

## INTEGRATING PERSONNEL MOVEMENT SIMULATION INTO PRELIMINARY SHIP DESIGN

D Andrews, L Casarosa and R Pawling, University College London, UK  
E Galea, S Deere and P Lawrence, University of Greenwich, UK

### SUMMARY

Traditionally, when designing a ship the driving issues are seen to be powering, stability, strength and seakeeping. Issues related to ship operations and evolutions are investigated later in the design process, within the constraint of a fixed layout. This can result in operational inefficiencies and limitations, excessive crew numbers and potentially hazardous situations.

University College London and the University of Greenwich are in the final year of a three year EPSRC funded research project to integrate the simulation of personnel movement into early stage ship design. This allows the assessment of onboard operations while the design is still amenable to change.

The project brings together the University of Greenwich developed maritime EXODUS personnel movement simulation software and the SURFCON implementation of the Design Building Block approach to early stage ship design, which originated with the UCL Ship Design Research team. Central to the success of this project is the definition of a suitable series of Naval Combatant Human Performance Metrics which can be used to assess the performance of the design in different operational scenarios.

The paper outlines the progress made on deriving the human performance metric from human factors criteria measured in simulations and their incorporation into a Behavioural Matrix for analysis. It describes the production of a series of SURFCON ship designs based on the RN Type 22 Batch 3 frigate, and their analysis using the PARAMARINE and maritime EXODUS software. Conclusions to date will be presented on the integration of personnel movement simulation into the preliminary ship design process.

### 1. INTRODUCTION

#### 1.1 PERSONNEL MOVEMENT ISSUES IN SHIP DESIGN

Human Factors (HF) have a significant impact on the design of ships and can be considered at two levels: that of micro-ergonomics and of macro-ergonomics. Micro-ergonomics applies at the detailed level of design, to achieve effective person-machine interfaces and to conduct specific maintenance and repair operations to the ship and its equipment. Historically, macro-ergonomics historically has been adopted as systems-based term, encompassing HF related organisational and management aspects of the design including designing the watch-keeping organisation and assessing the trade off between automation and overall manning [1].

Apart from these two levels of HF application there is the important aspect of addressing personnel movement on board ship as a major influence on the operability and usability of the whole ship. This is strongly related to the overall physical arrangements or architecture of the vessel. [2] In order to assess the aspects related to personnel movement in the ship, the configuration at an early stage of the design process has to be accurately yet flexibly modelled. That is to say the model must provide a broad definition of the main configurational features. Up to the present only after the overall form of the ship's layout has been finalised and the traditional naval architectural issues (e.g. powering, stability, strength and

seakeeping) have been addressed, are issues related to crewing, ship operations and evolutions then investigated, and then only within those overall design constraints. It can be seen that this relatively late consideration of personnel movement aspects could then result in significant operational inefficiencies and potentially hazardous environments, in particular on a combatant vessel.

Once the ship design is into the detailed development stage then detailed CAD models can be used by specialist experts to assess the relevant HF aspects, as part of evaluating the usability of a given design. A typical example of micro-ergonomics features appraisal is the use of computer generated models in conjunction with virtual reality and simulation software packages to perform real-time 3-D assessment of the practicality of both the operation and maintenance of onboard systems. An example of this was the simulation by VSTEP of the operator position and associated sightlines in a dredger. [3].

However, it has been argued in Reference 4 that computer aided graphics now provide the ship designer with the ability to consider the ship configuration in a more interactive manner from the earliest stages of design. Thus a wide range of HF issues related to ship operations can be considered at these early design stages, as they influence the location, layout and sizing of critical spaces such as the Bridge, Ship Control Centre, Operations Room, machinery spaces, accommodation

and the main access routes linking them. In addition to the main ship design stylistic decisions and considerations of gross layout and operational space design, one of the important aspects, where HF considerations can have significant design and cost impact, is in achieving a more efficient configuration, thereby reducing the required manning levels. Recent studies by CETENA S.p.A and the Italian Navy, aimed at reducing costs and optimizing manning, have featured a range of HF and Human-Systems Integration (HSI) issues. [5] Large-scale personnel movement and evacuation has also been investigated for the Royal Navy's Future Aircraft Carrier (CVF) design, given the ships' intended the large complement (circa 1200). The second set of authors from the Fire Safety and Engineering Group (FSEG) at the University of Greenwich (UoG) have undertaken simulations of evacuation for that carrier project using their maritimeEXODUS software, outlined in Section 2. [6]

The movement of personnel is one of the key areas of whole-ship usability that can be improved if it is assessed early enough in the design process. Analysis of the specific issue of personnel and passenger flow in evacuation from passenger vessels is currently covered by IMO MSC Circular 1033 [7] which provides a framework for the conduct of evacuation analysis for the whole ship. However, this only takes into account a single aspect of personnel flow (evacuation) and is undertaken to demonstrate compliance with standards, rather than assessment and improvement of the design at an early stage. Furthermore, it may be inappropriate for naval practice and evacuation procedures since it was defined for civilian passenger evacuation.

## 1.2 THE JOINT UCL/UoG PROJECT

Current work in the simulation of personnel movement in ships has focused on evacuation, or specific evolutions covering only part of the design. The UCL Design Research Centre (DRC) and UoG Fire Safety Engineering Group (FSEG) are investigating the application of simulation to personnel movements through out the ship, in a wider variety of operating conditions. This being undertaken as part of a project entitled "Guidance on the Design of Ships for Enhanced Escape and Evacuation", which is sponsored by the UK Engineering and Physical Sciences Research Council (EPSRC) and UK Ministry of Defence (MoD) Sea Technology Group (STG) (now the Sea Systems Group in the Defence Procurement Agency). [8] This three year project, which started in October 2004, has five key objectives:

- To explore the impact on naval ship configurational design of issues associated with crew manning numbers, function and movement;
- To identify key performance measures for successful crew performance in normal and extreme conditions;

- To extend the ship evacuation software maritimeEXODUS to include additional non-emergency simulation capabilities;
- To extend the ship design software SURFCON so that it can provide a modelling environment that interactively accepts maritimeEXODUS simulation output for a range of crew evolutions;
- To demonstrate an approach to ship design that integrates ship configuration design with modelling of a range of crewing issues through PARAMARINE / SURFCON.

