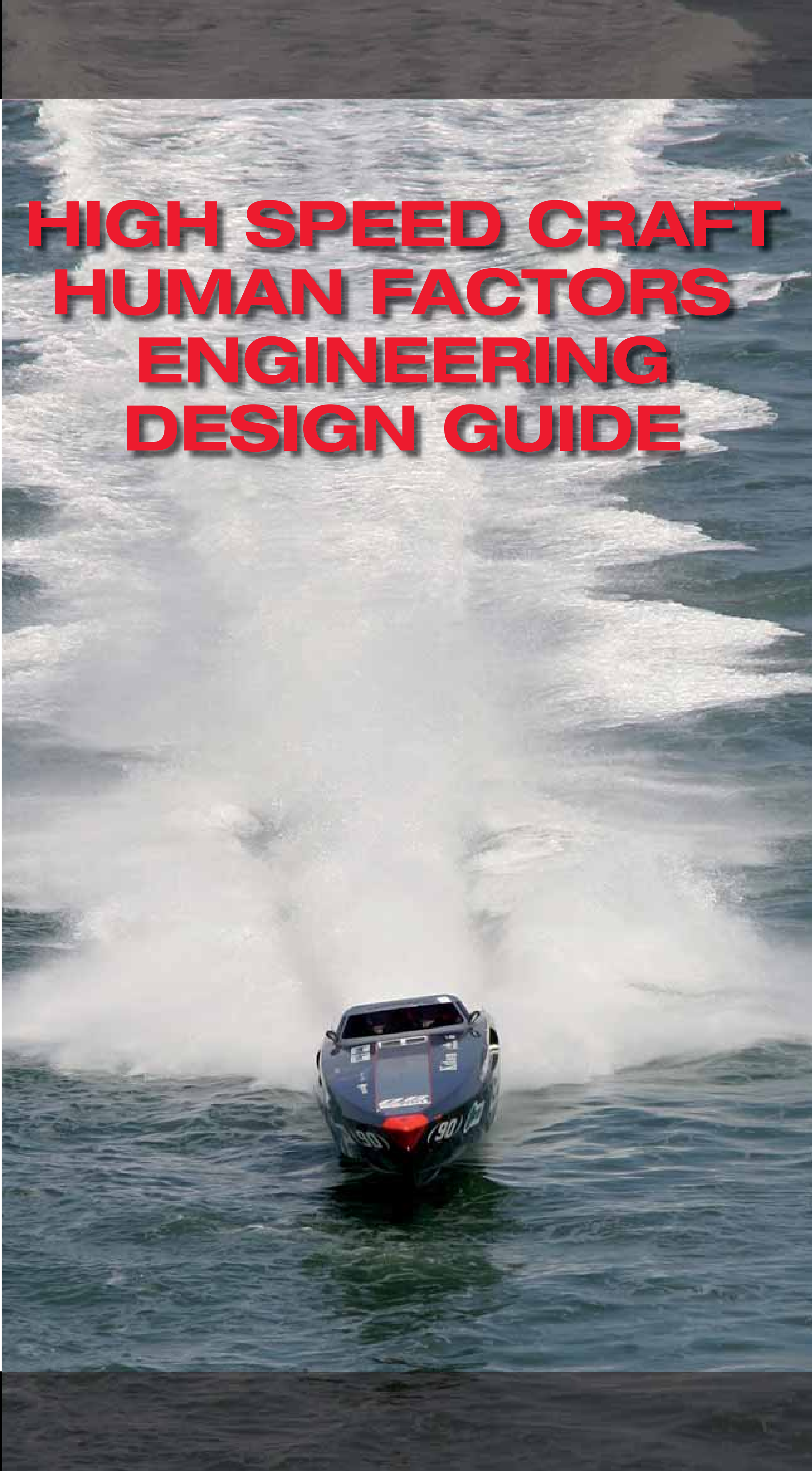
ABCD-TR-08-01 V1.0

HIGH SPEED CRAFT HUMAN FACTORS ENGINEERING DESIGN GUIDE



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CONTENTS

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LIST OF ABBREVIATIONS

ABCD-WG	American Australian Britaish Canadian Dutch – Working Group
ASIC	Air and Space Interoperability Council
ASCC	Air Standardization Coordinating Committee
C2	Command and Control
CAD	Computer Aided Design
CADMID	Concept, Assessment, Demonstration, Manufacture, In-service, and Disposal
CG	Centre of Gravity
COTS	Commercial-Off-The-Shelf
DNV	Det Norske Veritas
DOD	Department of Defense
DOF	Degrees of Freedom
DSTAN	(UK) Defence Standard
EU	European Union
GA	General Arrangement
HF	Human Factors
HFE	Human Factors Engineering
HFI	Human Factors Integration
HSB	High Speed Boat
HSC	High Speed Craft
IMO	International Maritime Organisation
IPT	Integrated Project Team
ISO	International Organisation for Standardisation
ITEAP	Integrated Test, Evaluation and Acceptance Plan
LOA	Length Overall
MCA	Maritime and Coastguard Agency
MIF	Motion Induced Fatigue
MII	Motion Induced Interruptions
MIL-STD	(US) Military Standard
MMI	Man-Machine Interface
MOD	Ministry of Defence
MSC	Maritime Safety Committee
MSI	Motion Sickness Incidence
MTA	Mission Task Analysis
NA	Naval Architect
OA	Overall Arrangement
OR	Operational Requirement
PPE	Personal and Protective Equipment
R&P	Resistance And Propulsion
RCD	Recreational Craft Directive
RNLI	Royal National Lifeboat Institution
RS	Repeated Shock
T&E	Test and Evaluation
TA	Task Analysis
TNA	Training Needs Analysis
S&V	Shock and Vibration
SA	Situational Awareness
SIL	Speech Interference Level
SIMS	Systems & Information Management System
SME	Subject Matter Expert
SOC	Special Operations Craft
SRD	Systems Requirements Document
UK	United Kingdom
URD	User Requirements Document
US	United States
USA	United States of America
WBV	Whole Body Vibration

INTENDED AUDIENCE

NAVAL ARCHITECTS

This Guide is designed so that it may be used as a resource for the Naval Architecture (NA) community. It is envisaged that it may be used as a (quick) reference that NAs can utilise in their every-day activities allowing them to rapidly gain a basic understanding of the Human Factors (HF) issues, potential design solutions, and where to go for further, more detailed information when required.

ACADEMIA

This Guide is designed so that it may be used as a resource for the academic Naval Architecture and Design community. It is envisaged that it could form the basis of a module/course or be used as reference material within individual lectures. The information on the HSC design process should allow students to obtain a greater understanding of how HF are integrated into the design of the craft.

PROCUREMENT AGENCIES

This Guide is designed so that it may be used as a resource for the HSC procurement/acquisition community. It is envisaged that the guideline may be referenced in tender documentation, therefore reducing the amount of detailed HF requirements that need to be included in the documentation. System suppliers may then be asked to document where and why they have not followed the advice within the document (i.e. compliance with the SRD). The guideline also provides advice on how to include objective HF requirements within the Specification and T&E processes and therefore assist in the procurement/acquisition acceptance process.

REGULATORY BODIES

This Guide is designed so that it may be used as a resource for Regulatory bodies (e.g. UK Maritime & Coast Guard Agency). It is envisaged that such bodies may use the guide as reference material when providing advice to HSC designers, manufacturers, and operators.

HUMAN FACTORS SUBJECT MATTER EXPERTS

This Guide is designed so that it may be used as a resource for the Human Factors SME community. It is envisaged that it may be used as reference and guidance material for HF SMEs who are not familiar with the specific requirements of HSC design and operation. The information on the HSC design process should allow them to obtain a greater understanding of the constraints and compromises involved in the design of HSC.

PREFACE

INTRODUCTION

This Guide is sponsored by the UK MOD Defence Equipment & Support Agency (DE&S); Directorate of Sea Systems[1] and supported by the ABCD Working Group. The development of the Guide followed conference presentations[2] and consultation with of an international group of High Speed Craft (HSC) stakeholders, to identify the Human Factors[3] (HF) requirements for the Guide, and how it should support Naval Architects (NA), Designers[4], and the HSC procurement process.

The 'ABCD[5] Working Group on Human Performance at Sea' is an ad-hoc international group consisting of hydrodynamics and HF researchers representing a wide spectrum of ship design, R&D and defence agencies. Formal government agreements are used to facilitate information exchange between the participants. The group consists of representatives from the US, Australia, UK, Canada and The Netherlands. Its aim is to provide navy staff, designers and operators with the knowledge to be able to quantify human performance degradation, associated with ship and boat motions that are necessary for the overall determination of the operational capabilities of a vessel. The aim is achieved by jointly planning and funding work which will develop criteria and models for specific aspects of human performance, that affect the ability of navy personnel to perform their allotted tasks effectively.

THE GUIDE

The guide uses a simplified theoretical NA design process, broken down into Feasibility, Main and Detail design phases, on to which HF design features are inserted at the appropriate points in the design process. The authors recognise that designers and manufacturers use a variety of design processes and timelines, but, it is anticipated that the design activities identified within the simplified process are recognisable to the majority of NAs and Designers, and therefore the appropriate HF input can be facilitated at the appropriate points during the design process used.

USING THE GUIDELINE

The Guide is divided into two Parts;

Part 1. This part provides background information and the development of an integrated NA-HF design process. It is designed to provide an introduction into the use of HF within the design process and how the authors developed the integrated NA-HF design process. This section also provides background information on the HSC design process for stakeholders who are not familiar with the design process within the procurement cycle.

Part 2. This part provides the HF information required to support the designer at the appropriate points throughout the HSC design and evaluation processes. It provides the Designer and stakeholders with HF information tailored to the design process phases (Feasibility, Main and Detail design phases), and at an appropriate level of detail for each phase. Additionally, more detailed information is provided for stakeholders who require more in-depth knowledge of specific HF issues.

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[1] United Kingdom, Ministry of Defence, Defence Equipment & Support Agency procures equipment for the UK Armed Services. The Directorate of Sea Systems, located with DE&S, provides technical support to the maritime procurement process.

[2] Dobbins, T. (2004) High speed craft design from a human centred perspective. *Conference proceedings Royal Institute of Naval Architects; SURV 6: Surveillance, Pilot and Rescue Craft*, London.

Pierce, E. and Dobbins, T. (2004) Development of a Human Factors Engineering Standard for High Speed Boats. Conference Proceedings. *Multi-Agency Craft Conference*, Norfolk, VA.

Dobbins, T. and Pierce, E. (2005) Developing a Human Factors Design Standard for High Speed Planing Craft. *Royal Institute of Naval Architects, Conference Proceedings; Rigid Inflatables*. Cowes, UK.

[3] The terms Human Factors (HF) and Human Factors Engineering (HFE) are used interchangeably within this guide.

[4] The terms Naval Architect and Designer are used interchangeably within this Guide.

[5] This is known as the "ABCD Group" due to the nationalities who form its membership: American, Australian, British, Canadian and Dutch researchers and defence agencies.

The HF information is divided into ten sections, within which more comprehensive information is provided. Subsequently case studies are provided as examples of how HSC have been designed with HF as an integral part of the design process. The HF sections are:

A. HSC Motion

B. Sight

C. Sound

D. Environment

E. Health & Safety

F. Man-machine interface

G. Habitability

H. Maintainability

I. Design review

J. Test & Evaluation

Each of these HF sections provide a short general introduction and cues to the HF issues to be addressed within the different design phases (Feasibility, Main and Detail). More detailed additional information is subsequently included with references where appropriate.

Many of the sections are designed so that they may be referred to as stand-alone sections (i.e. if a individual section is copied for distribution). Because of this, acronyms are given in full at the start of each section, and references and further reading is provided in the footnotes.

THIS GUIDE DOES NOT:

Provide detailed anthropometric data on which to base a HSC design. This is to ensure that the dimensions are not taken out of context, and because different nations have differing operator sizes. The designer should refer to the appropriate countries most up-to-date source of appropriate anthropometric data. Examples of anthropometric data sources are given within the appropriate Sections.

DISCLAIMER

The examples of the ergonomic design process and solutions contained in this document are provided for illustration purposes only, and do not reflect the official policy of any of the contributing organisations. The author's, contributors, sponsors and supporters take no responsibility for the content or any liability arising from its implementation.

DOCUMENT RELEASE CONDITIONS

This document has been prepared for the UK MOD and is distributed under the organisation of the ABCD Working Group. ***It may be used without restriction, but not reproduced in any format without permission.*** Refer to the Configuration information for additional details.

COMMENTS & FEEDBACK

The authors welcome comments and feedback on this guide and ***where appropriate will endeavour to incorporate these into future updates of the Guide***. These can be submitted at:

- hfguide@highspeedcraft.org
- www.highspeedcraft.org/hf-guide

UNDERSTANDING THE LAYOUT

‘TAKE HOME’ INFORMATION IS PROVIDED TO EMPHASISE THE IMPORTANCE OF SPECIFIC HF INFORMATION AT APPROPRIATE TIMES IN THE HSC DESIGN PROCESS.

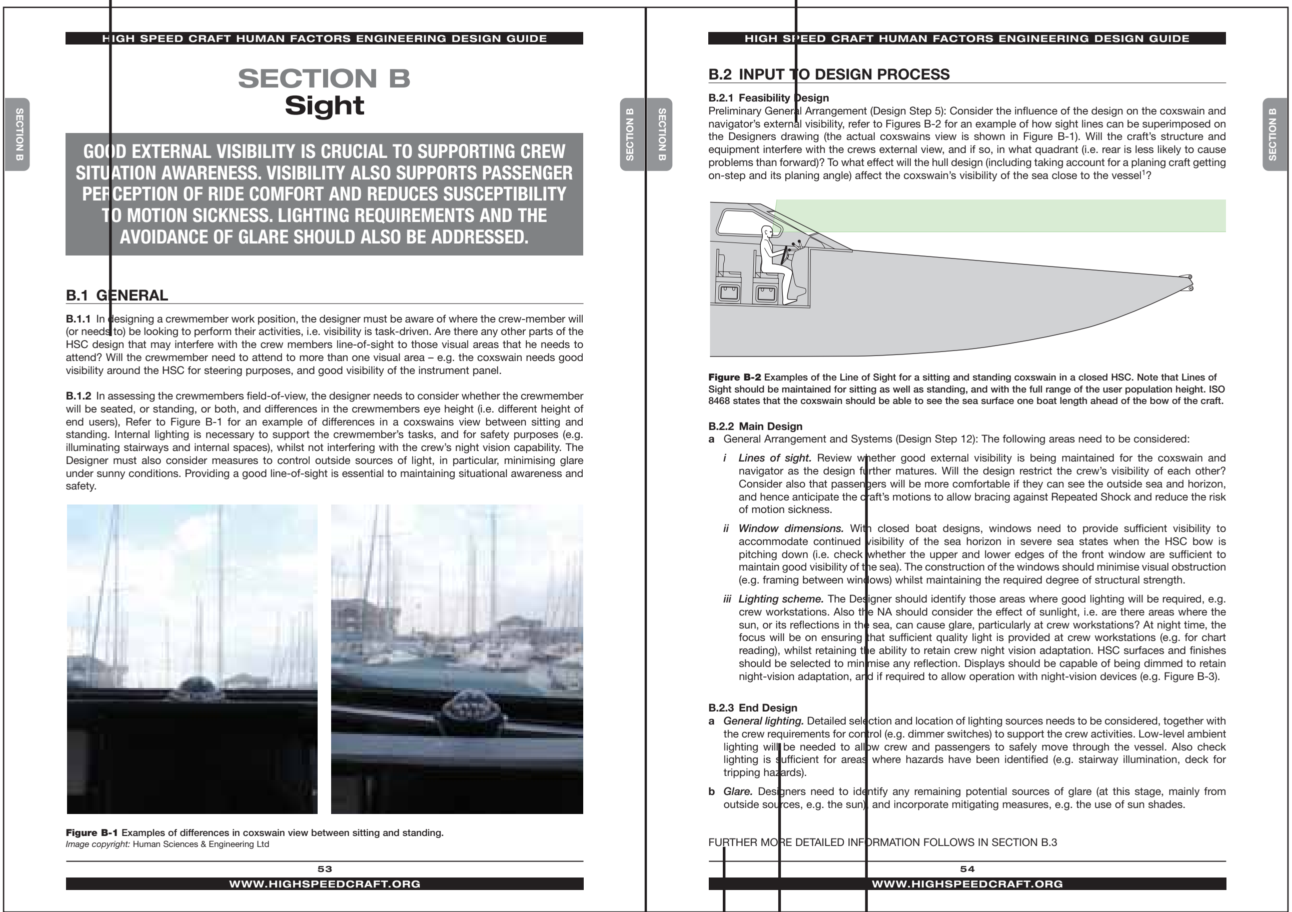
GENERAL

- Description of HF section and background information

INPUT TO DESIGN PROCESS

Feasibility Design

- Information related to the ‘Feasibility’ Phase of the design process



HIGH SPEED CRAFT HUMAN FACTORS ENGINEERING DESIGN GUIDE

SECTION B

SECTION B
Sight

GOOD EXTERNAL VISIBILITY IS CRUCIAL TO SUPPORTING CREW SITUATION AWARENESS. VISIBILITY ALSO SUPPORTS PASSENGER PERCEPTION OF RIDE COMFORT AND REDUCES SUSCEPTIBILITY TO MOTION SICKNESS. LIGHTING REQUIREMENTS AND THE AVOIDANCE OF GLARE SHOULD ALSO BE ADDRESSED.

B.1 GENERAL

B.1.1 In designing a crewmember work position, the designer must be aware of where the crew-member will (or needs to) be looking to perform their activities, i.e. visibility is task-driven. Are there any other parts of the HSC design that may interfere with the crew members line-of-sight to those visual areas that he needs to attend? Will the crewmember need to attend to more than one visual area – e.g. the coxswain needs good visibility around the HSC for steering purposes, and good visibility of the instrument panel.

B.1.2 In assessing the crewmembers field-of-view, the designer needs to consider whether the crewmember will be seated, or standing, or both, and differences in the crewmembers eye height (i.e. different height of end users), Refer to Figure B-1 for an example of differences in a coxswains view between sitting and standing. Internal lighting is necessary to support the crewmember’s tasks, and for safety purposes (e.g. illuminating stairways and internal spaces), whilst not interfering with the crew’s night vision capability. The Designer must also consider measures to control outside sources of light, in particular, minimising glare under sunny conditions. Providing a good line-of-sight is essential to maintaining situational awareness and safety.

Figure B-1 Examples of differences in coxswain view between sitting and standing.
Image copyright: Human Sciences & Engineering Ltd

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SECTION B

B.2 INPUT TO DESIGN PROCESS

B.2.1 Feasibility Design
Preliminary General Arrangement (Design Step 5): Consider the influence of the design on the coxswain and navigator’s external visibility, refer to Figures B-2 for an example of how sight lines can be superimposed on the Designers drawing (the actual coxswains view is shown in Figure B-1). Will the craft’s structure and equipment interfere with the crews external view, and if so, in what quadrant (i.e. rear is less likely to cause problems than forward)? To what effect will the hull design (including taking account for a planing craft getting on-step and its planing angle) affect the coxswain’s visibility of the sea close to the vessel[1]?

Figure B-2 Examples of the Line of Sight for a sitting and standing coxswain in a closed HSC. Note that Lines of Sight should be maintained for sitting as well as standing, and with the full range of the user population height. ISO 8468 states that the coxswain should be able to see the sea surface one boat length ahead of the bow of the craft.

B.2.2 Main Design
a General Arrangement and Systems (Design Step 12): The following areas need to be considered:

i Lines of sight. Review whether good external visibility is being maintained for the coxswain and navigator as the design further matures. Will the design restrict the crew’s visibility of each other? Consider also that passengers will be more comfortable if they can see the outside sea and horizon, and hence anticipate the craft’s motions to allow bracing against Repeated Shock and reduce the risk of motion sickness.

ii Window dimensions. With closed boat designs, windows need to provide sufficient visibility to accommodate continued visibility of the sea horizon in severe sea states when the HSC bow is pitching down (i.e. check whether the upper and lower edges of the front window are sufficient to maintain good visibility of the sea). The construction of the windows should minimise visual obstruction (e.g. framing between windows) whilst maintaining the required degree of structural strength.

iii Lighting scheme. The Designer should identify those areas where good lighting will be required, e.g. crew workstations. Also the NA should consider the effect of sunlight, i.e. are there areas where the sun, or its reflections in the sea, can cause glare, particularly at crew workstations? At night time, the focus will be on ensuring that sufficient quality light is provided at crew workstations (e.g. for chart reading), whilst retaining the ability to retain crew night vision adaptation. HSC surfaces and finishes should be selected to minimise any reflection. Displays should be capable of being dimmed to retain night-vision adaptation, and if required to allow operation with night-vision devices (e.g. Figure B-3).

B.2.3 End Design
a General lighting. Detailed selection and location of lighting sources needs to be considered, together with the crew requirements for control (e.g. dimmer switches) to support the crew activities. Low-level ambient lighting will be needed to allow crew and passengers to safely move through the vessel. Also check lighting is sufficient for areas where hazards have been identified (e.g. stairway illumination, deck for tripping hazards).

b Glare. Designers need to identify any remaining potential sources of glare (at this stage, mainly from outside sources, e.g. the sun), and incorporate mitigating measures, e.g. the use of sun shades.

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION B.3

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Sample spread

Main Design

- Information related to the ‘Main’ Phase of the design process

End Design

- Information related to the ‘End’ Phase of the design process

REFER TO ANNEX FOR FURTHER INFORMATION

- Details of further Information

PART 1

BACKGROUND HSC AND HF INFORMATION, AND THE DEVELOPMENT OF THE INTEGRATED DESIGN PROCESS

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1. INTRODUCTION

1.1 BACKGROUND

1.1.1 High speed craft (HSC) can subject their crew and passengers to one of the harshest operating environments of any mode of transport, with the shock and vibration (S&V) exposure potentially being of a greater magnitude than the forces experienced by a fast-jet pilot ejecting from their stricken aircraft[1]. Figure 1-1 proves a graphical example of a HSC impacting into a wave.

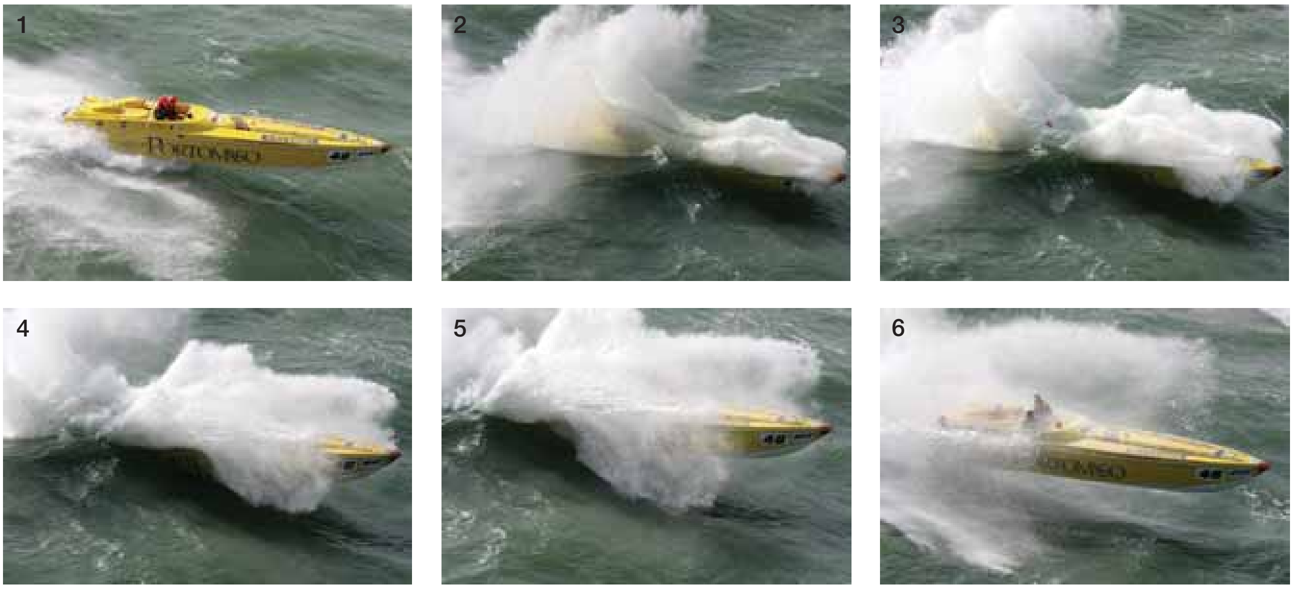

Figure 1-1 An example of HSC impacting into a wave.
Image Copyright: Powerboat P1

1.1.2 Enhancements in technology (principally power and propulsion systems) have seen the speed of HSC increase to the point where Situational Awareness (SA) and effective Command and Control (C2) are becoming increasingly important in the littoral environment. The potential consequences of reduced SA and C2 include the HSC crashing (Refer to Figure 1-2 and 1-3) with the risk of mechanical damage and ultimately injury or death.

Figure 1-2 HSC engine damage caused by a lack of situational awareness.
Image Copyright: Human Sciences & Engineering Ltd

[1] Dobbins, T.D., Myers, S.D. & Hill, J. (2006) Multi-axis shocks during high speed marine craft transits. *41st UK Conference on Human Response to Vibration.* Farnham, UK.

Latham, F. (1957) A Study in Body Ballistics: Seat Ejection. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, Vol. 147, No. 926 (Aug. 13, 1957), pp. 121-139.

Figure 1-3 An example of a HSC being recovered following an incident.
Image Copyright: Powerboat P1

1.1.3 Formal Systems Engineering design procedures[2] include Human Factors (HF) or Human Factors Engineering (HFE) as an integral part of the design process. This has been successfully achieved in many areas of systems design including the aerospace and automotive sectors. The inclusion of HF within the maritime sector has been more sporadic. Its importance has become more recognised, e.g. the publication of the 'Alert' bulletins[3] by the Nautical Institute with support from Lloyds Register, but some parts of the marine sector, i.e. small craft, do not appear to have taken the issues as seriously. This is unlikely to be due to a lack of interest, rather that the sector is principally populated with small enterprises with budgets that restrict the time and resources that can be devoted to the 'formal' inclusion of HF within the design of such craft.

1.1.3 The enhanced speed potential of small HSC, due to improvements in propulsion capability, has increased the magnitude of exposure of the crew and passengers to Repeated Shock (RS) and Whole Body Vibration (WBV), with the subsequent effects:

- Motion Induced Fatigue (MIF), resulting in reduced performance[4] (e.g. post-transit) and operational effectiveness.
- Acute (e.g. damaged vertebrae, refer to Figure 1-4[5]) and chronic injuries[6].
- Reduced Situational Awareness (SA).

Unfortunately the capabilities of the HSC's human occupants have not kept pace with this increase in speed potential and thus solutions are required to support the relatively fragile crew and passengers. Therefore, there is an increased requirement to focus more of the HSC design resources on the features related to the protection and comfort of the crew and passengers and the crew's situational awareness capability.

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[2] E.g. BS ISO 15288 Systems Engineering – System Life Cycle Processes and HF support from ISO/TR 18529:2000 *Ergonomics – Ergonomics of human-system interaction – Human centred lifecycle process descriptions.*

[3] www.he-alert.org

[4] Holmes S, Dobbins T, Leamon S, Myers S, Robertson K, King S. (2006) The effects of rigid inflatable boat transits on performance and fatigue. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

Myers S, Dobbins T, Dyson R. (2006) Motion induced fatigue following exposure to whole body vibration in a 28ft RIB. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

[5] Smith, G. CASE STUDY; Vertebral wedge fracture after speedboat 'splash down'. *J Royal Navy Medical Service*. 2007; 93(2):75-7.

[6] Ensign, W., Hodgdon, J., Prusaczyk, W.K., Ahlers, S, Shapiro, D., and Lipton, M. (2000), A survey of self-reported injuries among special boat operators; *Naval Health Research Centre*, Tech Report 00-48.

Carvalhais, A. (2004) Incidence and severity of injury to surf boat operators. *Conference Proceedings 75th SAVIAC Conference*, Virginia Beach, VA. October 2004.

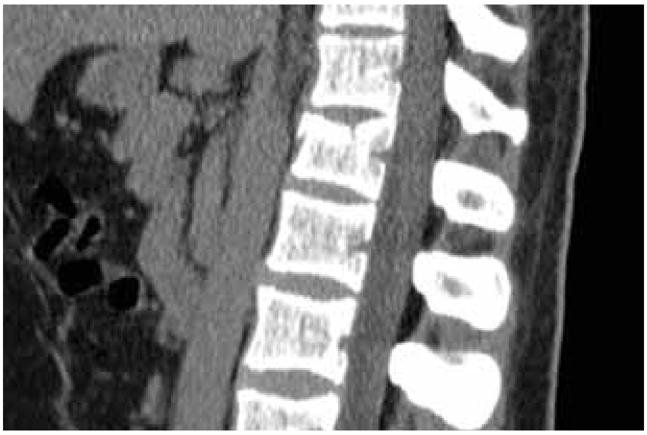

Figure 1-4 **CT scan image (lateral thoracolumbar) demonstrating a wedge fracture of the T12 vertebrae sustained during a RIB transit.**
Image reproduced with Journal[5] Editors permission.

1.1.5 The EU Physical Agents Directive limiting exposure to Whole-Body-Vibration (WBV)[7] will have an increasing impact on HSC design and operation. It has been shown that HSC can exceed the EU WBV ‘daily’ exposure limit in a number of minutes[8] in poor sea conditions. Therefore this legislation will drive the requirement for a greater emphasis on HSC HF, and particularly HSC motion (S&V) during the design process.

1.1.6 HF guidance documents have been produced for the design and procurement of engineering systems[9]. A number of these are principally generic documents and therefore there can be some difficulty in applying them to specific applications. A number of industry sectors have produced specific HF guidance for their applications, e.g. aviation. The marine sector has recognised this and produced a number of ship related documents, e.g. UK MOD MAP-01-010 HFI Management Guide, UK MOD MAP-01-011 HFI Technical Guide, BS ISO 8468 (Ship’s Bridge Layout and Associated Equipment – Requirements and Guidelines) and ASTM F1166-07 (Standard Practice for Human Engineering Design for Marine Systems).

1.1.7 It has been anecdotally observed that some HSC designers and manufacturers do not consider HF as a primary design driver, and have not made use of the HF guidance/standard documentation that is available. This may be due to the highly specific nature of HSC design and operations, and that the previously available HF guidance documentation was not specific, or easily applied to HSC.

1.1.9 This guide provides assistance to address a number of the HF issues related to the design and operation of HSC, specificaly:

- Enhanced HSC platform performance and safety.
- Enhanced operational capability and readiness
- Enhancement of the effectiveness of the HSC procurement/acquisition process.
- Facilitating stakeholder education, particularly for designers and naval architects.
- Reducing HSC through-life costs; i.e. reduced risk of injury, and therefore manning and compensation costs.
- Assisting HSC designers, manufacturers and operators to reduce WBV and noise exposure and therefore, where appropriate, to achieve compliance with the EU Physical Agents Directive (WBV and noise).

[7] European Union Directive (2002/44/EC) on the health and safety requirements regarding the exposure of workers to the risks arising from physical agents.

[8] Holmes S, Dobbins T, Leamon S, Myers S, Robertson K, King S. (2006) The effects of rigid inflatable boat transits on performance and fatigue. Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue, Panama City, FL, USA

[9] ISO 13407 Human-Centred Design Process. Refer to Section 6 for further information

1.2 SCOPE OF CRAFT ADDRESSED BY THIS GUIDELINE

1.2.1 In general, the scope of craft addressed by this guideline may be characterised by the crew/passenger being required to remain in their seating/standing positions during transits, particularly when operating in poor sea conditions. The types of craft that the guideline is envisaged to assist in the design of include:

- 3-12m or 10-40' RIB type craft (e.g. Figure 1-5).
- HSC (i.e. planning or semi-displacement) up to 30m or 100' (e.g. Figure 1-6).
- Novel hull designs, e.g. PASCAT, SES, wave piercing (Figure 1-7).
- Hovercraft (Figure 1-8).

