Integrating Ship Design and Personnel Simulation

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SYNOPSIS

When designing a ship, the traditional driving issues are seen to be powering, stability, strength and seakeeping. Consequently it is only when the broad form of the layout has been finalised that issues relating to crewing, ship operations and evolutions, such as evacuation, tend to be investigated within the overall design constraints. This can result in significant operational inefficiencies and potentially hazardous environments on board. The overall objective of this UK Engineering and Physical Sciences Reseasrch Council (EPSRC) funded multidisciplinary research project, which commenced in October 2004, is to show the advantages of integrating the cutting edge technologies of Escape Simulation and Ship Configurational Design. This will enhance the guidance for all parties in the design, regulation, construction and operation of ships with regard to the main aspects of personnel movement on board. To achieve this, the project draws on the well-established expertise of the University of Greenwich in the area of fire and evacuation modelling and of University College London (UCL) in the area of ship architecture design.

Crucial to the success of this project are the definition of suitable Human Performance Metrics (HPM). These human dynamics criteria are being used to test the suitability of the vessel layout for its intended purpose using the SURFCON CAD definition. A range of criteria, including environmental, procedural, personnel and geometric, have been defined and for a typical Royal Navy frigate. The personnel are considered to be in one of seven functional groups (e.g. operation & navigation, damage control & fire fighting, flight and propulsion & machinery). The human factors features in the SURFCON model that will interface with the maritimeEXODUS personnel simulation are presented, using the selected frigate as an example. The paper concludes by summarising the remainder of the work to be covered in the second half of this three year project, and draws initial conclusions on the scope that such an integration of personnel simulation into initial ship design opens up for the future practice of ship design.

HISTORY OF COMPUTER AIDED GRAPHICAL PRELIMINARY SHIP DESIGN (CAGPSD)

The UCL paper to the 2003 INEC (1), looking at the implications on a destroyer configuration of adopting an all-electric ship machinery philosophy, outlined the advantages of the design building block approach to initial ship design and considered it to be the key to an integrated design synthesis. This was seen as being facilitated by modern interactive computer graphics which now enable the designer to explore many important design aspects previously not addressed at the earliest stages of ship design, such as Human Factors.

While this approach to initial ship design has been propounded for over two decades as more holistic, (2, 3) it was only with the very specific example of submarine concept design that computer graphics could be said to be sufficiently user friendly to make the approach a practical ship design proposition (4). With the incorporation of SURFCON in PARAMARINE this has now been extended to a wide range of conventional and advanced surface ship types.

The approach to producing a new ship design is summarised in the International Marine Design Conference (IMDC) 03 paper (5) at Figure 5, reproduced below at Fig 1. This diagram indicates that there are a comprehensive set of analysis processes necessary to achieve a balanced design. However, most of these are unlikely to be used in the initial setting up of the design or even to achieve early iterations around the sequence of building blocks, geometric definition and size balance. In fact several of the inputs shown in Fig 1 are either specific to the naval combatant case highlighted in the previous INEC paper, such as topside features, or omit aspects which could be dominant in specialist vessels. For example the design of the internal ship configuration of vessels such as aircraft carriers, amphibious warfare vessels or cruise liners and large ferries, would be dominated by personnel and vehicle flow and it is the case of personnel flow that is the particular focus of the current paper.

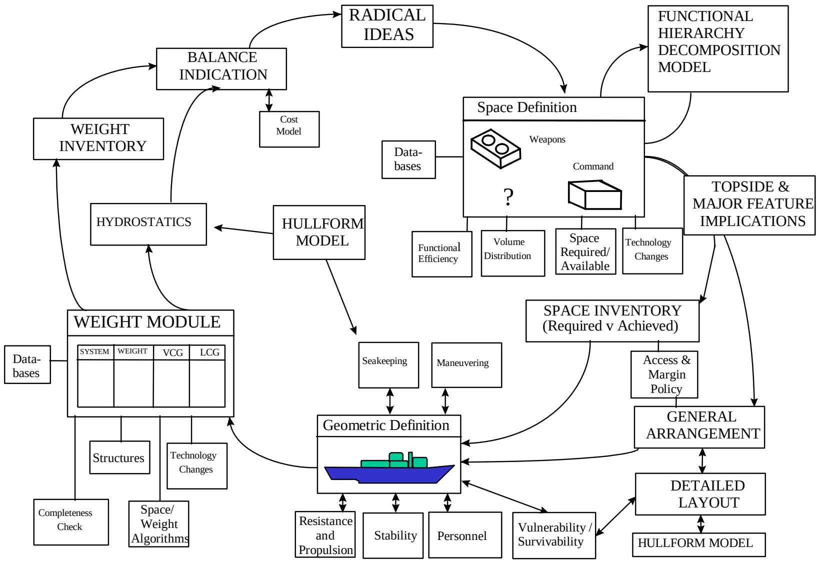

Fig 1 Overview of the Design Building Block Methodology applied to Surface Ship (5)