This work brings together two software packages and centres of knowledge; PARAMARINE / SURFCON, a graphically-centred early stage ship design tool used by the UCL DRC for preliminary ship design; and maritimeEXODUS, an advanced personnel evacuation and movement simulation tool developed by the FSEG at UoG. The project aims to enable the tools to readily interface and for them to be used to generate guidance, not only on design for evacuation but design for enhanced operational effectiveness with regard to personnel issues.

It is intended that this multidisciplinary research project will demonstrate the advantages of integrating the cutting edge technologies of Personnel Simulation and Ship Configurational Design. In so doing it will enhance the guidance for all parties in the design, regulation, construction and operation of ships with regard to the main aspects related to personnel movement on board.

## 2. RESEARCH TEAMS AND SOFTWARE

### 2.1 THE UCL DESIGN RESEARCH CENTRE AND THE SURFCON DESIGN TOOL

The UCL Design Research Centre (DRC) is a relatively new research organisation alongside the long standing Naval Architecture and Marine Engineering (NAME) Group within the Department of Mechanical Engineering at University College London. Its main area of research is in computer aided preliminary ship design using the Design Building Block approach and its implementation in the SURFCON tool.[4, 9] SURFCON is part of the PARAMARINE software produced by Graphics Research Corporation Limited is an object-based naval architectural design package utilising the commercial ParaSolids modeller as its core. [10] A screenshot of the system in use is shown in Figure 1. The user inserts objects in the "tree pane" on the left of the screen, which shows a logical hierarchal description of the design, whilst any spatial extents or graphical representation are shown in the "graphical pane" on the right of the screen. This provides a constantly updated graphical representation of the current state of the design, a particularly important feature when considering the layout of the vessel. PARAMARINE / SURFCON is not merely a graphical layout tool, it also contains objects for the assessment of the performance of the design across a

range of design capabilities, including resistance and propulsion, stability, manoeuvring and radar cross section, in order that each design study is both hydrostatically balanced and achieves the desired levels of performance. A typical numerical analysis is shown in the top right hand box of Figure 1.

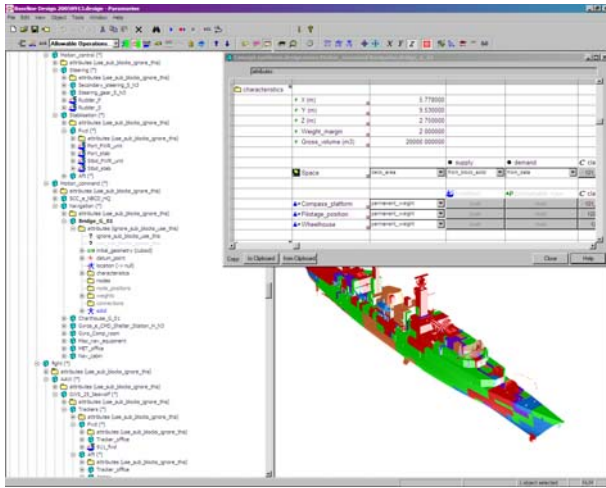


Figure 1: Multiple views of a Design Building Block using SURFCON.

The fundamental basis of SURFCON and the Design Building Block approach is the Design Building Block object. This is a placeholder or folder in the design space, which contains all descriptive information relevant to a particular function. For example, Figure 2 shows the hierarchical view of a block representing a mess deck for Junior Rates, and the corresponding graphical view.

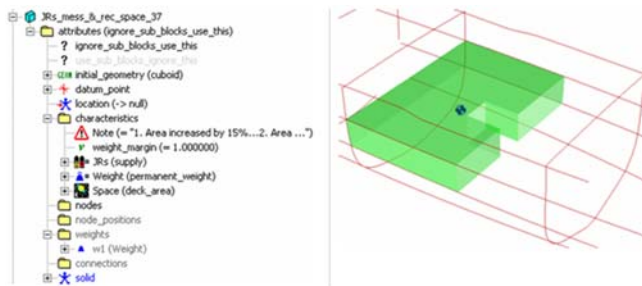


Figure 2: Design Building Block hierarchical and graphical views of a mess deck.

The Design Building Block approach to early stage ship design seeks to encourage a more holistic approach to the development of the ship design solution. Instead of a set of numerical steps or a mechanistic approach, where each aspect of the performance of the design is examined separately and in turn, the integrated nature of the SURFCON implementation in PARMARINE allows all relevant aspects of the design's effectiveness to be assessed at the earliest stages of design.

## 2.2 UoG FIRE SAFETY ENGINEERING GROUP AND maritimeEXODUS

The ship evacuation model maritimeEXODUS [6, 11, 12] produced by the Fire Safety Engineering Group (FSEG) of the University of Greenwich was used to perform the *personnel* simulations presented in this paper. The software has been described in detail in many publications [6, 11, 12] and so only a brief description of the software will be presented here. EXODUS is suite of software to simulate the evacuation and circulation of large numbers of people within a variety of complex enclosures. maritimeEXODUS is the ship version of the software. The software takes into consideration people-people, people-fire and people-structure interactions. It comprises five core interacting sub-models: the Passenger, Movement, Behaviour, Toxicity and Hazard sub-models. The software describing these sub-models is rule-based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules. Many of the rules are stochastic in nature and thus if a simulation is repeated without any change in its parameters a slightly different set of results will be generated. It is therefore necessary to run the software a number of times as part of any analysis. These submodels operate on a region of space defined by the GEOMETRY of the enclosure. The Geometry can be specified automatically using a DXF file produced by a CAD package or manually using the interactive tools provided. In addition to the representation of the structure itself, the abandonment system can also be explicitly represented within the model, enabling individual components of the abandonment system to be modelled individually.

maritimeEXODUS produces a range of output, both graphical and textual. Interactive two-dimensional animated graphics are generated as the software is running that allows the user to observe the evacuation as it takes place. In addition, a post-processor virtual-reality graphics environment known as vrEXODUS is provided enabling an animated three-dimensional representation of the evacuation (see Figure 3).