Figure 1-5 Example of a Rigid Inflatable Boat
Image source: zodiacc27.com

Figures 1-6 Example of High Speed Planing Craft

Figures 1-7 Example of Wave Piercing High Speed Craft
Image Copyright: VT Halamtic

Figures 1-8 Example of Hovercraft
Image Copyright: US Navy

2. HSC HF RESEARCH

RESEARCH ON HSC HAS DEMONSTRATED THE MAGNITUDE OF FATIGUE AND THE ABILITY OF SUSPENSION SEATING TO REDUCE FATIGUE.

2.1 The first work measuring the effects of HSC transits on physical performance was conducted by the US Navy[10] as part of a broader research programme to develop a standardised tool to assess the impact of environmental and physiological stressors on the conduct of operations and to evaluate techniques to mitigate the effects of these stressors.

2.2 Using the US Navy work as a basis Myers, Dobbins and Dyson[11] developed techniques to assess changes in physical performance following HSC transits. Initial trials demonstrated that running performance was significantly reduced in military operators following a high-speed transit of less than 2-hours in calm conditions, thereby supporting the existence of Motion Induced Fatigue (MIF). The term MIF was put forward by the ABCD-WG to describe this phenomenon. In order to identify the underlying causes of the MIF and the effectiveness of mitigation techniques, applicable to small HSCs, further trials were conducted using 28' RIBs (refer to Figure 2-1). A number of these trials are summarised below.

Figure 2-1 **An example of the 28' RIBs used in the trials described in Sections 2.3, 2.4 and 2.5.**
Image: Crown Copyright

2.3 Energy expenditure was measured (via Oxygen uptake) during rough and moderate transits with subjects sitting in a conventional fixed straddle seat (VT Halmatic, UK) and a commercially available suspension seat (Ullman Dynamics, Sweden). The key results[12] confirm that being a passenger in a RIB is not a highly aerobic activity like running. However, energy expenditure is elevated sufficiently to impact on performance following a long transit. Also demonstrated was that the suspension seat reduced energy expenditure compared to the fixed seat (refer to Figure 2-2), in rough sea conditions (Sea State 4-5).

[10] Hyde, D., Thomas, J.R., Schrot, J. and Taylor, W.F. (1997) *Quantification of special operations mission-related performance: Operational evaluation of physical measures*. Naval Medical Research Institute, NMRI 97-01.

[11] The majority of this work was conducted as part of a UK Engineering & Physical Sciences Research Council (Project No. EP/C525744) project conducted at the University of Chichester with additional support from the UK MOD.

[12] Myers S, Dobbins T, Hill, J. and Dyson R. (2006) Energy expenditure during transits in 28ft RIB in varying sea states. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

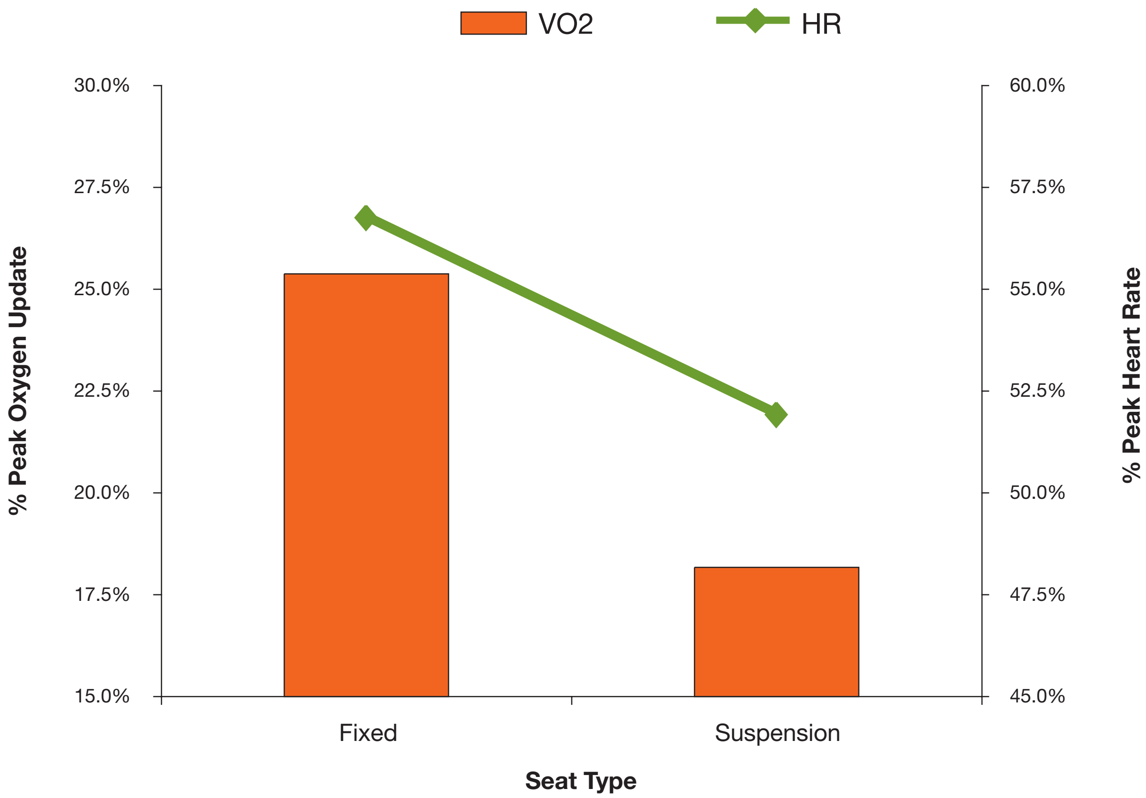

Figure 2-2a The effect of seat type on RIB passenger physiological responses during a 28' RIB transit at ~25 kts

Figure 2-2b The trials set-up to measure subject oxygen uptake in subjects at-sea on a 28' RIB.
Image Copyright: University of Chichester

2.4 The level of energy expenditure measured (refer to Section 2.3) would not account for the level of post-transit MIF typically observed. It was therefore proposed that as the physical work associated with mitigating the shocks during a transit are of a type associated the occurrence of micro-muscle damage (eccentric and isometric contractions) that this may have been a cause of the MIF. Therefore a biochemical marker of muscle damage, creatine kinase (CK), was measured in subsequent trials before, and up to 72 hours following a transit. Results (refer to Figure 2-3) showed that CK levels did increase in rough conditions, where the HSC motion was characterised by repeated vertical shocks, indicating the occurrence of muscle damage[13]. These elevated CK levels were also coincident with increased levels of self-reported pain and soreness in the majority of the trial subjects.

[13] Myers S, Dobbins T, Hall, B., Ayling, R., Holmes, S., King, S. and Dyson R. (2008) Muscle damage: a possible explanation for motion induced fatigue following transits in small high-speed craft. *Conference Proceedings; PACIFIC 2008 International Maritime Conference*. Sydney, Australia.

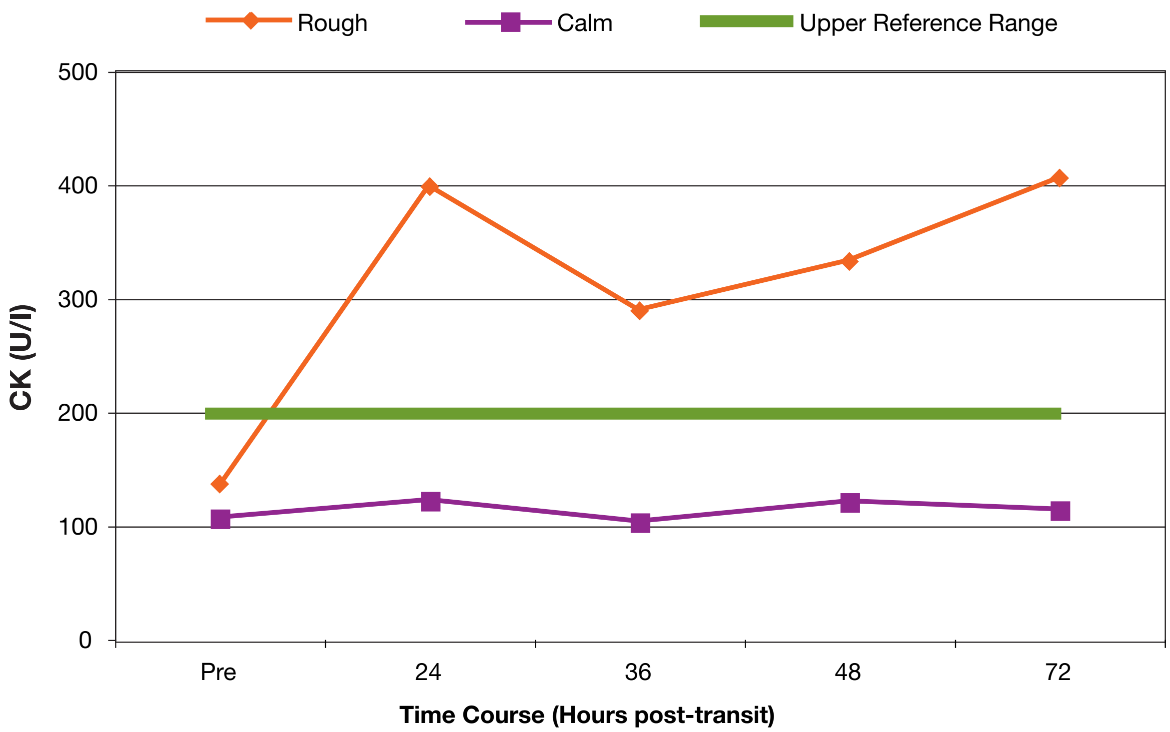

Figure 2-3 The mean (+/- SD) time course response (n=12) of a biochemical marker of muscle damage (CK) following a 3-hour transit in a 28' RIB in a Sea-State 1-2.

2.5 Two trials were conducted to assess the effectiveness of suspension seats in reducing MIF[14]. The trials clearly demonstrated (refer to Figure 2-4a) that the suspension seats maintained running performance (refer to Figure 2-4b) immediately following a 3-hour transit at pre-transit levels compared to passengers riding in fixed seats where large performance reductions were observed (e.g. up to 25%).

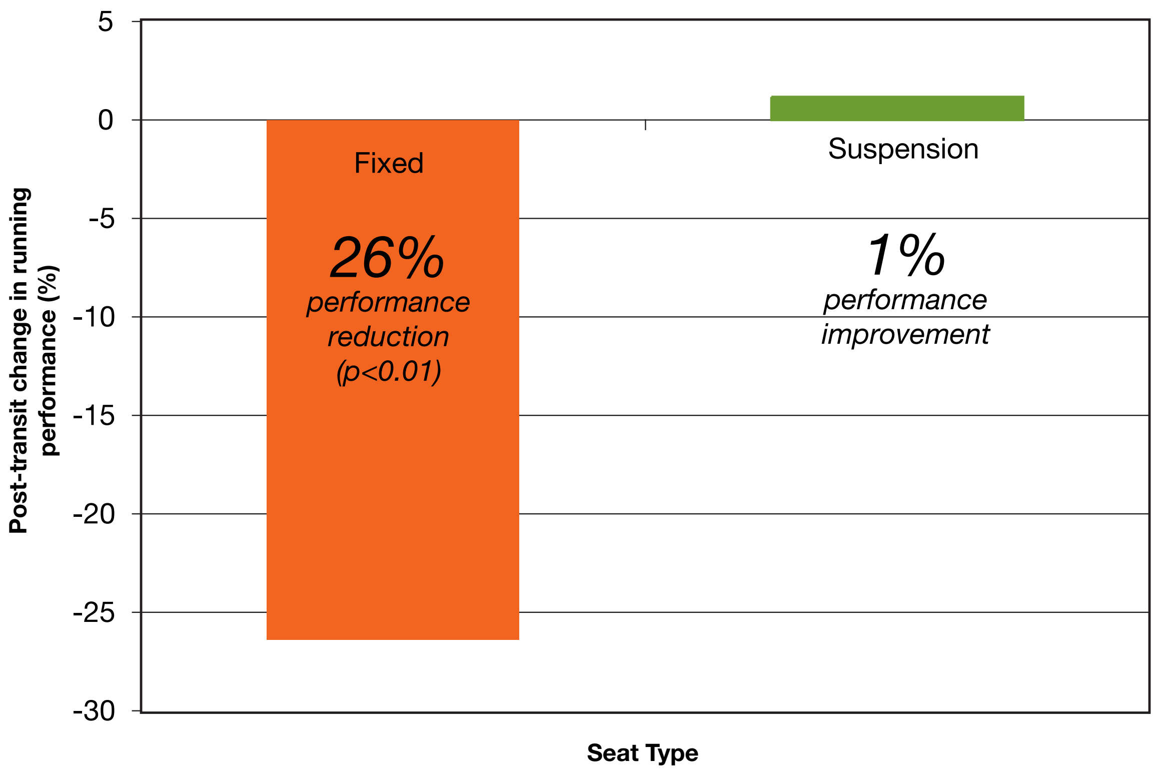

Figure 2-4a The changes in running performance (n=12) following a 3-hour transit in a 28' RIB whilst using either a fixed or suspension seat.

[14] Myers S, Dobbins T, King, S., Hall, B., Gunston, T., Holmes, S. and Dyson R. (2008) The effectiveness of shock mitigation technology in reducing motion induced fatigue in small high speed craft. *Conference Proceedings*; PACIFIC 2008 International Maritime Conference. Sydney, Australia

Figure 2-4b Trials subjects undertaking the running test to assess post-transit fatigue.
Image: Crown Copyright

2.6 The results shown above demonstrate that the previously anecdotal reports of MIF are real, and are of a magnitude to degrade HSC crew and passenger performance. The results also show that shock mitigation, in the form of a suspension seat, can reduce these negative effects. This research work also demonstrates that the assessment techniques may be used in the Test & Evaluation phase of HSC to assess the level of MIF that the HSC system produces.

3. BACKGROUND

3.1 The requirement to consider HF is an integral part of the equipment design and procurement process. In the USA, the importance of Human Systems Integration (HSI) (which encompasses Human Factors Engineering (HFE)) has been identified at the governmental level and is mandated in Department of Defence 5000 (The US DOD Defence Acquisition System). The Committee on Armed Services House of Representatives stated:

"The committee recognizes the need to consider human systems integration issues early in the development cycle. Too often, man-machine interface issues are not addressed until late in the development cycle after the configuration of a particular weapon or system has been set. What results is a degraded combat system that is not able to achieve its maximum performance and, at worst, becomes a liability on the battlefield."

3.2 The HF guidance[15] of the UK MOD Acquisition Management System is aimed at the MOD DE&S Integrated Project Teams (IPT) to assist them in their procurement activities. The UK MOD HF Standard is DSTAN 00-25 (Designing for Humans in Defence Systems)[16]. Its principal aim is to provide a source of human factors data and guidance for the designers of defence systems. The standard is presented in eight related parts. Within these sections, Part 19 provides explanation on how HF should be integrated into the systems design process. It states that the systems development process should:

a. ***Be user centred –*** involve users throughout the development process.

b. ***Integrate specialist knowledge –*** this refers to the different disciplines within Human Factors [and the requirement to employ HF Subject Matter Experts][17].

c. ***Be an iterative design process –*** this is essential to ensure that an optimal design solution evolves from the development process. Continual evaluation of all aspects of the design and requirements specification should ensure an effective and efficient design solution.

3.3 The US equivalent of DSTAN 00-25 is the Design Criteria Standard on Human Engineering (MIL-STD-1472F). The aim of the standard is to establish:

"...general human engineering criteria for design and development of military systems, equipment and facilities. Its purpose is to present human engineering design criteria, principles and practices to be applied to the design of systems, equipment and facilities so as to:

a. Achieve the required performance by operator, control and maintenance personnel.

b. Minimize skill and personnel requirements and training time.

c. Achieve required reliability of personnel-equipment combinations.

d. Foster design standardization within and among systems."

3.4 An additional factor, directly relating to HSC operations and the harsh marine environment, is that application specific HF support is required. An example of this necessity was described by Richard Roesch[18] (Branch Head, Human Systems Integration Branch, Naval Surface Warfare Center, Panama City, FL);

"To be effective Human Factors Engineers, we must honour our users, their requirements, tasks and equipment; and we must have a thorough understanding of their operational environment".

3.5 Therefore in addition to generic HF support there is the requirement to provide specialist support and documentation, by HF SMEs experienced in HSC design and operations, to end-users operating in extreme environments where there is an increased risk to their health and safety, as well as operational effectiveness and readiness. **THIS GUIDE IS DESIGNED TO PROVIDE SUCH SPECIALIST SUPPORT TO THE DESIGN AND PROCUREMENT PROCESS.**

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[15] UK MOD; An Introductory Guide: Human Factors Integration, MOD HFI, August 2000.

UK MOD; Human Factors Integration (HFI): Practical Guidance for IPTs, May 2001

UK MOD; The MOD HFI Process Handbook. Ed 1, 2005. www.hfidtc.com/pdf/HFI_Process_Booklet.pdf

[16] www.dstan.mod.uk

[17] Additional text added in [brackets] to aid clarity.

[18] Roesch, R. (2005) The Need for Human Factors Engineers to have a First Hand Experience in Extreme Operational Environments. 53rd meeting of the US DOD HFE Technical Advisory Group.

4. ANALOGOUS PLATFORMS – AIRCRAFT & LAND VEHICLES

NUMEROUS HUMAN FACTORS LESSONS HAVE ALREADY BEEN LEARNT BY THE AIR AND LAND COMMUNITIES; MANY OF THESE CAN BE READILY USED BY HSC DESIGNERS

4.1 In support of general HF standards (e.g. MIL-STD 1472 and DSTAN 00-25) the aircraft and car industries have for many years utilised HF design standards to enhance the performance and safety of their vehicles. As HSC have a similar crew workstation concept, i.e. the coxswain/pilot/driver remains in a static position to operate the vehicle, therefore the HF design standards are to some degree transferable across the vehicle types.

4.2 Air, and related vehicle standards have been developed by the Air Standardisation Coordination Committee (ASCC), now known as the Air & Space Interoperability Council[19] (ASIC). Examples of these along with general aviation and related HF standards include:

- ASCC AIR STD 61/116/13, The Application of Human Engineering to Aircrew Systems.
- NATO STANAG 3994: Application of Human Engineering to Advanced Aircrew Systems.
- NASA-STD-3000, Man-Systems Integration Standard.
- FAA Human Factors Design Standard (HF-STD-001)

4.3 The ASIC produces numerous HF standards and guidelines on specific issues. Where appropriate these documents are referenced in the appropriate sections of this Guide. Additional information[20] can be sourced from organisations such as the Human Systems Integration Information Analysis Centre[21], previously known as the Crew Systems Ergonomics Information Analysis Centre, and based at Wright-Patterson Air Force base, USA.

4.4 Land vehicles also have a number of HF standards that may be utilised, these include:

- DSTAN 00-25 Part 14: 2000. Military Land Vehicles Design.
- US Federal Motor Vehicle Safety Standards Part 571:
- Standard No. 101 – Controls and Displays.
- Standard No.123 – Motorcycle Controls and Displays.
- Standard No. 207 – Seating Systems.

4.5 Therefore lessons learnt from the aviation and automobile industries should be utilised whereever possible and appropriate, including the work undertaken on reducing the risk of injury during accidents/crashes. Examples of aviation HF design and assessment are shown in Figures 4-1 and 4-2.

[19] www.airstandards.com

[20] Detriot, M., Martin, C. and Beyer, S. (1995) Crew-Centred Cockpit Design Program. Gateway. Crew Systems Ergonomics Information Analysis Centre.

[21] www.hsiiac.org

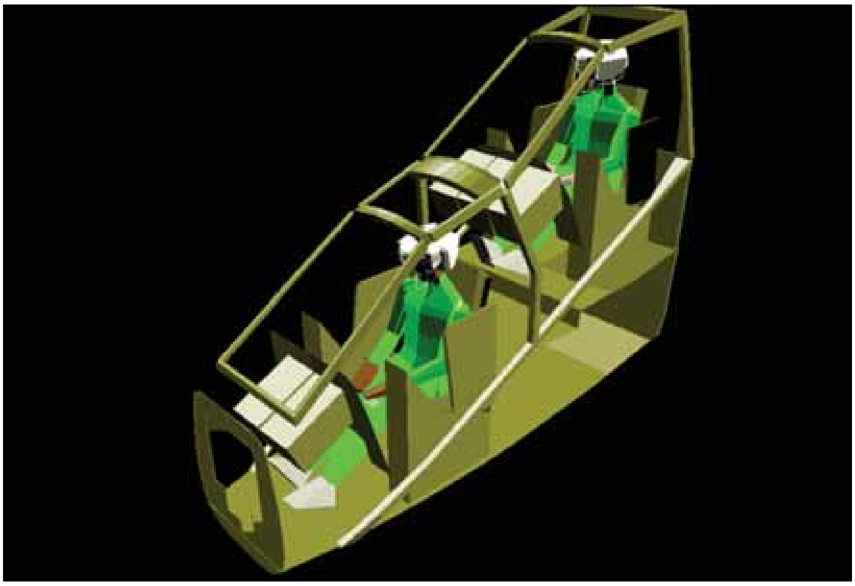

Figure 4-1 Helicopter cockpit developed using CAD
SAMMIE CAD, Loughborough University, UK.

Figure 4-2 F22 mock-up being used to assess cockpit ergonomics
Source: www.simpits.org

5. THE TRADITIONAL NAVAL ARCHITECTURE DESIGN PROCESS

THIS IS A VERY SIMPLIFIED OVERVIEW OF HOW SMALL HSC ARE 'TYPICALLY' DESIGNED. THE OVERVIEW IS USED TO DEMONSTRATE HOW HUMAN FACTORS MAY BE INTEGRATED INTO THE DESIGN PROCESS.

5.1 PREAMBLE

5.1.1 The design process described in this section has been developed by Lorne Campbell[1] and is a simplified overview of how relatively small HSC are typically designed. It is recognised that not all designers will use exactly the process described, indeed, some types of craft, or projects, will require a different design sequence, either by their nature, or as dictated by the client's requirements. The approach can vary depending on the type of craft being designed, e.g. increased emphasis on the crafts systems, and sometimes some of the stages described may be skipped. Therefore although some Designers may not agree with all of the information provided it is emphasised that the simplified process is used to illustrate how HF issues may be effectively integrated into the design process.

5.2 INTRODUCTION

5.2.1 The Naval Architect's (NA's) design process is often referred to as the 'Design Spiral'[2] to describe the iterative procedure that has to be followed during the practical design of small craft. Since small craft are usually designed by small offices – sometimes just one person – the design process is best laid out as a sequential, step by step, process. It is acknowledged that a larger office will probably work on different parts of the design at the same time, but looking at the process as a sequence of steps keeps the work units approximately in their correct order of priority. It will show which unit of work is subservient to the other even if the order of the steps is changed a little or they overlap.

5.2.2 Small offices cannot afford the time to proceed round and round the 'Spiral' and reliance is made on the designer's experience to cut this short. In practice, it is felt that the accompanying diagram (see Figure 5-1) gives a closer idea of the actual process. Having received the customer's requirements, the NA will want to prove to himself that these requirements can be met. If not convinced, then they will need to go back to the customer for a reappraisal. The diagram shows a first design loop, Feasibility Design, which the NA will proceed round quickly, in normal circumstances, and after one or two circulations the NA should be confident enough to proceed to the second larger loop (Main Design) where the true design is executed. This is the main intellectual work of the design and defines the whole craft. Once this has been completed to the NA's satisfaction, the 'End Design' area, where the small details are put together and finalised, is passed through. After this the design is ready for production.

5.2.3 It is often the case that different parts of the design process overlap, and often the actual build of the craft is started before the detail design is finished.

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[1] Lorne Campbell Design Ltd, UK. www.lornecampbelldesign.com

[2] DuCane, P. (1974) *High Speed Small Craft* (4th Ed.). Pub,David and Charles (Holdings) Ltd.

Dawson, D (1997) Once Around the Design Spiral. *Professional Boatbuilder Magazine*, No.49 (Oct./Nov. 1997)

5.2.4 It is almost inevitable that the requirements of a Coding or Classification Authority or Society will need to be complied with[3]. These requirements have to be fed into the design process as and when the NA is working on those relevant areas. Any such requirement should be specified at the beginning of the project (Steps 1–3), but sometimes it is left to the NA to note and state to the client that certain regulations must be met. In the following sequence of design steps, it is assumed that such requirements are considered at their relevant points.

5.2.5 On rare occasions, particularly with the design of an unusual craft, the NA will suddenly come up with an original/novel answer to a problem at some stage in the middle of the design process. If he thinks it is worth pursuing he will take it to the client to see if the client is i) willing to try the idea and, ii) willing to cover the inevitable extra cost and time that it will entail. If the 'idea' comes from the client then he would be expected to discuss it with the NA before deciding whether to interrupt the flow of work by introducing it. Introducing a new idea, or change of plan, after the design process has started should be avoided if possible, but in an imperfect world, this often happens and a re-negotiation of fees and timing has to be undertaken at that stage. If, due to bad planning and specification this happens frequently, the quality of the end product will be affected.

5.3 SPECIFICATION

5.3.1 Steps 1 to 3 – Specification:

5.3.1.1 The NA receives the craft requirements specified in one or more documents. These may be called the Capability Requirement, the User Requirement Document (URD) or the Systems Requirement Document (SRD). They can be grouped together under the Specification heading. It is possible that the NA may have had some input into the Specification. This would be to use the NA's previous experience or specialised knowledge to improve the chance of achieving the requirements. Human Factors requirements will be input here as well as for craft performance, etc.

5.4 FEASIBILITY DESIGN

5.4.1 Step 4 – Preliminary Overall (OA) Dimensions:

5.4.1.1 Normally these would be supplied with the Specification, but if left to the NA they would be selected using previous experience or based on similar craft, if any. There is often a size restriction or preference supplied in the Specification. If left open, the NA will estimate the craft size based on experience and other information supplied in the Specification. This may mean that an extra circumnavigation of the 'Feasibility Design' loop is required.

5.4.2 Step 5 – Preliminary General Arrangement (GA):

5.4.2.1 A sketch of the shape and layout (often on graph paper) is drawn to scale to give some idea of where items will be positioned within the length, beam and height estimated from Step 4. This often includes some thoughts on styling. A computer modelled preliminary hull shape can often be produced quickly by scaling a previous design. If this is the case (and every effort should be made to take advantage of this), preliminary floatation and static stability checks can also be made here, but information from Steps 6 and 7 is needed.

5.4.2.2 At this stage only the main items are considered, such as: hull length, width and depth; spaces for crew, passengers, machinery (including propulsion system), fluid tanks (e.g. fuel and water), heads/WC, galley, payload, specific special equipment, etc. It enables very approximate preliminary weights, Centre of Gravity (CG), and coefficients to be assessed. Often the process of preliminary weight and CG calculation (Step 6) throws up items missed from the sketch GA and causes its modification.

[3] SOLAS, EU Recreational Craft Directive, Lloyds, DNV, ASNE, SNAME, etc.

5.4.3 Step 6 – Preliminary Weight Estimate:

5.4.3.1 The weight and CG estimation is one of the most important of the whole design process. All other calculations are dependent upon the CG estimation so, if it is wrong, then most other calculations will need re-calculating. The weight sheet is started with estimates pulled from various sources, but for initial purposes weights of the main items, such as; hull and superstructure, machinery, fuel, crew and passengers, and cargo are totalled and increased by a percentage to account for ancillary systems, piping, wiring, etc. Information from Step 5 is used to assist this relatively quick calculation; particularly for the CG part of the estimate.

5.4.4 Step 7 – Preliminary Performance Checks:

5.4.4.1 The results of Step 7 enable an estimate of the performance of the craft. As well as the weight/CG input, experience of the craft type and its likely efficiency is required. Speed, power, fuel consumption/capacity and endurance are usually the important questions. If the performance is not in the right area or if it is found that not enough weight allowance has been made for fuel or power, for instance, then the NA knows that he will have to go round the 'Feasibility Design' loop again. He may well go on to Step 8 before doing this, however.

5.4.5 Step 8 – Hull Loading and Coefficients:

5.4.5.1 Even if it is known that the results of Step 7 are not satisfactory, the hull bottom loading (for planing craft) and other coefficients (depending on type of hull) should be estimated since these, also, may not be in the required area. Even if the coefficients change as a result of modifications caused by running through Steps 4 – 7 again, an experienced eye cast over the results of Step 8 will help with decisions made during this repeat.

5.4.5.2 If the Feasibility steps have cast doubt on the validity of the whole project as defined at the Specification stage – i.e. if not all of the requirements can be met – then Steps 1 - 3 may have to be revisited, although this is unusual and unlikely if Steps 1 - 3 have been competently assembled.

5.5 MAIN DESIGN

5.5.1 Step 9 – Detailed Weight and Centre of Gravity (CG) Calculations:

5.5.1.1 Once Steps 4 – 6 are deemed satisfactory, then the detailed Weight/CG sheet is filled out properly. It should cover every single item that it is thought will be fitted on the craft and percentage increase allowances for hull and superstructure shells, machinery, etc. The vertical, longitudinal and (sometimes) transverse positions of the CG are needed as well as the total weight (displacement) under different loading conditions. Transverse CGs are required on asymmetric craft and larger craft where there is more room for offset placement of items.

5.5.1.2 Since not all actual weights and their positions are known at this stage, estimates will have to be entered for unknown items. These numbers have to be continuously updated throughout the design process as and when they become available. At this stage the preliminary Sketch GA from Step 5 is used to give figures for the placement of the items. This is a 'chicken and egg' situation but there is no alternative. Designer's experience and information from previous relevant craft can help a great deal here and should be utilised as far as possible. Although weights are liable to change at all stages throughout the design process, once the 'End Design' stage is reached, changes are not likely to make a material difference. It is true, however, that the weight sheet continues to be updated (with accompanying dates) even after the design process is finished. The built craft is also weighed and checked for CG position so that the actual results can be compared with the calculated ones.