A further feature of the design building block approach that was outlined in some detail for the UCL prototype system, presented to IMDC 97 (6), which has been fully incorporated in the SURFCON element of PARAMARINE (7), is that of the "Functional" breakdown. This considers the ship description as comprising "Float", "Move", "Fight" and "Infrastructure" categories, which enables the designer to readily respond to the owner or user's request for the impact of additions or deletions to the operational capabilities which usually result from trying to reduce cost or change capabilities. An additional sub-function, which is managed under the main functional group of Float, is that of the main access routes, given their prime importance in personnel movement through the ship.

The 1997 UCL prototype also introduced the concept of a Master Building Block to denote how the overall aggregated attributes of the building blocks were brought together to provide the numerical description of the resultant ship design. With the prototype examples in 1997, the researcher used separate computer aids and then integrated manually using his own ship design expertise. Whilst this was acceptable for research, it was not considered satisfactory for a workable design system. The advantage of providing the design building block capability of SURFCON as an adjunct to the already established ship design suite of PARAMARINE is that the audited building block attributes within the Master Building Block can be directly used by PARAMARINE to perform the necessary naval architectural calculations to ascertain the balance or otherwise of the configuration. Typical information in the Master Building Block is of the following:

- Overall ship requirements: Ship speed, seakeeping, stability, signatures (in the case of a naval combatant);
- Ship characteristics: weight, space, centroid;
- Overall margins: weight, space, location for growth and enhancement.

Features incorporated in the SURFCON-PARAMARINE system enable the designer to conduct preliminary ship design studies using the design building block approach of Fig 1. The general procedure adopted in producing a new ship design study is therefore seen to be:-

1. An outline requirement for the ship is identified and a design style proposed;

2. A series of design building blocks are defined or selected, containing geometric and technical attributes;

3. Design building blocks are located as required within the ship configurational space;

4. Overall weight and space balance and performance (e.g. stability, powering) of the tentative ship design are assessed;

5. The configuration is then manipulated until the designer is satisfied;

6. Decomposition of the building blocks to greater levels of detail is undertaken as required and overall ship balance / performance maintained to an appropriate level.

The interaction with personnel flow simulation tools can be performed either at the third or fifth step enumerated above, i.e. prior to or following the achievement of naval architectural balance of the design. This depends on how much the judgements being taken to achieve the design balance are considered by the designer to be usefully informed by the outcome of the personnel simulation.

The incorporation of SURFCON within PARAMARINE gives access to a wide range of analytical tools to check the naval architectural viability of the SURFCON description, including the whole ship characteristics in the Master Building Block. That range includes:-

- Stability calculations against several stability criteria;
- Powering analysis for a range of assessments using most well established methods and methodical series;
- Seakeeping analysis for typical wave spectra;
- Longitudinal strength analysis;
- Ship vulnerability;
- Dynamic analysis;
- Manoeuvring.

The basis of the functional specification for SURFCON as a module within the PARAMARINE ship design software has been spelt out in the SURFCON descriptive paper (5) and this then provides the balanced design description on which personnel simulation can be undertaken.

OVERVIEW OF ESCAPE SIMULATION IN MARITIME APPLICATIONS

Traditionally, human factors in ship design have either been ignored, considered as an after thought or incorporated through a set of prescriptive rules. For example, consider the human factors aspects associated with evacuation. These issues have been incorporated into ship design through the specification of a set of prescriptive rules known as SOLAS (Safety of Life At Sea). These have usually been framed in the aftermath of a major disaster at sea (for example Herald of Free Enterprise, Estonia, Scandinavian Star) and address such aspects as the provision of emergency lighting, signage, number of life boats, number of exits within compartments, travel distance, dead end corridors. The assumption being that if the rules are followed, it will be possible to muster and abandon the vessel safely in the specified period of time. However, recently the International Maritime Organisation (IMO) have begun to introduce more sophisticated evacuation analysis into ship design. For example, the SOLAS High Speed Craft Code introduced the concept of performing critical path analysis of the evacuation arrangements (8) and required Ro-Ro passenger ships built after 1 July 1999 to have an early design stage evacuation analysis performed. However, today, more sophisticated evacuation analysis is possible through the use of computer simulation software, such as maritimeEXODUS (9, 10, 11).

