternative configurations were adopted, with the basic design results analysing also the impact in terms of design constraints. The major aim in the comparison of results was to demonstrate the consistency of the final results from the tool both for safety and design to cost.
As first step, a list of cut sets gathered for final consequence has been extracted by “fault tree”. The first two orders of magnitude, that are the most significant in terms of risk impact, have been evaluated to lighten the analysis without loss of accuracy.

There are 6 class of severity under study:

- Catastrophic for humans
- Catastrophic for ship
- Severe for humans
- Severe for ship
- Significant for humans
- Major for ship

The analysis was performed making a comparison between the basic design and the new configuration pointing out the relevant differences.

The consistency of the results is here reported to underline the accuracy of the proposed models as well as of the integrated tool.

4.4.1 Comparison between basic Vessel and configuration 1

Hereafter are shortly summarised the main changed parameters between the basic and the first alternative configuration (Conf 1)

Critical Parameters	Basic Vessel	Conf 1
L_{BP}	88 m	92,4 m
L_{OO}	100 m	105 m
B_{WL}	14,2 m	14,2 m
T	2,63 m	2,63 m
Δ	1332t (1300 m^3)	1400 t (1365m^3)
C_b	0.396	0.396
LCG	35,20 m	36.96 m
N_{PT}	8	10
P	20550 KW	21200 KW
tp	5 mm	6mm
b	500mm	250mm
SCF	1.5	1.3
Number of passengers	800	860
Number of cars	175	189
Wetted surface areas	1400	1470
Detection reliability	0.85	0.9
Required deadweight	340	357
Presence of paging system	No	No

Figure 7: Data of Basic Vessel and Configuration 1

4.4.1.1 Risk evaluation

The corresponding risk level results are summarised below:

Basic Vessel Alternative configuration 1

Effect on Property					Effect on Property			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	1.45E-03	1.45E-05
Major	0.1	4.46E-03	4.46E-04		Major	0.1	4.48E-03	4.48E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.49E-04	5.49E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	6.68E-04	6.68E-03
			9.03E-03					7.69E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.91E-03	1.91E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	4.83E-03	4.83E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	1.04E-03	1.04E-03
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	6.56E-05	6.56E-04
			3.37E-03					2.20E-03

Figure 8: Risk levels for basic vessel and configuration 1

4.4.1.1.1 Major points of influence

The major differences between top events, which influence the high severity classes (Catastrophic for ship and for human), are principally:

- Foundering incident: there is a decreasing of basic event "Critical local failure" due to the modifications in configuration 1 for panel dimensions and space framing, while "Critical global failure" is subject to increase, because the displacement increased in configuration 1, and this enlarged the load on the hull structure, so the probability of global failure is more increased. The results are consistent with reality.

- Collision in restricted water/open sea: the presence of two additional bulkheads in conf.1 increases the probability for the ship to remain afloat, while decreases the probability of sinking. The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

- Ignition event: in configuration 1 there is less probability of ignition because the detection system was improved, with relevant costs added. The detector reliability increases from 0.85 to 0.90. The model well defines the variation of this parameter.

- Striking with a fixed object in restricted water/open sea: the presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. The result is technical correct, because a higher number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

- Drift grounding/Powered grounding: the presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. Moreover, also the length variation leads to a better floatability against the probability of sinking. The results are consistent with reality, because the model take into account both a better watertight subdivision and a better reserve of buoyancy due to the increase of length.

4.4.1.2 Cost evaluation

The result of ICAF calculation performed by the tool is the follow: **ICAF** = 1.62 E+08
This is due to an improvement in human safety (2.20E-03 in configuration 1 against 3.37E-03 in basic vessel) and to an increase in terms of cost (the change in NPV value is –189589 euros).

4.4.1.3 Conclusion

In configuration 1, there is a reduction of human catastrophic consequence frequency of about 1.17×10^{-3} in respect to basic vessel. Considering a full load vessel (800 persons) and the 75% of people involved in the accident (600 people), this result means 0.702 fatalities per ship/year.

This improvement is obtained with an increased cost (NPV) of about 189 589 euros.