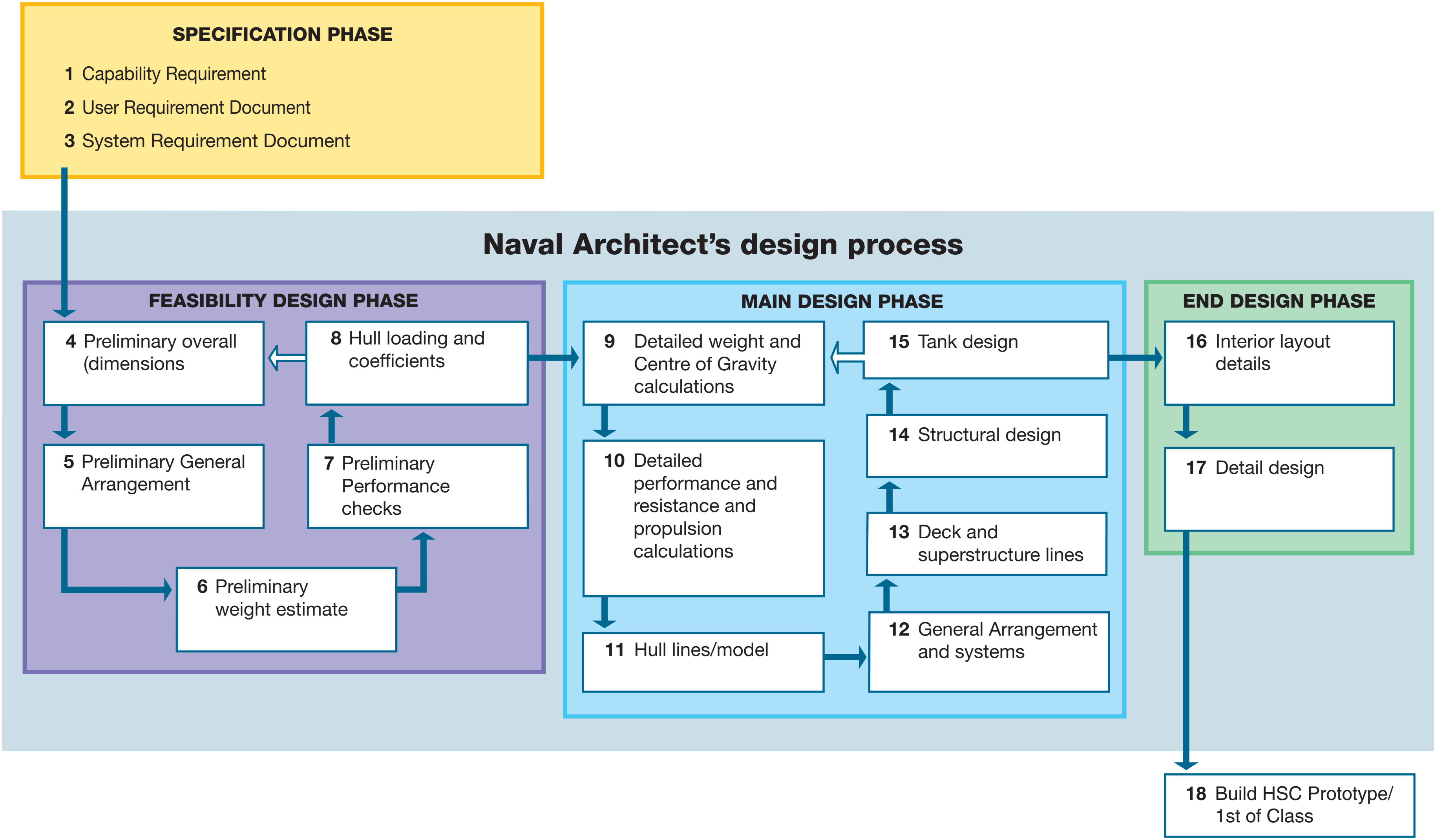

Figure 5-1 Traditional Naval Architect's design process

5.5.2 Step 10 – Detailed Performance and Resistance & Propulsion (R&P) Calculations:

5.5.2.1 Using the results of Step 9 the R&P calculations are now performed in detail. Rather than an overall approximate calculation based on weight and power as in Step 7, detailed calculations of hull proportions, dead-rise angle(s), CG position, etc., are all used, and proportions are systematically varied to optimise performance. Everything is a compromise, of course, and the NA bears in mind the ride and seagoing qualities required during the optimisation process. Normally the more efficient the hull, the worse are the ride qualities, although this does not always have to be the case.

5.5.2.2 Aerodynamic resistance is calculated and transmission, hull and propulsion efficiencies are also covered. Aerodynamics are based on the above water shape which is not yet fully established at this stage, so later adjustments may be required.

5.5.2.3 If model testing is performed (which is rare on craft below about 18 metres), then it is done at approximately this point (in a sequential design process). Since, however, the hull shape is needed for model tank testing – and the superstructure lines, also, if there is to be wind tunnel testing – the 'Main Design' loop has to be run through once before the model can be built. So model testing virtually guarantees two circumnavigations of the 'Main Design' loop.

5.5.2.4 Models may be instrumented to record motions as well as drag and if it is thought worth going for model testing, which can be very costly, then advantage should be taken of this. Sometimes wind tunnel testing is performed on small fast craft, even when no tank testing is conducted. This then gives better figures for aerodynamic drag (and lift) than just an estimate based on cross sectional area and a guessed drag coefficient. Whether this is worth doing depends on the percentage of the total resistance made up by the aerodynamic component.

5.5.2.5 Data logging of existing craft can show up accelerations, shock and vibration values. Thus, knowing the proportions and details of those craft in comparison with the proposed craft will enable the NA to make better decisions on deadrise, chine beam, etc.

5.5.3 Step 11 – Hull Lines/Model:

5.5.3.1 Hull lines are drawn based on the results of Step 10 plus input from the personal preferences of the NA as to proportions in the forebody, freeboard, sheer and stem lines, deadrise variation, etc. The NA also takes into account the requirements in the Specification, i.e. the type of duty required of the craft, the distance from shore and range required. This then allows the hydrostatics and stability to be checked properly; more accurately than at Step 5.

5.5.4 Step 12 – General Arrangement (GA) and Systems:

5.5.4.1 A proper GA drawing is now put together. This will show the position of all major components and enable their positions to be measured. Access, spaces and stowage are also considered here. By virtue of this it allows a good estimate of the positions of minor components as well. Structure encroachment must be allowed for when looking at spaces. The GA may have an effect on the weight sheet, of course, and may cause a second circulation round the 'Main Design' loop.

5.5.4.2 Systems have been bracketed with this stage, even though systems design is usually being carried out alongside other steps during the Main Design loop. Main layouts of plumbing, wiring, other systems, instrumentation, controls, console layout, etc., are covered. Systems can, of course, affect space, weights, accessibility, etc., and it depends, to a certain extent, on which system is being worked on as to where it is positioned in the Main Design loop.

5.5.4.3 It should be noted that the proposed production methodology must to be taken into account. There is no point in having a perfect design for maximised performance if it cannot be (economically) built. Also, account should be taken for number of craft to be produced as this will impact on production methodology.

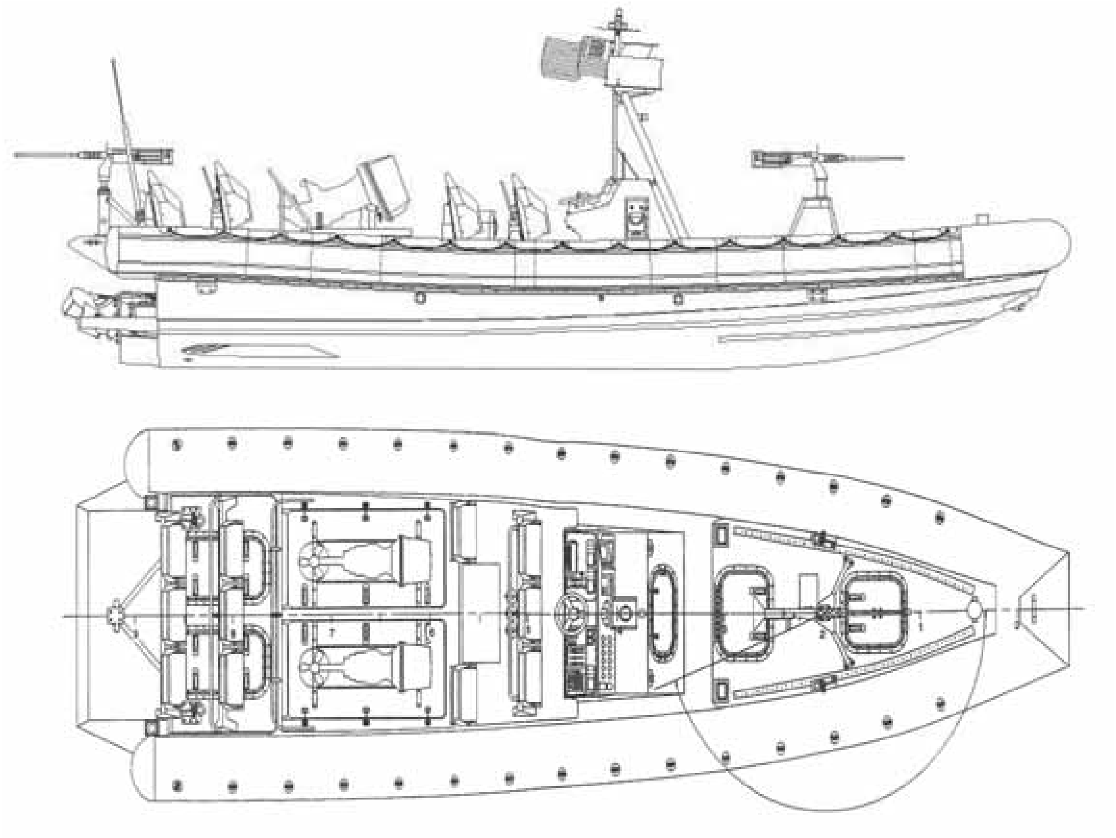

Figure 5-2 Example of a General Arrangement drawings of the USN 11m RIB[4]

5.5.5 Step 13 – Deck and Superstructure Lines:

5.5.5.1 Whether or not Step 12 requires modification of the weight sheet, the Deck and Superstructure shape is needed. It may affect the weight sheet (after the structure, Step 14, is designed) and it may affect the aerodynamics and hence the drag. The Superstructure lines are produced relying heavily on the GA drawing for such things as egress, access and other space requirements. Allowances need to be made for structure and other clearances. When working with 3D models that are going to be used in 5 axis machining of plugs/moulds all details have to be included in the model - i.e. hatch and cleat plinths, toe rail positions, door recesses, etc.

5.5.5.2 Styling sketches will have been done at various stages during the production of preliminary and proper GA drawings and at this stage. Some types of working craft evolve in their looks; the style being dictated by the equipment and function. There seems to be no reason, however, not to make the craft look pleasing to the eye once all other requirements have been taken into account. If the commander and crew of a craft like the looks of their machine, as well as the way it performs, they may well look after it better.

5.5.6 Step 14 – Structural Design:

5.5.6.1 During the production of the GA, some allowance should have been made for the internal space required for structural components. A figure for the weight of the structure will already have been estimated for the weight sheet and a good idea of the centroid of the structure will have been estimated from the centroid of the skin/plating surfaces. Once the skin/plating thicknesses and stiffener and bulkhead sizes and positions have been calculated, there is likely to be a modification to the weight sheet since a proper structural weight estimate can now be performed.

[4] 11-METER NAVAL SPECIAL WARFARE (NSW), RIGID INFLATABLE BOAT (RIB), FY 97. (Description, Operation, Maintenance, and Illustrated Parts Breakdown). S9008-CE-BIB-010, UNITED STATES MARINE, INC. (USZA22-96-D-0006). 02 FEBRUARY 1998.

5.5.6.2 If the structure, as calculated, makes a great deal of difference to the weights and causes an overall performance problem with the vessel then it is possible that the structure might have to be re-designed or more expensive materials employed in order to reduce the weight to an acceptable level. It may also require modification of the General Arrangement drawing if structural encroachment is greater than was allowed for. Again the structure may have to be changed instead.

5.5.7 Step 15 – Tank Design:

5.5.7.1 Tanks take up a lot of volume and, once filled with their respective fluids, they contribute much to the weight of the craft. Thus, they can materially affect the Weight Sheet, structural design and GA. This gives them great importance.

5.5.7.2 This and previous steps may well have affected the weight sheet to the extent that a return to Step 9 is needed, and from there it will be necessary to proceed through Steps 10 – 15 again although some of the individual steps may not need changing and can be passed through quickly. Only rare circumstances would require Step 15 to be changed significantly and the NA would not expect to have to go round the Naval Architecture loop a third time.

5.6 END DESIGN

5.6.1 Step 16 – Interior Layout Details:

5.6.1.1 The interior may be assembled and fitted during the build or may consist of a liner moulding. Although this design process is laid out in an approximate step by step sequence, in the larger offices many of these activities would be carried out alongside other design work and the production of drawings and parts often overlap. Despite the fact that the basic layout has been decided already, there is a chance that even this stage may affect the weight sheet and require a return to Step 9, but it would be unusual.

5.6.2 Step 17 – Detail Design:

5.6.2.1 The details of piping, wiring, instrumentation, controls, console layout, and other systems, are covered here. As stated above, in the larger design offices, many of the systems layouts and design proceed alongside other design work. Much of the console design/drawing, in particular, will often be tackled during stage 16 above, or earlier. The fact that this stage is at the end of the step sequence does not mean that it has not been thought of before. Various parameters and requirements will have been laid down earlier - many right at the beginning. This stage should not affect the preceding stages materially. The weight sheet will be updated with feedback from this step but the items involved should not be a high proportion of the total weight since the main systems weights are covered in the Main Design loop (see Step 12) and, therefore differences between actual and estimated weight at this stage should not require any changes to previous steps.

5.7 MISCELLANEOUS NOTES

5.7.1 After Step 17 Detail Design the boat build can be initiated. In most cases it may actually commence some time earlier (after Step 11 Hull Lines/Model). Broadly the sequence is as described above and the Human Factors requirement's association with each step should be correct even if the step order is changed. In actual practice the design does not really go in steps, it flows along and at different points it is realised that an answer is needed which is not at that point available. That answer is then found or calculated if possible, or estimated or allowed for if not yet discoverable, and then earlier parts of the process are adjusted and redone in consequence.

6. THE GENERIC HUMAN FACTORS DESIGN PROCESS

THIS HUMAN FACTORS DESIGN PROCESS IS BASED UPON THE DESIGN STAGES OUTLINED BY THE INTERNATIONAL ORGANISATION FOR STANDARDISATION (ISO) HUMAN-CENTRED DESIGN PROCESS STANDARD (ISO 13407).

6.1 SUPPORT TO HSC SPECIFICATION PRODUCTION (i.e. prior to NA Design Process)

6.1.1 PREPARATION FOR HSC DESIGN

a. Plan end-user[5] participation in design

i. End-users are assigned to assist the HSC design team

ii. Undertake visits to end-user premises to canvass wider review comments

iii. Undertake visits to view end-users operating with existing HSC

iv. Ensure the availability of a range of end-users to demonstrate HSC mock-ups and prototype as part of the Test & Evaluation process.

b. Identify where HF contributes to programme deliverables (e.g. document deliverables as part of milestone payment/project decision points; as part of demonstrating acceptance of HSC prototype).

6.1.2 UNDERSTAND AND SPECIFY THE CONTEXT OF USE OF THE HSC

a. Identify lessons learnt from previous HSC designs (e.g. talk to current HSC users, review causes of incidents and accidents involving HSC, consult people involved in previous HSC design).

b. Identify any existing performance data available from previous and existing HSC (e.g. operational history including reliability, test data collected during previous evaluation of HSC performance).

c. Arrange to collect any missing performance data necessary to guide the design and/or to evaluate HSC prototype, e.g. to provide a baseline from existing HSC.

d. Produce a description of the end-users (e.g. record details of crew compliment, roles, duties, skills, knowledge, training, physical strength, body dimensions and sizes[6], personal protective clothing and equipment).

e. Undertake, and document, a Task Analysis for the operators during the proposed missions. This should include:

i. Produce a description of the typical usage[7] of the HSC, i.e. describe the typical mission(s), e.g. transportation, range and speed, payload, missions, landing/launching sites.

ii. Produce a description of the operating environment[8] of the HSC, e.g. ambient temperatures, sea states, night conditions.

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[5] i.e. HSC crew and passengers, maintainers, and other support staff.

[6] If appropriate, identify if a generic/specific anthropometry source is to be used, e.g. DEFSTAN 00-25 Part 17, Royal Navy Anthropometric Data Survey, US DOD-HDBK-743 Military Handbook Anthropometry of U.S. Military Personnel. Other anthropometric data may be found at www.hsiiac.org

[7] The design specification or System Requirement Document should be an important source of this information (refer to Section 7).

[8] The design specification or System Requirement Document should be an important source of this information (refer to Section 7).

iii. Produce a description and prioritisation of the crew and passenger activities and the specific functions allocated to them (e.g. Coxswain functions, navigator functions, maintainer functions, loading/unloading payload, embarking/disembarking; refer to Table 6-1). This prioritisation will include the importance (especially when related to safety) and frequency of tasks, and the time required to complete them; Subsequent prioritisation will include the interface layout (refer to Section F; Man-Machine Interface) and the interactions between crew-members (i.e., a manual task that requires two people will require a greater space allocation). At this phase decisions can be made regarding whether a task should be performed manually or if it should be automated (i.e. an automatic fire suppression system vs. a hand-held fire extinguisher). These kinds of design decisions require tradeoffs be made between crew workload, safety and cost. When automating tasks the Designer should also consider the associated logistics and personnel requirements. Reduced manning on the HSC may significantly increase the manning required to maintain the HSC systems in port.

Coxswain	**Navigator**
Use meteorological instruments and weather forecasts. Manoeuvre and handle HSC including: • Berthing. • Manoeuvring in shallow water. • Manage and handle HSC in heavy weather. • Recovering persons and other floating objects. • Transferring personnel between vessels. • Launching from and recovery onto beach. Preserve safe trim and stability. Conduct fire prevention and fire-fighting. Conduct emergency procedures. Administer first aid. Use communication equipment. Seamanship: • Use and stow rope and wire. • Plan anchorage, safely deploy and recover anchor. • Make craft safe for towing.	Conduct passage planning and navigation under all conditions. Determine position (including use of electronic navigation systems). Conduct work with charts: • Read charts. • Measure distances and bearings. • Plot position (e.g. dead reckoning, estimated position). • Calculate course. • Read navigational publications (e.g. tides and currents). • Calculate time and height of high and low water; rate and direction of tidal streams. Perform navigational watch duties (i.e. watchkeeping). Operate and use radar (including interpret and analyse information). Use communication equipment.
Mechanic	**Crew**
Perform periodic maintenance (including conduct system checks). Conduct fault diagnosis. Conduct emergency operations (i.e. following breakdown of partial systems). Conduct emergency repairs. Use operation and maintenance manuals. Perform checks after unusual events (e.g. grounding, collision, fire, etc.)	Use lifejackets and personal protective clothing. Conduct fire prevention and fire-fighting. Conduct emergency procedures. Administer elementary first aid. Use communication equipment.

Note: Tasks may be re-distributed between crew-members to optimise craft performance.

Table 6-1 Examples of High Speed Craft Crew Tasks[9]

[9] Based upon A Common Standard of Training for Maritime SAR Unit Coxswains, Mechanics & Crew Members. International Lifeboat Federation, Poole, UK. November 2002.

6.1.3 SPECIFY THE END-USER REQUIREMENTS

a. Identify HF goals that contribute to achievement of HSC requirements; e.g.

i. Crew and/or passenger requirement (e.g. training) from the design specification or System Requirement Document.

ii. Legal requirement (e.g. maximum vibration exposure limit, noise level, risk assessment).

b. Outline how the achievement of HF goals can be demonstrated (e.g. method of assessment).

6.2 SUPPORT TO THE HSC DESIGN PROCESS: PRODUCE HSC DESIGN SOLUTION

6.2.1 Consult and follow HF guidance (refer to Sections A to I) within this Guide associated with specific steps in the integrated design process (refer to Section 8).

6.3 SUPPORT TO THE TEST AND EVALUATION PROCESS: EVALUATE HSC DESIGN AGAINST REQUIREMENTS

6.3.1 Evaluate whether human factor goals have been achieved (e.g. conduct crew workstation fitting trials, measure crew and passenger exposure to vibration and noise, perform usability assessment).

6.3.2 If HF goals have not been achieved, review the following stages for any incomplete information before conducting a further design activities.

a. Understand and Specify the Context of Use (Section 6.1.2)

b. Specify the End-User Requirements (Section 6.1.3)

7. HSC SPECIFICATION PROCESS

THE INPUT OF HF INFORMATION DURING THE SPECIFICATION PHASE HAS THE GREATEST OPPORTUNITY OF ENHANCING THE PERFORMANCE AND SAFETY OF THE HSC.

7.1 Prior to starting the design process, the specification of the craft has to be defined. This is best achieved through a step-wise process to ensure that the craft requirements are captured and defined in such a format that the Designer can use these as effective inputs to the design process. The four stages of the Specification Process are as follows:

7.1.1 Capability Requirement (CR)

At this point in the process, HF needs to be accepted as an integral part of the process (i.e. HFI[10] is undertaken – refer to Section 3), and that objective HF goals must be set for the Test & Evaluation of the prototype HSC. The Capability Managers (e.g. Ministry of Defence) must also ensure that the appropriate end-users and SMEs are assigned to the design project and that this allocation is continued through to the conclusion of the project.

7.1.2 User Requirement Document (URD)

It is essential to involve the end-users with the specification of the new craft. Without this it is highly unlikely that the HSC will be an optimum solution to the CR. The end-users can provide invaluable information on lessons learnt with current and previous designs (e.g. in the form of an HF issues log, recording positive and negative user experience). This includes HSC motion and control characteristics, common failures and ad-hoc design solutions to limitations/problems with previous/other HSC. The end-users should be defined in terms of their size (anthropometry) to ensure that the dimensions of the craft are appropriate. The use and operating envelope of the craft should be defined in detail so that the designer understands what solutions need to be found, e.g. a Riverine craft will be inherently different from a craft designed to operate in the open ocean. Following this the crew and passenger activities must be described to ensure that the appropriate Task Analysis can be conducted. The Task Analysis, which will identify issues such as individual tasks, work sharing, team working, etc. will then lead to the specifications of the equipment needed to support the use of the craft. Consideration should also be given to future user-populations, this would take account of changes in user recruitment profiles, e.g. the increasing computer-literacy of users to compliment the adoption of computer-based HSC systems, and changes in population fitness. Also the military, and other service organisations, has increasingly introduced women into roles traditionally held by men. Women on a HSC will drive significant changes in:

- Anthropometric (i.e. size) accommodations (especially with regard to functional reach).
- Lift limitations (one vs. two person lifts).
- Habitability (this includes morale and privacy issues).
- Occupational Health (this includes addressing feminine hygiene requirements).

The completion of the Task Analysis process will define the manning and the personal capability requirements (e.g. knowledge, skills and abilities) of the crew-members. These will in-turn drive some of the requirements for the potential automation HSC systems, and/or the level of simplicity the systems will need for operation by the crew. For example a HSC may be designed with minimal automation, but this is likely to increase the capability requirements of the crew to successfully operate the HSC systems, and therefore reduce the size of the population from which crew-member may be drawn/selected.

[10] For information on HFI refer to The MOD HFI Process Handbook. Edition 1, 2005. www.hfidtc.com/pdf/HFI_Process_Booklet.pdf

7.1.3 Research & Development (R&D)

Knowledge gaps are likely to have been identified at the CR and URD phases of the Specification Process. Therefore R&D activities should be undertaken to generate this missing information to ensure that the designer can be provided with a very specific design requirement. Development work within this phase could make use of available guidelines[11] on incorporating human performance modelling into the design of the HSC, establishing passenger MIF limits, solutions to reduce crew workload and fatigue, and reduce exposure to RS, WBV and noise.

7.1.4 Systems Requirement Document (SRD)

The drafting of the SRD is where the operational requirement is turned into an objective list of information for the Designer to use to develop the HSC. It will include information on dimensional and weight constraints, performance, environmental envelope[12], build classification and Health & Safety requirements. It is at this point that the HF input to the design has to be defined wherever possible in objective/measurable terms. Within Europe it is at this point that the requirement to comply with WBV and noise legislation will be included, whereas at the CR and URD phases, ride-quality will have been defined in terms of comfort, and ideally MSI, MII and MIF (refer to Section A). The SRD will have two further applications:

- Generate data that can be used by procurement and operational stakeholders to produce the 'Safety Case' for the operation of the craft.
- Form the basis of the Compliance Matrix against which the design of the HSC will be assessed during the Design Reviews and the Test & Evaluation Phase.

If possible the Designer should be involved in the drafting of the SRD as they will be able to provide input on what information is needed to allow them to efficiently undertake the Feasibility Design process.
Refer to Figure 7-1 for a graphical representation of this phase.

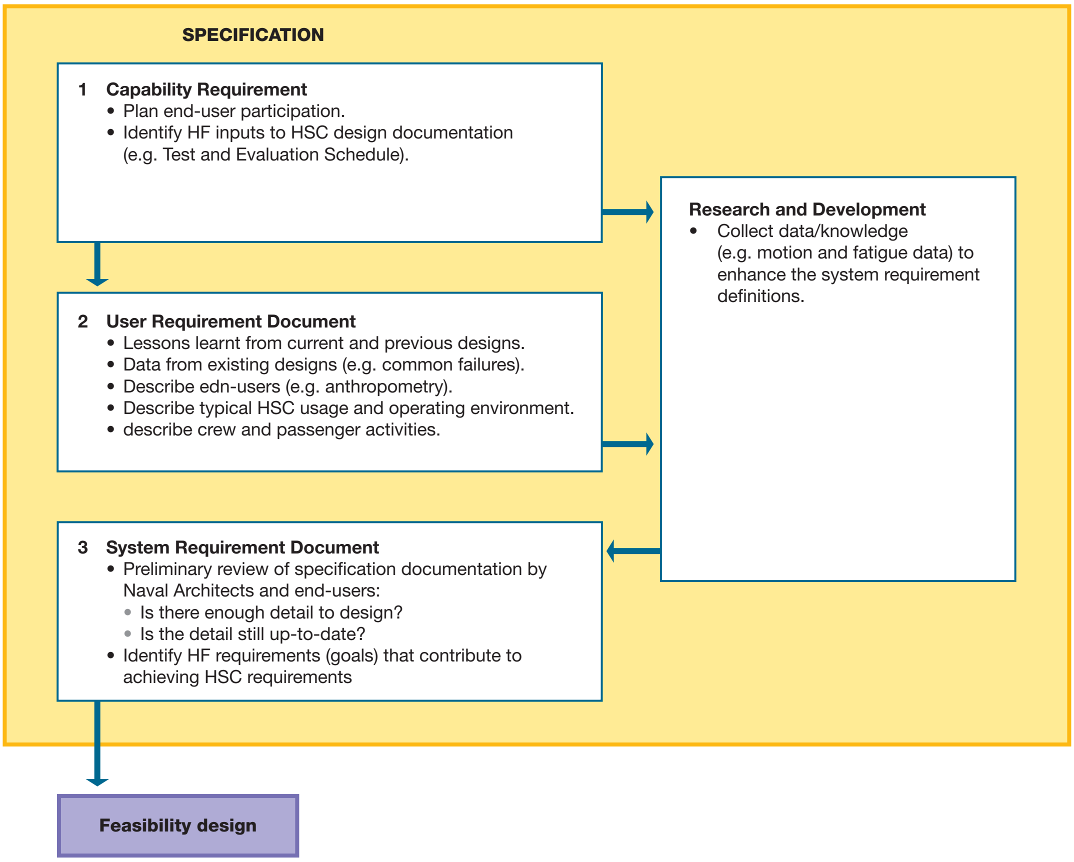

Figure 7-1 Human Factors input to the HSC Specification Phase

[11] AGARD-AR-356, A designers guide to human performance modelling.

[12] The definition of Environmental Envelope may include; geographical operational locations, sea conditions, temperature, wind speed, humidity, water depth, in-water debris, etc.

8. AN INTEGRATED DESIGN PROCESS

THIS INTEGRATED PROCESS IS DESIGNED TO ENSURE THAT HUMAN FACTORS SUPPORT IS INCORPORATED INTO THE DESIGN OF HSC.

8.1 Integrating The Naval Architecture and Human Factors Design Processes

8.1.1 The insertion of HF requirements into the specification process is the catalyst to ensuring that HF issues are addressed through the rest of the design and evaluation processes. In HF terms it may be considered to be the most important section of the design process as without HF insertion at this stage it is unlikely that the project will be successful. Consideration should be given to consulting with Human Factors Engineers, who ideally have experience of HSC operations, on issues requiring additional input to the development of design solutions.

8.1.2 Nine Human Factor areas (labelled A through to I) have been identified in order to support the integration of HF into the HSC Design Process. These nine HF areas are detailed in Table 8-1. They also form the basis for organising the detailed HF guidance notes that follow, together with additional information for stakeholders who require more detailed information.

8.1.3 When using these nine HF areas, each of the Design Process steps is considered in turn to identify the HF considerations that are associated with the design step. Figures 8-1 through to 8-3 detail the HF input to the Feasibility Design, Main Design, and End Design. HF input to each design step (where applicable) is identified by the corresponding HF Area letter and category (e.g. A. HSC Motions), with a further breakdown where appropriate.

8.1.4 A number of additional HF activities have been introduced into the design process. During the Specification Phase (Section 7), there may be a need to conduct Research and Development to fully specify the HSC performance, e.g. to collect motion and fatigue data. Throughout each of the three design sub-processes, Design Review activities (Section I) are concerned with conducting a review of the HSC design (including the HF contribution), appropriate to the maturity of the design. Test and Evaluation (Section J) follows the construction of an HSC prototype (or First of Class), and emphasises the link between Design Reviews during the overall design process and the contribution this makes to the final acceptance of the HSC by the End-User.

8.1.5 Data is available from a number of sources that can be used to inform the User Requirement Document and System Requirement Document (refer to Section 7) of the craft's capabilities and specifications. Examples of these include reports on the use of HSC used in the offshore industry[13], descriptions of crew tasks for search and rescue craft[14] and other HF Guideline documents such as DEFSTAN 00-25 and MIL-STD 1472.

8.1.6 The HF support to the HSC design process is summarised in Figure 8-4 in an identical format to the original NA Design Process (refer to Figure 5-1) from which the main differences can be seen. Figure 8-4 and Table 8-1 can also serve as a checklist in their own right, indicating at a glance which sections of this guide the Designer should refer to for further HF guidance, i.e. the letters following 'HF' within each design activity box indicating the HF areas that require consideration.

[13] Tipton, M., Eglin, C., Golden, F. and David, G. (2003) The performance capabilities of crews of daughter craft involved in offshore operations in the oil and gas industries. UK Health & Safety Executive, Research Report 108.

Pike, R.D. (2005) Improving the performance of rescue craft used for rescue and recovery in support of the oil and gas industry. UK Health & Safety Executive, Research Report 371.

Robson, J.K. (2005) Use and operation of daughter craft in the UKCS. UK Health & Safety Executive, Research Report 307.

[14] International Lifeboat Federation (2002) A Common Standard of Training for maritime SAR Unit Coxswains, mechanics & Crew Members.