Figure 3: vrEXODUS output showing mustering in a large passenger ship.

The software has a number of unique features such as the ability to incorporate the effects of fire products (e.g. heat, smoke, toxic and irritant gases) on crew and passengers and the ability to include the impact of heel and trim on passenger and crew performance. The software also has the capability to represent the performance of both naval personnel and civilians in the operation of watertight doors, vertical ladders, hatches and 60 degree stairs. Another feature of the software is the ability to assign passengers and crew a list of tasks to perform. This feature can be used when simulating emergency or normal operations conditions. As part of the current project, the software's capabilities has been extended through the inclusion of a number of new task capabilities required for normal operations scenarios and include; a 'terminate' command, used in the normal operations scenarios allowing crew to stay at their last location once a task has been completed; a 'repeat' command, used to allow crew to repeat predefined set of tasks a number of times as is required in the patrol task; a 'search compartment' command which instructs crew to enter a list of assigned compartments to undertake a search as part of the blanket search scenario. In addition, a separate utility program has been developed (the Human Performance Metric Analyser) which automatically constructs the matrix of human performance scores from maritimeEXODUS output that are used in the evaluation of the vessel design.

### **3. HUMAN PERFORMANCE METRICS**

In order to gauge the HF performance of a vessel it is essential to define a range of relevant Evaluation Scenarios (ES) against which the vessel will be tested. These scenarios will effectively define the scope of the challenges that the vessel will be subjected to. In order to gauge vessel performance across a range of criteria, the ES are made up of both evacuation and normal operations scenarios. Relevant evacuation scenarios may include those required by MSC Circular 1033 [7] or their naval equivalent [13]. The normal operations scenarios will very much be dependent on the nature and class of vessel and may include for example time to complete 'State 1 Preps'.

As members of the ship's complement may be involved in undertaking different tasks during a particular ES, the ship's complement is divided into subgroups. Membership of each subgroup is determined by the

nature of the tasks undertaken by the individuals in the particular ES, with each subgroup being made up of people undertaking a common set of tasks. These subgroups are labelled Functional Groups (FG). An example of a FG is the 'damage control and fire fighting' group. In practise there may be several FG on board the vessel whose performance must be evaluated e.g. 'Damage control and fire fighting', 'Warfare', 'Flight'.

To evaluate the performance of the FGs in undertaking the tasks required to complete the ES, a range of Performance Measures (PM) are defined. A PM for a naval vessel normal operations scenario may involve the total number of water tight doors opened and closed during a particular operation. The suitability of the vessel layout will be evaluated for fitness of purpose through some combination of the PM resulting from the execution of the ES. The evaluation scenarios considered in the current implementation of the HPM are, Evacuation Action Stations, Evacuation Normal Day Cruising, Evacuation Normal Night Cruising, State 1 Preps and Blanket Search.

Collectively the particular combination of ES and PM that results in a meaningful measure of the performance of the crew and vessel are described as a Human Performance Metric (HPM). Clearly, the HPM will be specific to the type and class of vessel being investigated. For example, an aircraft carrier will have a different HPM to a submarine. However, the underlying concept of the HPM will be common to all types of vessels and indeed, some of the various components that make up the HPM may even be similar across different types of vessels.

Thus to evaluate the human performance of a particular vessel design X, a series of PMs are evaluating representing the performance of the FGs in a range of ESs as illustrated in Figure 4. The collection and combination of PMs is known as the HPM. Use of the HPM is intended to aid the ship designer in analysing evacuation/normal operations simulations results quickly and efficiently as well as highlighting any problematic areas within each design. The HPM works by systematically evaluating one layout design against another, whether this is two variants of the same design or two completely different designs.

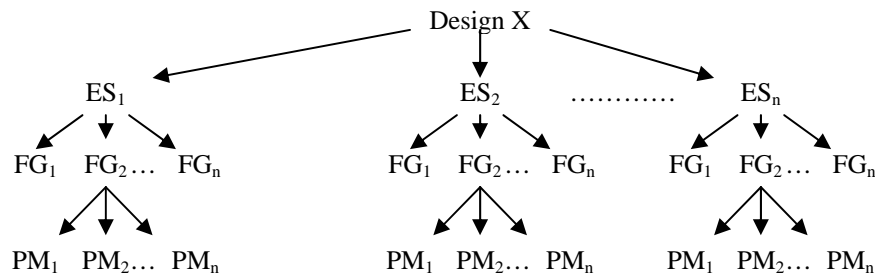


Figure 4: Tree diagram setting out the relationship between the various components of the HPM.

The performance of the vessel in each ES is graded and given a score based on a weighted combination of the normalised PMs. The overall Vessel Performance (VP) is then based on a weighted combination of the scenario scores. The final HPM is depicted in Table 1. The VP for design X can then be compared against the VP for all other designs to determine which design produced the

best overall performance. The matrix is also diagnostic in that it allows the identification of which measures contributed to the poor performance in regard to personnel movement of a rejected vessel design, or which PM could be improved in a successful design.