4.4.2 Comparison between basic and configuration 2

Hereafter are shortly summarized the main changed parameters between the basic vessel and the second alternative configuration

Critical Parameters	Basic vessel	Conf. 2
L_{BP}	88 m	88 m
L_{OO}	100 m	100 m
B_{WL}	14,2 m	14,2 m
T	2,63 m	2,63 m
Δ	1332t (1300 m^3)	1334 t (1301m^3)
C_b	0.396	0.396
LCG	35,20 m	35.20 m

Critical Parameters	Basic vessel	Conf. 2
N_{PT}	8	10
P	20550 KW	20550 KW
tp	5 mm	6mm
b	500mm	250mm
SCF	1.5	1.3
Number of passengers	800	800
Number of cars	175	175
Wetted surface areas	1400	1400
Detection reliability	0.85	0.9
Required deadweight	340	340
Presence of paging system	No	No

Figure 9: Data of Basic Vessel and Configuration 2

4.4.2.1 Risk evaluation

The corresponding risk level results are summarised below:

Basic Vessel — Alternative configuration 2

Effect on Property					Effect on Property			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	1.45E-03	1.45E-05
Major	0.1	4.46E-03	4.46E-04		Major	0.1	4.48E-03	4.48E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.49E-04	5.49E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	6.55E-04	6.52E-03
			9.03E-03					7.56E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.91E-03	1.91E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	4.83E-03	4.83E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	1.04E-03	1.04E-03
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	5.00E-05	5.00E-04
			3.37E-03					2.05E-03

Figure 10: Risk levels for basic vessel and configuration 2

4.4.2.1.1 Major points of influence

The major differences between top events, which influence the high severity classes (Catastrophic for ship and for human), are principally:

- Foundering incident: there is a decreasing of basic event "Critical local failure" due to the modifications in configuration 2 for panel dimensions and space framing, while "Critical global failure" remains constant, because the displacement is the same than basic vessel, so the load on the hull structure is again the same. The results are consistent with reality.

- Collision in restricted water/open sea: the presence of two additional bulkheads in conf.2 increases the probability for the ship to remain afloat, while decreases the probability of sinking. The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

- Striking with a fixed object in restricted water/open sea: the presence of two additional bulkheads increases the probability for the ship to remain afloat, while decreases the probability of sinking. The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

- Drift grounding: the presence of two additional bulkheads in conf.2 increases the probability for the ship to remain afloat, while decreases the probability of sinking. The result is technical correct, because an augment of number of bulkheads leads to a better watertight subdivision, that increases the ship floatability after damage.

4.4.2.2 Cost evaluation

The result of ICAF calculation performed by the tool is the follow: **ICAF** = 1.24 E+08
This is due to an improvement in human safety (2.05E-03 in configuration 2 against 3.37E-03 in basic vessel) and to an increase in cost (the change in NPV value is – 164760 euros).

4.4.2.3 Conclusion

In configuration 2, there is a reduction of human catastrophic consequence frequency of about $1.32x10^{-3}$ in respect to basic vessel. Considering a full load vessel (800 persons) and the 75% of people involved in the accident (600 people), this result means a reduction by 0.792 fatalities per ship/year.
This end result is obtained with an increased cost of about 164 760 euros.

4.4.3 Comparison between basic and configuration 3

Hereafter are shortly summarized the main changed parameters between the basic vessel and the third alternative configuration

Critical Parameters	Basic vessel	Conf 3
L_{BP}	88 m	83.6 m
L_{OO}	100 m	95 m
B_{WL}	14,2 m	14.2 m
T	2,63 m	2.63 m
Δ	1332t (1300 m^3)	1265 t (1234m^3)
C_b	0.396	0.396
LCG	35,20 m	33.44 m
N_{PT}	8	8
P	20550 KW	19850 KW
tp	5 mm	6
b	500mm	250
SCF	1.5	1.3
Number of passengers	800	740
Number of cars	175	161
Wetted surface areas	1400	1330
Detection reliability	0.85	0.9
Required deadweight	340	323
Presence of paging system	No	Yes

Figure 11: Data of Basic Vessel and Configuration 3

4.4.3.1 Risk evaluation

The corresponding risk level results are summarised below:

Basis Vessel | Alternative configuration 3

Effect on Property					Effect on Property			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.45E-03	1.45E-05		Minor	0.01	9.07E-04	9.07E-06
Major	0.1	4.46E-03	4.46E-04		Major	0.1	1.97E-03	1.97E-04
Severe	1	5.48E-04	5.48E-04		Severe	1	5.16E-04	5.16E-04
Catastrophic	10	8.02E-04	8.02E-03		Catastrophic	10	3.20E-04	3.20E-03
			9.03E-03					3.92E-03