	HF Area	Area Descriptions
A	**HSC Motions**	Motion effects • Fatigue (MIF) • Balance (MII) • Motion-sickness (MSI) Accelerations Impacts and motions in all the 6 degrees of freedom Motion measurement and analysis Shock and vibration mitigation Seat support issues
B	**Sight**	External and internal line-of-sight (instruments, etc.) External and interior lighting
C	**Sound**	Noise exposure Communication
D	**Environment**	Weather protection PPE • Clothing • Helmets Atmosphere (ventilation, claustrophobia) Temperature Humidity Smell
E	**Health and safety**	Mechanical Safety Electrical safety Fire Safety Physical Safety
F	**Man-machine interface** [Human-machine interface]	Design crewmember workstation Crew & passenger size (Anthropometry) Instrumentation Controls Relationship between controls and displays Use of COTS equipment
G	**Habitability**	Local comfort • Crew & passenger size (Anthropometry) • Bunks • Cabin headroom • Galley • Hygiene • Sharp and hard objects • Access / egress
H	**Maintainability**	Maintenance • Assembly/dismantling • Stowage • Shore-based and at-sea activities
I	**Design review**	Formalised design review and acceptance procedures • Stakeholder and end-user consultation • CAD Drawings • Mock-ups and user-trials

TABLE 8-1 Human Factor areas to support the Integrated Design Process

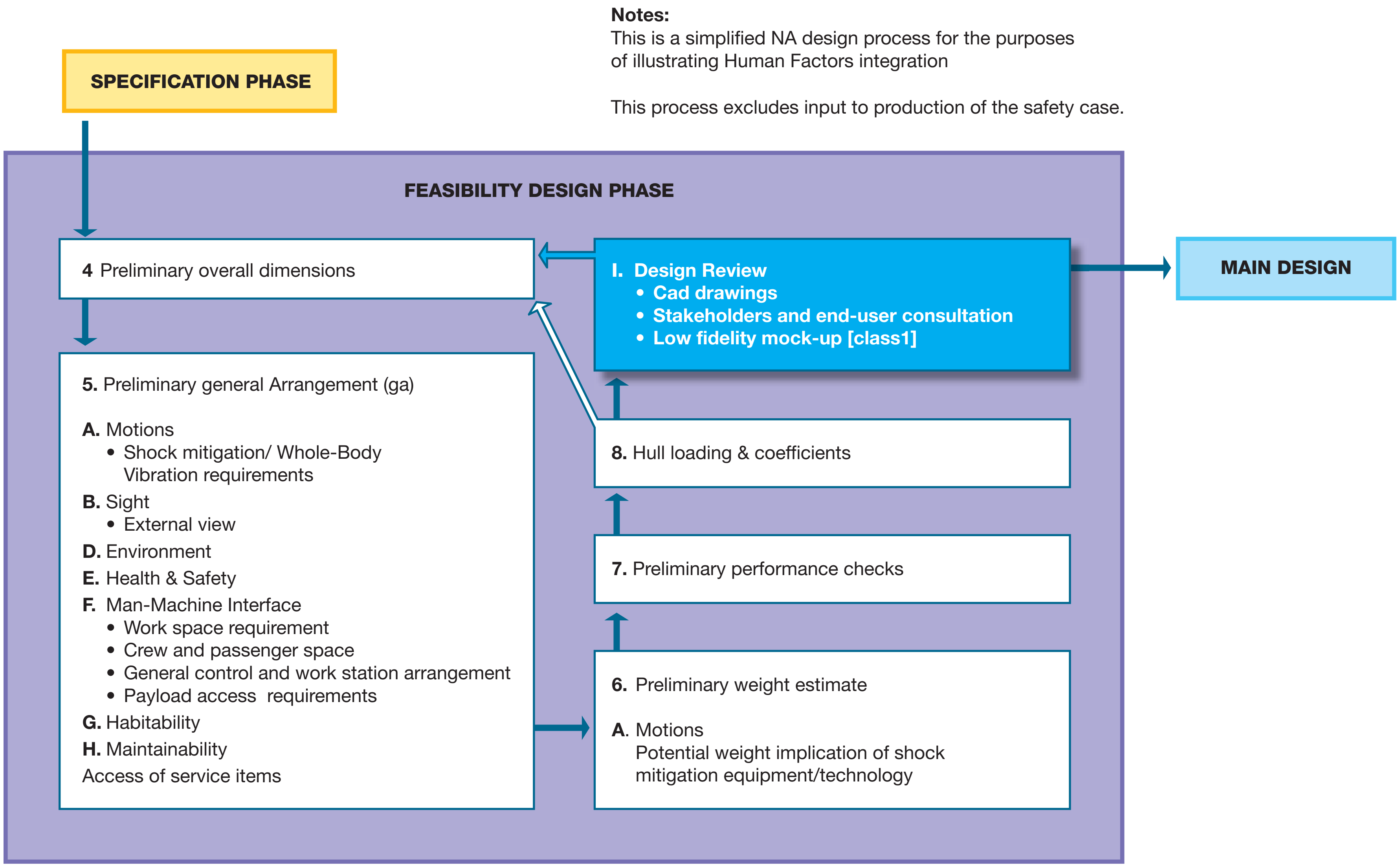

Figure 8-1 HF input to Feasability Design

Notes:
This is a simplified NA design process for the purposes of illustrating Human Factors integration

This process excludes input to production of the safety case.

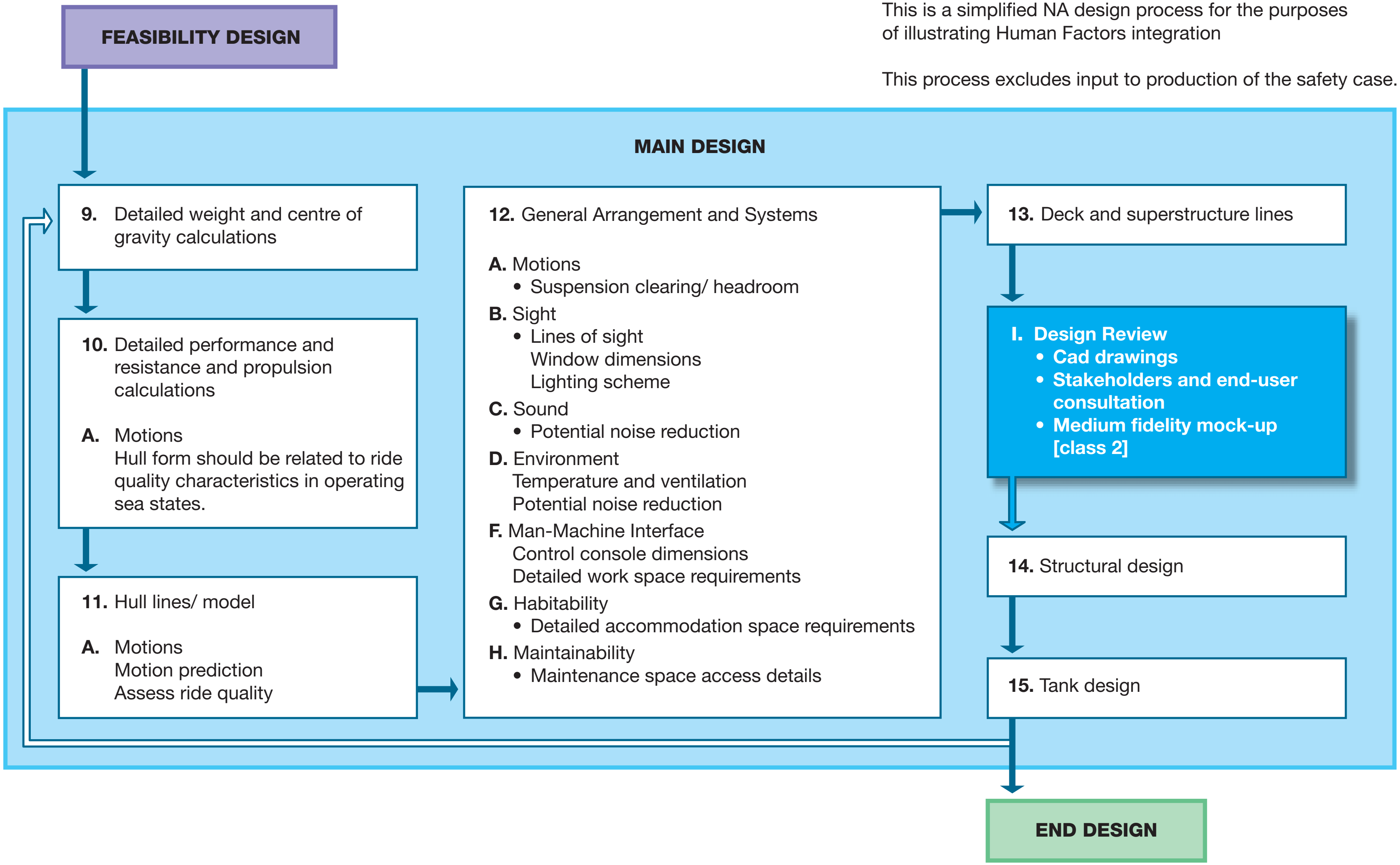

Figure 8-2 HF input to Main Design

MAIN DESIGN

END DESIGN

16. Interior layout details

A. Motions
Motion artefacts of MMI interaction

B. Sight
- General lighting
- Glare
- View (crew line-of-sight)

D. Environment
- Noise protection
- Temperature and humidity

F. Man-machine interface
- Console/instrument layouts
- Seating
- Task lighting
- Lighting to accommodate night-vision systems
- Controls: using PPE
- Controls: using gloves

H. Maintainability
- Maintenance

I. Design Review [3]
- **Stakeholders and end-user consultation**
- **Cad drawings**
- **Medium fidelity mock-ups [class 3]**

17. detail design

F. Man-machine interface
- Seamanship requirements [URD/ SRD defined crew activities]

H. Maintainability
- Internal
- External

Notes:
This is a simplified NA design process for the purposes of illustrating Human Factors integration

This process excludes input to production of the safety case.

18. Build HSC Prototype/first of class

19. Test and evaluation

HF items for assessment
- **System test against URD and SRD**
- **Seamanship**
- **Identified training requirements**
- **Usability: in operation**
- **Usability: maintenance**
- **Motion measurement and analysis**
- **Procurement acceptance**

Figure 8-3 HF input to End Design and Test & Evaluation

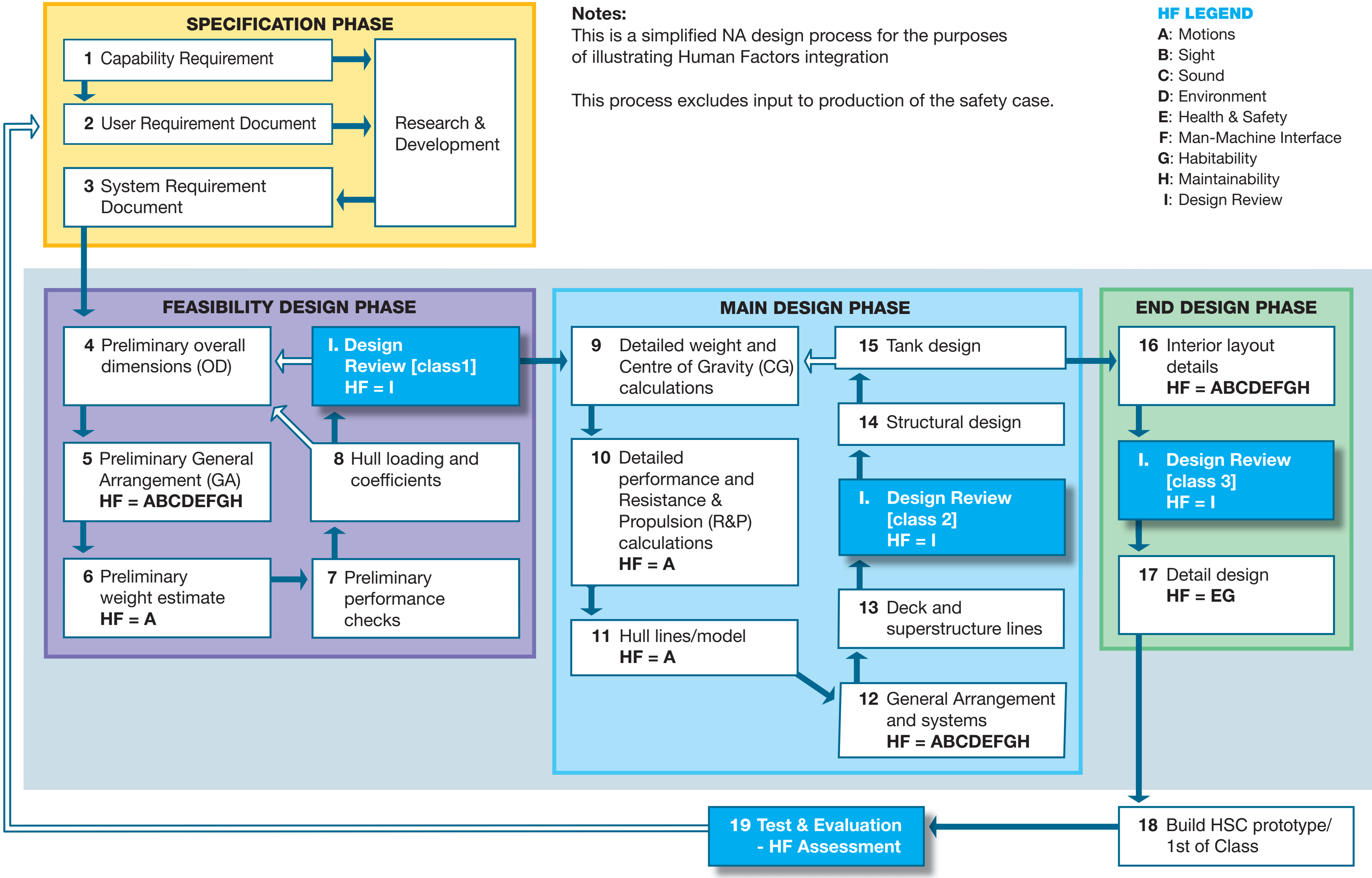

Figure 8-4 Integrated High Speed Craft design process (overview)

PART 2

HIGH SPEED CRAFT HUMAN FACTORS INFORMATION

Image copyright: XSMG

SECTION A
HSC Motions

HSC MOTION MUST BE CONSIDERED IN THE DESIGN PROCESS DUE TO ITS POTENTIAL TO DEGRADE PERFORMANCE AND INCREASE THE RISK OF ACUTE AND CHRONIC INJURY. WHERE REGUIRED, SHOCK & VIBRATION MUST ALSO BE MINIMISED FOR COMPLIANCE WITH THE EU VIBRATION LEGISLATION

A.1 GENERAL

A.1.1 The harsh dynamic environment encountered by operators aboard HSC may be characterised as two types of motion. These are briefly described in Table A-1[1].

Type	Description of Environment
I	The environment is predominantly characterized by repeated shocks or transient vibrations (e.g. wave impacts of high speed crafts) and may contain some underlying vibration. Exposure can be of any duration.
II	The environment is characterized as predominantly sinusoidal in nature, where occasional shocks or transient vibrations are present. Exposure can be of any duration.

Table A-1 High Speed Craft Motion Descriptions

A.1.2 The operational environments, which include Repeated Shock (RS) and Whole Body Vibration (WBV), have a detrimental effect on the crew and passengers (refer to Sections 1 and 2) that includes reducing operational effectiveness and readiness. This effect is typically described in two areas:
The performance of the crew and passengers (i.e. Motion Induced Fatigue (MIF)).
The increased risk of acute and chronic injury.

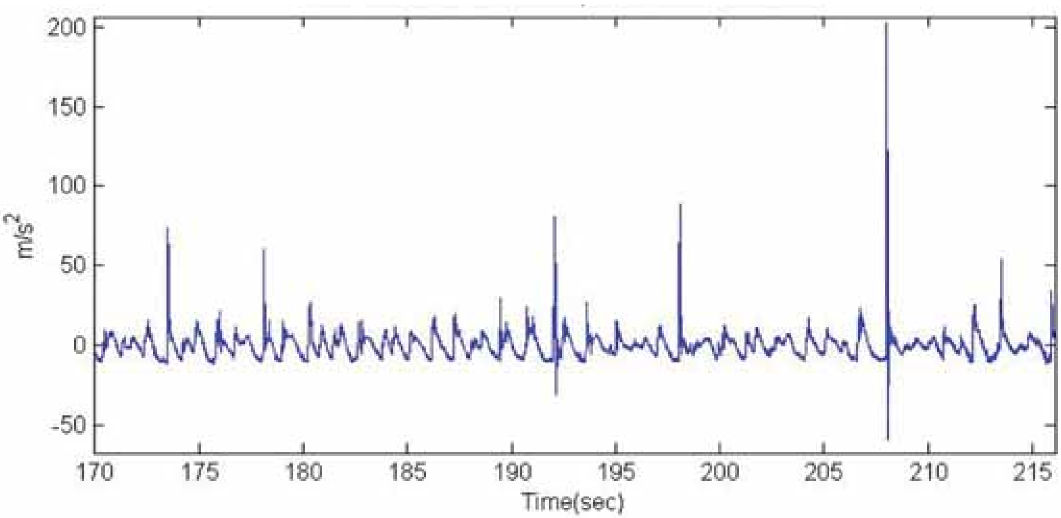

Figure A-1 **An example of 28' RIB Z-axis deck accelerations during a transit at ~40kt in a Sea State 1-2[2]. Note the regular accelerations of ~2g and the peak acceleration of ~20g.**

[1] Descriptions based on ASTM F1166-07 Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities.

[2] Data courtesy of QinetiQ Centre for Human Sciences, 2007.

A.1.3 The means by which craft motion can affect human performance have been described in a model developed by members of the ABCD Working Group[3]. The model[4] is made up of three factors and is shown graphically below (Figure A-2) in a simplified format:

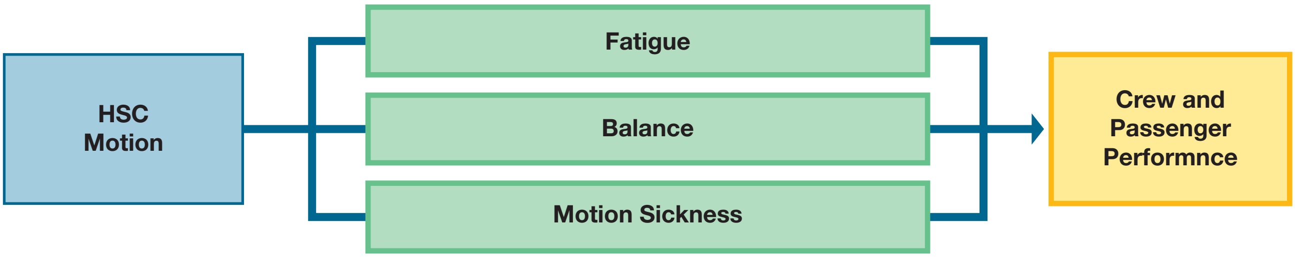

Figure A-2 ABCD-WG Model of Human Performance at Sea

Fatigue – The motion of the craft causes fatigue, which degrades the work capacity (physical & cognitive) of the individual. This is known as Motion Induced Fatigue (MIF). Refer to Sections 1 and 2 for further information on MIF.

Balance – The motion experienced on HSC can cause individuals to lose their balance and therefore it takes longer to complete tasks. This increase in task time has to be factored into the operation of the HSC system, or solutions devised to make the task simpler. This issue is known as Motion Induced Interruptions (MII).

Motion Sickness – Motion sickness can cause people to become incapacitated and unable to operate effectively. This is known as Motion Sickness Incidence (MSI).

A.1.4 The risks of acute and chronic injury are manifested in an increase in spinal, knee, arm, or neck injury. This can be from a single high-energy event (e.g. a 20g impact[5]) or the result of a long-term exposure to a large quantity of smaller energy events (e.g. multiple 2g impacts, refer to Figure A-1). For example, for predominately military HSC crewmen, there is a significantly higher incidence of back and knee injuries than what is observed in the general military population, who are not typically exposed to the HSC operational environment[6].

A.1.5 The motion of HSC, in response to the Type 1 environment, may be characterised as a low level of whole-body vibration (WBV) interspersed with repeated stochastic impact events, refer to Figure A-2 for an example of 28' RIB deck acceleration (peak Z-axis acceleration of ~20g). Such impacts can be in excess of 25g[7] and subsequently the crew can suffer from MIF8 and the risk of acute[9] and chronic injuries[10]. The need to reduce the risk of injury is supported by duty-of-care responsibilities, and within the European Union by the Physical Agents Directive that limits exposure to WBV[11].

[3] www.abcd-wg.org

[4] Colwell, J.L. (2005) Modeling ship motion effects on human performance for real time simulation. *Naval Engineers Journal*, Winter 2005, pp 77-90.

[5] Dobbins, T.D., Myers, S.D. & Hill, J. (2006) Multi-axis shocks during high speed marine craft transits. *41st UK Conference on Human Response to Vibration*. Farnham, UK.

[6] Ensign, W., Hodgdon, J., Prusaczyk, W.K., Ahlers, S, Shapiro, D., and Lipton, M. (2000), A survey of self-reported injuries among special boat operators; *Naval Health Research Centre, Tech Report 00-48*.

[7] Dobbins, T.D., Myers, S.D. & Hill, J. (2006) Multi-axis shocks during high speed marine craft transits. *41st UK Conference on Human Response to Vibration.* Farnham, UK.

[8] Holmes S, Dobbins T, Leamon S, Myers S, Robertson K, King S. (2006) The effects of rigid inflatable boat transits on performance and fatigue. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue,* Panama City, FL, USA.

Myers S, Dobbins T, Dyson R. (2006) Motion induced fatigue following exposure to whole body vibration in a 28ft RIB. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

[9] Smith, G. CASE STUDY; Vertebral wedge fracture after speedboat 'splash down'. *J Royal Navy Medical Service*. 2007; 93(2):75-7.

A.1.6 The control of the ride experienced by the crew and passengers is dependant on the following variables (see below), all of which (except the environment) may be designed/manipulated to enhance S&V mitigation.

a Sea state encountered

b Coxswain craft-control skill

c HSC speed

d Hull geometry

e Deck

f Seat

g Human musculoskeletal shock absorption and posture control (refer to A.1.7), e.g. legs, torso and arms

A.1.7 Operator posture is as critical as any design consideration for shock mitigation. The human spine is designed to compress during a fall and can absorb a considerable amount of impact provided that it is aligned with the direction of force. As the human spine becomes misaligned (i.e. more perpendicular) to the force vector, a shearing effect is imparted between vertebras, which can lead to injury. This 'poor posture' is often observed on HSC where the location of the controls force the operator to lean forward in their seat/bolster. Dr. Dale Bass (University of Virginia, Center for Applied Biomechanics) has estimated that poor posture can reduce the effectiveness of a suspension seat by as much as 30%.

A.1.8 The Integrated Design Process (refer to Section 8, Figure 8-4) should consider the potential options available to the designer to minimise crew and passengers exposure to S&V in accordance with both the User Requirement Document (URD) and System Requirement Document (SRD). As well as the issue of WBV exposure the designer must consider other issues, e.g. Man-Machine Interface (Section F), related to the more detailed design of the HSC. These may appear to be of less overall importance but make a big difference in the successful operation of the craft.

A.1.9 Although motion sickness per se may not be considered to be a major issue for HSC, its effects should be considered as HSC can spend a significant period loitering on-station. Motion sickness is dependent on motion exposure duration, with sickness generally increasing for up to six hours, after which habituation starts to take place[12]. Sickness, fatigue and postural stability are mutually dependent and it has been shown that in HSC operations, 90% of un-adapted crew may suffer from MSI[13]. It has also been shown that sickness and task performance are highly correlated, i.e., when sick, more than 50% of all naval tasks in a fully habituated crew may fail[14]. Even when not really sick, i.e. not feeling nauseated, but only feeling 'under the weather', 20% of all tasks may already fail, as compared to less than 5% in a crew feeling perfectly okay[15]. It should also be recognised that when put ashore, the after-effects may still be detrimental to performance. Furthermore, the coxswain generally suffers less from motion sickness than the passengers, especially when the passengers have a reduced external view (e.g. in a covered HSC and at night). Therefore efforts should be made to ensure the occupants have an adequate external view of the horizon[16] and a supply of fresh air.

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[10] Ensign, W., Hodgdon, J., Prusaczyk, W.K., Ahlers, S, Shapiro, D., and Lipton, M. (2000), A survey of self-reported injuries among special boat operators; *Naval Health Research Centre, Tech Report 00-48*.

Carvalhais, A. (2004) Incidence and severity of injury to surf boat operators. *Conference Proceedings 75th SAVIAC Conference*, Virginia Beach, VA. October 2004.

[11] European Union Directive (2002/44/EC) on the health and safety requirements regarding the exposure of workers to the risks arising from physical agents.

[12] Colwell JL. (1994) Motion sickness habituation in the naval environment. DREA Technical Memorandum, Defence Research Establishment Atlantic, Dartmouth, N.S., Canada 94/211.

[13] McCauley ME, Pierce E, Price B. (2006) High speed vessel operations and human performance. *ABCD Symposium on Human Performance at Sea*, Panama City, FL, 25-26 April, http://tmquest.tm.tno.nl/abcd.

[14] Colwell JL. (2000) NATO Performance Assessment Questionnaire (PAQ): Problem severity and correlations for ship motions, fatigue, seasickness and task performance. *DREA Technical Memorandum*, Defence Research Establishment Atlantic, Canada DREA TM 200-142.

[15] Bos JE. (2004) How motions make people sick such that they perform less: a model based approach. *NATO RTO/AVT-110 Symp. Habitability of Combat and Transport Vehicles: Noise, Vibration and Motion*. Prague, CZ, 4-7 October: 27.1-11.

[16] Brendley, K.W., Marti, J., Bender, G., Cohn, J., Muth, E. and Stripling, R. (2003) Controlling Motion Sickness With Motion-Coupled Visual Environments, *Proceedings of the ASNE Human Factors Symposium*, Washington, USA.

A.2 INPUT TO DESIGN PROCESS

A.2.1 Feasibility Design

a Preliminary General Arrangement (Design Step 5): The requirements of the URD and SRD for craft ride/motion characteristics should be examined, particularly in relation to the S&V exposure of the crew and passengers, and the subsequent requirements for S&V mitigation.

b Preliminary Weight Estimate (Design Step 6): The potential weight implication of any S&V mitigation equipment/technology should be taken into account.

A.2.2 Main Design

a Detailed Performance and Resistance & Propulsion Calculations (Design Step 10): The prototype hull form should be related to the required ride quality characteristics for operational sea states.

b Hull Lines/Model (Design Step 11): Motion predictions will be made for the prototype hull form and assessed against the required ride characteristics, e.g. minimise S&V. To minimise MSI, predictions can be made based on vertical motion[17] or on 6 Degrees of Freedom ship motion[18].

c General Arrangement and Systems (Design Step 12): The size and characteristics of any S&V mitigation systems must be accounted for to ensure the appropriate clearances (e.g. additional headroom with suspension seats) are provided.

A.2.3 End Design

a Interior Layout Details (Design Step 16): Increasing motion inhibits the individuals' ability to interact effectively with the HSC instrumentation and controls. For example, display details/numerals have to be increased in size so that they are legible, and buttons have to be larger to increase the ability to accurately use them. Both of these increase the size requirements of the consoles. Refer to Section F, Man-Machine Interface, for additional information.

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION A.3

[17] ISO 2631-Pt1: (1997) Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration: General requirements.

[18] Bos JE, Dallinga RP. (2006) Fundamental issues on human discomfort aboard small craft, and how to apply this to yacht design. *Small Craft Symposium*, 15-18 November, Bodrum, Turkey.

A.3 ADDITIONAL INFORMATION

A.3.1 HUMAN RESPONSES

A.3.1.1 In order to fully understand how to properly address the HSC motions, it is necessary to understand the human response to vibration motions in general. The majority of the human responses to vibration have been shown to occur in the range between 0.05 Hz to 80Hz[1]. Some of these responses are summarised in Table A-1, but, many factors including: posture, any equipment worn, and support such as from backrests or headrests can affect these responses:

Frequency (Hz)	Effect
0.05 – 2	Motion sickness, peak incidence occurs at ~0.17 Hz
1 – 3	Side-to-side and fore-and-aft bending resonances of the unsupported spine
2.5 – 5	Strong vertical resonance in the vertebra of the neck and lower lumbar spine[2]
4 – 6	Resonances in the trunk[3]
20 – 30	Resonances between head and shoulders[4]
Up to 80 Hz	Localised resonances of tissues and smaller bones

Table A-1 Descriptions of Human Responses to Motions of Increasing Frequency

A.3.1.2 To date, the majority of WBV research has been sinusoidal in nature with limited consideration of impacts. Also stochastic vibration has not been comprehensively assessed. Multifactorial motion has been investigated, i.e. the combined effect of vibration and low frequency motion, and a cumulative effect identified. Refer to Figure A-3 for a graphical representation.

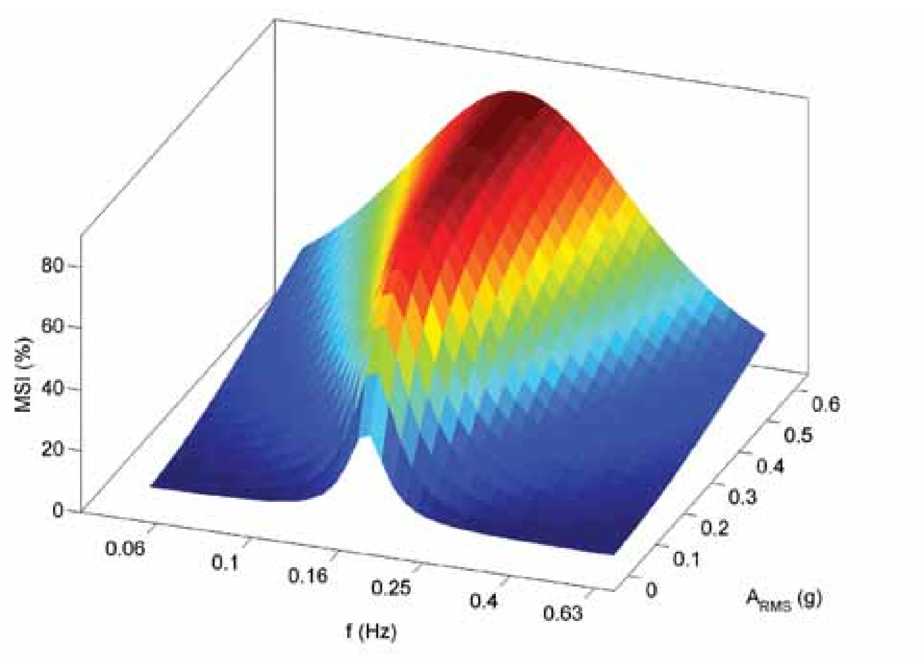

Figure A-3 Motion sickness incidence calculated by a physiologically based model[5].

f(Hz)	Motion frequency
MSI (%)	Percentage of individuals suffering from Motion Sickness
ARMS(g)	Average vibration level

[1] Mansfield, N.J. (2004) Human Response to Vibration. ISBN 0-4152-8239-X

[2] Hedge, A. (2007) Course Notes, DEA 350, Human Factors: Ambient Environments, Cornell University

[3] Hedge, A. (2007) Course Notes, DEA 350, Human Factors: Ambient Environments, Cornell University

[4] Hedge, A. (2007) Course Notes, DEA 350, Human Factors: Ambient Environments, Cornell University

[5] Bos JE, Bles W. (1998) Modelling motion sickness and subjective vertical mismatch detailed for vertical motions. *Brain Research Bulletin* 47:537-542.

A.3.1.3 Sinusoidal vibration vs. stochastic[6] vibration and shock/impact

HSC rarely expose the occupants to regular (i.e. sinusoidal) vibration, which is the mode for which the majority of the WBV research has been undertaken for examining human responses. HSC may demonstrate sinusoidal vibration if operating in benign conditions, but in general the motion is erratic (i.e. stochastic) in nature and may be described as a series of repeated impacts occurring at irregular intervals. Therefore it may be considered that traditional vibration analysis may not be appropriate for a motion environment principally characterised by stochastic impacts. This requirement to assess repeated impacts has been recognised[7], and firstly addressed with respect to the risk of musculoskeletal injury from land vehicle exposure[8], and is now being validated using the same analysis techniques for the HSC environment[9].

A.3.2 MOTION MEASUREMENT AND ANALYSIS

The assessment of HSC motion is dependant on the use of the appropriate measurement techniques and methodology. The measurement methodology is based on the requirements of the assessment and analysis to be undertaken. There are two different requirements that may be addressed, these are:
Naval Architecture requirements – based on the hydrodynamic performance and structural analysis of the craft. These requirements are not addressed in this Guide.
Human Factors requirements – based on the responses of the human to the motions of the HSC.

A.3.2.2 The importance of 3 Degrees of Freedom measurements

Although the accelerations measured perpendicular to the HSC deck are generally of the highest magnitude, the lateral and longitudinal accelerations have also been shown to be high[10]. This is because the HSC does not impact with the water with the deck perpendicular to the water surface, and the water surface is unlikely to be perpendicular to the gravity vector. Refer to Figure A-4 for a graphical example of a HSC landing on its port side. This results in the crew and passengers being exposed to vector accelerations which cause the individual to be continually working to maintain their posture and stop them from being ejected from their seat/bolster position. Also, HSC crews describe the longitudinal, and particularly the lateral accelerations as being particularly uncomfortable and frustrating to deal with. Vertical accelerations, are generally of a greater magnitude, but can typically be coped with over short durations by standing with slightly bent knees and allowing the legs to absorb the majority of the force. For single runs, of longer duration, MIF conflicts with using the body as a shock absorber. For craft that will be used by the same individuals repeatedly, the cumulative effects of standing can result in sports type injuries to the knees (i.e., torn ligaments). For each of these circumstances seated solutions should be considered.