Design X Evaluative Scenario	Functional Groups					Scenario Score
	FG <sub>1</sub>	FG <sub>2</sub>	---	FG <sub>n</sub>	--	
ES <sub>1</sub>	a <sub>1</sub>	a <sub>2</sub>	--	a <sub>n</sub>	--	SS <sub>1</sub>
ES <sub>2</sub>	b <sub>1</sub>	b <sub>2</sub>	--	b <sub>n</sub>	--	SS <sub>2</sub>
:	:	:	--	:	--	---
ES <sub>n</sub>	d <sub>1</sub>	d <sub>2</sub>	--	d <sub>n</sub>	--	SS <sub>n</sub>
:	:	:	--	:	--	---
Overall Functional Group Scores	SFG <sub>1</sub>	SFG <sub>2</sub>	---	SFG <sub>n</sub>	---	
Overall design performance						$VP_{DESIGN(X)}$

Table 1: Summarised form of the HPM for design X.

#### 4. DEMONSTRATION OF THE INTEGRATION OF SIMULATION AND DESIGN

##### 4.1 PROCEDURE

Figure 5 shows the overall procedure for utilising the two software tools for the analysis of personnel movement in early stage design. The upper boxes

show the software tools used and the lower boxes show the operations undertaken in each of the tools. The software set consists of PARAMARINE – SURFCON, maritimeEXODUS and interface software tools developed during the joint EPSRC project.

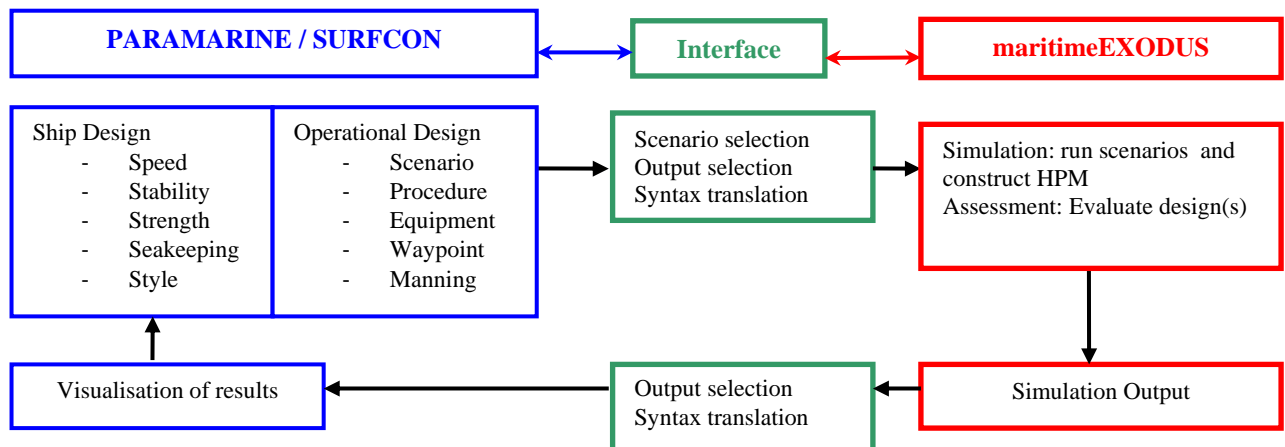


Figure 5: Procedure for personnel movement analysis using separate tools within the joint EPSRC project.

#### 4.1 (a) PARAMARINE / SURFCON

All modelling of the design is undertaken in PARAMARINE / SURFCON, with design features modelled sufficiently to allow the analysis of traditional naval architectural issues. Additional model features are incorporated to allow the investigation of the operations undertaken by the crew. This includes details of the crew's ranks and Functional Groups, and a description of the procedures they are to use in each of the personnel movement scenarios that are to be used to assess the ship design. These features are implemented as a series of tables, formatted to be easily human-readable, and human-comprehensible. These tables are linked to the spatial model of the ship to indicate the main spaces (waypoints) used by each crew member in the scenarios – see Figure 5.

PARAMARINE / SURFCON is also used to visualise the results of maritimeEXODUS simulations in the context of the ship design. In addition to making use of the existing tabular displays of numerical results, the ship design software is used to present graphical representations of both these results and animations of the simulations. The PARAMARINE / SURFCON is being modified by GRC, following specifications developed in the joint EPSRC project, to enhance graphical displays of simulation outputs. This concept of displaying these results, overlaid on the ship design in an interactive manner, places the numerical analyses in context and assists the designer in identifying both the causes of poor performance and possible solutions or improvements for further investigation. It will also contribute to the designers' understanding of the HF related elements of the ship design.

#### 4.1 (b) INTERFACE TOOLS

The prototype interface toolset consists of a combination of C++ programs, several Excel spreadsheets and macro routines translating and transferring all the information between the two software packages. This is a developmental system, and is not intended to be the final tool, but provides the basic functionality needed to allow SURFCON and maritimeEXODUS to be used together. The implementation of this prototype interface software and its use, has also allowed a more precise specification of the required functionality to be developed in future tools that integrate personnel movement analysis into early stage ship design. This includes issues such as the most efficient way to define the operational procedures to be used by the crew in the simulations, and comprehensive and effective post-processing visualisation and representation of the results.

In transferring information from PARAMARINE / SURFCON to maritimeEXODUS the interface tools resolve the many parametric links between Design Building Blocks. The complex design model can be

reduced to absolute locations of the geometry (the layout as 2D deck plans), connectivity items, (doors and hatches, ladders and stairs), and functional spaces (operations room, important equipment items such as gas turbines and liferafts). The instructions describing the scenarios to be simulated are defined in the SURFCON model in tabular form, so that they can be linked to the features of the ship design in the spatial model. This information is transferred to maritimeEXODUS via a "scenario generator" tool, which generates the itineraries (instructions) for each crew member in the simulations requested. Although human interaction is required to run the translation tools, no alteration of the representation of the ship is performed here, maintaining the consistency of the models used by the design and analysis tools.

#### 4.1 (c) maritimeEXODUS

With the layout of the vessel, connections between accessible spaces, simulation scenarios and crew procedures defined via the Interface tools, maritimeEXODUS is used to perform the simulations. maritimeEXODUS utilises a stochastic model of behaviour, so multiple simulation runs are performed for each of the scenarios. A representative simulation is selected from the multiple runs to populate the HPM. The process of generating the HPM is automatic, a specially developed software tool reading the maritimeEXODUS output and automatically populating the HPM.