Effect on Human Safety					Effect on Human Safety			
Name	Weight	Frequenc	Risk		Name	Weight	Frequenc	Risk
Minor	0.01	1.91E-03	1.91E-05		Minor	0.01	1.48E-03	1.48E-05
Significant	0.1	4.82E-03	4.82E-04		Significant	0.1	2.36E-03	2.36E-04
Severe	1	1.06E-03	1.06E-03		Severe	1	7.25E-04	7.25E-04
Catastrophic	10	1.81E-04	1.81E-03		Catastrophic	10	3.49E-05	3.49E-04
			3.37E-03					1.33E-03

Figure 12: Risk levels for basic vessel and configuration 3

4.4.3.1.1 Major points of influence

The major differences between top events, which influence the high severity classes (Catastrophic for ship and for human), are principally:

- Foundering incident: there is a reduction of basic event “Critical local failure” due to the modifications in configuration 3 for panel dimensions and space framing, while “Critical global failure” is subject to reduction, because the displacement decreases in configuration 3, and this reduces the load on the hull structure, so a global collapse is less probable. The results are consistent with reality.
- Ship in dangerous/marginal dynamic stability zones: this event is related with the dynamic stability model. The parameters involved in the calculation are principally the ship main dimensions. Since the configuration 3 have smaller values of some of them, the model assess it is more dangerous from a dynamic point of view.
- Collision in restricted water/open sea: the related basic event values in fault tree have a drop due principally to the introduction of paging system in conf.3. This seems not confident with reality, so this aspect is improvable.
- Ignition event: in configuration 3 there is less probability of ignition because the detection system was improved, with relevant costs added. The detector reliability increases from 0.85 to 0.90. The model well defines the variation of this parameter.

- Striking with a fixed object in restricted water/open sea: the related basic event values in fault tree have a drop due principally to the introduction of paging system in conf.3. This seems not confident with reality, so this aspect is improvable.
- Powered grounding: once time again, the related basic event values in fault tree have a drop due principally to the introduction of paging system. This effect is stronger than the lesser reserve of buoyancy assessed by the model for conf.3, so the powered grounding probability decreases.
- Drift grounding: the length variation leads to a worst floatability against the probability of sinking. The results are consistent with reality, because the model take into account a lesser reserve of buoyancy due to the reduction of length.

4.4.3.2 Cost evaluation

4.4.3.3 Cost evaluation

The result of the ICAF calculation performed by the tool is the following figure:

ICAF = -3.27 E+08.

This is due to an improvement in human safety (1.33E-03 in configuration 3 against 3.37E-03 in basic vessel) and to a decrease in cost (the change in NPV value is 666454 euros).
This type of value comes from different considerations.
First of all it should be noted a great decreasing in NPV value, because the costs decreases coherently with the ship main dimensions, but the gain assess by the model is always the same as in basic configuration. The model is not sensible to deadweight modification, but it is referred only to the market data inputted in the tool, so all the three configurations have the same assessed gain per year. This aspect is surely improbable, because the market demand is too conservative, and it doesn't consider different travelling seasons.
As second remark, the presence of paging system has a strong influence on evaluated the risk level: the event "Internal communication failure" is less important, and all the events connected with it have a drop in their frequencies of occurrence.
The combined effect of the above consideration leads to have minor cost than in the basic configuration, but more human safe life.

4.4.4 Global conclusion

The above results show how it' s possible to evaluate the costs connected with saving human life.
The tool provides an evaluation methodology that could be integrated, with expert experience, inside the design process. Once determined a certain number of alternative configuration, the decision making for design to cost could be performed through ICAF value. The designer has to weigh up different cost for human safety, and then choose among different solutions the most appropriate by the risk/cost effectiveness point of view.
The correct quantify of ICAF value is given by the experience of each designer.

WP6 work package has reached its goal, which is to demonstrate the reliability of results. The tool was tested through a well defined project, and the results obtained in term of risk and cost evaluation show consistency with the reality. That derives from the goodness of developed work.

From these introductions, the tool constitutes an important starting point towards the fully integration process of the safety requirements into the different design phases.