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[6] Definition of stochastic: random or probabilistic but with some direction

[7] Alem, N. (2005) Application of the New ISO 2631-5 to Health Hazard Assessment of Repeated Shocks in U.S. Army Vehicles. *Ind Health* 43, 403-412.

[8] ISO 2361-Pt5: Method for evaluation of vibration containing multiple shocks.

[9] Bass, C., Ziemba, A., Lucas, S., Salzar, R. and Peterson, R. (2006) Evaluation of Criteria for Assessing Risk of Impact Injury in High Speed Craft. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

Peterson, R. and Bass, C., (2006) Consideration of Impact Injury During Acquisition of Military High Speed Craft. *Conference Proceedings; ABCD Symposium on Human Performance at Sea: Influence of Ship Motions on Biomechanics and Fatigue*, Panama City, FL, USA.

[10] Dobbins, T.D., Myers, S.D. & Hill, J. (2006) Multi-axis shocks during high speed marine craft transits. *41st UK Conference on Human Response to Vibration*. Farnham, UK.

Figure A-4 An example of how a HSC often lands on its side thus resulting in an impact with a considerable lateral component (gX) in addition to a vertical component (gZ), where gZ equates to the axis perpendicular to the HSC deck.
Image copyright: Powerboat P1

A.3.2.3 Rotation

In addition to linear or translational vibration, HSC are exposed to high levels of rotational motion where the HSC pitches, rolls (see Figure A-5), and to a lesser degree yaws. Because of the harsh shock environment it is currently technically difficult to measure the absolute angle of the HSC with respect to gravity, and even more difficult to relate the HSC attitude to the surface of the water. From a human response perspective it may be more relevant to assess the angular acceleration or angular velocities that the crew are exposed to rather than the specific attitude. As discussed above, the lateral and longitudinal accelerations are very uncomfortable for the HSC occupant and require a high level of muscular work to maintain postural stability. This high physical workload may be one of the causes of MIF experienced in HSC. In addition, in loitering conditions, it is the rotational motions of roll and pitch, combined with heave, that contributes to MSI.

Figure A-5 An extreme example of a HSC rolling whilst operating in choppy sea conditions

A.3.2.4 Specific event vs. long term monitoring

Depending on the operational scenarios for the HSC, the measurement techniques should account for the requirements to capture entire operational exposure. In addition, the total expected lifetime exposure time of the individual operators must be considered. This determines the type of data that needs to be collected. For example, the measurement equipment may need to assess the WBV exposure during long transits (e.g. > 8 hours) and specific impact events (e.g. a single 25g impact). Also, it may be necessary to monitor the total exposure of individual operators over their lifetime. Whatever the need, it is no longer considered technologically unfeasible to collect and maintain a large volume of data, and the computer processing capability is now readily able to analyse that data.

A.3.2.5 ABCD-WG HSC Motion Measurement Guidelines[11]

The ABCD Working Group held a workshop, sponsored by the UK MOD's Directorate of Sea Systems, in March 2007 to identify the specific measurement and signal conditioning requirements for HSC motion. Attendees included representatives from the defence, academia, and research communities from the UK, US, NL, CA and AUS. A standardised measurement methodology was agreed. The outcome of the workshop is documented in an ABCD Technical Report[12]. The guideline highlights the following S&V measurement issues:

[11] ABCD-TR-08-02 v1.0 HIGH SPEED CRAFT MOTION MEASUREMENT GUIDELINES. ABCD Working Group on Human Performance at Sea.

[12] www.abcd-wg.org

- Translational and rotational motion
- Maximum and minimum frequency
- Amplitude range
- Measurement axes and locations
- Other issues

A.3.2.6 Analysis of WBV

A.3.2.6.1 Currently there are a number of WBV analysis methods available. These include:

a Route Mean Square (r.m.s.) (ISO 2631 Pt 1[13]).

b Vibration Dose Value (VDV).

A.3.2.6.2 It should be recognised that there are limitations with these analysis techniques for the Repeated Shock environment experienced on HSC. An example of this limitation includes the VDV, which although designed for motion that includes some repeated shocks, is still limited in its ability to describe HSC S&V motion. Cripps et al[14] suggest the following:

"The VDV approach is derived from discomfort tolerances with fairly short exposure times and low magnitudes of acceleration. Their ability to predict injury in this case is questionable for two reasons: firstly, the relationship between discomfort and injury is unknown; and secondly, the low frequency motion and repeated shocks encountered in lifeboats are completely different from the type of motion that has been used to validate the standards."

A.3.2.6.3 The ISO 2631 Pt 5[15] is an analysis technique that predicts the risk of injury to the lumbar spine. It was developed for a Repeated Shock environment but the initial development process only validated shock magnitudes up to 4g, therefore its application to the HSC environment is currently limited. This has been recognised by the USN and therefore they are undertaking further development to validate the analysis techniques for higher RS magnitudes[16]. Further, more detailed information on HSC motion analysis and the development of the ISO 2631P-5 analysis is provided in Section A.3.2.7.

A.3.2.7 Specific HSC Motion and Exposure Analysis

A.3.2.7.1 One of the more challenging and important HSC biodynamics problems is the repeated shock issue, or musculoskeletal injury produced by craft-water impacts. Recent studies provide compelling evidence of a disproportionate rate of musculoskeletal injuries onboard HSC, and suggest that the lumbar spine is the most prevalent and debilitating injury site and that lumbar spine injury is often cumulative[17]. Models and standards for assessing the possibility of chronic injury from HSC impacts are therefore needed to design safe craft and seats, and to assess craft and seat systems at sea.

[13] ISO 2631-1:1997 Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part 1: General Requirements.

[14] Cripps, R., Rees, S., Phillips, H., Cain, C., Richards, D. and Cross, J. (2003) Development Of A Crew Seat System For High Speed Rescue Craft. *Conference proceedings, FAST 2003*, Naples, October 2003.

[15] ISO 2361 Pt5: Part 5: Method for evaluation of vibration containing multiple shocks.

[16] Bass, C., Ash, J., Salzar, R., Peterson, R. and E. Pierce, E. (2008) Prediction of injury risk for occupants of high speed planning craft. *Conference Proceedings; PACIFIC 2008 International Maritime Conference*. Sydney, Australia.

[17] W. Ensign, J. Hodgdon, K. Prusaczyk, S. Ahlers, D. Shapiro, and M. Lipton, "A Survey of Self-Reported Injuries Among Special Boat Operators," NHRC Technical Report 00-48, Naval Health Research Center, San Diego, 2000.

Carvalais, A. "Incidence and Severity to Surf Boat Operators," Proceedings, 75th Shock and Vibration Symposium (SAVIAC '04), Virginia Beach, VA, October 2004.

A.3.2.7.2 Considerable research has been devoted to the identification, development, and comparative evaluation of models and standards for application to the HSC repeated shock problem[18]. Some of the more common and well documented methods include:

- **Waveform Methods**
  - Acceleration Amplitude (e. g., 1/10th highest)
  - Acceleration Onset Rate (e. g., 1/10th highest)
- **Energy and Spectral Methods**
  - Acceleration Root-Mean Square (RMS)
  - Acceleration Power Spectral Density within Specified Bandwidth
  - ISO 2631 Part 1 (1985) (RMS in 1/3-octave bands)
  - ISO 2631 Part 1 (1997) (RMS and VDV in 1/3-octave bands)
- **Dynamic Methods**
  - Dynamic Response Index (DRI) (e. g., 1/10th highest)
  - ISO 2631 Part 5 (2003)

A.3.2.7.3 These methods provide for measurement of a craft dynamics time history of sufficient duration to characterize the stochastic nature of impact dynamics for the given craft/seat/posture configuration, seaway, craft direction relative to the seaway, and speed. For example, analysis of a waveform characteristic such as acceleration amplitude (i. e., "g") may be performed by computing the average of the 1/3rd or 1/10th highest amplitudes within the properly measured and filtered acceleration time history, analogous to the determination of significant wave height.

A.3.2.7.4 These methods and their application to the impact injury problem have been the subject of numerous investigations. Village et al., for example, discusses the shortcomings of many of the impact injury assessment methods in use in the mid 1990s[19]. This work led to the development of the ISO 2631 Part 5[20]. During the period 2003 through 2005, Peterson et al.[21], Alem et al.[22], and Bass et al.[23], performed comparative evaluations of alternative methods leading to the general conclusion that, while none of the methods in use were ideal, the ISO 2631 Part 5 was superior given its emphasis on cumulative lumbar spine injury, its physics-based approach, its general agreement with experimental trials data, and its suitability for application to many HSC problems.

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[18] J. Village, et al., "Development of a Standard for the Health Hazard Assessment of Mechanical Shock and Repeated Impact in Army Vehicles," USAARL Contract Report No. CR 95-1, U. S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, May 1995

Peterson, R., Pierce, E., Price, B., and Bass, C., "Shock Mitigation for the Human on High Speed Craft – Development of an Impact Injury Design Rule," presented at NATO Applied Vehicle Technology AVT-110 Symposium, Prague, Czech Republic, October 2004

Peterson, R., "Impact Injury and the High Speed Craft Acquisition Process," presented at the Human Factors in Ship Design Safety and Operation Conference, Royal Institute of Naval Architects, London, England, February 2005

Alem, N., Hiltz, E., Breaux-Sims, A., and Bumgardner, B., "Evaluation of New Methodology for Health Hazard Assessment of Repeated Shock in Military Tactical Ground Vehicles," presented at NATO Applied Vehicle Technology AVT-110 Symposium, Prague, Czech Republic, October 2004

Bass, C., Salzar, R., Ziemba, A., Lucas, S., and Peterson, R., "The Modeling and Measurement of Humans in High Speed Planing Boats Under Repeated Impacts", Proceedings of the 2005 International IRCOBI Conference, International Research Council on Biomechanics of Impact, Prague, Czech Republic, September 2005

[19] J. Village, et al., "Development of a Standard for the Health Hazard Assessment of Mechanical Shock and Repeated Impact in Army Vehicles," USAARL Contract Report No. CR 95-1, U. S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, May 1995

[20] International Standards Organization, "Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part 5: Method for Evaluation of Vibration containing multiple shocks, ISO 2631-5: 2004(E), 2004

[21] Peterson, R., Pierce, E., Price, B., and Bass, C., "Shock Mitigation for the Human on High Speed Craft – Development of an Impact Injury Design Rule," presented at NATO Applied Vehicle Technology AVT-110 Symposium, Prague, Czech Republic, October 2004

Peterson, R., "Impact Injury and the High Speed Craft Acquisition Process," presented at the Human Factors in Ship Design Safety and Operation Conference, Royal Institute of Naval Architects, London, England, February 2005

[22] Alem, N., Hiltz, E., Breaux-Sims, A., and Bumgardner, B., "Evaluation of New Methodology for Health Hazard Assessment of Repeated Shock in Military Tactical Ground Vehicles," presented at NATO Applied Vehicle Technology AVT-110 Symposium, Prague, Czech Republic, October 2004

[23] Bass, C., Salzar, R., Ziemba, A., Lucas, S., and Peterson, R., "The Modeling and Measurement of Humans in High Speed Planing Boats Under Repeated Impacts", Proceedings of the 2005 International IRCOBI Conference, International Research Council on Biomechanics of Impact, Prague, Czech Republic, September 2005

A.3.2.7.5 The ISO 2631 Part 5 includes two principal components: a model of the seated lumbar spine that predicts lumbar spine dynamics from seatpan accelerations, and a fatigue-based injury model, derived from laboratory tests of cadaver spine tissue. These models are used to calculate an ‘S_{ed8}’ value from a recorded or simulated boat motion. The Sed8 predicts the overall daily compressive stress experienced by the spine and can be used to estimate the likelihood of injury from exposure to the harsh RS environment typical of HSC[24].

A.3.2.7.6 For seated HSC occupants, the ISO 2631 Part 5 is applied to three-axis seatpan acceleration data in a fashion similar to that of the ISO 2631 Part 1, where in both cases the occupant is assumed to be in firm contact with the seat. The effect of both hull and seat design is inherently considered. Application of this standard (and any of the other candidate methods) becomes more challenging for standing or standing/leaning occupants, or for occupants whose buttocks are by intention or by design separated from the seat during portions of the time history or impact event. For such postures and configurations the basic recommended procedure, currently in development, is to retain the injury model component of the ISO 2631 Part 5, and replace its seated human dynamics model with another model that better represents the occupant posture.

A.3.2.7.7 A shortcoming within the ISO 2631 Part 5 is that its seated human spine dynamics model becomes erroneous for high magnitude impact conditions, since the model is based on human volunteer laboratory test conditions where the acceleration levels were constrained[25]. This shortcoming has recently been investigated by the University of Virginia Center for Applied Biomechanics, using the human dynamics model MADYMO[26]. This research has led to the development of a more robust spine dynamics model.

A.3.2.7.8 Further research is needed to fully validate the ISO 2631 Part 5 for its intended seated application to the repeated shock problem, and to develop human dynamics models for other postures with which to drive the injury component of the standard. Rigorous validation of models and standards can be accomplished only with long-term epidemiology within the environment where repeated shock and impact injuries actually occur. A HSC health monitoring system, based on the predictions provided by ISO 2631 Part 5, is currently under development that holds promise for cost-effective impact injury epidemiology at sea[27].

A.3.2.7.9 In addition to the analysis methods described above and in Section A.3.2.6 (Analysis of WBV) other descriptive methods may also been used. These have been well received by operators and non-technical stakeholders who have been able to comprehend the data presented more easily than the results of r.m.s, VDV or ISO 2631 Pt-5 analysis. An example of a descriptive analysis of the impacts recorded from the deck of a 28' RIB travelling at ~40kts, in a Sea State 1-2, for three hours is shown below in Figure A-6.

[24] Peterson, R., Pierce, E., Price, B., and Bass, C., “Shock Mitigation for the Human on High Speed Craft – Development of an Impact Injury Design Rule,” presented at NATO Applied Vehicle Technology AVT-110 Symposium, Prague, Czech Republic, October 2004.

[25] Bass, C., Ash, J., Salzar, R., Peterson, R., and Pierce, E., “Prediction of Injury Risk for Occupants of High Speed Planing Craft,” to be presented at ABCD/Pacific2008 Conference, Sydney, Australia, January 2008.

[26] www.tass-safe.com

[27] Peterson, R., Pierce, E., Blankenship, J., and Bass, C., “High Speed Craft Health Monitoring System,” to be presented at ABCD/Pacific2008 Conference, Sydney, Australia, January 2008.

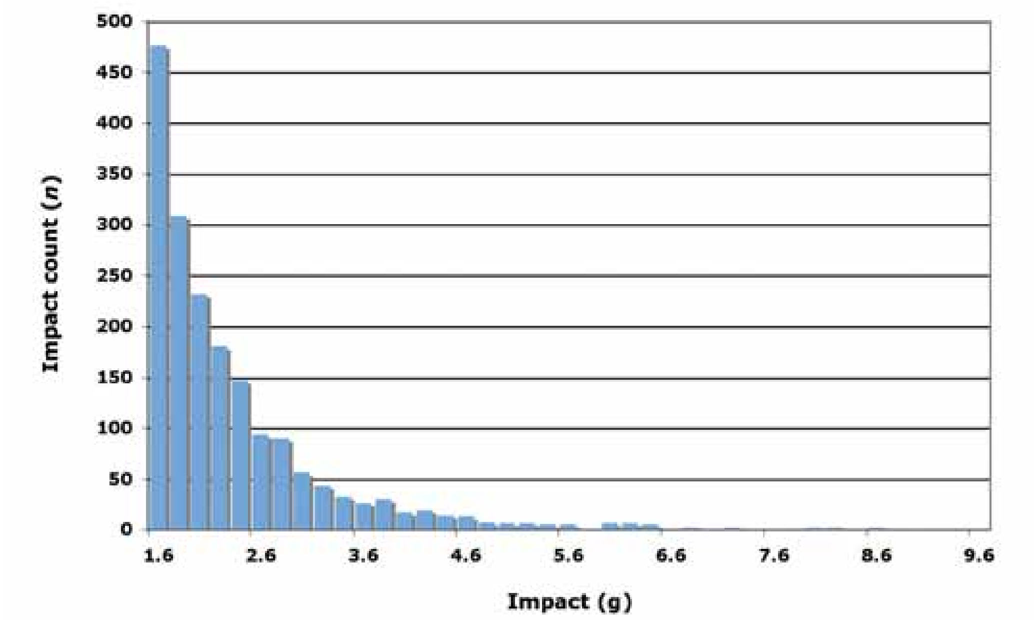

Figure A-6 An example of descriptive data analysis illustrating the occupants exposure to repeated shocks during a three-hour RIB transit at ~ 40kt in a Sea State 1-2[28].

A.3.2.7.10 The ISO 2631 Pt-1 and VDV analysis methods are based on comfort research undertaken on a sample of the general population. It has been suggested that habituated HSC operators perceive the RS and WBV exposure of a HSC differently to the general public. Unpublished data[29] has shown that experienced HSC operators perceive WBV (or rather RS exposure) differently to the population used to develop vibration standards (i.e. ISO 2631-Pt1), with the habituated crew describing the ride as being more comfortable than the measured value would predict. Therefore the applicability of the current standards for the HSC environment can be questioned.

A.3.2.7.11 As with the ISO 2631 Pt-5, further research is needed to identify HSC motion exposure analysis techniques (e.g. descriptive data analysis techniques) that provide data in a form that has greater meaning to the end-user community. The human exposure measures should also be linked to HSC motion assessment techniques that HSC Designers use, thus allowing a greater predictive capability between the hydrodynamics/motion of a prototype HSC and the occupants exposure to S&V, and its resultant effects on MIF, Situational Awareness and risk of injury.

A.3.2.8 EU WBV Legislation[30]

The EU legislation restricting exposure to WBV applies to HSC operations in EU Countries. HSC designers and manufacturers should take account of this legislation when developing HSC and attempt to reduce WBV and RS wherever possible.

A.3.3 SHOCK MITIGATION

The amount of shock mitigation required for a particular craft is dependant on the purpose/mission of the HSC. For example, a craft that must maintain a high level of speed in all sea state conditions will have a different (i.e. greater) mitigation requirement than a craft that only needs high speed in very minimal sea state conditions. In addition, a craft that is used infrequently and with different operators (e.g. Search & Rescue craft) will have different crew lifetime exposure values than a craft that is used frequently with the same operators (i.e. US Special Operations Craft).

[28] Data courtesy of QinetiQ Centre for Human Sciences, 2007

[29] Dobbins, T & Myers, S 2008

[30] European Union Directive (2002/44/EC) on the health and safety requirements regarding the exposure of workers to the risks arising from physical agents.

A.3.3.2 The desired shock mitigation can be incorporated into the design of the HSC. It is suggested that the S&V should be mitigated/reduced close to the source. However, the purpose/mission of the craft may dictate design criteria to which shock mitigation may not be feasible. For example, if the purpose of the HSC is pleasure, then less emphasis 'may' be placed on hull design in lieu of a more aesthetic hull shape. This would put more emphasis on other mitigating techniques. For military applications, hull form may be the most emphasised mitigating technique with moderate emphasis on other techniques. Therefore the following technological solutions may be considered in the following order:

a Hull (mono vs. multi-hull, dead rise angle).

b Ride control (e.g. Maritime Dynamics (USA)).

c Suspended deck (e.g. SeaActive (UK)

d Suspension seats (Refer to Figure A-7a and A-7b).

i Passive suspension

a. Full seat (e.g. RNLI/Frazer-Nash (UK), Ullman Dynamics (Sweden), Stidd/Taylor (US), FB Design (Italy), Shockwave (Canada)).

b. Straddle seat (e.g. Ullman Dynamics (SWE), Shockwave (Canada), FB Design (Italy)).

ii Semi-active suspension (e.g. ActiveShock Inc. (US)).

Figure A-7a Examples of 'Commercial Off The Shelf' 'full seating' suspension seats
NOTE: This is not a comprehensive list of HSC suspension seats.

RNLI-FNC Suspension Seat
Image copyright: RNLI

ActiveShock Inc Semi-Active Suspension Seat
Image copyright: US Navy

Ullman Dynamics 'Atlantic' Suspension Seat

Figure A-7b Examples of 'Commercial Off The Shelf' 'straddle style' suspension seats and standing bolster.
NOTE: This is not a comprehensive list of HSC suspension seats.

Ullman Dynamics 'Biscaya' Seat

FB Design 'Techno Moto' Seat

Shockwave Jockey Seat

STIDD 870V53 Advanced SM Bolster

A.3.4 HSC SEATS & WORKSTATIONS

A.3.4.1 The following seat support issues should be considered:

a **Lateral stability;** anecdotally, HSC crews often describe having lateral support as giving them a feeling of security. This support has the potential, if inappropriately designed, to enhance the risk of injury, particularly to the neck. Figure A-7 demonstrates how the spine bends in response to a lateral acceleration when supported around the upper torso or shoulders, and at the hips. Note the following characteristics:

i *Torso/shoulder lateral support* **–** the torso remains stationary leaving the neck to bend sharply thus putting stress on the vertebrae, disks and supporting structures.

ii *Hip lateral support* **–** the spine bends along its length distributing the bending stress through its structure, thus leaving the weaker and more vulnerable neck structure in its normal alignment.

b **Seat cushion shock amplification effect;** HSC Designers should be aware that soft comfortable seat cushions have the potential to amplify the magnitude of an impact. A soft cushion can rapidly compress and 'bottom out' in response to a severe shock as the air inside it is pushed aside and the foam matrix collapses[31]. This can result in an effectively rigid surface providing minimal protection to the seat occupant. For lower magnitudes of vibration, foam cushions will act as mechanical filters, reducing vibrations at higher frequencies, perhaps over 20 Hz, but amplifying some lower frequencies. The foam material, thickness, contouring and covering material will all affect the response of a cushion.

c **Foot straps;** These can provide an added feeling of security, reducing the risk of being displaced from the seat/HSC. But, foot-straps can also be a 'trip hazard' when moving around the HSC. A further issue relates to the optimal location of foot-straps as these are often difficult to locate them so that they are comfortable for both tall and short crew members and whilst both sitting, leaning and standing.

d **Restraint systems;** Restraint systems can be required to restrict the movement of the occupants. In all-weather lifeboats restraints may be used to keep the occupants in their seats as the boat capsizes and self-rights, stopping them from being injured by falling our of the seats. Restraints also help to keep the occupant in contact with the seat, thus reducing the risk or magnitude of seat cushion shock amplification.

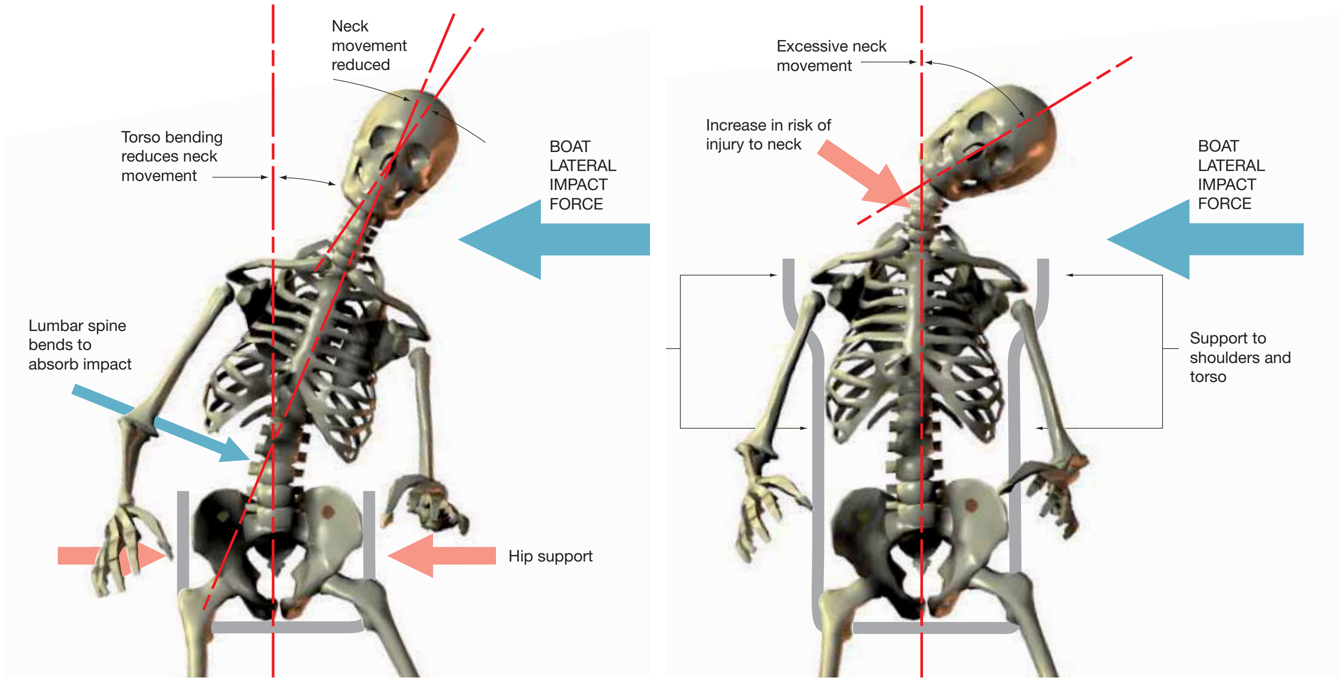

Figure A-7 A graphical example of the effect of HSC seat lateral support on spine deflection.
NOTE: this is a simplified diagram of the complex musculoskeletal responses. *Source;* Johan Ullman and Trevor Dobbins

A.3.4.2 HSC workstation design

The design should consider the following issues[32], but with the appreciation that HSC motion often leads to unreliability and failure in adjustable equipment.

a The critical dimensional factors of the seated crewmember workstation include:

i the correct eye position relative to sights, displays and any other visual requirements.

ii an adjustable seat height, the seat base, backrest depth and breadth, along with the squab and backrest angles to provide correct postural support.

iii clearance for the lower limbs, including space for entry and exit.

iv hand and/or foot reach requirements for operating controls.

v a common eye height for large and small operators, achieved by adjusting the seat.

[31] Hilyard, N.C. (1982) *Mechanics of cellular plastics*, Chapters 1, 2B and 4. Applied Science Publishers, London.

[32] Adapted from DSTAN 00-25 Part 19 Section 4 Workspace Design.

b Restraints and Harnesses. The following issues should be considered:

i Most shock mitigating seats are optimised to treat the occupant and seat as a single unit. Lap-belt type restraints secure the occupant to the seat cushion, providing the greatest benefit from the suspension unit, and reducing the probability of injuries resulting from secondary impacts, i.e. buttocks impacting the seat or occupant impacting the seat or consol in front of him (refer to Section A.e.4.1).

ii Whilst the use of lap belts is now more widely accepted by the HSC community, the use of shoulder harnesses is less accepted. This is due to the concern that if the upper torso is restrained, lateral forces will primarily act upon the upper cervical spine, resulting in a considerably worse injury. Refer to Figure A-8 for examples of suspension seats fitted with restraints.

iii All restraints shall be fully adjustable to accommodate the full anthropometric range of users dressed in the maximum and minimum bulk of clothing.

iv All restraints shall be capable of being stowed when not in use.

v Restraints shall be designed with a quick release and fastening mechanism that can be operated and adjusted whilst wearing gloves.

vi The fastening mechanisms on many commercially available restraints are not suitably corrosion resistant for the marine environment. This can result in the restraint being unusable or jamming. Care must be given to select a restraint with an appropriate level of marinisation.

Ullman Dynamics Atlantic Suspension Seat with full restraint harness

Ullman Dynamics Atlantic 'Biscay' Jockey Seat with lap strap

ActiveShock, Inc. Semi-Active Suspension Seat with lap strap

Figure A-8 Examples of HSC suspension seats using full restraint harness and lap strap.

SECTION B

SECTION B
Sight

GOOD EXTERNAL VISIBILITY IS CRUCIAL TO SUPPORTING CREW SITUATION AWARENESS. VISIBILITY ALSO SUPPORTS PASSENGER PERCEPTION OF RIDE COMFORT AND REDUCES SUSCEPTIBILITY TO MOTION SICKNESS. LIGHTING REQUIREMENTS AND THE AVOIDANCE OF GLARE SHOULD ALSO BE ADDRESSED.

B.1 GENERAL

B.1.1 In designing a crewmember work position, the designer must be aware of where the crew-member will (or needs to) be looking to perform their activities, i.e. visibility is task-driven. Are there any other parts of the HSC design that may interfere with the crew members line-of-sight to those visual areas that he needs to attend? Will the crewmember need to attend to more than one visual area – e.g. the coxswain needs good visibility around the HSC for steering purposes, and good visibility of the instrument panel.

B.1.2 In assessing the crewmembers field-of-view, the designer needs to consider whether the crewmember will be seated, or standing, or both, and differences in the crewmembers eye height (i.e. different height of end users), Refer to Figure B-1 for an example of differences in a coxswains view between sitting and standing. Internal lighting is necessary to support the crewmember's tasks, and for safety purposes (e.g. illuminating stairways and internal spaces), whilst not interfering with the crew's night vision capability. The Designer must also consider measures to control outside sources of light, in particular, minimising glare under sunny conditions. Providing a good line-of-sight is essential to maintaining situational awareness and safety.

Figure B-1 Examples of differences in coxswain view between sitting and standing.
Image copyright: Human Sciences & Engineering Ltd

B.2 INPUT TO DESIGN PROCESS

B.2.1 Feasibility Design

Preliminary General Arrangement (Design Step 5): Consider the influence of the design on the coxswain and navigator's external visibility, refer to Figures B-2 for an example of how sight lines can be superimposed on the Designers drawing (the actual coxswains view is shown in Figure B-1). Will the craft's structure and equipment interfere with the crews external view, and if so, in what quadrant (i.e. rear is less likely to cause problems than forward)? To what effect will the hull design (including taking account for a planing craft getting on-step and its planing angle) affect the coxswain's visibility of the sea close to the vessel[1]?

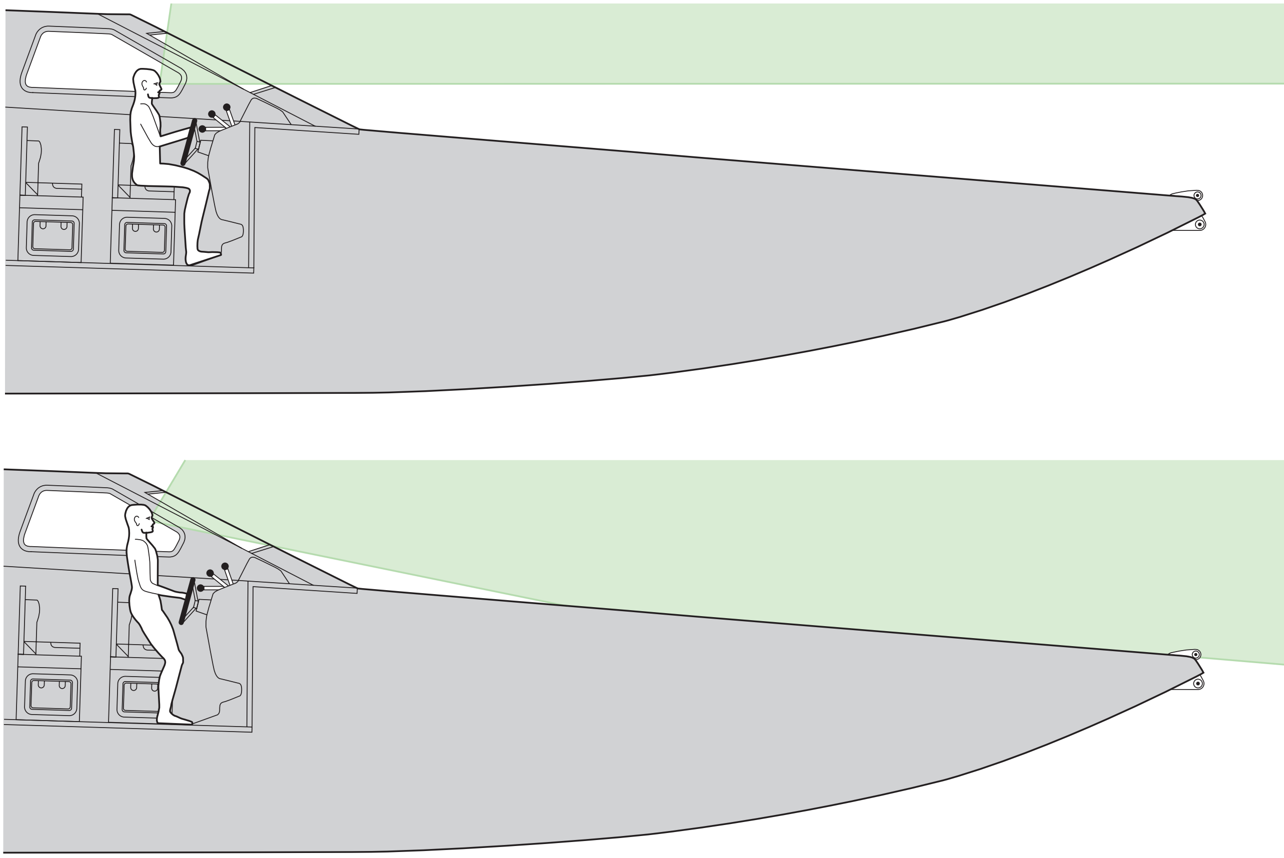

Figure B-2 Examples of the Line of Sight for a sitting and standing coxswain in a closed HSC. Note that Lines of Sight should be maintained for sitting as well as standing, and with the full range of the user population height. ISO 8468 states that the coxswain should be able to see the sea surface one boat length ahead of the bow of the craft.

