SURVIVABILITY: THE HUMAN ELEMENT

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SUMMARY

Modern warship design is facing a number of drivers in terms of design, procurement and operation and these have both direct and indirect impacts on issues such as survivability and the human element. Guidance has been developed regarding Human Factors Integration (HFI), but this has generally focussed on detail design and fatigue. The UK MOD HFI Initiative describes HFI with 7 more holistic domains which are seen to have wider ship design impacts. This paper considers three current drivers on warship design for their impacts on survivability in the context of the human element. There were seen to be some interactions between different aspects of modern warship design and operation that again require a more holistic assessment of HF issues. The paper concludes that, although a more holistic approach is required, the increasing computerisation of the preliminary ship design process should allow tools to be developed to support this.

1. INTRODUCTION

Figure 1 summarises the NATO definition of survivability [1]. It is important to note that survivability as a whole encompasses three main aspects; susceptibility, vulnerability and recoverability. Much progress has been made in recent years in the assessment of warship survivability, including software tools such as SURVIVE [2] and it is now suggested that rather than being a downstream part of design assessment, survivability should be included as part of design development [3] [4].

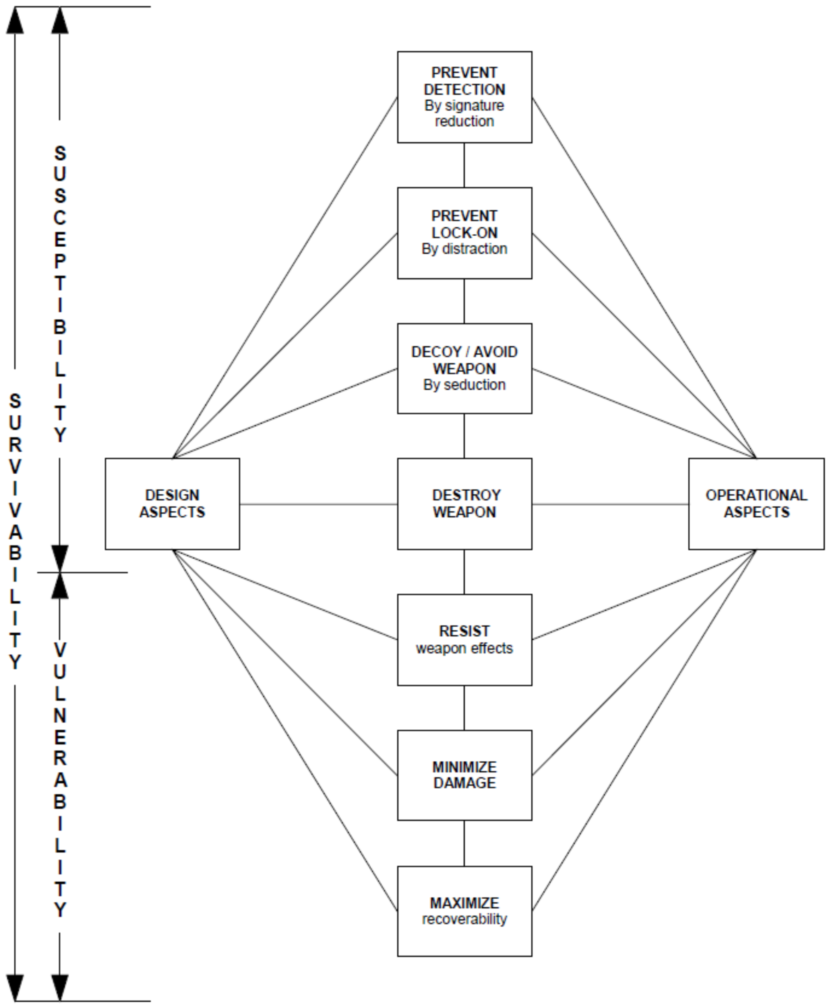

Figure 1: The definition of survivability, encompassing susceptibility, vulnerability and recoverability [1]

The UK MoD Warship Engineering Management Guide (WEMG) lists Human Factors (HF) as a "transversal" – something that impacts all aspects of the design. HF is then defined as; "the systematic application of relevant information about human capabilities, limitations, characteristics, behaviour and motivation to the design of products and systems, the procedures people use and the environment in which they use them." [5] This quote illustrates the holistic and integrative characteristic of HF design – a wide range of quantitative, qualitative and contextual issues have to be taken into account. But the transversal nature of HF – its' effect on other aspects of the warship design and operation – mean that HF must be taken into account.