EXODUS is suite of software developed by the Fire Safety Engineering Group of the University of Greenwich to simulate the evacuation and non-emergency circulation of large numbers of people within a variety of complex enclosures with maritimeEXODUS being the ship version of the software. This goes beyond the traditional examination of layout and safety features, allowing designers, certification authorities and operators to incorporate human performance and environmental factors into a variety of scenarios. The EXODUS software takes into consideration people-people, people-fire and people-structure interactions and comprises five core interacting sub-models: the Passenger, Movement, Behaviour, Toxicity and Hazard. 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. 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, including modelling the individual components of that system.

maritimeEXODUS 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 through the use of Fractional Effective Dose (FED) toxicity models (12) and the ability to include the impact of heel and trim on passenger and crew performance (10). Through a research contract with the UK Ministry of Defence (MoD), the capabilities of maritimeEXODUS have recently been extended to include the capability to represent the performance of both naval personnel and civilians in the operation of typical naval fixtures and fittings, thus allowing maritimeEXODUS to simulate better key components of naval vessels not typically found on board civilian ships. Another unique feature of the software is the ability to assign passengers and crew a list of tasks to perform (11), which can be used when simulating emergency or non-emergency conditions. For example, as part of an emergency evacuation scenario it may be necessary to assign passengers with an itinerary of tasks that must be completed prior to proceeding to the assembly station, such as visiting a pre-defined location to collect lifejackets. A non-emergency application may involve the investigation of a theatre emptying and filling for the next show or assessing a critical heavily manned space, such as an aircraft carrier hangar. In such a situation, passengers may be assigned the task of leaving a theatre and heading for a bar area while passengers in the bar area may be assigned the task of heading for the theatre region. This feature is very powerful as it enables the user to specify any number of complex and varied types of tasks for the simulated personnel to undertake.

In recognition of the ability of evacuation modelling tools such as maritimeEXODUS, IMO recently introduced a new set of guidelines for the adoption of sophisticated evacuation modelling techniques, known as the Interim Guidelines for evacuation analysis of new and existing passenger ships including ro-ro (13). These guidelines define two benchmark scenarios, “day” and “night” along with two variants, that must be simulated as part of the certification process. While arbitrarily defined, they establish a baseline performance for the vessel and crew thus allowing comparison with both the set target time and alternative designs. Despite these developments, crew/passenger human factors analysis is not integrated with ship design and the process is, more often than not, considered as an after thought, usually for the purposes of verifying that the vessel meets the required standard once the vessel has been designed and, in many cases built.

The primary impediments to adopting human factors into the design cycle are two fold. Firstly, a General Arrangement (GA) is required by the evacuation/human factors software in order to undertake the simulation. However, by the time that the GA has been developed it is too late to noticably influence ship configuration and overall layout. Thus, a means must be developed to incorporate human factors issues earlier in the design cycle through the interaction with ship configuration software (e.g. SURFCON-PARAMARINE). Secondly, while it is possible to identify improvements in ship performance due to configurational changes, it is less clear how ship configuration changes may lead to improvements in human performance. Thus it is essential to define a Human Performance Metric by which crew/passenger performance can be gauged. This project is developing and will demonstrate a generic approach that integrates human factors into preliminary ship design. Initially the development will focus on naval vessels to demonstrate proof of concept on a demanding set of ship operations.

INTEGRATION OF CAGPSD AND PERSONNEL SIMULATION

The multidisciplinary research described in this paper has the aim of integrating the leading technologies of personnel simulation and of ship configurational design. It should enhance the guidance for the preliminary design stages of ships in regard to personnel movement on board ships during evolutions, such as escape, damage control and storing, and be of benefit to all parties involved in their design, regulation, construction and operation The project has five objectives:-

1) To explore the impact on naval ship configurational design of issues associated with crew manning numbers, function and movement.
2) To identify key performance measures for successful crew performance in normal and extreme conditions.
3) To extend the ship evacuation software maritimeEXODUS to include additional non-emergency simulation capabilities.
4) To extend the ship design software so that it can provide a modelling environment that interactively accepts maritimeEXODUS simulation output for a range of crew evolutions.
5) To demonstrate an approach to ship design that integrates ship configuration design with modelling of a range of crewing issues through PARAMARINE-SURFCON.