4.4.5 List of abbreviations and symbols for section 4.4

L_{BP}	Length between perpendicular
L_{OO}	Length overall
B_{WL}	Breadth Waterline
T	Draught
Δ	Displacement
LCG	Longitudinal Center of Gravity
N_{PT}	Number of Transverse bulkhead
P	Power
tp	Plate thickness
B	Stiffener spacing
SCF	Stress Concentration Factor
NPV	Net Present value
ICAF	Implied Cost to avert a Fatality

5 LIST OF DELIVERABLES

The following table shows the list of deliverables completed in accordance with the 'Description of Work' originally planned:

Title	No.	Author	Document ID	Issue date
Confirmation of main causes	D1.1.0	DAP	S101.10.03.056.001	2002-02-25
Formulation of models	D1.2.0 (combined D121, D122 & D123)	DAP	S101.20.03.054.001A	2002-09-11
Implementation of models for human error	D1.3.1	FORCE	S101.31.01.052.001	2003-08-22
Implementations of models for mechanical and automation failures	D1.3.2	DAP	S101.23.03.051.001	2003-08-22
Implementation of models for manoeuvrability errors	D1.3.3	SIREHNA	S101.33.11.052.001	2003-06-30
Implementation of integrated model for controllability	D1.3.4	DAP	S101.34.03.054.001	2004-04-13
Ship Motions Hazards: Confirmation of Main Courses	D2.1.0	SIREHNA	S102.10.11.054.001	2001-12-03
Formulation of Model for Human Factor	D2.2.1	VTT	S102.21.07.052.001A	2003-06-10
Formulation of Models	D2.2.2 & D2.2.3	SIREHNA	S102.22.11.52.001A	2003-01-07
Implementation of Models for Human Factor	D2.3.1	VTT	S102.31.07.052.001	2003-12-22
Implementation of Models – Seakeeping and Availability Models	D2.3.2	SIREHNA	S102.32.11.052.001A	2003-10-28
Implementation of Models – Broaching Models	D2.3.3	SIREHNA	S102.33.11.052.001A	2003-12-02

Title	No.	Author	Document ID	Issue date
Confirmation of Main courses	D3.1.0	ABS	S103.10.06.054.001	2001-11-30
Formulation of Loads	D3.2.1	ABS	S103.21.06.052.001	2004-06-28
Formulation of FE Modeling	D3.2.2	NTUA	S103.22.14.052.001	2003-10-27
Formulation of Linear and Non-linear Models	D3.2.3	UNEW	S103.23.06.054.001	2004-05-17
Fatigue and Longevity Model	D3.2.4	UNEW	S103.24.13.051.001A	2002-12-12
Structural Foundering Risk Cost Model	D3.3.0	UNEW	S103.30.13.053.001A	2003-09-30
Structural Foundering Risk Cost Model User's Manual (Voluntary deliverable)	D3.3.0	UNEW	S103.30.13.060.004A	2003-09-30
Containment of Damage and Fire – Confirmation of Main Courses	D4.1.0	SSRC	S104.10.09.054.002	2002-02-22
Formulation of Models -Containment of Damage and Fire	D4.2.0	SSRC	S104.20.09.054.001A	2002-12-23
Risk/Cost Containment Model	D4.3.0	SSRC	S104.30.09.054.001A	2003-10-13
Verification and Validation Procedure/Scheme – Main Causes	D5.1.0	BV	S105.10.02.053.001	2002-05-14
Verification and Validation Procedure/Scheme – Models	D5.1.2	BV	S105.12.02.053.001	2003-10-17
S@S Project tool	D5.2.0-D5.3.1-D5.3.2	BV /UNEW	Software on CD-rom	2004-06-30
Design for Safety Methodology	D5.5.0	UNEW	S105.40.13.054.001	2004-08-20
Baseline Ship Safety Results	D6.1.0	METTLE	S106.10.12.053.001C	2004-05-12
Enhanced Design	D6.2.0	CETENA	S106.20.16.057.001A	2004-08-24
Comparison of Final Results	D6.3.0	FIN	S106.30.08.057.001B	2004-08-24

6 RESULTS AND CONCLUSIONS

The main outcome of the project is a formalised methodology for design for safety of HSC. This methodology is a practical procedure relying on an integrated design tool, able to compare in terms of risk and cost several alternative preliminary designs of a HSC. The methodology is based on the Formal Safety Assessment approach as per the interim Guideline by IMO (1997/2002).

The Project 'Tool' is organised around a generic safety model and a cost model bound together by the parameters of the proposed design. A parameter is a variable that impacts the safety level and cost of the ship, i.e. a change in the parameter's value causes a change to the safety characteristics and to the cost of the ship. The parameters are basic parameters of naval architecture and other parameters related to operational environment (e.g. intended route) or owner requirements (e.g. ship's availability) for instance.