This paper will briefly review some drivers on modern warship design, before outlining how HF as a domain is structured for integration into defence projects in the UK. The general state of HF integration into preliminary ship design will be outlined, and the relationship between the different elements of HF and survivability will be discussed. Selected drivers on modern warship design will be examined for their implications in the interplay between survivability and the human element, before the paper concludes with a consideration of how HF can be better included in ship design in the future.

2. DRIVERS ON MODERN WARSHIP DESIGN

Warship design is a complex multidisciplinary activity, which is influenced by endo- and exogenous factors, relating to the requirements on the design, the design and procurement environment and the processes used. Some key influences of interest to the HF and survivability domains are outlined below.

2.1 DESIGN AND PROCUREMENT

Reduced Budgets – Defence budgets continue to be constrained and this effects both the UPC and TLC of modern warships.
Use of Computers in Design – The increasing use of computer based modelling and analysis, including simulation and Virtual Reality (VR), in the preliminary stages of design offers the potential for design teams to consider more aspects of the systems performance in the same timeframe, if the new tools are used appropriately.
PTs –Project Teams (formerly Integrated Project Teams) are a fundamental part of MoD activities, and offer a mechanism to ensure that multi-disciplinary aspects such as Human Factors are considered by other domain experts.

2.2 CHANGING OPERATIONS

Operations Other Than War – Traditionally warships have been designed for performance in "high-end" wartime operations, and then normally used in peacetime operations apparently requiring much lower levels of capability. However increasingly these "low-end" operations may be considered from the earliest stages of warship design.
Adaptability – Future warships may be required to be adaptable over a range of timescales, from short term tactical reconfiguration, to longer term, through life changes to role and function. The need to address these different activities has led to the adoption of solutions such as mission bays, vehicle decks and modularity, seen in the Danish Absalon Class "Flexible Support Ships" and future RN Type 26 "Global Combat Ship", which even eschew historical naming conventions reflecting the variety of their design missions.
Offboard Systems – There is increasing interest in the use of offboard systems, particularly unmanned systems.

2.3 MANNING AND PERSONNEL

Joint Operations – Joint operations are those involving multiple branches of the Services and they are seen to increasingly be the norm for future operations. Joint operations may involve the deployment of numbers of non-naval personnel aboard warships.
Reduced Manning – Reducing crew sizes is a potential route to reducing the TLC of future warships, and can also ease difficulties with recruitment.
Use of Reserves – In concert with reducing crew sizes and joint operations, an increasing proportion of future warship crews may be reservists.
Changing Skillsets – The skillsets required for warship crews may change in future, due to changing combat and hotel systems and technology.

2. HUMAN FACTORS INTEGRATION

In terms of military capability, whether a system will achieve its required level of operational effectiveness in the field depends not only on the technical performance of the hardware and the software that make up the system but the capabilities and limitations of the people who will operate and support it. Failure to address the people who are part of the system and the environment in which it will be operated can lead to an overall system that fails to achieve the expected levels of operational effectiveness or safety. Unless identified and addressed at early phases of procurement, solving problems in design is likely to be high cost and require:

- Equipment redesign or modification
- Increases in manpower numbers or a need for personnel with a higher level of skill
- Additional training time or resources

To address these problems UK MOD has established the Human Factors Integration (HFI) initiative. This is a systematic process for identifying, tracking and resolving human related issues ensuring a balanced development of both technological and human aspects of capability, together with supporting tools and techniques. A fundamental concept within HFI is that people are an important part of the system and that system integration is key to achieving operational effectiveness.

HFI should also be seen as an integral part of the Systems Engineering approach. The systems concept is central to the implementation of HFI and the overall goal of both HF and HFI is to design an optimal system consisting of operator, equipment and the environment in which they operate.

The UK MOD HFI Initiative is described in 7 domains shown in Figure 2. It should be noted that this domain structure is different from the U.S. Human Systems Integration (HSI) domains which exclude Social and Organisational, but instead include Habitability and Survivability.

MANPOWER
Numbers of people.

PERSONNEL
The type of people, their skills & experience.

TRAINING
Provision of essential job skills.

HUMAN FACTORS ENGINEERING
Integrating people with technology within the operational environment.

SYSTEM SAFETY
Safety risks when the system functions abnormally.

HEALTH HAZARDS
Hazards to health resulting from normal operation and support.

SOCIAL & ORGANISATIONAL
Soft systems issues, including situational awareness, trust, team working, distributed decision making, organisational structures.