The Graphical User Interface of maritimeEXODUS can display the design model being assessed, and within the developmental context of the joint EPSRC project, this is used to check for any errors that may have resulted from the translation process. maritimeEXODUS can also display the results of simulations in tabular and graph form. It can also record animations of the simulation and produce graphical representations of some personnel movement metrics that have a spatial context. Currently these are viewed by the UoG researchers running the maritimeEXODUS simulations, and then sent to the UCL naval architects who alter the design. Modifications currently being undertaken will allow maritimeEXODUS to fully exploit the developing PARAMARINE / SURFCON functionalities to display results in the form of tables, graphs and graphics overlaid in the same software environment as the ship design. This will close the loop shown in Figure 5 and allow the naval architects to utilise the results of maritimeEXODUS in a more direct manner, as an input in the early stage design of ships.

#### 4.2 VESSELS

The design being investigated in the joint EPSRC project is that of the Type 22 Batch III Frigate. The Type 22 Batch III is an established front line vessel in

the Royal Navy and is being used as the base-line ship design (Variant 1). Importantly for the JOINT EPSRC project, a complete definition of the required personnel movements during operation evolutions was available for this class of vessel (i.e. the Watch and Station Bill).

The SURFCON model of the vessel is at a very high level of definition relative to most early stage ship designs, based as it is on the General Arrangements of the in-service vessel. In addition to the layout of the internal spaces, the model also includes the connectivity items referred to in Section 4.1, such as doors and ladders. The model also includes items of equipment, such as salvage eductors, life rafts and prime movers that could require crew interaction in some scenarios. Figure 6 shows an area on No 2 Deck near amidships, with the connectivity items visible. A 2D view generated from the SURFCON model is also shown.

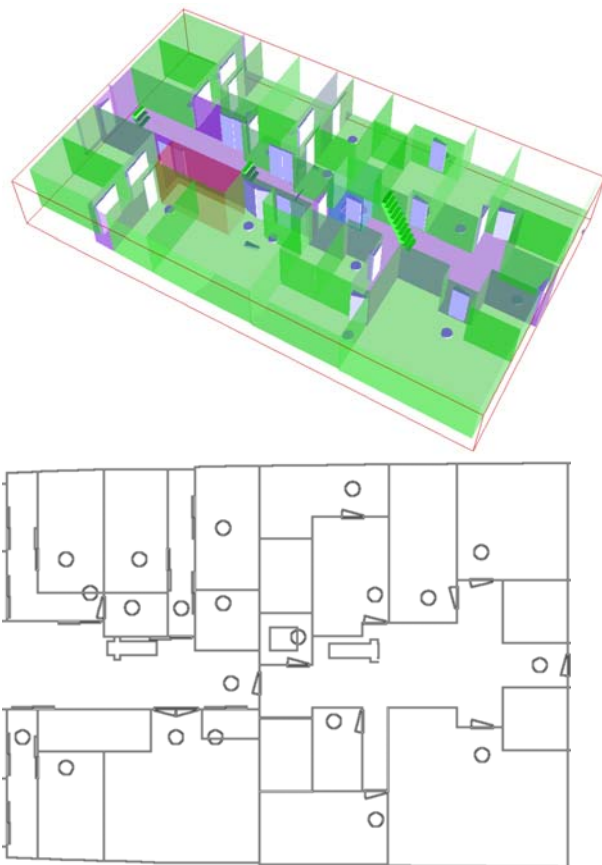


Figure 6: PARAMARINE / SURFCON 3D model with 2D drawing showing level of detail for Type 22 batch III Frigate

In addition to the spatial model, the Design Building Blocks also contain numerical properties: -

- Permanent weights that scale with ship size;
- Variable weights for ammunition and stores;
- Consumable fluids supply and demand;
- Electrical power supply and demand;
- Propulsive power supply and demand.

This numerical and graphical model represents a balanced design solution and can be modified by the designer. However, the complexity of the model leads to a very high number of connections between the Design Building Blocks and this increases the time and effort required to modify the model. Table 2 compares the level of detail of the Type 22 Batch III model with previous UCL DRC SURFCON designs. [14, 15]

JOINT EPSRC Type 22 Batch III	
Design Building Blocks	453
Equipment Items	120
Connectivity Items	348
UCL LCS Trimaran [14]	
Design Building Blocks	235
Equipment Items	105
Connectivity Items	0
UCL Dock Mothership [15]	
Design Building Blocks	236
Equipment Items	67
Connectivity Items	0

Table 2: Comparison of detail in PARAMARINE / SURFCON design models

Table 2 shows that, as well as an increase in the number of entities caused by the addition of connectivity items to the model, the overall level of detail in the baseline is much greater than in those models typically found in early stage ship design. This increases the risk that the analysis will not be performed until too late in the design process to make significant changes.

A single variant of the Type 22 Batch III design has been produced, which features a double passageway on Nos 1 and 2 Decks (variant 2), in contrast to the single passageway of the baseline vessel. These two designs are at the same level of detail, but represent two significantly different solutions to internal access, that in the Royal Navy have traditionally been pursued in frigates (single passageway) and destroyers (double passageway) as a stylistic choice rather than one based on analysis. This variant is a balanced design with numerical and spatial aspects, and so the new design has different overall characteristics – the increased area requirements have caused an increase in beam of 2.25m to a maximum of 17m, leading to a 4.3% increase in displacement and a small decrease in maximum speed.

#### 4.3 ANALYSIS OF HPM OUTCOMES

The use of the HPM concept in evaluating the relative performance of the two design variants is demonstrated in this section. For simplicity, only two evaluation scenarios are considered, one evacuation (Normal Day Cruising: ES<sub>1</sub>) and one normal operations (State 1

Preps: ES<sub>2</sub>) scenario. The aim of this analysis is to determine which design variant is the most efficient in terms of its HF performance and whether any improvements to that preferred design can be identified.