The feature that distinguishes the design building block tool, as a unique aspect of this proposal, is its graphical basis in combination with a preliminary ship design capability. Thus balanced ship design solutions are produced based on a built up physical description of component design building blocks reflecting the customers and users requirements in the broadest sense, not limited to the traditional naval architecture features dominated by underwater hull description. This can be seen by comparison with current state of the art Computer Aided Ship Design tools. These are either driven by the major concern to support the main shipbuilding demand for a detailed level of ship component description necessary to construct the vessel (e.g. TRIBON, NAPA, FORAN and CATIA) or to provide the largely naval architecture analysis to evolve the design from the initial preliminary sizing (e.g. MaxSurf, GODDESS, FlagShip, ShipShape and the Classification Societies (e.g. DNV/LRS/ABS) packages) (see ICCAS 2005 (14)).

Within PARAMARINE – SURFCON the overall balanced ship characteristics are held in the Master Building Block, which constitutes the overall ship description. This description can reflect the full range of customer and user requirements, including through life costing, human factors, health and safety issues, environmental issues, supportability, sustainability, reliability and adaptability. Using the design building block approach the designer can devise the emergent ship design solution to reflect the main requirements of the customer and the end users. The design building blocks can also be readily reconfigured, throughout the preliminary design phases, to ensure that emergent features can be given due weighting. In addition new options can be readily explored to exploit their possible advantages for efficient personnel movement. It is also considered that such a graphically centred design approach will readily interface with the more detailed design focus of Integrated Product Models. IPMs are part of the Integrated Product Data Environment capability that advanced shipyards have already invested in, and the ability of graphical based concept tools to interface with IPMs has been recently demonstrated by Graphics Research Corporation Limited (GRC) with the portability of SURFCON to TRIBON (7). Thus innovative early design proposals can be readily implemented in ship acquisition with the potential efficiencies predicted by the proponents of Concurrent Engineering.

The impact of improved personnel movement features on a full range of performance and cost attributes will be investigated on a range of ship studies using the preliminary ship design tool. It is hoped these investigations will provide or illustrate suitable proposals for improvements on the overall ship design. The project is being undertaken in three distinct phases: the Development Phase (DevP), the Integration Phase (IP) and the Demonstration Phase (DemoP). In the DevP, an approach is being produced linking ship configuration with crew performance and being tested through application to an existing vessel design. In the IP this approach is being refined through the integration of the key software components into a prototype analysis environment. Finally, a new ship concept will be explored using the proposed approach and prototype analysis environment in the DemoP.

The design being investigated in the DevP and DemoP is that of the Type 22 Batch III Frigate (monohull). 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. Once the baseline vessel has been modelled, possible improvements will be proposed and further analysis undertaken using PARAMARINE - SURFCON for their effects on ship performance. The results of each analysis may indicate further areas for improvement and analysis with the iterative process continuing for several cycles to identify the quasi optimal layout. The impact on ship costs from the outcome of each iteration will be examined against the achieved benefits to identify when the investigations have reached the stage of diminishing returns. During the project possible improvements to both the HFM and the maritimeEXODUS software are being identified and implemented.

As part of the IP, requirements for interfacing the two sets of tools will be identified in full, an approach suggested and implemented to give a prototype design environment. In the DemoP (final phase), a different type of frigate will be modelled and investigated using the HFM and the prototype design environment. It is expected this will give a quasi-optimal vessel design. The final outcome will be guidance, based on the investigations, which can then be used to improve the human factors features of future warships.

PRODUCTION OF HUMAN PERFORMANCE METRICS

Crucial to the success of this project will be the definition of suitable Human Performance Metrics (HPM). These, essentially, will provide the human dynamics criteria by which the HF suitability of the vessel layout will be evaluated and will be specific to the type and class of vessel being investigated. For example, naval vessels and passenger ships will have very different HPM. Equally, an aircraft carrier will have a different HPM to a submarine, as will a cruise ship compared to a high speed craft. 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 be similar across different types of vessels.

A list of measures has been produced establishing which behavioural components might be of value to the ship designer; i.e. those aspects of the crew function which can be represented numerically. A sub-set of these will form part of the HPM in order to represent those conditions that are of general interest. The actual measures included will be modified as our understanding of their relative importance develops, although the list is sufficiently general to encapsulate a variety of different maritime scenarios. As a result, some of the measures may have little value in some of the scenarios being examined and this will be addressed in the HPM (represented as a matrix) through the use of weighting coefficients modifying the contribution of the measures to the overall personnel movement 'score'. These general measures include, for example, the time spent during the simulation at critical levels of congestion, the predicted number of resulting fatalities (in the extreme case of evacuation), the time spent in preparation, the time spent performing actions, the time spent in transition, the total simulation time and the number of operations performed.