Figure 2: The 7 domains of the UK MOD HFI initiative

4. HUMAN FACTORS IN NON-MARITIME DEFENCE DOMAINS

Human Factors, as an engineering discipline, has grown in importance in line with the complexity of system design. As far back as WWII, it was recognised that the crews of tanks, ships, submarine and aircraft were being required to assimilate and process increasing levels of information and to control multiple concurrent functions. This fuelled research into the psychology of work and the effects of the working environment on human performance.

The design of the military fast jet cockpit is one application where the demand for Human Factors knowledge and expertise is perhaps most readily evident. The control of sensor, communication and weapon technologies place significant mental demands on aircrew and the speed and manoeuvrability of the platform demand high levels of physical strength and fitness. The design of cockpit interfaces must enable the crew to perform tasks rapidly, effectively and safely. Novel human machine interfaces such as Direct Voice Input and Output, Head and Eye-Pointing technologies and Augmented Reality displays have been introduced into the modern fast jet cockpit in order to improve whole system performance through better integration of the human component.

Across all defence domains, advances in digitisation and connectivity are placing increasing demands on human ability to make sense of large volumes of information, both as individuals and as part of command teams responsible for making decisions. The combat systems used by operators need to be able to support the acquisition and maintenance of high levels of situational, whilst maintaining acceptable levels of workload and human error. The introduction of well- designed automation can increase whole system performance by supporting human activity. However, ill-conceived and poorly implemented automation risks isolating people from the control loop, reducing situational awareness and contributing to human error.

It is well understood that the physical environment can have a significant effect on human performance. The application of Human Factors design guidance, tools and techniques to the design of workspaces and working environments in land, air and maritime domains will improve the ability of operators, maintainer and support personnel to carry out their tasks efficiently and safely.

The relationships between human performance and factors such as lighting, temperature/ humidity, vibration and noise levels are well understood and design standards and guidance are well-documented.

Today, Human Factors is widely recognised as an important part of whole system design, with experts contributing to the design of a wide range of commercial and defence systems.

5. HUMAN FACTORS IN SHIP DESIGN

Human Factors have been considered in some aspects of warship design, for example the layout of spaces such as the bridge and ops room. This has, however, generally focussed on specific aspects, such as sea-sickness, for example the established NATO standards [6]), and other physical effects [7], the detail design of spaces and user interfaces ("micro-ergonomics") [8] or error making due to fatigue etc. [9].

Human error is the focus of the EC funded FAROS project [10], which adopts a probabilistic approach to the evaluation of risks in ship operation. Recent regulations governing civilian vessel design have started to move from deterministic, prescriptive approaches to probabilistic and goal-based standards. This was first applied to damaged stability in SOLAS 2009 [11] then expanded to fire safety on passenger ships [12]. The FAROS project aims to integrate models of the ship design characteristics that effect human performance, taking into account aspects such as motions, noise and vibration, accessibility etc., and then to use these to quantify the likely risks to personnel, passengers and wider society and the environment, as illustrated in Figure 3. The FAROS project focusses on the design and operational aspects that can lead to fatigue as this is a key HF issue in civilian operations. To quote the MCA; "*Fatigue kills: careers, clients, crew*" [13].

One task carried out under the FAROS project was a literature review of the available models linking external factors such as motions, vibration and layout to human performance [14]. This review is significant in that it illustrates the current limits of understanding in this complex subject; although quantitative models were available, they were found to be of a binary nature, i.e. all external factors below some value were modelled as having no effect on performance. There was claimed to be little evidence to support this binary approach, which serves both to illustrate the complexity of this aspect of Human Factors and to caution designers seeking to "optimise" a design based on the existing models.