B.2.2 Main Design

a General Arrangement and Systems (Design Step 12): The following areas need to be considered:

i ***Lines of sight.*** Review whether good external visibility is being maintained for the coxswain and navigator as the design further matures. Will the design restrict the crew's visibility of each other? Consider also that passengers will be more comfortable if they can see the outside sea and horizon, and hence anticipate the craft's motions to allow bracing against Repeated Shock and reduce the risk of motion sickness.

ii ***Window dimensions.*** With closed boat designs, windows need to provide sufficient visibility to accommodate continued visibility of the sea horizon in severe sea states when the HSC bow is pitching down (i.e. check whether the upper and lower edges of the front window are sufficient to maintain good visibility of the sea). The construction of the windows should minimise visual obstruction (e.g. framing between windows) whilst maintaining the required degree of structural strength.

[1] ISO 8468 Ed. 3. (Annex A) recommends the coxswain should be able to view the sea surface at a distance of one craft length (LOA) or less over the bow dead ahead from the helm position.

iii *Lighting scheme.* The Designer should identify those areas where good lighting will be required, e.g. crew workstations. Also the NA should consider the effect of sunlight, i.e. are there areas where the sun, or its reflections in the sea, can cause glare, particularly at crew workstations? At night time, the focus will be on ensuring that sufficient quality light is provided at crew workstations (e.g. for chart reading), whilst retaining the ability to retain crew night vision adaptation. HSC surfaces and finishes should be selected to minimise any reflection. Displays should be capable of being dimmed to retain night-vision adaptation, and if required to allow operation with night-vision devices (e.g. Figure B-3).

Figure B-3 Example of a Coxswain using a night vision device for operating a HSC at night.
Image copyright: US Navy

B.2.3 End Design

a *General lighting.* Detailed selection and location of lighting sources needs to be considered, together with the crew requirements for control (e.g. dimmer switches) to support the crew activities. Low-level ambient lighting will be needed to allow crew and passengers to safely move through the vessel. Also check lighting is sufficient for areas where hazards have been identified (e.g. stairway illumination, deck for tripping hazards).

b *Glare.* Designers need to identify any remaining potential sources of glare (at this stage, mainly from outside sources, e.g. the sun), and incorporate mitigating measures, e.g. the use of sun shades (refer to Figure B-4).

Figure B-4 Example of an antiglare shade being used on the inside of a HSC window
Image copyright: Human Sciences & Engineering Ltd

c *View (crew line-of-sight).* The full visual line of sight from each crew workstation can be evaluated in full, for example, using CAD modelling with human modelling software (e.g. SAMMIE CAD[2], JACK[3], etc.) for appropriateness against the tasks conducted at the workstation. The crew line of sight for instrument and control consoles can also be assessed for optimal fit with the crew/operator's field-of-view (see Section F).

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION B.3

[2] www.lboro.ac.uk/departments/cd/docs_dandt/research/ergonomics/sammie/home.htm

[3] www.ugsplm.com/en_us/products/tecnomatix/human_performance/jack/index.shtml

B.3 ADDITIONAL INFORMATION

B.3.1 FIELD OF VIEW

B.3.1.1 Generally, important information (e.g. situational awareness) should be positioned in the centre of the crewmember's visual field (within the central 30 degrees of the viewer's horizontal line-of-sight, and from eye height down to 30 degrees of the viewer's vertical line-of-sight). Low priority information should be positioned within the central 60 to 70 degrees of the viewer's horizontal line-of-sign, and within 30 degrees above and 40 degrees below the viewers vertical eye height[1].

B.3.1.2 For the field of view of HSC[2] the operating position should be suitably located to allow a view all around the horizon for navigation and manoeuvring. The total arc of blind sectors from dead ahead to 22.5° abaft the beam on either side shall not exceed 20°, seen from a seated position at the workstation for navigation and manoeuvring. Each individual blind sector shall not exceed 5°. The clear sector between two blind sectors shall not be less than 10°. Additional guidance can be found in ISO11591[3].

From a seated position at a navigation and manoeuvring workstation it shall be possible:

a to see the bow of the craft.

b to view the sea surface at a distance of one craft length (LOA) or less from the hull over an arc from dead ahead to the beam on each side.

c to observe leading marks (marks in line) astern for accurate track monitoring in congested waters, and

d to observe the distance of the craft's forward and stern part on either side to a wharf from a position at the controls for speed and course, if separate docking workstations are not located in adequate positions.

B.3.1.3 A graphical interpretation of the field-of-view is shown in Figure B-5.

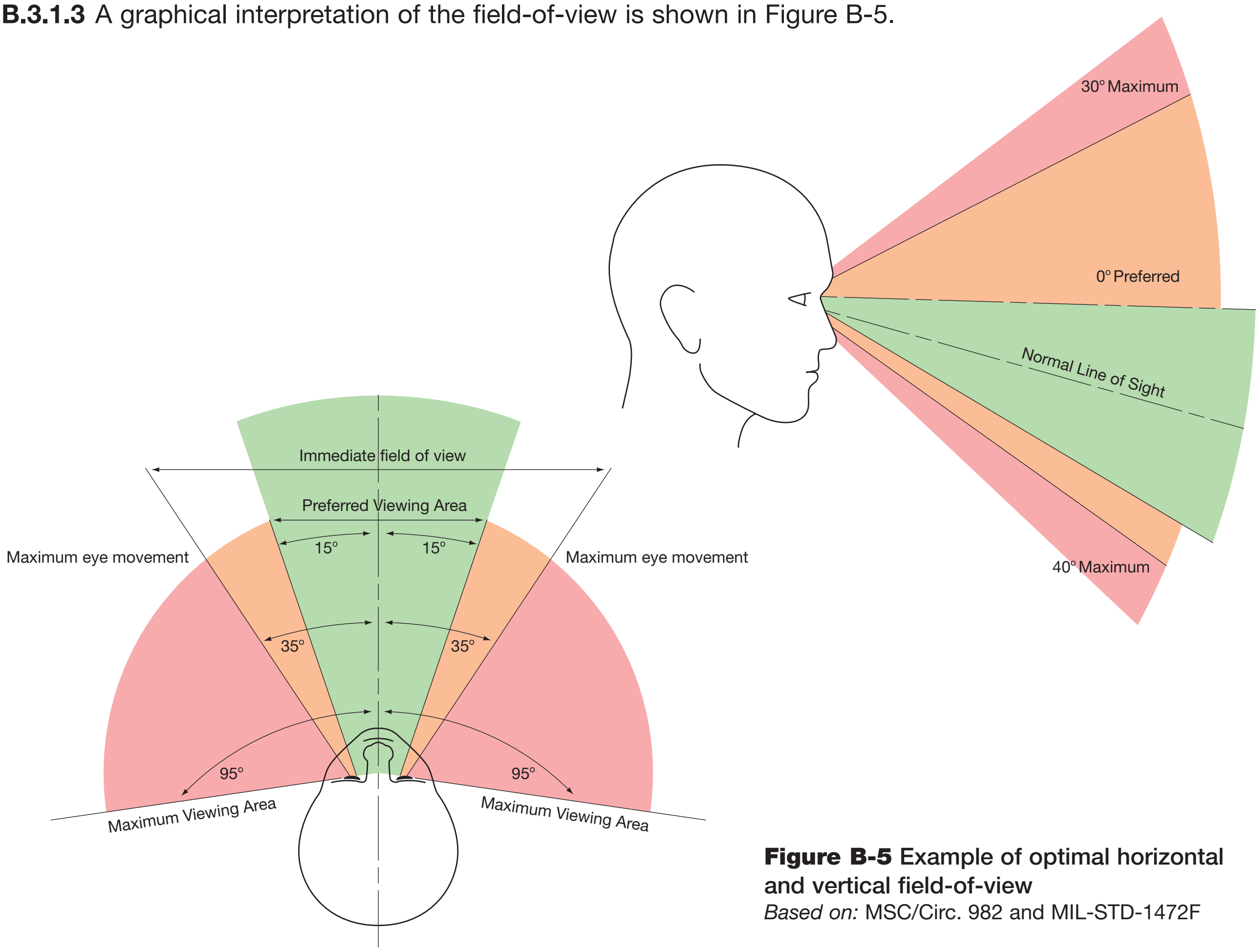

Figure B-5 Example of optimal horizontal and vertical field-of-view
Based on: MSC/Circ. 982 and MIL-STD-1472F

[1] Optimum range for vertical eye height assumes head movement is limited, e.g. through helmet use.

[2] From Annex A of ISO/CDV 8468 Ed. 3. (Draft) Ship's bridge layout and associated equipment — Requirements and guidelines

[3] ISO 11591:2000. Small craft, engine-driven — Field of vision from helm position.

B.3.2 LIGHTING COLOUR[4]

B.3.2.1 The Colour of HSC cockpit/workstation lights should be dictated by the operational Task Analysis (refer to Section 6). When maximum dark adaptation of the crew is not required, low brightness white light (preferably integral and adjustable) should be used; however, when maximum dark adaptation is required, low luminance [0.07-0.35 cd/m2 (0.02-0.10 ft-L)] red light (greater than 620 nm) should be provided. The colour of lighting in turn drives the colour selection of displays and labels. All emergency controls used under only white lighting shall be coloured red. If red lighting is to be used during any portion of a voyage, controls which would have been coded red shall be coded by orange-yellow and black striping and other colour coding shall be kept to a minimum. If night-vision device compatibility is a consideration, the display illumination colour must be low-density blue-green light (incandescent filament through a high-pass filter with a 600-nm cut-off). The colour selected shall provide the operator(s) with the capability to obtain the required display information rapidly and accurately with unaided eye vision or via viewing with the night vision device. The colour selected shall also provide the operator(s) with the ability to obtain the required display information rapidly and accurately during any daylight condition. The lighting shall also be continuously variable to the full OFF position (i.e., in the OFF position, no current should flow through the lamps).

[4] Reference: ASTM 1166B, Section 7.

SECTION C
Sound

EXCESSIVE NOISE CAN PRESENT A HEALTH HAZARD, IN ADDITION TO INTERFERING WITH CREW COMMUNICATIONS.

C.1 GENERAL

C.1.1 In HSC noise sources include the water hull interaction, engine and drive system, wind and communications, (see Figure C-1 for a graphical representation). Excessive noise levels present two risks within HSC. Firstly, they present a health hazard. Secondly, they interfere with crew communications and the use of radio equipment. Noise also presents a nuisance factor, and thereby interferes indirectly with crew performance. Low frequency noise can also have a significant vibration component (see Section A). As a general observation, noise levels will adversely affect communications before they reach a level that poses a health hazard, although this cannot be assumed.

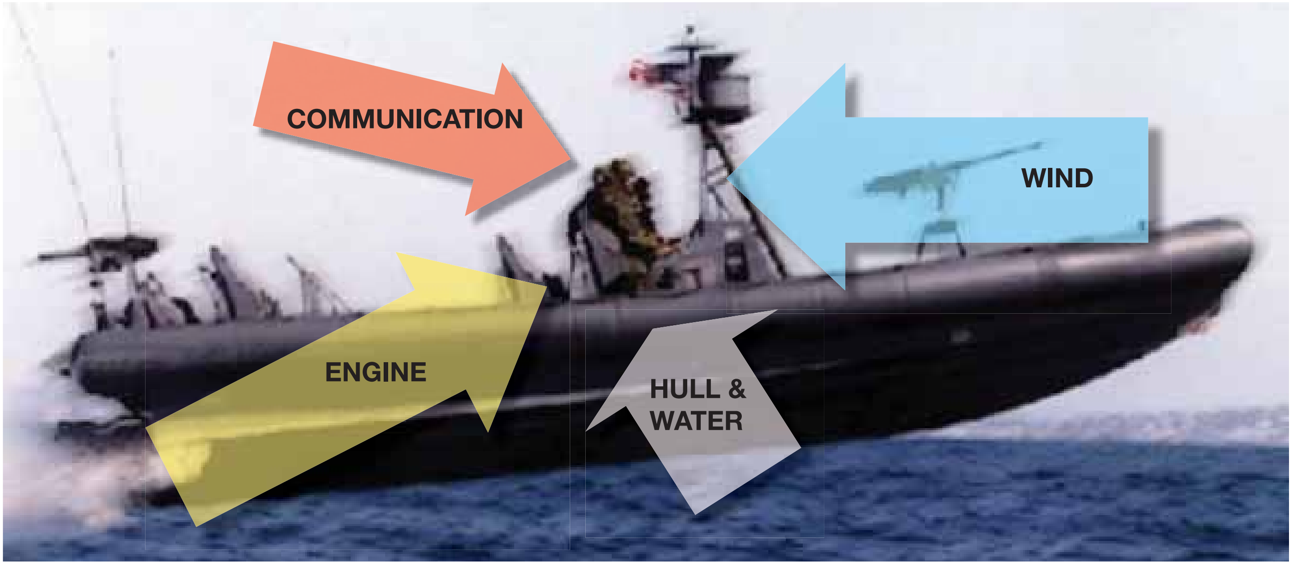

Figure C-1 Diagram illustrating sources of noise exposure acting on the crew and passengers of an open HSC
Image copyright: US Navy

C.1.2 For personnel not using hearing protection, the limit of noise exposure set by the EU Physical Agents Directive[1] and the UK DSTAN[2] is an 8 hour Leq[3] at the operator's ear of 80 dB(A) per continuous 24 hour period. Noise exposure testing should include all noise sources. Exposure to noise should in any case be reduced to the lowest level practicable. Previous noise assessments[4] have shown that noise levels on a RIB, travelling at between 30 and 40 Kts can exceed 85dB(A) in 12 minutes, and 90dB(A) in 36 minutes.

C.1.3 Typical speech levels for a face-to-face conversation in a normal office environment will be approximately 65 dB at a distance of one metre. For background noise levels in excess of 50-55 dB(A), speakers will tend to raise their voice by 5dB for every 10 dB increase in background noise level (i.e. the signal-to-noise ratio will deteriorate with increased background noise). A loud shout has a level of about 85dB at a distance of about one metre.

[1] European Union (EU) Physical Agents (Noise) Directive (2003/10/EC).

[2] DSTAN 00-25 Part 20 Section 7

[3] Equivalent continuous sound level

[4] Holmes, J. and Padden, G. (2001) Noise exposure of Geeko helmet users when travelling in excess of 30 Kts. INM Report No. 2001.023.

C.1.4 Direct assessment of interference by noise on communication can only be conducted using intelligibility tests, but these can be expensive and time consuming. Speech interference by noise is more often estimated using physical measurements suitably weighted (A-weighted) to reflect typical speech frequencies, and where it is assumed that speakers adopt their voice level appropriate to the noise. The four standards most commonly recognised are ISO/TR 3352:1974[5], ANSI S3.14-1977[6], MIL-STD-1474 (Noise Limits) and DSTAN 00-25 Pt-16, Section 6 (Verbal Communication). At a distance of one metre from the speaker, a Speech Interference Level (SIL) of 65dB is the maximum acceptable for ‘just reliable’ communication according to ANSI, whilst ISO set a maximum SIL of 60dB for a ‘conversation in raised voice considered to be satisfactorily intelligible’ at a distance of 0.85 metres from the speaker.

C.1.5 Noise mitigation measures include reducing the noise level at source e.g. through soundproofing (preferable, but this can be problematic if space is limited), hearing protection, and the use of microphones. Hearing protection improves the reception of speech and warning alarms somewhat (in people with normal hearing) by reducing the overall level of sound (speech and noise will be equally reduced at all frequencies). However, without training, people naturally tend to speak quieter when wearing hearing protection.

C.1.6 Microphones can be employed to optimise the sound-to-noise ratio by placing the microphone very close to the mouth and by using a noise-cancelling microphone. Long term root mean squared (r.m.s.) speech levels at 15-20mm from the mouth can easily exceed 100dB without unduly raising the vocal effort. The effectiveness of noise-cancelling microphones is not uniform across the sound spectrum[7]. Noise-cancelling microphones are particularly sensitive to noise generated by wind; anecdotal reports from experienced HSC crews support this. The effect may be partially offset by the use of a foam windshield over the microphone.

C.2 INPUT TO DESIGN PROCESS

C.2.1 Feasibility Design

a ***Preliminary General Arrangement (Design Step 5):*** Choice of closed vs. open boat design will influence communication issues; open boat designs will have high background noise levels from machinery and wind; closed-boat design will need to consider potential communication issues between crew in cabin and crew on the outside deck. Identify the major sources of noise on the HSC (e.g. engines) and estimate whether the noise levels are likely to interfere with communication (e.g. by measuring noise levels at ear level on HSC with similar engines). If so, consider noise mitigation options (e.g. engine baffling, noise insulation) and include estimates for additional weight and space.

C.2.2 Main Design

a ***General Arrangement and Systems (Design Step 12):*** Incorporate noise mitigation measures into HSC design, ensuring noise transmission/vibration issues are avoided.

C.2.3 End Design

a ***Interior Layout Details (Design Step 16):*** Include design for any communication systems, ensuring system provides good coverage of all crew working areas. Check that the communications system will support all crew/passenger activities including seamanship tasks (refer to the *crew and passenger activity* description conducted as part of the specification – see Section 6) and that it integrates with all of the clothing/equipment worn by the operators.

[5] ISO/TR 3352:1974. Acoustics – Assessment of noise with respect to its effect on the intelligibility of speech.

[6] ANSI S3.14-1977: For Rating Noise with Respect to Speech Interference.

[7] DSTAN 00-25 Pt-16, Section 6 (Verbal Communication).

SECTION D
Environment

EXTREME ENVIRONMENTAL CONDITIONS DEMAND CLOTHING AND PERSONAL PROTECTIVE EQUIPMENT THAT CAN MAINTAIN HUMAN PERFORMANCE AND SAFETY. LESS SEVERE ENVIRONMENTS CAN ALSO HAVE DETRIMENTAL EFFECTS IF THEY CAUSE DISCOMFORT.

D.1 GENERAL

D.1.1 The environment, and protection from it, has the potential to affect crew activities both directly (e.g. getting wet in an open boat, foul weather clothing interfering with crew visibility and mobility) and indirectly (e.g. operator discomfort can adversely affect level of attention, fatigue, and motivation).

D.1.2 Adverse weather conditions require the crew and passengers to wear clothing (including gloves) that can interfere with the performance of an activity. Conversely, bright sunlight conditions can lead to discomfort glare[1] (see Section B.2.3.b) and the potential for heat stress and heat illness. Cold stress from a combination of low temperatures (e.g. Figure D-1) and high wind velocity (open HSC routinely travel at >40kts/75km/h) is a serious risk; see Section D.3.1 for a guide to the interpretation of wind-chill factor[2].

Figure D-1 Example of RIB operating in freezing conditions
Image source: www.earth.ox.ac.uk/~helenj/at_sea.html

D.1.3 The comfortable range of temperature for accomplishing light work while dressed appropriately for the season or climate is 21 to 27 degrees Centigrade in a warm climate or during the summer, and 18 to 24 degrees Centigrade in a colder climate or during the winter.[3]

D.1.4 Where possible humidity should be maintained at between 20% and 60%, and preferably within the range 40% to 45%. It is recognized that this is impossible for some designs of HSC (e.g. open RIBs).

D.1.5 Any air-conditioning or mechanical ventilation system to regulate temperature and humidity should be adjustable to maintain the temperature and humidity in the range shown above in D.1.3 and D.1.4. Air conditioning systems should be designed to ensure cold air discharge is not directed at personnel (e.g. crew workstations). The preferred air velocity for ventilating systems is 0.3 m/s, and the maximum air velocity should not exceed 0.5 m/s.

D.1.6 Exposure to fumes (e.g. diesel) increase the crew and passengers susceptibility to motion sickness and general nausea, and therefore should be avoided.

[1] Anshel, J. (2005) *Visual Ergonomics Handbook*, CRC Press.

[2] Refer to DSTAN 00-25 Part 20 Section 6 for a discussion of temperature issues.

[3] Refer to ISO MSC/Circ. 982 Section 5.2 Work Environment for further details.

D.2 INPUT TO DESIGN PROCESS

D.2.1 Feasibility Design

a *Preliminary General Arrangement (Design Step 5):* Identify machinery requirements to support optimal environmental conditions (e.g. heating, ventilation) and include these items within preliminary weights. Include allowance within crew and passenger spaces for machinery.

D.2.2 Main Design

a *General Arrangement and Systems (Design Step 12):* The following areas need to be considered:

i ***Temperature and ventilation.*** Design of crew and passenger work positions should take account of heating, cooling, and ventilation requirements, including the location of major components. Installation of ventilation facilities needs to consider cooling requirements (e.g. will machinery generate significant amounts of heat?) and ventilation to prevent the build-up of diesel (and other) fumes.

ii ***Shade from the sun.*** For an open HSC, the Designer should include features (e.g. Bimini cover) to protect the crew and passengers from the direct rays of the sun (both against ultraviolet rays and excess heating from infrared rays) and prevent direct glare from sunlight.

iii ***Potential noise reduction.*** Noise mitigation measures (e.g. engine baffling, noise insulation) should be incorporated into the design, ensuring noise transmission/vibration issues are avoided (see Section C.2 for further details).

iv ***Storage for Environmental Protective Clothing.*** If the operation or design of a HSC dictates that operators must occasionally wear cold weather clothing, chemical protective clothing, etc. then the craft designer is obligated to account for where these items are stored when not in use. When designing for storage; frequency of use, criticality, and speed with which items must be accessed should all be considered. In other words, if an operator has seconds to DONN a chemical protective outer garment, do not make him have to leave is duty station to find it.

D.2.3 End Design

a *Interior Layout Details (Design Step 16):* The following areas need to be considered:

i ***Noise protection.*** Ensure noise levels are below the maximum permitted exposure levels in the main work areas, and that areas where noise level exceeds permitted level are well signposted (see Section C.2 for further information).

ii ***Temperature and humidity.*** Both global and local controls need to be provided to enable personnel to maintain a comfortable temperature, and to ensure that air currents from ventilation systems do not interfere with crew activities.

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION D.3

D.3 ADDITIONAL INFORMATION

D.3.1 CALCULATION OF COLD STRESS (Wind Chill Factor)

D.3.1.1 The most serious risks associated with cold stress are frost-bite and hypothermia. Frost-bite occurs when flesh is exposed to sub-zero temperature. Hypothermia is a fall in body temperature. Suitable clothing and appropriate space heating should be capable of preventing either of these conditions. The cooling power of an environment is commonly expressed in the Wind Chill Scale. Table D-1 below provides an indication of the likelihood of frostbite (indicated by the colour, ranging from olive green for low likelihood of frostbite, to brown for *very extreme likelihood*) based upon the air temperature and wind speed. The exact formula for calculating wind chill is available, together with a wind chill calculator, from the Environment Canada, Wind Chill Program[1]. Note: The wind chill formula does not take into account the effects of humidity or precipitation (e.g. sea spray) that would increase the rate of heat loss, and hence increase the windchill factor value.

Wind Speed		Air Temp(°C)					
Knots	(km/h)	5	0	-5	-10	-15	-20
2.7	5	4	-2	-7	-13	-19	-24
5.4	10	3	-3	-9	-15	-21	-27
8.1	15	2	-4	-11	-17	-23	-29
10.8	20	1	-5	-12	-18	-24	-30
13.5	25	1	-6	-12	-19	-25	-32
16.2	30	0	-6	-13	-20	-26	-33
18.9	35	0	-7	-14	-20	-27	-33
21.6	40	-1	-7	-14	-21	-27	-34
24.3	45	-1	-8	-15	-21	-28	-35
27.0	50	-1	-8	-15	-22	-29	-35
29.7	55	-2	-8	-15	-22	-29	-36
32.4	60	-2	-9	-16	-23	-30	-36
35.1	65	-2	-9	-16	-23	-30	-37
37.8	70	-2	-9	-16	-23	-30	-37
40.5	75	-3	-10	-17	-24	-31	-38
43.2	80	-3	-10	-17	-24	-31	-38

Table D-1 Wind Chill Chart[2]

D.3.1.2 For example: an open RIB traveling at 40kts/75km/h, in a still air temperature of 5°C will result in a wind-chill of -17°C. If the sea is rough and the occupants are wet the risk of cold injury will be further increased.

[1] Environment Canada's Wind Chill Program, including wind chill calculator, is available at http://www.msc.ec.gc.ca/education/windchill/charts_tables_e.cfm

[2] Chart taken from http://www.msc.ec.gc.ca/education/windchill/windchill_chart_e.cfm

D.3.2 PERSONAL PROTECTIVE EQUIPMENT

D.3.2.1 The designer of the HSC should take account of the requirements of the crew and passengers when dressed to cope with adverse weather conditions. Examples of the clothing and equipment worn are outlined below.

a Helmet/hat.

b Clothing.

  i Waterproof outer layer.

  ii Insulative under layer(s).

c Life jacket.

d Gloves.

e Shoes/boots.

f Eye protection.

g Additional equipment (radio, flare, knife, etc).

D.3.2.2 The wearing of such equipment results in the individuals having reduced mobility and dexterity. The design of the HSC must take this into account (refer to Section F; Man-Machine Interface).

SECTION D

SECTION E
Health & Safety

HEALTH AND SAFETY IS A STATUTORY REQUIREMENT, AND THE DESIGNERS WILL NEED TO DEMONSTRATE COMPLIANCE.

E.1 GENERAL

E.1.1 This section is intended as guidance only, and should be consulted alongside any existing Health & Safety legal and/or contractual requirements, i.e. nothing within this section amends nor precludes any existing Health & Safety obligations.

E.1.2 Specific Health & Safety areas for HSC are covered in legislation and background literature. By designing to 'classification' standards (e.g. Lloyds, DNV, etc.), the NA should address many Health & Safety issues. Specific problems that are not so well addressed include manual handling in confined spaces, trip hazards, and recovery of objects and people from the water.

E.1.3 In general, the key to the management of Health & Safety issues is the early identification of potential hazards. Ideally, the HSC should be designed to avoid these hazards, and where this is not practicable, designed to reduce the incidence and severity of injury.

E.1.4 As a high level checklist of issues, the NA may wish to consider issues such as:

- **a** ***Mechanical safety:*** Are crew and passengers protected from injury against machinery and moving parts?
- **b** ***Electrical and electronic safety:*** Is the risk of electrocution minimised?
- **c** ***Fire protection:*** Are measures in place to minimise fire hazards?
- **d** ***Physical protection:*** Are crew and passengers protected from injury from sharp edges and corners, slipping and tripping hazards, and overhead obstructions? Are the risks associated with the manual handling of loads kept to the lowest reasonably practicable? Injury through manual handling (e.g. back injury), and slips and trips still accounts for a large proportion of total industrial injuries.

E.1.5 The following risks are particularly pertinent to crews of High Speed Craft:[1]

- **a** Risk of capsize of the boat (see Figure E-1)
- **b** Risk of falling overboard both when alongside and in the open sea
- **c** Risk from loosing grip and being thrown against a rigid part of the boat
- **d** Risk of slipping when moving about in the boat and striking a solid part of the boat
- **e** Risk of injury and of being thrown overboard due to the violent movements of the boat
- **f** Risk of head injury from objects falling from above when alongside or from being struck by the lifting hook or striking the head against a solid part of the boat
- **g** Risk of finger/hand entrapment or pinching during hook on and release

[1] Pike, R.D. (2005). *Improving the performance of rescue craft used for rescue and recovery in support of the oil and gas industry.* Health and Safety Executive: Research Report 371.

Figure E-1 RIBs, which are inherently more stable than other high-speed monohulls are still at risk of capsizing in certain conditions.

E.1.6 Measures to counter these risks include the following:

- **a** Waterproof and immersion-proof clothing
- **b** Safety helmet
- **c** Minimise loading on spinal column and joints
- **d** Handholds at crew workstations
- **e** Footstraps correctly sited adjacent to seating
- **f** Non-skid deck covering
- **g** Provision of equipment to assist man-over-board and equipment recovery
- **h** Lifting equipment design to remove or reduce entrapment risks
- **i** Alarms and countermeasures (i.e., automated fire suppressant systems)

E.1.7 Design that addresses Health & Safety issues can form input to the Safety Case.[2]

E.2 INPUT TO DESIGN PROCESS

E.2.1 Feasibility Design

Preliminary General Arrangement (Design Step 5): Assemble any Health & Safety regulations that need to be observed in the construction of the HSC. Identify the main sources of potential hazard to crew and passengers. Incorporate additional space allowance in payload space and other areas where manual handling tasks are anticipated. Incorporate sufficient space allowance on deck for stowage of items. Consider crew and passenger escape and evacuation where appropriate (refer to Figure E-2).

Figure E-2 Example of a submerging HSC demonstrating the need to include escape and evacuation design features as well as ensuring the HSC has the appropriate structural strength.
Image copyright: Tom Newby

[2] UK MOD JSP 430, Ship Safety Management System Handbook; Safety Case definition: "a comprehensive and structured set of safety documentation, which is aimed to ensure that the safety of a specific vessel or equipment can be demonstrated by reference to: safety arrangements and organisation, safety analyses, compliance with standards and best current practice, acceptance tests, audits, inspections, feedback, provision made for safe use including emergency arrangements".

E.2.2 Main Design

a ***General Arrangement and Systems (Design Step 12):*** Ensure all major (system) components are designed in compliance with regulations. Decking surfaces should be non-slip and quick-draining[3]. Design headroom[4] and doorways to minimise overhead obstructions. Design stowage areas around large and awkward items.

E.2.3 End Design

a ***Interior Layout Details (Design Step 16):*** Exclude, guard or pad all sharp edges and corners. Ensure all hazards are clearly marked. Provide hand and grab rails (refer to Figure E-3) to enable personnel to maintain their postural stability, and if required, move more safely in bad weather.

b ***Detail design (Design Step 17):*** Alarm and warning signals are often used to denote non-normal or emergency situations. For HSC it is important to consider the noise environment when selecting an audio alarm solution, and provide a redundant, easily recognized visual alarm. Very specific guidance on incorporating alarms into craft design is available in Section 7 of ASTM 11665.

Figure E-3 Example of hand holds (shown in yellow) used to help HSC occupants to maintain their postural stability
Image copyright: FB Design

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION E.3

[3] ISO 11812:2001. Small craft – watertight cockpit and quick-draining cockpits.

[4] Design overhead height to accommodate the standing height of the largest users and the appropriate clearance considering the dynamic environment (refer to Section A). See Annex F for information on body size (anthropometry) advice

[5] ASTM F1166-07 Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities.