The evacuation scenario (ES<sub>1</sub>) involves the ship's complement moving towards their designated emergency stations ready for the call to abandon ship and so only involves one FG, FG<sub>1</sub>. For simplicity, the normal operations scenario (ES<sub>2</sub>) incorporates two FGs, one representing the entire ship's complement FG<sub>1</sub>, and a second representing the damage control and fire fighting group FG<sub>2</sub>. Part of the crew in FG<sub>2</sub> move to their appropriate Fire and Repair Party (FRPP) stations where they check all the fire fighting equipment and dress in full Fearnought clothing. At the same time, other crew members from FG<sub>2</sub> close all the water tight (WT) doors on the vessel in order to bring the vessel to WT integrity Condition Z. For simplicity, both design variants have the same ship's complement and number of crew in FG<sub>2</sub>. This means that the results produced from the HPM will be a direct result of the change in arrangement between the single passageway (variant 1) design and the double passageway (variant 2) design.

In total some 18 PMs are used in the analysis and a set of weights have been defined for each of the PMs and ESs. The weights for the PMs associated with pass/fail evacuation criteria take the greatest values while the weight for the normal operations ES is 50% greater than the weight for the evacuation scenario.

Providing a greater weight for ES<sub>2</sub> emphasises the importance of achieving high HF efficiency in normal operations. In both scenarios, the crew are assumed to take the shortest route to their destination, whether this is an emergency station in the evacuation scenario or a duty station in the normal operations scenario. In reality the crew may take different routes to their target destination however, in order to simplify the analysis the shortest distance route has been implemented.

The results for the analysis are displayed in Table 3 and Table 4. As can be seen from Table 3 and Table 4, variant 1 produces a Vessel Performance score of 118 while variant 2 produces a VP score of 132. Thus it can be concluded that variant 1 is the more favourable design in terms of its HF performance according to the measures we have identified, producing an overall vessel performance that is some 12% better than variant 2. However, the difference between the two design variants is not great, and furthermore, we note that variant 2 outperformed variant 1 in the evacuation ES, returning a 5% better performance, while variant 1 outperformed variant 2 in the State 1 Preps ES, returning a 22% better performance. The greater emphasis placed on the normal operations scenario (through the larger weight given to this scenario) increases the overall difference between the two vessels, strengthening the position of variant 1 over variant 2.

Variant 1						
Evaluation scenario	Functional Groups				Scenario Score	Scenario Weight
	FG <sub>1</sub>		FG <sub>2</sub>			
	weight	score	weight	score		
ES <sub>1</sub>	1	45.87	0	0	45.9	1
ES <sub>2</sub>	0.5	47.78	0.5	48.76	48.3	1.5
Overall functional group scores	81.71		36.57			
Overall Vessel HF Performance						118

Table 3: HPM for variant 1

Variant 2						
Evaluation scenario	Functional Groups				Scenario Score	Scenario Weight
	FG <sub>1</sub>		FG <sub>2</sub>			
	weight	score	weight	score		
ES <sub>1</sub>	1	43.79	0	0	43.8	1
ES <sub>2</sub>	0.5	62.14	0.5	55.81	59	1.5
Overall functional group scores	90.4		41.86			
Overall Vessel HF Performance						132

Table 4: HPM for variant 2



The results from the HPM suggest that variant 2 is marginally the superior layout for evacuation while variant 1 returns a significantly better performance in normal operations. This suggests that the overall HF performance of the preferred design (variant 1) can be enhanced through improving the performance of the vessel in the evacuation scenario.

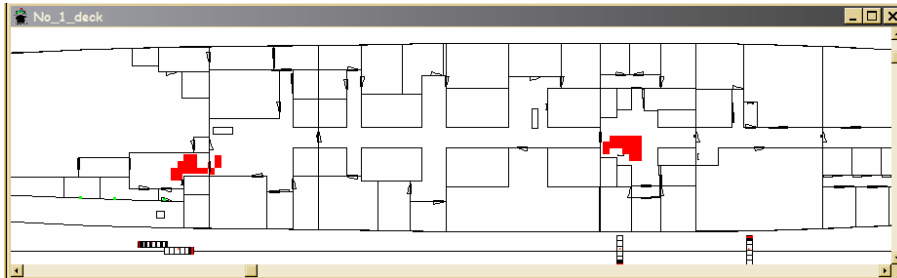


Figure 7: maritimeEXODUS output for variant 1 showing location of 2 regions of severe congestion located on No 1 Deck.

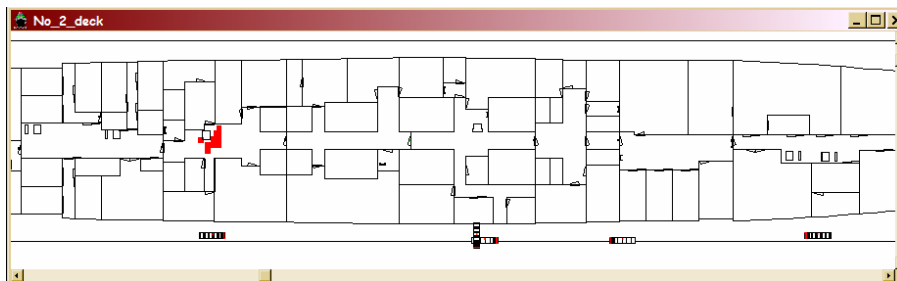


Figure 8: maritimeEXODUS output for variant 1 showing location of 1 region of severe congestion located on No 2 Deck.