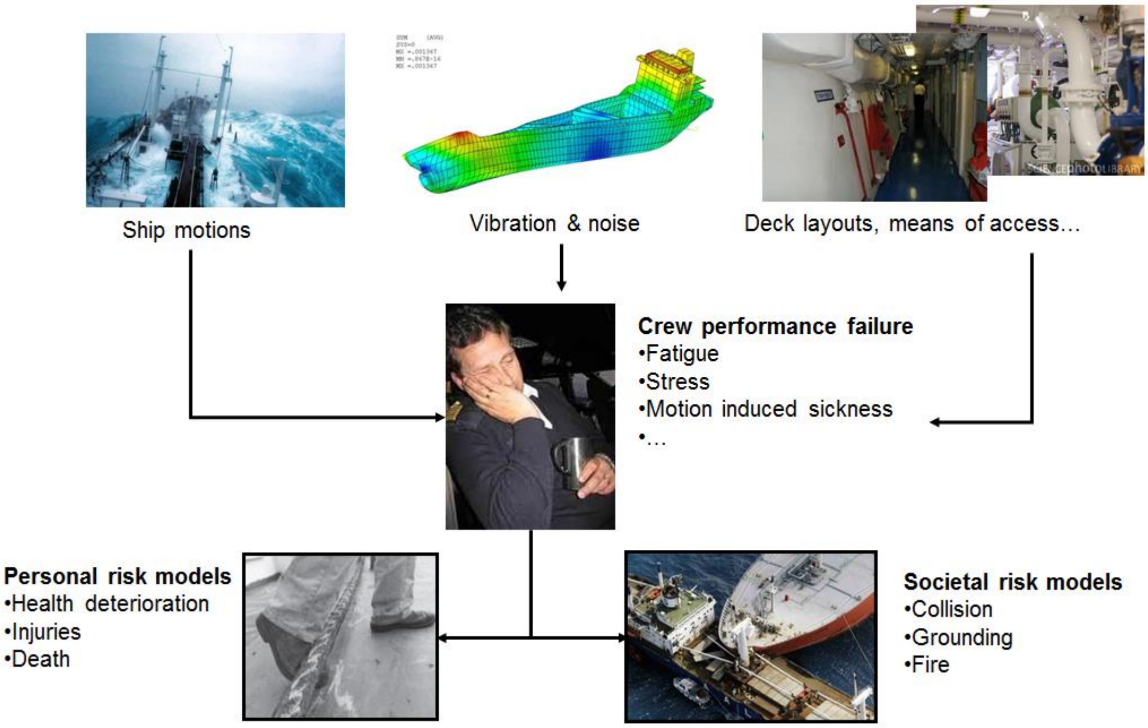

Figure 3: The FAROS project aims to integrate the wide range of design aspects that can affect human performance

5. HUMAN FACTORS WITHIN NAVAL SHIP SURVIVABILITY

It is possible to consider the importance of HF within survivability from two perspectives; the 7 HFI domains as shown in Figure 2 and the three elements of survivability shown in Figure 1.

5.1 CONSIDERING THE HFI DOMAINS

Manpower – The reduction in crew in numbers removes humans from the 'line of fire' (which is positive for crew survivability), but also reduces the level of resource available both to maintain high alert states and also to perform damage control activities and sustain the capability when under attack. Therefore potentially reducing survivability of the capability offered by the combination of platform and payload.

Personnel – The cognitive and physical characteristics of people forming crew complements will likely change in the future, with more women able to take up combat roles and the increasing use of Reservists. Greater levels of automation and autonomy, together with advances in C4ISR technologies will place a greater emphasis on the cognitive capabilities of the operators and maintainers of maritime platforms. The physical requirements for damage control tasks may mean that equipment and tool design will need to account for the changing characteristics of the user population.

Training – Training has traditionally been the primary mechanism to ensure recoverability in particular. However, training regimens may need to be changed to adapt to reduced manning, new technologies etc. The future increased use of Reserves may impact upon the training requirements or practicality of wide-ranging training regimes. This may combine with the increased tendency towards "joint" operations to impact the ability of embarked personnel to coherently inter-operate to maximise survivability.

Human Factors Engineering – This effects the allocation of functional decision making when integrating survivability-related technologies. A key area is the maximization of Situational Awareness (SA) through HCI design, communications protocols, command team workspace layout to optimise communications, application of task analysis and human performance assessment as part of a human-centred approach to system design.

System Safety – Although safety is normally thought of as a statutory / peacetime aspect, it concerns the elimination of abnormal behaviours and thus the approaches adopted are equally as valuable to improve performance during wartime. Attention must be paid to how safety-related attitudes and behaviours are developed and maintained. How does the system prevent human error (or minimise the impact of human error) which may lead to a threat to people of capability (e.g. threat evaluation and response selection, course planning, weapon release etc.).

Health Hazards Assessment – The methods used for HHA can be used to identify design features that improve survivability. These include; the development and use of novel materials and structures to improve survivability; impact absorbing, heat/fire resistant, stealthy (RF/EO) etc. Location of personnel with respect to hazard sources (radiation, explosives, fuel, machinery etc.).