The risk model materialises under a logical form the various scenarios of accidents that may be encountered by a HSC. The logic of the risk model is based on the risk contribution tree methodology. Fault trees and event trees describe the hazardous situations that may be encountered by the ship.

The Project 'Tool' appears in practice as a software, which can be used by designers to optimize the design with regard to cost and safety. The 'Tool' was at the end of the project as the last workpackage tested for a number of designs by the shipyard partner Fincantieri, who arrived at the following conclusions:

'The results show how it is possible to evaluate the costs connected with saving human life. The tool provides an evaluation methodology that could be integrated, with expert experience, inside the design process. Once determined a certain number of alternative configuration, the decision making for design to cost could be performed through ICAF value.

The tool constitutes an important starting point towards the full integration of the safety requirements into the different design phases.'

7 DISSEMINATION AND ACKNOWLEDGEMENTS

7.1 List of Partners' Relevant Publications

7.1.1 BV and UNEW Publications

Delautre, S., Birmingham, R., Astrugue, J-C., McGregor, J., (2003) "Application of risk based methodology to the preliminary design phase of high speed craft", FAST 2003

Birmingham, R., McGregor, J., Astrugue, J-C., (2003) " Development of a safety based design tool for High Speed Craft", IMDC'03

Birmingham, R., McGregor, J., Delautre, S., Astrugue, J-C., (2004) "Risk Evaluation at the Preliminary Design Stage of a High Speed Craft", SNAME Journal of Ship Production Special Edition.

Birmingham, R., McGregor, J., Besse P., Delautre, S., ''Creating a framework for rsik based design'', IMDS - OCT'04

7.1.2 DTU Publications

Jensen, J.J. and Mansour, A.E.: Estimation of Ship Long-term Wave-induced Bending Moment using Closed-form Expressions". Trans. RINA, pp. 41-55, 2002.

Jensen, J.J. and Mansour, A.E.: "Estimation of the Effect of Green Water and Bow Flare Slamming on the Wave-Induced Vertical Bending Moment Using Closed-Form Expressions", Proceedings 3rd International Conference on Hydroelasticity in Marine Technology, pp. 155-161. Ed. R. Eatock Taylor, The Oxford University, Oxford, Sep. 2003.

Jensen, J.J.:"Fast Evaluation of Ship Responses in Waves", Submitted to ICHD2004, Perth, Australia, 24-26 November 2004

Olsen, A.S., Schrøter, C. and Jensen, J.J.:"Encountered Wave Height Distributions for Ships in the North Atlantic Sea", Submitted to PRADS´04, Travemünde, September 2004

Jensen, J.J., Mansour, A.E. and Olsen, A.S.: "Estimation of Ship Motions using Closed-Form Expressions", Ocean Engineering, Vol. 31, pp 61-85, 2004

Mansour, A.E., Jensen, J.J. and Olsen, A.S.: "Fast Evaluation of Container Securing Arrangements", Submitted to PRADS´04, Travemünde, September 2004

7.1.3 SSRC Publications

A keynote address has been delivered to the recent FAST 2003 conference on the risk/cost model developed as part of the activities of this project.

Konovessis, D., Vassalos, D. and Cabaj, D.: "Developments on a Probabilistic Risk/Cost Model for Large-Scale Flooding Consequence Analysis of High Speed Monohulls"

A journal paper on this model is under preparation at this moment.

7.2 S@S Home Page

During the project S@S has taken the advantage of sharing files between partners by using the Internet. Very early in the project phase the coordinators decide to establish a web site hosted by the coordinators at FORCE Technology.

The web was built on a two level platform. The top-level site was a public site explaining in overall terms about the S@S-project and exhibits the partners involved. Second level was an internal site only accessible for the partners involved in S@S. Partners has throughout the project delivered files, documents and presentations to the web site, which has given a transparency for everybody to take part in discussions and just follow other WP's.

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[3] Implementation of models - Seakeeping and availability models, S@S deliverable No. D2.3.2, ID S102.32.11.052.001B.

8.2 Listed by SIREHNA

“Guidance to the master for avoiding dangerous situations in following and quartering seas”, IMO MSC/Circ.707, 19 October 1995.

8.3 Listed by NTUA

Todd, F.H.: ” Ship Hull Vibration”, Edwart Arnold Publ. 1961

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9 APPENDIX 1 – BV LEAFLET ON THE S@S PROJECT

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