A detailed analysis of the PMs associated with the evacuation ES can suggest areas in which the performance of variant 1 can be improved. Investigation of the PMs reveals that variant 1 experienced five areas of severe congestion (three of which are displayed in Figure 7 and Figure 8) compared to only two regions of severe congestion in variant 2. It is interesting to note that while both variants comfortably meet the time to muster requirement, they both fail to meet the congestion standards set in [13] for evacuation and so both variants would be deemed to have failed the evacuation requirements. A detailed analysis of these congestion regions (which is beyond the scope of the current paper) may suggest that either procedural or structural changes may be required to remove the congestion areas. A similar analysis of the State 1 Preps ES can be undertaken to suggest why variant 1 is superior to variant 2. In contrast to the conclusion of the evacuation analysis, a preliminary investigation of the normal operations ES suggests that the average level of congestion experienced by each crew member is much greater in variant 2 which detrimentally impacts the performance of the crew. It is important to note that the starting and end locations of crew and the number of crew in the various starting locations are quite different for these two ESs.

## 5. FURTHER WORK

### 5.1 LOWER RESOLUTION MODELS

To overcome the difficulties found in modifying the high-resolution models of the baseline Type 22 Batch III Frigate and the double-passageway variant, a series of low-resolution models are being developed. These will more closely represent the level of detail available in the early stages of ship design. The low-resolution models will represent:-

- Baseline Type 22 Batch III;
- Double passageway variant;
- Variant with all cabin accommodation to modern standards (groups of cabins represented by single Building Blocks);
- Medium-resolution cabin based accommodation variant (individual cabins each represented by Building Blocks).

The first two designs will allow a comparison of maritimeEXODUS simulation results from high and low resolution versions of the same design. This is a vital issue if any analysis is to be integrated into early stage design. There is a trade off between how much detail is

needed in the design for effective simulation of operations and the need to retain flexibility for early stage design. A related issue is to investigate how much input is required from the designer to define all aspects of the simulation; certain inputs, such as the Watch and Station Bill, could be generated from a library of options, rather than requiring designer input to commence analyses.

## 5.2 HPM

The ES used to define the HPM will be extended to include several more evacuation and normal operations scenarios. These will include a selection of the evacuation scenarios identified in [13] and the Blanket Search and Family Day normal operations scenarios.

## 5.3 SENSITIVITY ANALYSIS

For a given set of ESs, the conclusions drawn from an analysis of the HPM will be dependent on the user defined weights. An inappropriate setting of the weights may amplify unimportant performance differences between variants and mask important differences. Thus in setting the weights a clear understanding of one's priorities in evaluating the designs is essential. To develop a better understanding of the impact the weights may have on an evaluation, a weight sensitivity analysis is currently underway.

## 5.4 GUIDANCE

As indicated by the project's title, "Guidance on the Design of Ships for Enhanced Escape and Evacuation", the main purpose of the project is to provide guidance on this issue. This will cover several areas:

### 5.4 (a) The Design of Ships

This project aims to provide guidance on the design of ships that can be directly used by the MoD. This will be achieved through the assessment of alternative access and accommodation arrangements. In addition, the project is seeking to identify any features or procedures that could be adopted as "good practice" in design for evacuation and personnel movement related operations.

### 5.4 (b) The Detail Design Process

This new capability of simulating, as part of the design, the movement of personnel from the early stages of ship design will affect the manner in which design is undertaken. The development of the design procedure is highly coupled to the development of the software tools and this project aims to provide guidance on the best approaches to be adopted. These will ensure effective assessment of personnel movement issues at an early stage. This includes issues such as the level of detail required in the model and the performance measures that are most useful to record effective ways of using them in

an interactive design environment. Another issue is how best to iterate the design to a solution. The two approaches currently under consideration are to take a single design and modify it to improve the performance, or to produce a range of designs with different styles and then assess them all in comparison, against both traditional ship design criteria and the newly-available personnel movement performance criteria.

### 5.4 (c) The Wider Design Process

Another issue to be addressed is how to integrate the assessment of personnel movement in operational scenarios into the overall design process. The procedures used could be fixed and defined by naval rules, or could be treated as another aspect of the design to be improved. The performance of the personnel could become another aspect of the design to be included in cost-benefit and cost-performance analyses. If such aspects are considered then the main resultant outcome for the integration of personnel movement and ship architecture will be to facilitate the exchange of information between the ship designer and manning / personnel procedures experts. This would result in their different needs being incorporated in a single decision making process and facilitate a joint working environment.

## 6. CONCLUSIONS

This three year project by UCL and UoG is developing tools and approaches for integrating the assessment of personnel movement into the early stages of ship design.

As part of this work, a method, known as the HPM, has been developed to assess the HF performance of naval vessels. The methodology is intended to be used as a comparative tool, where the performance of one variant is compared with the performance of an alternative variant. However, if appropriate standards are defined, the approach could also be used to evaluate absolute vessel performance. The methodology is capable of discriminating between competing designs by selecting the design with the best HF performance across a range of relevant scenarios. The approach is also diagnostic, providing a means to identify areas in crew/vessel performance which can be improved. Furthermore, the technique is both systematic and transparent, allowing user priorities to be clearly stated as part of the methodology. User priorities can be identified through the selection of the evaluation scenarios to be investigated and the weights assigned to the various components of the HPM.

In addition to the technical issues of modelling and software modification there is the more general consideration of procedural integration. This project represents the start of bringing whole-ship ergonomics and HF to the fore in ship concept design, such that major design choices can be informed by what has historically been an under-represented issue. This is just

one significant area where preliminary ship design can be made more responsive to the aspects of importance to not just owners, but also operators and users.

The two universities and their MoD partner have already explored metrics for the Type 22 frigate and evaluated the issues surrounding the interfacing of the two software packages. The latter task shows that there is a wide range of possible metrics, evolutions and modelling issues appropriate to this interfacing.

While this project addresses the design of naval vessels, the principle behind the proposed approach and the ability of the tools to interface in a seamless manner, has direct applicability, particularly, to the design of commercial passenger vessels.

The approach proposed of a Design Building Block based synthesis, in conjunction with the simulation of personnel movement, provides the appropriate front end to a comprehensive design approach for such complex systems. So from design investigations, emergent guidance on configurations, appropriate to efficient personnel movement, can be provided in a manner that will not conflict with the wider procurement needs, leading to clearer requirements, fostering a better basis for competitive responses from industry.