Social and Organisational – This aspect includes the improvement of information flows to support threat identification and assessment, with attendant team location considerations such as the trade-offs between information flow and survivability (co-location of command teams versus distributed command teams). The broader organisational aspects include 'Crew Resource Management' programs to enable junior staff to challenge the decisions taken by senior officers and again the issue of joint operations with embarked forces who may have a different skill set, particularly with regards to survivability aspects.

5.2 CONSIDERING SURVIVABILITY

The HFI Technical Guide, MAP-01-011, produced by the UK MOD Sea Systems Group, now part of the Naval Authority Group (NAG), contains some technical information relating HF and survivability, but it is in the context of shock loads on personnel, ergonomic effects of modern reduced RCS upperdeck design etc. [15]. It is important to appreciate that the relationship between survivability and HF is more holistic.

Traditionally, the aspect of survivability most closely associated with Human Factors has been Recoverability, as this deals with the ability of the crew to repair damage and restore at least some of the ship's capability. It is generally understood that the impact of a threat weapon will lead to some loss of capability of the warship. However, it is expected that recovery efforts will allow the restoration of some capability after some period of time, as generically shown in Figure 4.

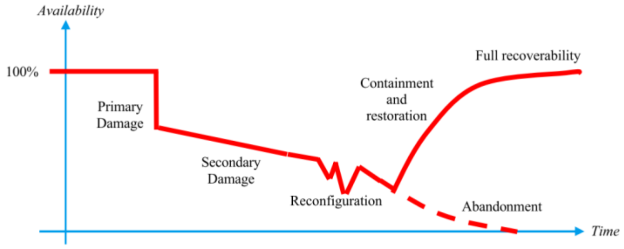

Figure 4: Loss of capability and subsequent recovery after damage, from [16]

This has potentially led to a dichotomy in that susceptibility and vulnerability are largely driven by technical design features and combat systems and thus amenable to numerical analysis and trade-offs whilst recoverability is driven by training and personnel and is not. However, the SURVIVE software can assess damage control effectiveness once a detailed design has been developed [16] and more recently an early stage method for the numerical analysis of recoverability and its integration into the overall evaluation of survivability has been proposed by Piperakis et al [17].

In addition to the possibility of applying some form of quantification to recoverability, it should also be noted that in fact susceptibility and vulnerability will be influenced by Human Factors and an analysis which does not include the human as part of the system may be incomplete. For example, the use and state of watertight hatches during crucial evolutions has been examined using simulations [18], which will influence vulnerability.

Human Factors will also influence susceptibility. The FAROS project described above is an example of an attempt to quantify the influence of the Human Element on susceptibility and vulnerability (in the form of collisions and groundings of civilian vessels). In addition to issues such as fatigue which are of particular interest in the civilian sector, naval operations introduce additional complexities such as the maintenance of situational awareness and the functional roles that the crew and embarked personnel play in operating defensive systems, particularly against certain types of threats.

6. DISCUSSION: REDUCED MANNING

Compared to the current Type 23 Frigate, the Royal Navy has opted to reduce manning costs of the new Type-26 by adopting a modular approach to complementing. The core crew required to operate and maintain the ship in a strictly non-combat role, is perhaps 30% less than the standard Type 23 crew. This crew will be augmented for specific operational capabilities by small mission teams shared across the fleet. The Type 45 Daring class destroyer has a complement 25% less than the Type 42 Sheffield class it replaces. The new Queen Elizabeth Class aircraft carrier, despite being about 3 times larger and certainly more capable than the old Illustrious class, has roughly the same ship's complement.

3.1 EFFECTS ON SURVIVABILITY

Reducing the number of crew on the ship has some survivability benefits. The most obvious is that it puts fewer people at risk within a single ship. If a smaller crew were evenly spread out over the length of the ship then it would place less people in the immediate vicinity of localised damage (a single missile strike for example). However, a smaller crew may, in conventional design philosophies, actually be more concentrated and thus be more vulnerable to a single strike in certain key areas.

There are other perhaps less obvious implications of reduced manning that must be carefully considered to avoid a negative impact on survivability. A smaller crew will have fewer people immediately available for managing the internal battle. Due to the likelihood of the ship already being at Readiness State 1 in the event of damage, the crew will already be fully utilised. This will include a number of damage control parties but a smaller crew will have fewer people to man these. If further back up is required for wide spread damage or to replace exhausted personnel, this must come at the expense of other tasks, so reducing recoverability.