In this project our primary focus is on naval vessels and in particular escort type surface combatants and hence the HFM will reflect this i.e. as Naval Combatant Human Performance Metrics (NCHPM). If successful, a number of HPM could be developed for different types of vessels. For demonstration purposes in addition to the two IMO evacuation scenarios, three additional scenarios are being investigated. These are the performance of a blanket search (as part of a damage control evolution), a change of readiness state (e.g. defence to action stations) and a family day visit by the public. Furthermore, some of these will also be examined when the ship is at a 20º angle of heel.

The definition of the scenarios involves; number of crew, crew starting locations, crew response times, crew duties, crew target locations and allowable routes. all of which will be undertaken in consultation with the MoD partner, the Sea Technology Group (STG). It is also necessary to define for each scenario in the NCHPM crew/vessel performance targets. These may be based on an absolute performance target (e.g. for evacuation scenarios to complete evacuation within a prescribed time (e.g. IMO specified limits)) or relative performance targets. In the latter case, the aim is simply to produce an improved performance with each iteration of the vessel's configuration. For example, one relative performance target could be to minimise the time for a damage control party to assemble and reach the scene of the incident. The evaluation of the overall vessel design can then be performed using a Performance Function (PF) that combines individual results from each of the scenarios with each scenario being assigned weights dependent on vessel type and role.

To address all of these requirements the maritimeEXODUS software is undergoing a range of enhancements. This includes the development of additional output parameters to measure performance in the scenarios required for the definition of the HPM and additional modelling capability, in order to perform the identified circulation scenarios. The latter are expected to involve additions to the itinerary functionality currently available within maritimeEXODUS so that new requirements can be accomodated. In addition, it is proposed to enhance the decision-making capabilities of the automata to accommodate the scenarios examined.

WORK TO DATE ON INTERFACING THE TWO SYSTEMS

As stated in the aims of the project, enhancements to both sets of software tools are being undertaken, either to utilise existing capabilities for a new type of analysis or to add new capabilities altogether. Work has already been carried out on using maritimeEXODUS for the simulation of personnel movement on existing warships (15).

Prototype interface software is being developed to reliably and consistently edit and transfer operational and procedural information, together with the SURFCON definition of the ship, to maritimeEXODUS, thus allowing the rapid selection or input of the scenarios and procedures to be used within the simulations. This interface software also facilitates the generation of a flexible and interactive display of the results of those simulations. This takes two forms; the HPM described in the previous section and a graphical representation described in the first section. A PARAMARINE / SURFCON model of the ship and a mock-up of a possible visualisation of a maritimeEXODUS simulation on a design building block (SURFCON) derived layout is shown in Fig 2. The prototype software link will be used to test the concept and identify potential refinements to the approach.