In conclusion, the outcomes from this project are expected to indicate where design can be improved. This should have a direct impact on the through life costs of the vessel, provide a major saving for ship operators, improve the efficiency of the ship design process, reduce design and build time and costs and ensure that the vessel is safer and more efficient for the personnel on board.

## 7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the UK EPSRC under grants GR/T22100/01 and GR/T22117/01.

## 8. REFERENCES

1. GILMORE, D J and MILLARD, D, 'Integrating Micro- And Macro-Ergonomics', *Proc. of Human Factors and Ergonomics Society Annual Conference*, Chicago, October 1997
2. ANDREWS, D J, 'The Use of Simulation in Preliminary Ship Design', *Proceedings of 12<sup>th</sup> International Conference on Computer Applications in Shipbuilding*, Busan, Korea, August 2005
3. RINA, 'Sightline Study: Using Real-time 3D Technology to Optimise the Design Process', *The Naval Architect*, London, April 2003
4. ANDREWS, D J, 'A Creative Approach to Ship Architecture', *RINA International Journal of Maritime*

*Engineering*, Sept 2003, Discussion and Author's response *IJME* Sept 2003, *Transactions RINA* 2004

5. CARTA, A, CATALDI, A, MOLINI, A, RICCO, S and BISSO, C, 'Human-System Integration Issues for a Low-cost, Optimal-manning, High Performances Frigate', *INEC 2004 Marine Technology in Transition*, Amsterdam, March 2004
6. DEERE, S, GALEA, E R, LAWRENCE, P and GWYNNE, S, 'The Impact of the passenger response time distribution on ship evacuation performance', *The Transactions of The Royal Institution of Naval Architects*, Vol 148, Part A1 (Journal of Maritime Engineering), ISSN 1479-8751, 2006
7. International Maritime Organisation, 'Interim Guidelines for Evacuation Analyses for New and Existing Passenger Ships', IMO MSC/Circ 1033, 6 June 2002
8. GALEA, E and ANDREWS, D J, "Guidance on the Design of Ships for Enhanced Escape and Operation", EPSRC Project Proposal Feb 2004 commenced Oct 2004
9. ANDREWS, D J and PAWLING, R, 'The Application of Computer Aided Graphics to Preliminary Ship Design' *Proceedings of IMDC06*, Ann Arbor MN May 2006.
10. BOLE, M and FORREST, C, 'Early Stage Integrated Parametric Ship Design', *Proceedings of 12<sup>th</sup> International Conference on Computer Applications in Shipbuilding*, Busan, Korea, August 2005
11. GALEA, E R, LAWRENCE, P, GWYNNE, S, SHARP, G, HURST, N, WANG, Z and EWER, J, 'Integrated fire and evacuation in maritime environments', *Proceedings of the 2nd International Maritime Safety Conference on Design for Safety*, Sakai Japan, Publisher Ship and Ocean Foundation, 27-30 Oct 2004
12. BOXALL, P, GWYNNE, S, FILIPPIDIS, L, GALEA, E R and COONEY, D, 'Advanced Evacuation Simulation Software and its use in Warships', *RINA International Conference on Human Factors in Ship Design, Safety and Operation*, Feb 2005
13. 'Chapter VII Escape Evacuation and Rescue', "ALLIED NAVAL ENGINEERING PUBLICATION 'ANEP - 77', NAVAL SHIP CODE", NATO Naval Armaments Group, Maritime Capability Group 6, September 2006
14. ANDREWS, D J and PAWLING, R, 'Innovative Ship Design for High Speed Adaptable Littoral Warfare', *RINA International Conference Warship 2006: Future Surface Ships*, London, June 2006

15. ANDREWS, D J and PAWLING, R, 'Fast Motherships - A Design Challenge', *RINA International Conference Warship 2004: Littoral Warfare & the Expeditionary Force*, London, June 2004

design of ships utilising the design building block approach.

## 8. AUTHORS' BIOGRAPHIES

Brief biographies are required for all authors:

**D Andrews** was appointed Professor of Engineering Design at University College London in September 2000 following a career in ship design and acquisition management in the UK Defence Procurement Agency. He leads the design research in computer aided ship design, design methodology and design practice. He is a Fellow of RINA, Fellow of IMechE and was elected to the Royal Academy of Engineering in 2000. He is a Vice President of RINA.

**E Galea** is CAA Professor of Mathematical Modelling and Director of the Fire Safety Engineering Group (FSEG). He has worked in the area of fire safety for over 20 years. He serves on several international standards committees in the areas of human behaviour and fire safety including, BSI (UK), ISO and SFPE (USA) and has been a UK delegate to a number of IMO FP committees including FP46, FP50 and FP51, contributing to the framing of MSC circular 1033 and its recent modifications. Along with FSEG colleagues, he was winner of the RINA award for innovation in safety for 2001 for the development of maritimeEXODUS.

**P Lawrence** is Reader in Evacuation Modelling within FSEG and manages the software engineering component of all EXODUS products. Along with FSEG colleagues, he was winner of the RINA award for innovation in safety for 2001 for the development of maritimeEXODUS.

**S Deere** completed a BSc in Computing and Mathematics at the University of Greenwich in 2004. He is currently completing a PhD thesis within FSEG investigating mathematical models for the assessment of evacuation and HF performance of crew on naval vessels.

**Richard Pawling** completed the MEng in Naval Architecture and Marine Engineering at University College London in 2001. He is currently a research assistant completing a PhD thesis investigating the application of the Design Building Block approach to innovative ship design.

**Lorenzo Casarosa** joined the Italian Naval Academy and served as an Engineering Officer for nine years. A graduate in Naval Architecture and Marine Engineering from University of Trieste, he is presently a Ph.D. student at University College London working on the integration of HF and operability into the early stage