A similar problem with reduced crew sizes is a lower resilience to unexpected loss. Essential skills and knowledge to maintain capability may be shared amongst fewer higher-value individuals. It can be anticipated that a certain proportion of a ship's crew may be sick at any one time. In an operational scenario, key personnel can be injured or killed leading to a drop in capability for both the internal and external battle.

The use of smaller core complements with teams of specialists may also have a detrimental effect on recoverability, as the specialists may not have the training to provide the long-term support to recoverability efforts that full-time naval crew may provide. These augmentees may effectively be "payload" in that they are providing some part of the ships capability – perhaps the primary role in the case of Operations Other Than War (OOTW) – but are less capable of fulfilling other tasks. Training of augmentees can improve this, but that comes at additional cost.

3.2 DESIGN APPROACHES AND SOLUTIONS

From the holistic survivability perspective, reducing manning and associated costs per ship may reduce recoverability but allow a greater proportion of a fixed defence budget to be spent on more ships or more capable equipment elsewhere, potentially reducing susceptibility or vulnerability.

System automation is often seen as a key enabler to reduced manning. However, the result is often personnel heavily reliant on information displays and control panels. In an engine maintenance task, for example, rather than regular manual checks by experienced engineers, a modern engine may have multiple internal sensors connected to a sophisticated condition monitoring system. When the system is working correctly, a well-designed human-computer interface may provide the operating engineer with the same or greater level of awareness than in manual systems. However, in a survivability scenario, it's possible certain elements may be damaged and malfunctioning or entire systems may be off-line. Situation awareness can rapidly deteriorate and the correct remedial action is not always obvious.

Many of the considerations above must be addressed at the strategic level by the customer before setting a new ship's requirements, as they relate to broader organisational issues as indicated by the 7 HFI domains. However, once a crew size has been determined, is it possible to design ships and systems in a way to improve crew survivability by limiting the impact of damage on essential situation awareness, and ensuring the correct course of action is also the most obvious?

7. DISCUSSION: COMBAT SYSTEMS

7.1 DISTRIBUTED COMBAT SYSTEMS

Western warships have tended towards a single, centralised operations room from where all aspects of the combat system are controlled. Split operations rooms have been suggested as a means to enhance survivability of at least part of the ships combat system after a single missile hit [19]. A further alternative, used in some Soviet vessels, is to use a "battery command" type approach, where each weapons system is controlled by local operators with the equivalent of the operations room having a co-ordinating role [20].

Such approaches have the benefit of reduced vulnerability and improved recoverability, but there is a potential adverse impact on susceptibility. Consideration needs to be given to the potential impact on the ops room team if they are not co-located. Could a distributed ops room degrade the shared situational awareness of the team? Could the captain still understand the battle space if it was planned over two locations? Could decisions be compromised or errors occur as a result of this distributed team working?

As designers, we need to address how distributed teams could be supported to ensure the capability (the ops room objectives) is not degraded. Distributed teams have been formally defined as "teams whose members are dispersed across distance and time, are linked together by some form of electronic technology, and physically interact with each other rarely or not at all" [21]. As a result of the physical separation, traditional communication and coordination can be more difficult for distributed teams, which can result in restricted information flow, reduced situation awareness and degraded communication.

Designing software interfaces that fully capture or replace team communication is difficult; teams are complex with high task interdependencies [22]. One of the key elements of team performance is shared cognition with poor shared cognition often resulting in poor team performance [23]. Therefore it is imperative that the software used by a distributed team supports the ability for a team to still establish a shared mental model or situational awareness.

Human-Computer Interaction (HCI) addresses the design of the interface between the user and the equipment/computer and consideration needs to be given to the design of the hardware equipment to support the dispersed nature the operations room team. The software and hardware tools used must also be consistent with the processes and procedures used and the expectations and previous experience of the operators. A crew who have only ever operated within a centralised combat management environment would not be expected to perform well when placed into distributed one. However, with the rise of on-line multiplayer gaming of increasing fidelity and complexity, involving in some cases simulated combined-arms operations with players on multiple continents [24] it may well be the case that future recruits are already familiar with these methods of operation – but can such familiarity be sustained through the wider training process and actually be effective under the increased stresses and complexity of a combat environment?

7.2 OFFBOARD SYSTEMS

Beyond the potential for distributed combat systems within the warship itself, the capability offered by a warship is becoming more distributed through the use of offboard systems – particularly unmanned ones. In addition to this, increased communications bandwidth, contemporary political considerations and the tendency towards reduced manning are all leading to the potential for more decision making to be moved off of the warship and to shore bases or command vessels. The warship is thus operating less as an independent unit and more as a node in a complete integrated system or network.