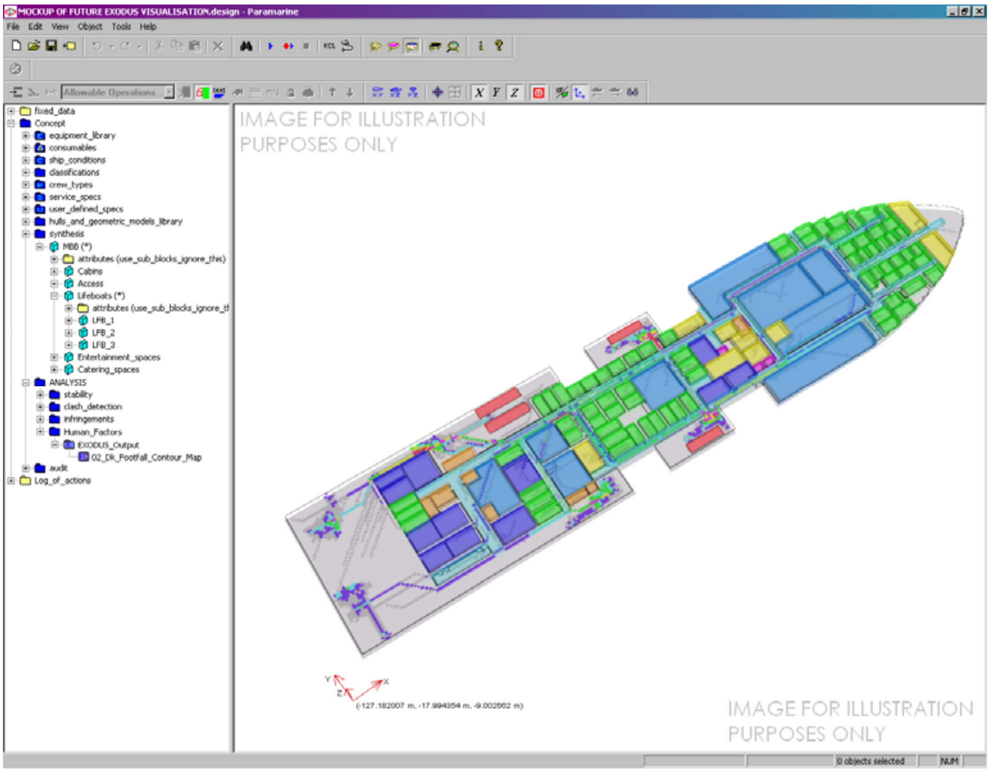

Fig 2 An early mock-up of the possible output of maritimeEXODUS and SURFCON

This new capability for the early stages of ship design affects the manner in which design is undertaken. While the development of the software tools providing the required information in a prompt and intuitive manner is vital, there are however, a number of procedure-specific issues to be considered:

(a) Levels of Detail and Designer Input: There is a trade off between how much detail is needed in the design, for effective simulation of operations, and the need to retain the flexibility of the early stage design. A related issue is how much input is required from the designer to define all aspects necessary for the simulation.

(b) The Iterative Design Process: New options for modelling and analysis will be opened up and so the question arises as to how these can best be used in the context of the early stages of an iterative design process. Is it best to adopt a "series approach", where the designer assesses a single design, and modifies it, as needed, to maximise the effectiveness metric, while considering the whole ship effects of each modifications? Or should a "parallel approach" be adopted, where a number or significantly different design solutions are simultaneously compared and the best features adopted for use in the final design?

(c) The Wider Design Process: The procedures used by the simulated crew in the scenarios could be fixed, or treated as another aspect of the design to be improved. Thus total manning numbers could be assessed as the procedures and design change. An important task of the new tool set will be facilitating the exchange of information between the ship designers and the manning / procedures experts, in order to incorporate their different needs in a single decision making process. Possibly, this new approach will create an interactive and flexible common working environment for these parties and may be the first step in designing the ship and its personnel features jointly.

As well as developing the new tools and approach, the project aims to provide ship design guidance that can be directly used by the MoD and its industrial suppliers. To achieve this aim, a variety of different vessel configurations and design issues are to be considered, using the Type 22 Batch III frigate as a baseline. These include improved access or accommodation standards, and the impact of distributed prime movers associated with an All Electric Ship configuration. In addition, the project seeks to identify any features or procedures that could be adopted as "good practice" in design for evacuation and for personnel related operations.

CONCLUSIONS AND FUTURE WORK ON PROJECT AND BEYOND

While this project addresses the design of naval vessels, the principle behind the proposed approach and the tool set to be produced, has direct applicability to the design of commercial and passenger vessels. For ships the overall layout or

General Arrangement is the primary mechanism for taking into account the view of the specialist users and of subsystem and equipment designers, while maintaining overall design cohesion. The output from this project will consist of an integrated tool set, enabling the ship designer to explore the interaction of personnel movement with the ship design, in a range of scenarios and a set of case studies using the tool set, which can provide the basis for guidance and benchmarks for assessment of proposals. This will save considerable time and money in the ship design phases but also in the vessels through life costs, which can be several times its procurement cost. The project will provide evidence that if personnel related considerations are left too late in the design procedure, this could result in unnecessarily high ownership costs. This will highlight how necessary it is to introduce consideration of these aspects into the formative stages of the design in order that trade off studies can comprehend through life cost consequences.

It follows that a more comprehensive design description is required in the preliminary stages, which the design building block approach facilitates. It is thus possible to focus on the Human Factors aspects given the largest element of the through life cost of a naval combatant is usually that directly attributable to the cost of the personnel required to operate the ship and its systems. The relationship of design for maintenance with design for efficient personnel movement can give rise to design conflicts, which the building block based design description in conjunction with personnel flow analysis will expose early in the design. The approach proposed of a 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 investigations and the 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 which will foster a better basis for competitive responses from industry.

In conclusion, this project will lead to improved ship design which will 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 time and costs, for the naval architects and shipyards, and ensure that the vessel is safer and more efficient for the personnel on board.

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