SECTION E

E.3 ADDITIONAL INFORMATION

E.3.1 MANUAL HANDLING

E.3.1.1 It is important to consider manual handling (e.g. lifting, handling, etc.) activities, as it relates to between 25 to 30% of all work-related accidents. Also back complaints are a significant cause of time lost at work and are common amongst HSC operators[1].

E.3.1.2 Consider whether two people might be required to conduct manual handling of heavy items, or even whether lifting equipment is required in some instances, e.g. a davit. As a rule of thumb, a weight of up to and including 25kg (for a man) can be carried close to the waist between elbow and knuckle height (the optimum carrying position) with minimal risk[2].

E.3.1.3 Risks from manual handling can come from one of three areas. As a rule of thumb, avoid manual handling tasks that involve the following[3].

a The tasks; do they involve:
- Holding loads away from the body?
- Twisting, stooping, or reaching upwards?
- Large vertical movement?
- Long carrying distances?
- Strenuous pushing or pulling?

b The loads; are they:
- Heavy, bulky or unwieldy?
- Difficult to grasp?

c The working environment; are there:
- Constraints on posture?
- Bumpy, obstructed, or slippery floors?
- Variations in floor level (e.g. steps)?
- Hot/cold/humid conditions?
- Gusts of wind or other strong air movements?
- Poor lighting conditions?
- Restrictions on movement or posture from clothes or personal protective equipment (PPE)?

E.3.1.4 Manual handling tasks on HSC will include throwing items, e.g. ropes for mooring purposes, laying anchor, throwing lines for man-overboard purposes. Lifting tasks will include lifting anchor, retrieving items and people from sea level (e.g. man-overboard recovery).

E.3.1.5 The stability of the “ground” – the inevitable movements of the HSC mean that the operator is much more likely to lose their balance than if performing the same activity on land. Remember the maxim: “one hand on the task [i.e. lifting and handling], one hand on the ship” – wherever possible, design manual handling tasks to be performed one-handed.

E.3.1.6 Manual handling tasks will also take longer to complete due to the motion of the craft, this concept is called ‘Motion Induced Interruptions’ (MII – refer to Section A.1.3) and has in past been predominantly examined with respect to larger displacement ships[4]. This issue should be addressed in the Specification phase[5] of the design as well as in the Detail Design phase.

[1] Smith, G. CASE STUDY; Vertebral wedge fracture after speedboat ‘splash down’. *J Royal Navy Medical Service.* 2007; 93(2):75-7.

Ensign, W., Hodgdon, J., Prusaczyk, W.K., Ahlers, S, Shapiro, D., and Lipton, M. (2000), A survey of self-reported injuries among special boat operators; *Naval Health Research Centre, Tech Report 00-48.*

Carvalhais, A. (2004) Incidence and severity of injury to surf boat operators. *Conference Proceedings 75th SAVIAC Conference,* Virginia Beach, VA. October 2004.

[2] UK Health & Safety Executive *Getting to grips with manual handling: A short guide.* http://www.hse.gov.uk/pubns/indg143.pdf

[3] Adapted from: UK Health & Safety Executive *Getting to grips with manual handling: A short guide*.

[4] Bridger, R.S., Grist, D., Lowten, M., Jones, H., Crossland, P., Evans, M.J. and Pethybridge, R.J. (2002) Motion-Induced-Interuptions to task performance on RV Triton; Statistical and ergonomic aspects. INM Report No. 2002.043

[5] Crossland, P. and Rich, K.J.N.C. (2000) A method for deriving MII criteria. Conference Proceedings, Human Factors in Ship Design and Operation. RINA, London, UK.

E.3.1.7 Cold and damp conditions will significantly reduce (hand) grip strength. Alternatively, if gloves are worn, equipment must be designed with this in mind (e.g. larger grips and handle loops).

E.3.1.8 Keep in mind that a formal manual handling risk assessment will be conducted at some point in design.

E.3.1.9 For further information and guidance, refer to the UK Health & Safety Executive website[6] and the UK Maritime & Coastguard Agency[7].

E.3.2 MANUAL HANDLING: INPUT TO DESIGN PROCESS

E.3.2.1 Feasibility Design

a *Preliminary GA (Design Step 5):* Identify main manual handling tasks (e.g. (un)loading of payload, recovery of man overboard, recovery of HSC) and any lifting equipment requirements (e.g. davits/hoists). Refer to Figures E4 and E-5 for illustrated examples of manual handling issues and requirements.

E.3.2.2 Main Design

a *GA & Systems (Design Step 12):* Design space envelopes around sites of manual handling to allow good accessibility. Incorporate general design features to assist lifting (e.g. design lower deck areas to accommodate man-overboard recovery). Establish position of any lifting equipment (review position with stakeholders/end-users to ensure optimal arrangement).

E.3.2.3 End Design

a *Interior layout details (Design Step 16):* Incorporate handles, grips and other supports into design. Provide good lighting. Ensure passageways and deck space are clear of tripping hazards and obstructions. Incorporate stowage areas for unused items, and deck equipment for good seamanship housekeeping practices (e.g. winches).

SECTION E

Figure E-4 (Above left, above) Examples of typical boat-crew postures required for working on small HSC; the examples shown are the awkward retrieval of Unmanned Underwater Vehicles (UUVs).
Image copyright: US Navy

Figure E-5 (Left) Example of equipment used to improve manual handling; the device shown is the 'Jason's Cradle' which is designed for the recovery of man-overboard victims.
Source: www.landandmarine.co.uk

[6] Health and Safety Executive website http://www.hse.gov.uk

[7] UK Maritime and Coastguard Authority. *Manual Handling and You: Your Safety at Sea*. Booklet available free from the MCGA on request. http://www.mcga.gov.uk

SECTION F
Man-Machine Interface

POOR MAN-MACHINE INTERFACES CAN UNDO THE POSITIVE EFFECTS OF GOOD HSC DESIGN, DE-MOTIVATE WELL-TRAINED OPERATORS, AND INTERFERE WITH THE ATTAINMENT OF OPTIMAL SYSTEM PERFORMANCE.

F.1 GENERAL

F.1.1 Man-Machine Interface (MMI) is concerned with fitting the workspace to suit the operator. Task Analysis is the design driver for MMI development and takes into account both the importance and frequency of use of the displays and controls. Here, it is extended beyond the concern for the fit of controls and displays (e.g. instrumentation) to include the whole layout of the workspace, and hence it inevitably overlaps with Sections B - Sight, C - Sound, F - Habitability, and G - Maintainability. The motion of HSC operating on poor sea conditions exacerbates MMI issues and therefore must be considered at all phases of the design process. An example of where HSC MMI issues have been addressed is shown in Figure F-1.

Figure F-1 An example of HSC Man-Machine Interface design solutions. The RNLI Tamar Class Lifeboat engine throttles are operated via finger-tip control; also visible are the trackball and its control buttons to the right of the throttle controls, SIMS display screen, radio microphone and cup-holder.
Image Copyright: RNLI

F.2 INPUT TO DESIGN PROCESS

F.2.1 Feasibility Design

a *Preliminary General Arrangement (Design Step 5):* The following areas need to be considered:

i ***Work space requirements –*** The Designer should consider the high level crew requirements, e.g. the coxswain will need to combine maintaining a good external view with monitoring the instrumentation panel; the navigator may need flat surfaces for conducting chartwork; the maintainer requires good access to servicing areas.

ii ***Crew and passenger space –*** The Designer needs to consider general space requirements for people, i.e. that all crew spaces need to accommodate a certain envelope of space for people to fit. General space envelopes can be used to estimate the area required for seating passengers. See Section F-3 for discussion on using body size (anthropometric) data to approximate height and width clearance requirements for the largest users.

iii ***General control and workstation arrangement –*** Does the proposed layout of the workstations support coordination between crewmembers?

iv ***Payload access requirements –*** Clearance is required around stowage areas to enable the crew to perform lifts in compliance with Health & Safety regulations (e.g. can two-man lifts be accommodated for heavier items).

v ***Maintenance –*** Consideration should be given to undertaking maintenance and repair tasks both along-side and at-sea; these considerations should include easy accessibility, heat protection, the use of captive nuts, etc.

F.2.2 Main Design

a *General Arrangement and Systems (Design Step 12):* The following areas need to be considered:

i ***Control console dimensions –*** Will the crew be able to comfortably reach (e.g. without leaning forward from suspension seats) all critical and frequently used controls? In practice, this will entail designing controls to be within the comfortable reach of the smallest users (refer to Section F.3.1). Also ensure that the height of the console does not interfere with external visibility requirements (refer to Section B).

ii ***Detailed workspace requirements –*** Consider what tasks at each workstation are likely to be the most demanding on workspace requirements. For example; for maintenance tasks, what are the heaviest and bulkiest items that need to be removed; seamanship tasks (e.g. securing the vessel) may require additional space to throw items.

F.2.3 End Design

a *Interior Layout Details (Design Step 16):* The following areas need to be considered:

i ***Console/instrument layouts –*** Consider the following:

- Whether the control and instrument layout is clear.
- Is there a good integration of controls and displays (e.g. grouping of related controls and displays, refer to Section F.3.2.1.3).
- Will the displays need to be increased in size to ensure they are viewable under the anticipated vibration conditions?
- Are gauges and displays designed so that any deviation from normal operation is immediately apparent (e.g. designing so all indicators are at 12 o'clock when operating normally).
- Will controls be suitable for the grosser hand motor-movements experienced on HSC? Hand rest and grasp bars may be necessary to support hand stability.
- See Figure F-2 for an example of a HSC console layout.

ii ***Seating –*** The seating should accommodate the appropriate range of operator sizes (anthropometry), or the operators should be able to adjust the seating/interface (e.g. footrest) to accommodate their particular body size (e.g. raise the seat for taller users) in order to be comfortable, whilst at the same time being appropriate for operating and monitoring the controls and displays (refer to Section A.3.4 – HSC Seats and Workstation).

iii ***Task lighting –*** This needs to be appropriate to the task, i.e. of greater intensity where a finer level of visual acuity is required to perform the task. It also needs to be designed to avoid any lighting issues, e.g. unwanted glare, excessive lighting contrasts between different workspace areas.

iv ***Lighting to accommodate night-vision requirements –*** The Designer will need to provide low-level continuously adjustable lighting to enable the crew to maintain night-vision adaptation. Red lighting should be avoided if night vision systems are to be used. Refer to Section B.3.2 (Lighting Colour) for further information.

v ***Emergency Lighting –*** The Designers needs to include emergency lighting systems in the event of main power failure, capsize, etc.

vi ***Controls using Personal Protective Equipment (PPE) –*** PPE clothing can restrict the operator's reach envelope and freedom of movement. Any design reviews should be conducted to take account of PPE.

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v*ii* ***Controls using gloves –*** Gloves are likely to affect the operator's sensitivity and accordingly his ability to use fine hand-movements and receive tactile feedback. In general, controls must be larger to accommodate both gloved use, this is in addition to the need for larger buttons/controls due to the extreme HSC S&V motion. DSTAN 00-25[1] provides minimal control dimensions for gloved use. The adoption of a design solution should be followed up with a documented user-trial assessment in the appropriate conditions. An example of the difficulty of effectively operating a COTs display controls whilst wearing gloves is shown in Figure F-3.

b ***Detail Design (Design Step 17):*** Seamanship requirements should conform to activities defined in User Requirement Document and System Requirement Document. This may include details of cleat arrangements, tank filling locations, etc.

Figure F-2a An example of a coxswain and navigator workstation showing console/instrument layout.
Image copyright: FB Design

Figure F-2b An example of the difficultly of operating COTS marine displays when using gloves.
Image copyright: Human Sciences & Engineering Ltd

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION F.3

[1] Defence Standard 00-25 Human Factors for designers of systems. Part 19.

F.3 ADDITIONAL INFORMATION

F.3.1 DESIGN OF CREW MEMBER WORKSTATION

F.3.1.1 Crewmember workstation and workspace design principles

F.3.1.1.1 The crewmember workstation envelope must be compatible with the size (anthropometric dimensions) of the operators using the equipment. Dimensions of the larger operators are used for determining clearances and near (i.e. minimum) limits of reach, especially when the seated crewmember has either a seat backrest or other obstruction interfering with the rearward movement of the elbows. Reach dimensions of the small crewmember should be used to determine the far (i.e. maximum) limits of reach, particularly when the crewmember is either standing behind a bench or seated and harnessed to a non-adjustable seat.

F.3.1.1.2 Equipment positioning should therefore be based on the reach limits dictated by both large and small crewmembers. In addition, the effect of clothing (and PPE) which can restrict movement and adds to the clearance requirements must be taken into account.

F.3.1.1.3 It is recommended that all types of layout should be verified in either a three-dimensional, full-size mock-up or computer model, where representative crew members undertake a User-Trial, or man-models representing the extremes of the expected crewmember population can actually be formally tried in the layout (refer to Section I for further details).

F.3.1.2 Considerations in designing workstations and workspaces

F.3.1.2.1 *Clearance:* Clearance at various levels is important for:

- Access to and from the workplace
- Ease in grasping and operating controls
- Ease in adjusting location/posture to undertake tasks
- The avoidance of physical discomfort or injury.
- All of these factors may be greatly influenced by seat restraints that the crewmember may need to use, and by the clothing and PPE worn to insure safety and/or to provide life support.

F.3.1.2.2 *Reach:* Dimensions of the larger (95th percentile) operators are used for determining fit and clearance. Horizontal reach dimensions (forward functional reach) of the small (5th percentile) operator wearing minimum clothing should be used to determine the far (i.e. maximum) limits of reach and location of controls etc. See Section F.3.1.5 below for further details. The installation of optical systems shall be such that crewmen can sit and use them whilst retaining a straight posture.

F.3.1.2.3 *Seating:* For both safety and well-being, seats must face the forward direction of travel whilst the HSC is on the move. Seating should be of the appropriate dimensions (this may include an appropriate degree of adjustability) to provide the correct postural support for the full anthropometric range of users (see Section A.3 for further details on crew and passenger seating).

F.3.1.2.4 *Space Envelopes:* Practical workspace envelopes evolve as the HSC design develops. Having applied the key static dimensions in the initial outline design, 3D computer modelling and/or studies are carried out. Then, using representative clothed and equipped operators, assessments are performed on full-scale mock-ups and later on prototypes. The computer-modelling phase is intended to allow design alternatives to be considered and minimises the need for changes to full-scale mock-ups. The prototype assessment has the important role of confirming the workspace envelopes allocated in the earlier design phases and ensuring that unscheduled changes have not subsequently been made.

F.3.1.2.5 Following any earlier outline modelling activities or design studies, formalised User-Trial assessments shall be carried out on full-scale mock-ups of crew compartments and crew stations, using crew and passengers who are representative of the specified user-population of the HSC being designed.

F.3.1.2.6 Prototype assessment checks shall be carried out at appropriate stages to ensure that agreed HF design features and space envelopes are not subjected to unscheduled modification due to other design activities.

F.3.1.2.7 Practical spatial envelopes shall be provided to allow members of the specified user population to occupy, operate and move around in each crew station efficiently under all operational conditions, wearing all specified clothing assemblies.

F.3.1.3 Working Environment

F.3.1.3.1 The control of RS and WBV, noise, light, thermal radiation, pressure etc, should be accomplished at the source, or if this is not possible, at the workplace. For example, proper orientation of a display panel can reduce the effects of glare from an ambient light source. Structural support for a hand or arm can reduce vibration effects and improve the precision of manual control. Independent seat suspension, seat padding and contoured seating can reduce postural stress from repeated shock and vibration, as well as fatigue from long duty periods in confined quarters.

F.3.1.3.2 The final version of a workspace layout within an overall crew station design must be checked by carrying out an HF assessment using a full scale mock-up and a representative range of crewmen, i.e. a formalised User-Trial (refer to Section I for further details).

F.3.1.4 Compatibility of Clothing Bulk with Other Equipment

F.3.1.4.1 Gloves may affect dextrous tasks involving the operation of keypads, panels, controls and alphanumeric keyboards. Clearances around, and access to, equipment including hand and foot controls shall accommodate specified bulky clothing items worn such as gloves and boots. The design shall ensure adequate feedback to the operator to enable him to perform his tasks efficiently when wearing the specified hand and footwear.

F.3.1.4.2 The need for bulky clothing can be reduced if heating is provided at the work position, but this inevitably involves trade-offs (e.g. greater expense); in addition, operators will resort to bulkier clothing in the event that the heating system fails.

F.3.1.5 Example of Operator Reach Envelope

F.3.1.5.1 The critical relative dimensions for work carried out on horizontal desks and workstations are below shown in Figure F-4. The figure should be considered as guidance only of the typical sizes and considerations for a workstation. Amendments will probably be required for specific applications. Frequent crewmember tasks should be conducted within the normal area, defined as the area that can be conveniently reached with a sweep of the forearm, the upper arm hinging in a natural position at the side of the body (i.e. with the elbow bent). To accommodate the smallest user, ISO 8468[1] suggests locating controls within 350mm to 500mm from the shoulder joint. Infrequent crewmember tasks can be conducted within the maximum area, defined as the area that could be reached by extending the arm from the shoulder. To be within the reach of the smallest user, ISO8468 suggests controls should be located no further than 670mm from the shoulder joint.

[1] ISO 8468 Ship's bridge layout and associated equipment – requirements and guidelines.

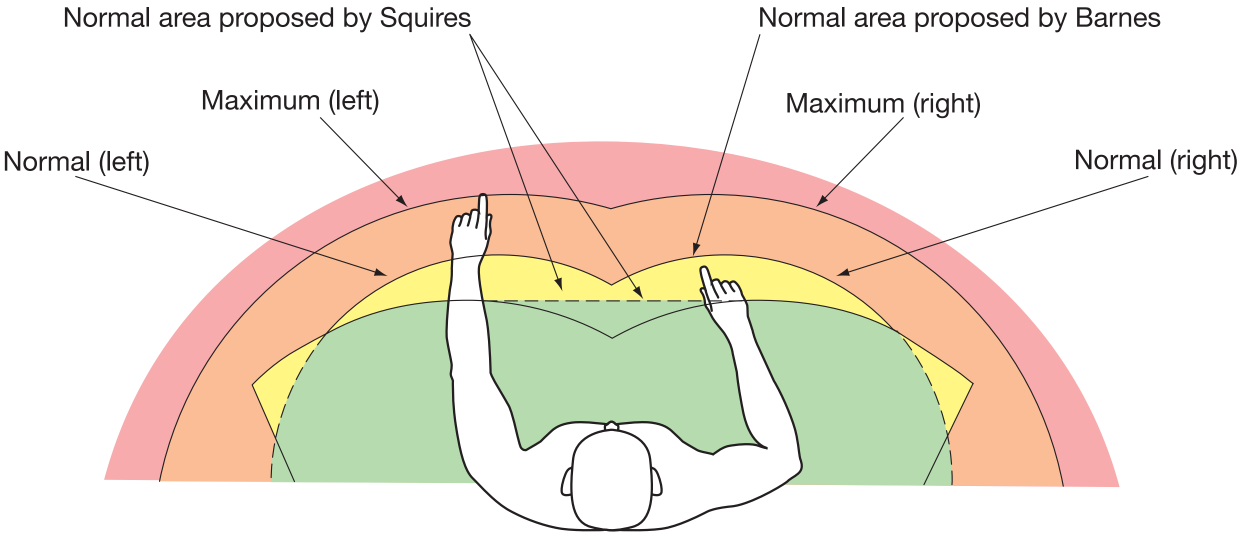

Figure F-4 Effective Reach Parameters[2]

F.3.1.5.2 Workplace layout should accommodate a range from at least the 5th to 95th percentile[3] of the user population. Further examples of workstation layout and dimensions for military users are provided in Section 4.3.1.22 of DSTAN 00-25 Part 19, whilst examples of commercial bridge shipping workstations are provided in ISO8468[4].

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F.3.1.6 Considerations for closed boat designs

F.3.1.6.1 The clear ceiling height should be designed to include allowance for the installation of overhead panels and devices. The IMO Maritime Safety Committee Circular 982 (MSC/circ. 982) suggests a minimum clear height of 2.1 metres between the deck surface covering and the lower edge of any overhead mounted equipment in open areas, passageways and at standing workstations. An additional headroom allowance will be required, as crew and passengers will become airborne during the dynamic motion of the HSC. Also the use of for any headwear worn by the crew and passengers will need to be taken into account.

F.3.1.6.2 All doors should be operable with one hand.

F.3.1.6.3 Portable items, such as safety equipment, tools, lights, pencils, etc. should be stored at appropriate places, specially designed wherever necessary. Refer to Section H (Maintainability) for further information.

F.3.1.7 Control consoles

F.3.1.7.1 Single operator consoles should be sized and configured so that all relevant controls can be reached from a fixed working position (e.g. sitting, standing, or both) typical of those adopted on a HSC. The console should be designed such that from the normal working position the total required left-to-right viewing angle should not exceed 190 degrees, and preferably be reduced whenever possible through appropriate control-display layout. The height of the consoles[5] should not interfere with any external visual tasks (e.g. visibility around the HSC for the coxswain). The console should accommodate sufficient legroom depth[6] for crewmembers, particularly if seated operation is to be accommodated. An example of a HSC console is shown in Figure F-5

F.3.1.7.2 The crew workstation for manual steering should preferably be located on the ship's centre-line. If the workstation for manual steering is located off the centre-line, special steering references for use by day and night should be provided, e.g. sighting marks forward.

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[2] Reproduced from Defence Standard 00-25 Part 19.

[3] The 5th to 95th percentile of the population would not include the smallest 5% and the largest 5% of individuals.

[4] ISO 8468 Ship's bridge layout and associated equipment – requirements and guidelines, BS ISO 8468.

[5] IMO MSC/Circ. 982 suggests a maximum console height of 1200mm.

[6] IMO MSC/Circ. 982 suggests a depth allowance of 450mm for upper legroom, and a lower legroom depth of 600mm.

Figure F-5 An example of HSC crew workstation
Image copyright: Powerboat P1

SECTION F

F.3.2 INSTRUMENTATION

F.3.2.1 Design to support crewmember task requirements

F.3.2.1.1 Instrumentation should directly support the crewmember in the performance of their activities. The following should be remembered:

- Displays should be clear and direct and support the user in any control response.
- Displays should present the simplest information consistent with their function.
- Only necessary and immediately usable information should be displayed.
- Displays should be as uncluttered as possible.
- Highly important and/or frequently used information should be permanently displayed.
- Information on a display should be grouped according to obvious principles, e.g. by crewmember tasks, system function, sequence, etc. based upon the user's requirements in performance of the ongoing tasks. Information groups should be visually distinct, e.g. separated by blanks, lines, colour coding, or other means.
- A digital readout should not be used where the reading changes rapidly.

F.3.2.1.2 Critically important information should be displayed close to the operator's 'normal' line of sight. Similarly, frequently used displays should also be positioned so that they do not require gross movement of the head or eyes, especially if viewing them forces the operator to shift attention from the primary task, e.g. external situational awareness. Where explicit or implicit task sequences exist, information should be presented left-to-right and top-to-bottom or in clockwise rotation. Preferred viewing areas, as illustrated in the Figure F-6, and applied to the design of a HSC in Figure F-7, should be reserved for the most important and frequently used displays.

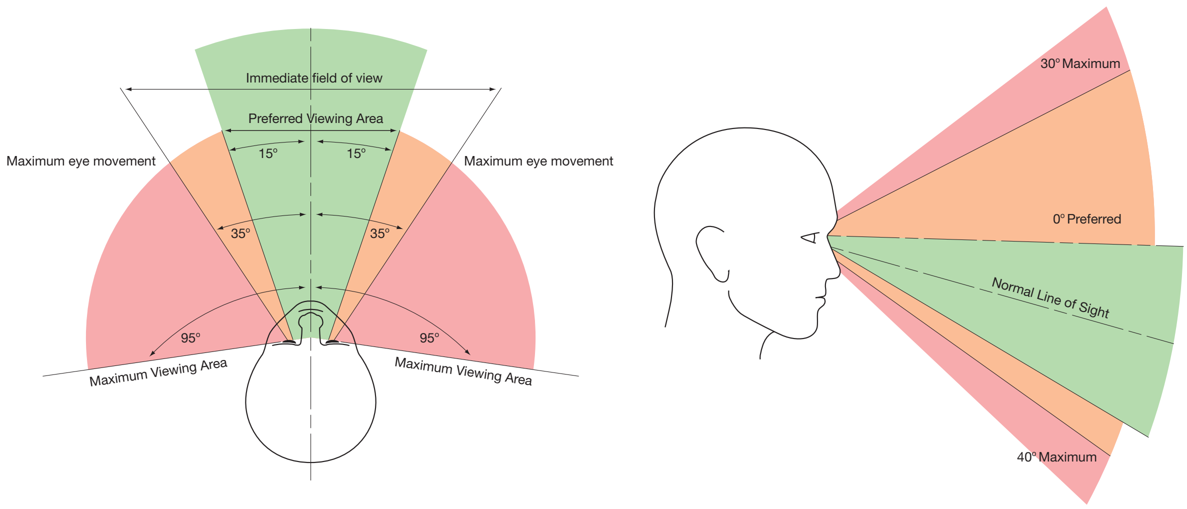

Figure F-6 Example of optimal horizontal and vertical field-of-view
Ref: IMO MSC/Circ. 982 and MIL-STD-1472F

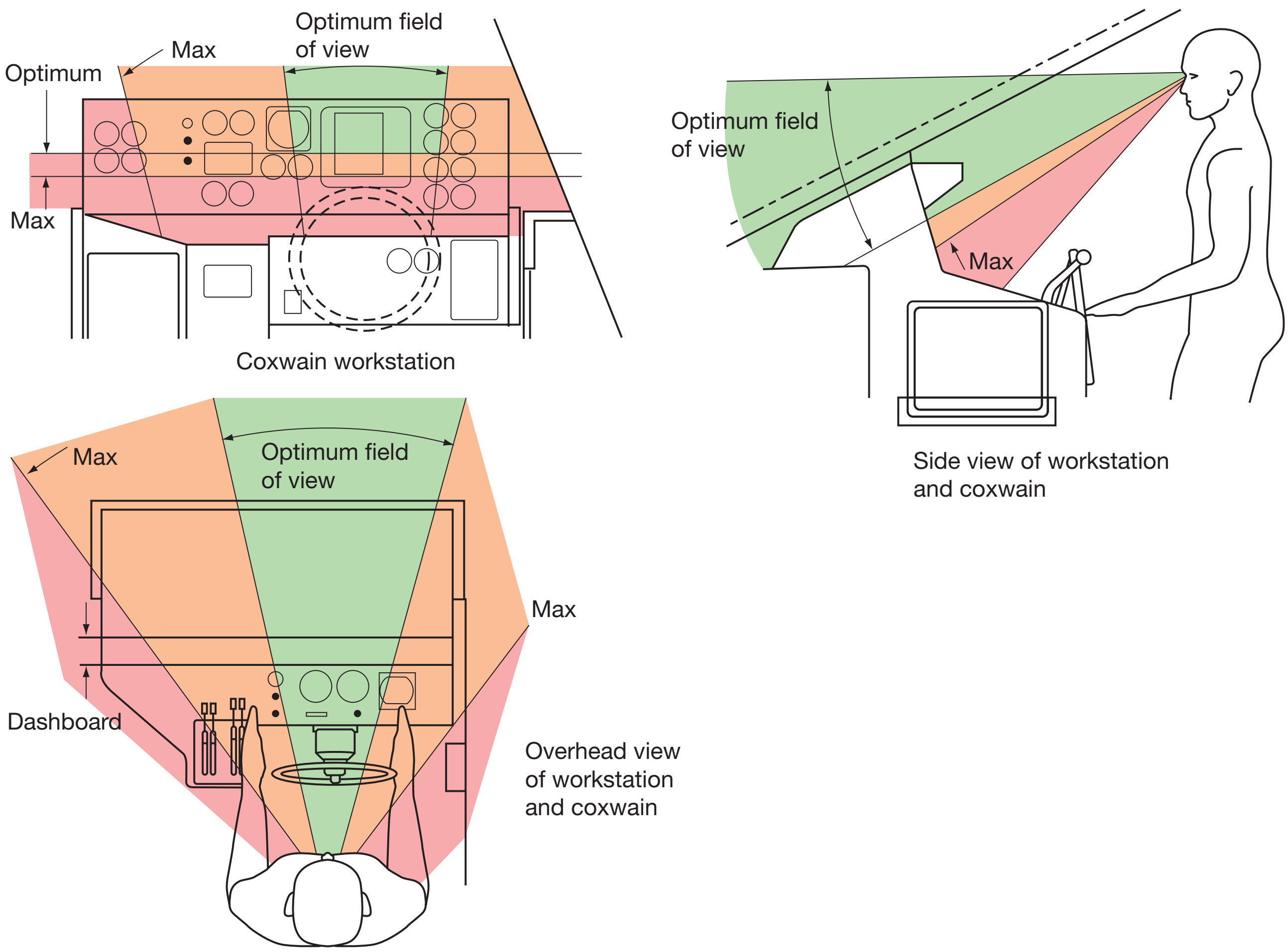

Figure F-7 Example of a HSC workstation assesment to optimise coxswain field-of-view.

F.3.2.1.3 Aircraft instrumentation has been iteratively developed over time to the point where the layouts are now accepted as best practice. The transfer of these layout concepts to HSC has been described[1] and its application will make the HSC instrumentation (and therefore operational status) easier for the crew to interpret, as well as being relatively simple layout to implement. Additional design information is also available from a number of aircraft design guidelines[2]. In general the engine displays are laid out in columns, with individual engine condition parameters arranged in rows to allow for rapid scanning and interpretation (Refer to Figure F-8).

Figure F-8 **An example of multiple engine instruments (twin engine) arranged in columns for easy comparison.**
Image copyright: Human Sciences & Engineering Ltd

F.3.2.1.4 Instrumentation and displays should be provided with lighting to permit them to be legible under all ambient lighting conditions (refer to Section B - Sight).

F.3.2.1.5 Guidance on specific types of hardwired instruments (e.g. counters, dials, gauges) can be found in Section 9 of DSTAN 00-25 Pt-19[3]. This includes a list of questions (Section 9.1.1.2) to assist the designer in understanding the tasks that instrumentation must support. Further support should also be available in the form of the crew Task Analysis documentation that was developed during the Specification Phase (refer to Section 6, Table 6-1, for a description of HSC crew tasks).

F.3.2.2 Control/Display Layout Integration

F.3.2.2.1 The functional grouping, importance and frequency of use, as well as the sequence of operation must all be considered when positioning controls and displays, and in co-locating controls and displays that functionally relate to each other[4].

F.3.2.2.2 The design and layout of controls and displays should ensure that they are operable, readable and understandable to the desired level of functionality over the whole range of possible lighting conditions.

F.3.2.2.3 Controls, displays and vision devices shall be located in front of each crewman in natural positions, with the highest priority devices being allocated prime positions. Controls shall ideally be positioned between elbow and shoulder height. Instrument panels and display screens shall be located at or below sitting eye height. All controls and displays shall be operable when wearing normal clothing or cold weather clothing.

F.3.2.2.4 Coxswain controls and driving displays shall be within easy reach (i.e. without needing to extended arms) and field-of-view of the coxswain – however – this must be considered with respect to the demands of extended duration use (e.g. >8 hours) in rough sea conditions that may result in acute and chronic musculoskeletal injury.

[1] Husick, C. (2000) Designing an Instrument Panel, Professional Boatbuilder, 65, pp 33-37.

[2] ASCC AIR STD 61/113/01G. Numerals and letters for aircrew stations.

ASCC AIR STD 61/116/6D. Human engineering design criteria for the use of aircrew station controls and displays.

ASCC AIR STD 61/116/15H. Location and arrangement of flight and engine parameter displays in aircrew workstations.

ASCC STD 61/116/27. Numbering of engines and their associated controls and displays in aircraft.