As with reduced manning in general, these approaches have the survivability benefits both for capability – by dispersing it and moving infrastructure and command elements further from potential threats – and for personnel – by removing them from direct threat. However, this further complicates the social and cognitive aspects of distributed decision making with the potential for issues of boredom, commitment and crew cohesion to consider. The introduction of unmanned vehicles as a means to improve survivability through reducing susceptibility again has potentially adverse effects on vulnerability and recoverability.

With solid-state radars and Vertical Launch Systems (VLS), traditional weapons systems are potentially becoming simpler to repair or feature "graceful degradation". However, the same may not be true of the mechanised handling systems required in the mission bay of a UXV carrying combatant. As was noted by Pawling and Andrews [25] the mission bay is not a "big metal box", but will contain mechanically complex equipment vital to the operation of the ships main military capability. As with the wider aspects of recoverability, the skills required and numbers of maintainers for these systems should be considered from a survivability perspective – will a minimal crew have enough skilled individuals to conduct physically intensive repairs to mechanical systems, or even to operate manual reversionary modes if these are available?

8. DISCUSSION: OPERATIONS OTHER THAN WAR

The increasing importance of Operations Other than War and littoral operations in warship design introduces additional dichotomies to an already complex problem, with some being of particular interest to survivability and the human element. These are outlined in Table 1, with these being extremes on a spectrum rather than a pure binary split.

"High End" Wartime Operations	**←→**	**"Low End" OOTW**
High capability threats under positive control	←→	Low capability threats with poor command and control
Varying times of high and low tempo	←→	Constant low tempo of operations and stress
Permissive Rules of Engagement (RoE)	←→	Restrictive RoE
Effectors are primarily weapons	←→	Effectors are primarily people
Losses may be compared with military effect	←→	Losses have disproportionate political and practical impacts
Survivability of capability important	←→	Survivability of crew and embarked forces important

Table 1: Comparison of "high-end" and "low-end" operations indicating the complexity of the latter

8.1 CREW AND CAPABILITY SURVIVABILITY

One intersectional aspect is the comparison of the survivability of the *crew* versus the survivability of the *capability*. During low-intensity warfare and OOTW, political considerations (including the desire to avoid escalation) may lead to an emphasis on the survivability of the crew at the expense of the capability offered by the vessel, whereas during high-intensity operations the crew are placed at risk to preserve the fighting capability of the vessel (for example in damage control).

8.2 PROTECTION AGAINST LOW END THREATS

Survivability of warships against "low end" threats such as small arms and other man-portable weapons takes on an additional significance when personnel are considered. Although such weapons are unlikely to sink a warship they may disable key equipment and so should be considered in design to avoid a "cheap kill". However, this is complicated by the fact that, for many OOTW, the crew and embarked personnel *are* in fact, the capability of the vessel both in attack, (for example a small RM force) and defence (upper deck gun crews).

8.2 (a) Mission Bays:

Embarked forces accommodation and assembly areas such as mission bays may present a significant concentration of vulnerable personnel (and capability). They may have a large surface area, making armouring difficult, and extend to the complete width of the ship (for boat operations over the side), so preventing shielding with other compartments. It may be the case that mission bays and adaptable spaces should be designed to allow protected spaces to be configured towards the centreline to provide protection to personnel. One possible material solution is a configuration such as that used in the Danish Absalon, with wing compartments that may provide some protection to a centreline mission bay.

8.2 (b) Upperdeck Weapons:

The hazards to exposed upperdeck personnel are well illustrated by the infamous case of HMS Chester at the battle of Jutland where gun crews were severely injured because the open-backed mounts (typical of many warships of that time) did not provide sufficient protection from shell splinters [26]. Attackers wielding small arms and Rocket Propelled Grenades (RPG) will present a similar threat to exposed upperdeck personnel. The limited Rules of Engagement (RoE), confused surface picture and resulting close ranges of littoral and OOTW engagements may actually significantly increase the chances of surface warships taking fire in "low end" operations.

Whereas theoretical "high end" long range combat by missile may be best fought with all crew under cover, OOTW may require upperdeck crew for situational awareness, manning of additional small weapons etc. and thus it becomes important to consider the protection afforded to these crew under small arms attack. The consequences of injury or death are further magnified by the political sensitivities and the potential for such engagements to be dependent on these same upperdeck personnel for defence. It will not be possible to provide complete protection at all times, but consideration must be given to how to reload, clear stoppages etc. in modern automated Small Calibre Guns if they are in exposed positions (to gain the best arcs of fire).

8.3 THE ADAPTABLE WARSHIP

Adaptability was noted in Section 2 as a driver on modern warship design, and this ties in with the contrasts outlined earlier in this section, as a vessel should be designed to operate in radically different modes. Although traditionally warships designed for "high end" operations have been used for what seem to be less arduous tasks and warships are now being designed to operate with highly variable crew numbers, and this imposes some additional demands on the design of hotel systems. Additionally, it must be borne in mind that incidents such as groundings or collisions – the latter being a particular hazard during policing operations – present a survivability challenge over the entire range of operations. Thus when the wider issues of survivability and the human element – and the interaction of these – are considered it may be the case that some of the "low end" tasks actually impose significant requirements on the design.

9. INCORPORATING THE HUMAN ELEMENT INTO THE WARSHIP DESIGN PROCESS

The SSG MAP-01-010 HFI Management Guide, provides guidance on both the general scope of HFI in Naval projects and on its application [27]. This is then further detailed by MAP-01-011 which provides guidance on many technical aspects of design for improved HF [15]. At 629 pages the latter is very detailed but it is important to make use of the organisational, procedural and technical tools available in the modern warship design environment to ensure that this "transversal" aspect of ship performance is assessed at an early stage.

PTs provide an ideal framework to incorporate HF experts at the earliest stages of design, but as has been illustrated by the examples discussed in this paper, good HFI, which contributes to the overall effectiveness of the warship, is not only a matter of detail design but also the overall configuration and large-scale design choices. Thus this expertise must be employed at the formative, early stages of ship design, and importantly naval architects, should be familiarised with at least the basic concepts of macro-scale HFI, and the concept of the crew as a fundamental component of the military system, rather than as operators or passengers.

The increasing use of computers in the early stages of ship design offers an additional route to ensure that holistic HFI issues are considered at an early, formative stage. Computerisation of design processes is a "non-zero sum game", in that they can increase the capabilities of design teams, but only if they are utilised effectively – otherwise time may be spent reaching a desirable outcome by passing through many undesirable ones in succession.

The primary difficulty in utilising computers for HFI analysis is that they require clear, quantified descriptions of the problem. However, there may be potential for their use as knowledge management tools. Recent research in capturing and applying knowledge regarding general arrangements design may provide one method to apply expert knowledge from other domains such as HFI. [28] [29].

10. CONCLUSIONS

Modern warship design is facing a number of exo- and endogenous drivers in terms of the design and procurement environment, the nature of tasking and future uncertainty and crewing concepts and structures. Human Factors have previously been considered in ship design, and some technical guidance is available, but generally it has focussed on the detail level of "micro-ergonomics" and the incidence of fatigue which is of particular interest in the civilian sector.

The UK MoD HFI initiative defines 7 domains; manpower, personnel, training, human factors engineering, system safety, health hazards, and social and organisational. These can be interpreted in the context of survivability as requiring assessment of HF issues from a wider perspective than has usually been the case. Survivability is a complex subject that incorporates many aspects of ship design and operation. This includes the human element in two different ways; firstly factors effecting the performance of the personnel as part of the ship system, and secondly the trade-off between the survivability of the crew and the survivability of the capability. These HFI domains provide a useful framework for considering the interplay of these different issues.

This paper has considered three of the current drivers on warship design for their impacts on survivability in the context of the human element; Reduced manning; future combat systems including offboard systems; and Operations Other Than War (OOTW). In all cases there were seen to be some interactions between different aspects of modern warship design and operation that again require a more holistic assessment of HF issues. Reduced manning and future combat systems were seen as having potential effects on personnel performance that could negatively impact survivability – when considered in its entirety – that relate to the technological solutions adopted. The third example, OOTW, was seen as having different implications for the HF aspect of survivability. A comparison of "high-end" and "low-end" operations indicates that the latter may have the more significant implications on ship design and operation when the Human Element is considered.

Although this paper argues that a more holistic approach is needed to properly incorporate HF in warship design and in particular to capture its interaction with survivability, it is noted that changes to the design and procurement environment make this a possibility. The use of IPTs is seen as an ideal mechanism for incorporating HF expertise at the earliest stages of design. Importantly, the increasing use of computers in preliminary ship design is seen as increasing the range of issues that can be considered, with the main research question being how best to use them to handle the holistic, high level HF issues and expertise identified as being most useful in the preliminary design stage.

11. REFERENCES

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