[3] UK MOD Defence Standard 00-25 Part 19:Human Engineering domain

[4] Husick, C. (2000) Designing an Instrument Panel, Professional Boatbuilder, 65, pp 33-37.

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F.3.2.3 Alarms

F.3.2.3.1 The manner of presenting alarms should be clear, distinctive, unambiguous and consistent. Alarms should be presented through both visual and, if appropriate, auditory means. The number of alarms should be minimised.

F.3.2.3.2 Visual alarms should clearly be different from routine information, and designed to flash for at least 50% of the cycle with a pulse frequency in the range 0.5Hz to 1.5Hz. Visual alarms should not interfere with crewmember night vision (refer to Section B – for further lighting guidance).

F.3.2.3.3 Audible alarms should be used simultaneously with visual alarms, and should be silenceable upon crew operator acknowledgement. Audible alarm sound pressure, one metre from the source, should be at least 10 dB(A), and preferably 20 dB(A), above ambient noise levels existing during normal operations, whilst not exceeding 115 dB(A) in a closed space. Persistent alarms should be assessed with reference to occupational noise limits.

F.3.2.4 Examples

F.3.2.4.1 RIB coxswain workstation enhancement

F.3.2.4.1.1 The coxswain workstation of the VT Halmatic Arctic RIB was redesigned and optimised using significant input from end-users[5]. The images below demonstrate how a work sharing regime was instigated between the 1st and 2nd coxswains. It can be seen how the number of 1st coxswain instruments have been reduced and moved to the new 2nd coxswain's station. The 2nd coxswain now takes responsibility for navigation, communications and secondary engine monitoring, leaving the coxswain free to concentrate on the control of the craft, refer to Figure F-9. Also note how the coxswain throttle position was relocated to reduce chronic shoulder strain.

Figure F-9 Example of RIB Coxswain Workstation Enhancement
Image copyright: Human Sciences & Engineering Ltd

[5] Dobbins, T., Hill, J. & Chapman, J. (2005) Enhancing rib operational performance through the use of user-focused-design. Conference Proceedings, Rigid Inflatables, Royal Institute of Naval Architects, Cowes, UK.

F.3.2.4.2 RNLI Systems & Information Management System (SIMS)

F.3.2.4.2.1 The crew workstations with the RNLI Tamar class lifeboat are the result of an integrated design process which involved a significant HF input[6]. The crew are provided with information via flat-screens which have been configured so that each specific workstation is optimised to the role of the crew member, e.g. helm, navigation, engineer, etc. An example of how the displays are laid out is shown below in Figure F-10. The Figure identifies the generic features of the SIMS displays.

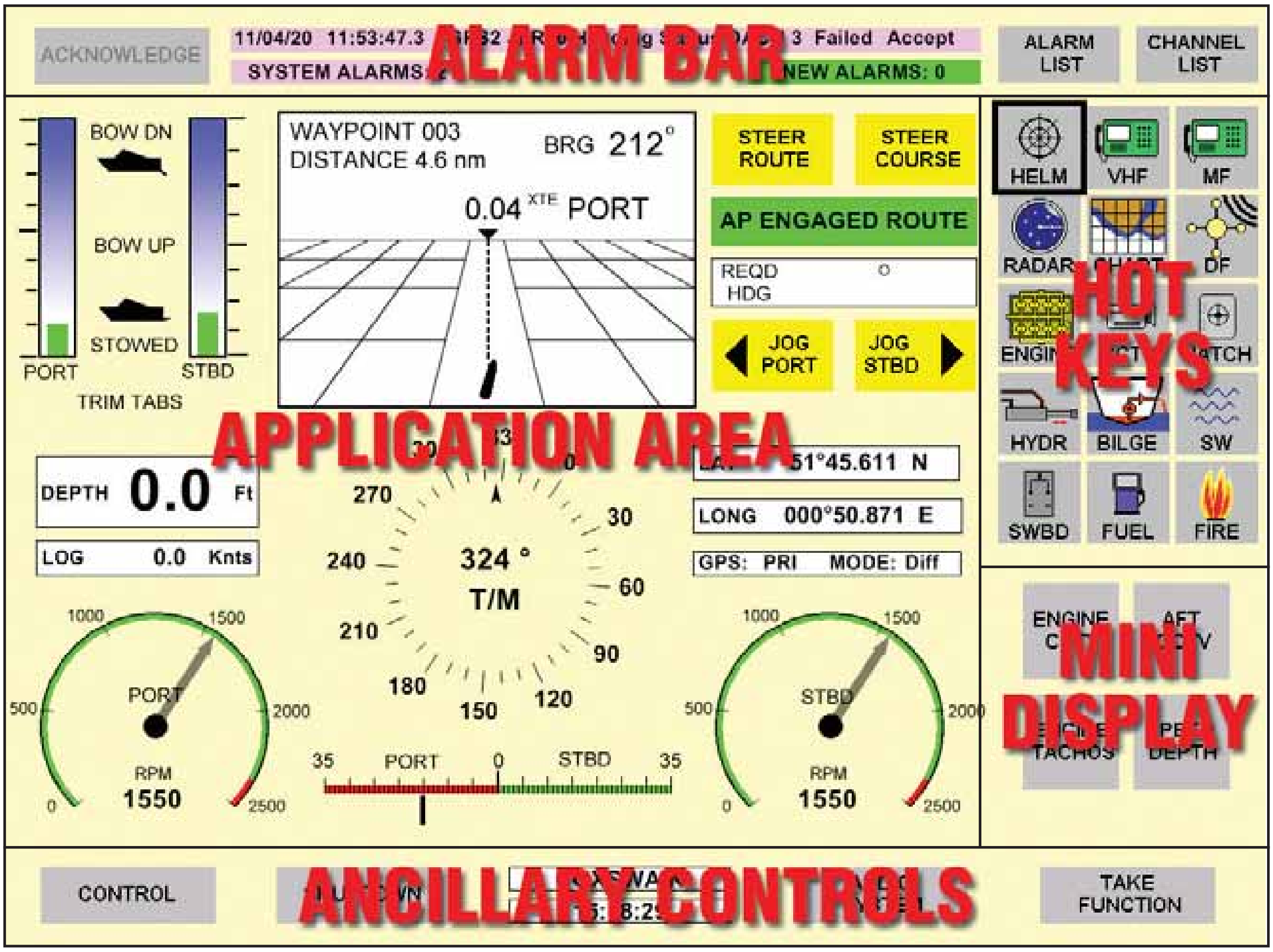


Figure F-10 Coxswain (Helm) information displayed on the RNLI SIMS indicating display areas
Image copyright: RNLI

F.3.2.4.2.2 The SIMS systems has the ability to display a number of specific display screens to the crew. From a number of positions a crew member can have control of the particular craft systems from the screen displayed, in other positions they will only have display for information purposes. Examples of the specific display screens are shown below in Figure F-11.

[6] Nurser, J. and Chaplin, N. (2004) Development of integrated electronic system and human-machine interface in a new class of lifeboat. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

Helm Display

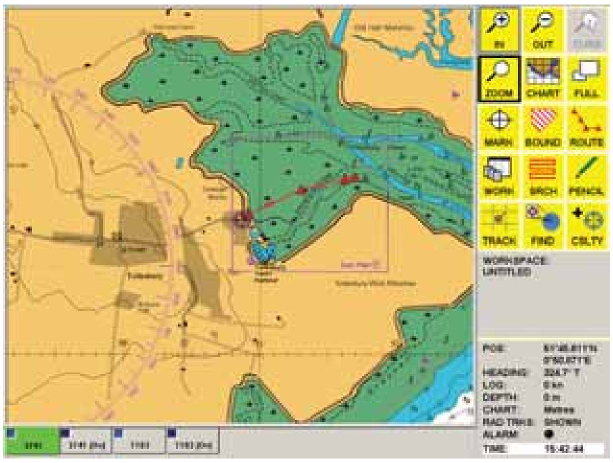
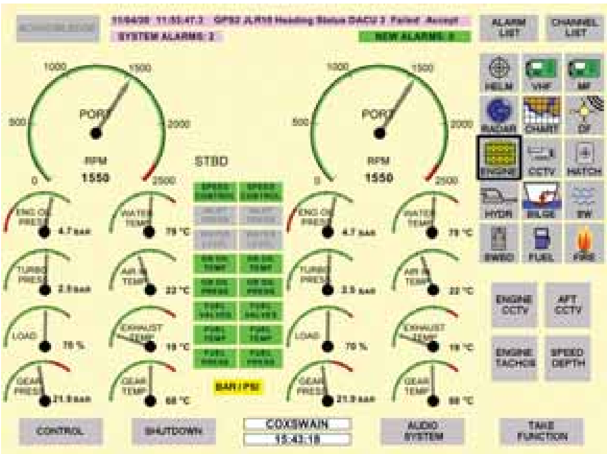
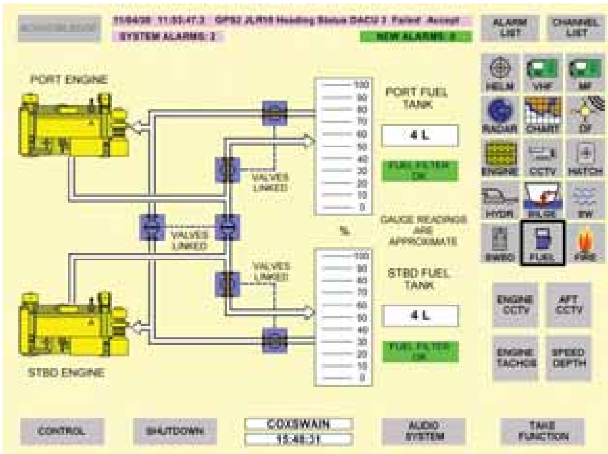


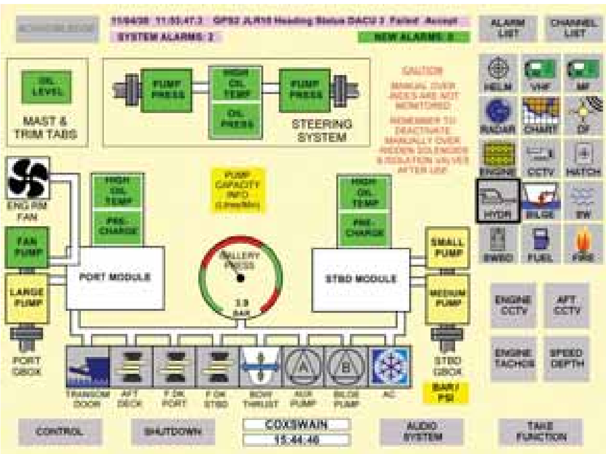
Chart Display



Engine Display



Fuel System



Hydraulic System

VHF Radio Display

Figure F-11 Examples of RNLI SIMS Information Screens

Image copyright: RNLI

F.3.3 CONTROLS

F.3.3.1 Guidance on specific physical control types is provided in Section 7 of DSTAN 00-25 Pt-19[1] where an overview of control types is described in Table 7.2.1, (page 191). Controls should be easy to identify and operate due to the harsh S&V environment they will be operated in.

F.3.3.2 Control hierarchy

F.3.3.2.1 It should be noted that each crew workstation will be developed for a specific application (e.g. coxswain, navigator, etc. Refer to Table 6-1: Examples of High Speed Craft Crew Tasks) and therefore the control layout should be developed for that specific use. Note may also be given to the ability of computerized systems functionality to be transferred between command stations, (e.g. Section F.3.2.4.2: RNLI Systems & Information Management System (SIMS)). The design and location of the craft's controls should be developed using the following hierarchy.

a *Primary:* These are the principal control elements that are needed at a specific workstation, e.g. steering at the coxswain's workstation, chart-plotter control at the navigator's workstation. These will be positioned first and ideally without compromise to other functions

b *Secondary:* These controls should be located subordinate to the Primary controls

c *Tertiary:* These controls should be located subordinate to the Secondary controls

Note: refer to Section F.3.1.5 for information on operator reach envelope and the location of controls.

F.3.3.3 Control Principles

F.3.3.3.1 Related control/display design should adhere to human expectations. Table F-1 below summarises specific compatibility principles that adhere to human expectation and should be referred to when designing controls and respective displays. Controls should provide visual, auditory and/or mechanical feedback to indicate that a controller adjustment has been registered. The controls for the most important and/or frequently used functions should be assigned to only one function (i.e. important functions should have a dedicated control device).

Principle	Description
Principle of location compatibility	Controls should be located to the corresponding display, and their spatial arrangement should allow users to tell easily which control is used for a particular display.
Principle of movement compatibility	The indicator of a display should move in the same direction as its control.
Principle of conceptual compatibility	The layout and the operational methods of controls should be consistent with expectations of the intended user population.
Principle of compatibility of display orientation	For analogue displays, the orientation and ordering of the display should be consistent with those of the mental representation.
Principle of compatibility of display movement	The direction of movement of the moving part of a display should be consistent with user expectation.

Table F-1 Compatibility principles in designing controls and displays[2]

F.3.3.3.2 The most important and frequently used controls should have the most favourable position with respect to ease of reaching and grasping from the user's normal working position (refer to Section F.3.1.5, Figure F-3). Controls should be located so that simultaneous operation of two controls will not necessitate a crossing or interchange of hands. Controls that are operated in association with specific displays shall be positioned to ensure easy operation as a combined activity.

[1] Defence Standard 00-25 Part 19: Human Engineering domain.

[2] Salvendy, G. (1997) Ed. Handbook of Human Factors and Ergonomics. 2nd Ed. Wiley-Interscience Publishers.

F.3.3.3.3 The designer should consider the consequences of accidental and unintended actuation of controls. Whenever possible, immediate remedial control action should be available to the user (i.e. the control effect should be immediately reversible). In addition switches may use some form of guard or covering to stop accidental operation (see figure F-12).

Figure F-12 An example of a guard over switches to stop accidental operation when operating HSC in a harsh motion environment.
Image copyright: FB Design

F.3.3.4 COTS limitations

F.3.3.4.1 It has been articulated by HSC users that COTS displays and controls are often ineffective for use on HSC[3]. In general terms the numerals are too small to be read in a motion environment and the controls (e.g. buttons) are difficult to use due to their small size. Also refer to Section F.2.3.a.vii relating to the operation of controls with gloved hands. It is recognized that designers may only be able to source COTS controls and displays due to time and financial constraints, but they should be aware of the potential limitations they are designing into the craft.

F.3.3.4.2 Many HSC will use COTS equipment to reduce the development and production cost. This equipment, e.g. chart plotter, generally has relatively small buttons for interacting with the systems. In the harsh motion environment experienced by HSC crew this can make operating the equipment effectively very difficult or impossible. A simple solution to this is to provide 'rails' alongside the controls with which to steady the operators hand and allow effective operation of the button(s) and other controls with the thumb. An example of this is shown below in Figure F-13.

Figure F-13 An example of the use of a 'rail' to steady the operators hand when using equipment/switches/trackball in a harsh motion environment.
Image copyright: Human Sciences & Engineering Ltd

F.3.3.5 Control labelling

F.3.3.5.1 Labels must meet the visual requirements of the operator in terms of size, illumination and contrast. It must be possible for the operator to read the legend while performing the task. Labels should be appropriate, brief, clear and unambiguous, and contain the basic information needed. Labels should be

[3] Dobbins, T. (2004) High speed craft design from a human centred perspective. Conference proceedings Royal Institute of Naval Architects; SURV 6: Surveillance, Pilot and Rescue Craft, London.

located either on the controls or adjacent to them, normally above. Labels should be sufficiently close to the control to avoid confusion over which label applies to which control. The selection and use of terminology for labels should be consistent between labels and controls. If shape coding is used, codes should be based on established standards or conventional meanings. When abbreviations or acronyms are used, they should be meaningful, in common usage and kept to a minimum. The units of measurement (e.g. volts, PSI, inches, etc.) should be indicated.

F.3.3.5.2 Colour coding should only be used as a supplement to other coding methods, as colour-blind operators may otherwise be unable to distinguish the displays meaning. Avoid the use of more than five colours. Colours should be clearly distinguishable. Emphasis should be placed on use of red for emergency controls, and sharply contrasting colours (e.g. black and yellow) for critical controls.

F.3.3.6 EXAMPLES

F.3.3.6.1 US Navy MkV Special Operations Craft coxswain throttle and steering system integrated with the Stidd-Taylor V5 suspension seat.

F.3.3.6.1.1 The introduction of the Stidd suspension seat onto the MkV SOC resulted in sub-optimal Man-Machine Interface interaction. To enhance the effectiveness of the coxswains workstation the throttles and steering control was moved from the craft console to arm rests of the suspension seat. An example of the design solution is shown below in Figure F-14, along with the resulting integration of the seat with the controls.

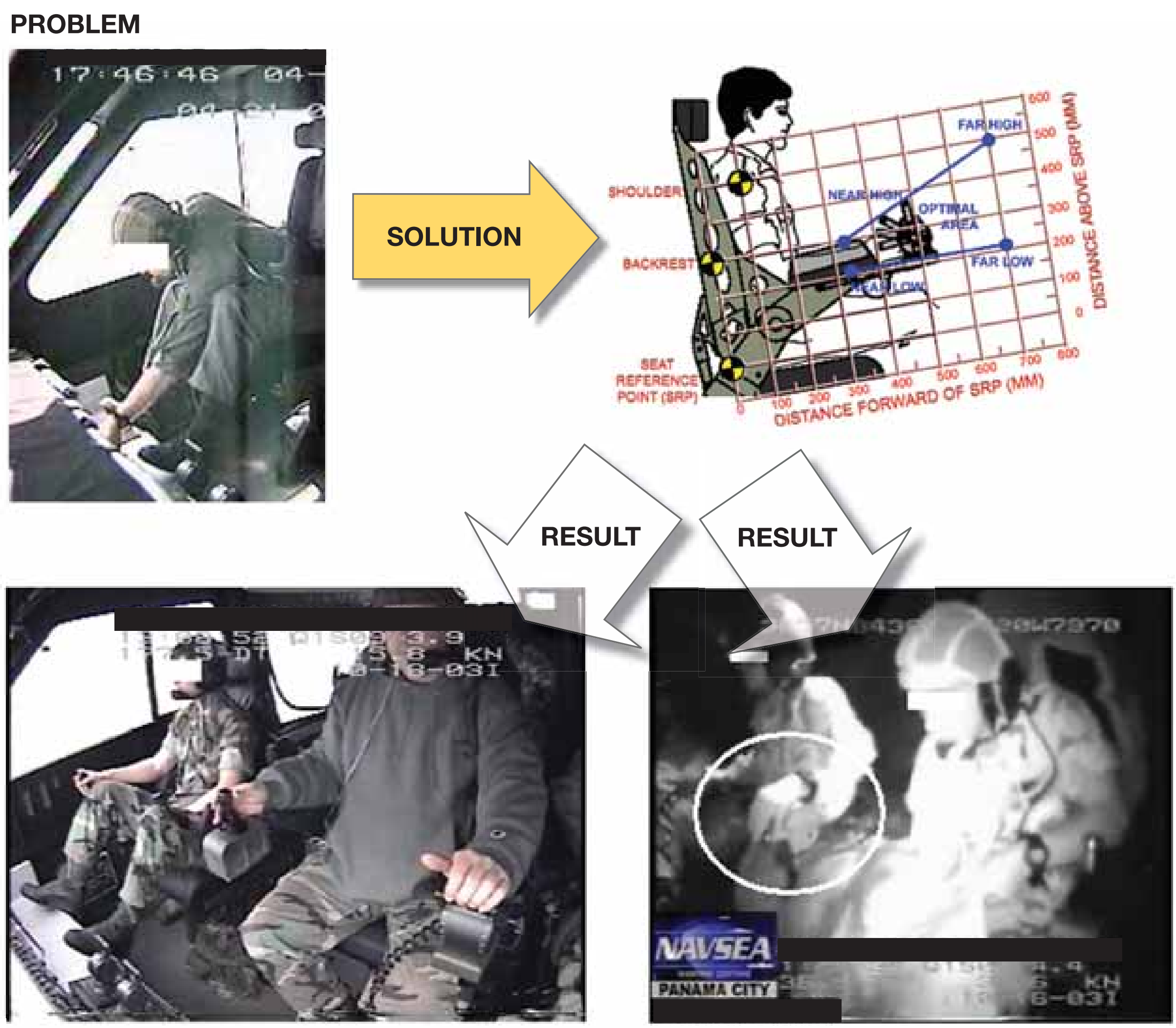


Figure F-14 MkV SOC Coxswain operating the seat-mounted throttle (left hand) and tiller (right hand) controls during a daytime exercise.
Image copyright: US Navy

MkV SOC Coxswain operating seat-mounted throttle (circled) and tiller controls during a night-time exercise, image acquired using IR camera.

F.3.3.6.2 RNLI Tamar-class lifeboat coxswain throttle, steering system and SIMS integrated with the RNLI/Fraser-Nash suspension seat.

F.3.3.6.2.1 The development of the RNLI Tamar-class lifeboat included a suspension seat that would cope with high levels of S&V. This demanded an increase in seat travel displacement over previously fitted suspension seating, and therefore it was recognized that the coxswain would require a new Man-Machine Interface with which to control the craft[4]. As with the US Navy MkV Special Operations Craft (refer to Section F.3.3.6.1), the solution was integrate the controls into the arm rests of the seats. The resultant design is shown below in Figures F-15 – F-17.

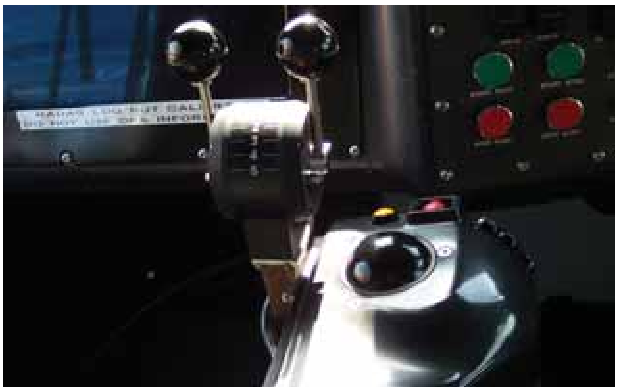


Figure F-15 Throttle and SIMS control located On right hand arm of the suspension seat - Coxswain view.
Image copyright: RNLI

Figure F-16 Throttle and SIMS control (trackball and buttons)
Image copyright: RNLI

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Figure F-17 Example of coxswain using arm-rest mounted throttle (right hand) and tiller (left hand) controls on the RNLI Tamar Class Lifeboat.
Image copyright: RNLI

[4] Nurser, J. and Chaplin, N. (2004) Development of integrated electronic system and human-machine interface in a new class of lifeboat. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

Cripps, R., Cain, C., Phillips, H., Rees, S. and Richards, D. (2004) Development of a new crew seat for all weather lifeboats. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

SECTION G
Habitability

CREW AND PASSENGERS SHOULD BE SAFE AND COMFORTABLE WHEREVER POSSIBLE.

G.1 GENERAL

G.1.1 Habitability covers a broad range of human requirements, some of which are examined in more depth in other sections of this Guide (as indicated below). On a selective basis, habitability issues can include consideration of the following factors[1]:

a Crew and passenger space considerations – location, adjacencies, size, shape, access, colour schemes.

b Mission duration, e.g. 2 hours vs. 72 hours (e.g. subsistence and heads/WC facilities).

c Surface coverings – decks, bulkheads, deckheads, (i.e. floor, walls, ceilings) etc.

d Furnishings.

e Sleeping accommodation.

f Personal space-dimensions, access, privacy.

g Passageways.

h Messing.

i Motion [see Section A].

j Vibration [see Section A].

k Noise [see Section C].

l Atmosphere – temperature, humidity, ventilation, pollutants [see Section D].

m Lighting – visibility, readability, glare, adaptation [see Section B].

n Clothing [see Section D].

G.1.2 Studies have demonstrated that poorly addressed habitation leads to a reduction in morale/motivation with expected degradation of human performance (i.e., increase in error rates especially with regard to monitoring tasks).

G.1.3 Central to designing for habitability is designing to accommodate the physical dimensions (i.e. anthropometrics) of the end-users. Further details on selecting and using anthropometric data to assist in the design of working and living areas is provided in Section G.3. Whilst anthropometric data provides a useful estimate of end-user body sizes (e.g. for use in CAD modelling), the suitability of the resultant design will need to be validated using representatives from the user-community, i.e. conduct a formalised User-Trial (refer to Section I; Design Review. I.1.2 – Review Tools).

G.2 INPUT TO DESIGN PROCESS

G.2.1 Specification Design

a *User requirement document (Design Step 2):* Assemble description of end-user population (see Section 6). If approximating end-user body sizes with existing anthropometric data, an agreement must be reached on which data set is to be used (e.g. Royal Navy survey data, US Military Data, etc.).

[1] Selective extracts from UK MOD MAP-01-011 HFI Technical Guide.

G.2.2 Feasibility Design

a ***Preliminary General Arrangement (Design Step 5):*** Estimate width and height requirements (to accommodate largest crew and passenger sizes) for passageways to be included within main-space estimates. Locate working areas in locations of best 'ride-quality', and as far as practicable away from machinery items (i.e. to minimise noise and vibration).

G.2.3 Main Design

a ***General Arrangement and Systems (Design Step 12):*** Check width and height requirements for passageways, doorways, and other ingress/egress points are not being encroached upon by other structures. Include insulation to minimise noise and vibration transmission to working and living areas. Design seating to face forward. Although bunk spaces have traditionally been aligned longitudinally (i.e. fore aft), the alignment should be dictated by the ride characteristics of the proposed vessel. For example if a vessel is expected to have severe roll characteristics and unremarkable pitch characteristics, it is better to align the bunks athwart ship (i.e., starboard-port). See Figure G-1 for a typical example of restricted access and egress to a craft's bunks

Figure G-1 Example of bunk accommodation demonstrating restricted movement, and awkward ingress and egress.
Image copyright: US Navy

G.2.4 End Design

a ***Interior Layout Details (Design Step 16):*** Check for any encroachment into passageway, doorways and other ingress/egress points. Select non-slip flooring and consider drainage facilities for disposing of excess seawater. Choose furnishings and surface coverings with ease of maintenance and cleaning in mind. Design heating facilities (for messing) to minimise incidence of injury through heat and spillage of hot food, and with good housekeeping in mind. Provide guard rails, etc. on bunks to minimise incidence of occupants rolling out of bunks with severe ship motions. Consideration should be given to details such as the provision of drinking facilities for use whilst underway, refer to Figure G-2 for an example of a cup holder designed for use on a HSC. Also note that such features may adopt alternative uses, so it is essential to provide equipment storage for small items at numerous locations around the crew's workstations.

Figure G-2 Example of a cup holder, and its secondary use for general storage (e.g. communications headset, hand-held VHF radio, etc.).
Image copyright: Human Sciences & Engineering Ltd

NOTE: **This guide is not designed to provide a wealth of information on habitability as HF issues relating to extended durations on board HSC are generally covered in HF Standards and Guidance documents[2] relating to larger craft**

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION G.3

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[2] Examples of general maritime HF standards include UK MOD MAP-01-011 HFI Technical Guide.

G.3. DESIGNING FOR THE PHYSICAL SIZE OF THE USER

G.3.1 Working with human body dimensions (anthropometrics) usually comes down to considering one of three basic questions:

- **a** *Clearance* **–** Is this space sufficient to accommodate the largest user (e.g. door width)?
- **b** *Reach* **–** Is the device within the reach of the smallest user (e.g. positioning controls comfortably within hand reach)?
- **c** *Fit* **–** Is there sufficient adjustment to accommodate all users and their equipment comfortably, from the smallest to the largest (e.g. harness adjustment to secure users) ?

G.3.2 Ultimately, a true assessment of whether the design is suitable can only be conducted using examples of the intended user group, using volunteers who approximate to the smallest and largest users of the group. This needs to be conducted using the thickest clothing (including gloves) worn by the users, any helmets and other items of PPE that users may be required to wear.

G.3.3 Approximations may be made (e.g. during feasibility design) using body size (anthropometric) tables[1]. The smallest users are normally described as under the 5th percentile and the largest users being 95th percentile or over, for the populations size – the population mean being the 50th percentile. The Designer must ensure the HSC is useable by both of these operators. Designers should note the dimensions are nude, and therefore additional allowances are necessary for the effects of clothing, shoes, helmets, etc. The designer should consult with the users to obtain details for these items. The following is a selective list of body dimensions and a brief explanation of how they might be of use to designers.

- **a** ***Stature* –** Use to define the minimum height of overhead items, e.g. headroom, doorway height. Use data for the tallest user.
- **b** ***Standing and sitting eye height* –** Use to calculate user line-of-sight (in conjunction with optimum/preferred field-of-view angles and diagrams) for instrumentation and external visibility when standing and/or sitting. Use data for both shortest and tallest users.
- **c** ***Standing shoulder height* –** Use as a reference point for calculating maximum zone of reach for a standing operator. Use data for both shortest and tallest users.
- **d** ***Standing elbow height* –** Use to determine the height of working surfaces for standing operators, for the height of arm rests on standing shock mitigation systems, and as a reference point for calculating comfortable zone of reach for frequently used controls. Use data for both shortest and tallest users.
- **e** ***Sitting height* –** Use to define the minimum clearance between the seat and overhead items. Use data for the tallest user. If the seating incorporates movement/displacement for shock mitigation, minimum clearance should be calculated from the highest seat position.
- **f** ***Sitting eye height* –** Use to calculate user line-of-sight (in conjunction with optimum/preferred field-of-view angles and diagrams) for instrumentation and external visibility when sitting. Use data for both shortest and tallest users. Consider how any seat adjustment for short and tall users might affect the seat.
- **g** ***Sitting shoulder height* –** Use as a reference point for calculating maximum zone of reach for a seated operator. Use data for both shortest and tallest users.
- **h** ***Sitting elbow height* –** Use to define the height of desk surfaces, keyboards, armrests, etc. for a seated operator, and as a reference point for calculating comfortable zone of reach for a seated operator.
- **i** ***Elbow functional reach* –** Use to calculate the maximum forward distance for operating frequently and continuously used controls (posture assumes relaxed upper arm), e.g. engine throttle. Use data for shortest user.
- **j** ***Shoulder breadth (bideltoid)* –** Use to determine the seat clearance (i.e. width) required at shoulder level. Use data for the widest user.
- **k** ***Elbow/Elbow breadth* –** Use to determine the seat clearance required at elbow level. Use data for the widest user.
- **l** ***Elbow Span* –** Use to determine "elbowroom" width required within the workspace. Use data for the widest user.

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[1] For example, Defence Standard 00-25 Part 17 for UK Service Personnel; Pheasant and Haslegrave (2006) *Bodyspace: Anthropometry, Ergonomics and the Design of the Work* for UK civilian populations. US DOD-HDBK-743 Military Handbook Anthropometry of U.S. Military Personnel. Other sources may be found at www.hsiiac.org and national databases.

G.4 STORAGE

G.4.1 On small HSC storage is always at a premium. The equipment; HSC, operational, and crew and passenger personal equipment need to stowed away so as not to interfere with the operation of the HSC, e.g. to ensure clear walkways. Therefore innovative storage solutions have to be devised. Examples of typical HSC storage are shown below in Figure G-3.

Figure G-3 Examples of under-seat and roof storage utilised on a HSC.
Image copyright: Human Sciences & Engineering Ltd

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SECTION H
Maintainability

MAINTENANCE NEEDS TO BE CONSIDERED FROM THE OUTSET TO ENSURE MINIMUM MAINTENANCE TIME AND TO MAXIMISE OPERATIONAL READINESS.

H.1 GENERAL

H.1.1 It is imperative that designers allow for the need to carry out maintenance tasks efficiently and rapidly when considering how they will design a HSC.

H.1.2 In order to assist in adopting an ease of maintenance philosophy and integrating it into the design process from the beginning, an analysis of maintenance activities (this forms part of the description of the crew and passenger activities preparatory HF work – see Section 6) should be conducted. This is part of the Specification Phase and covers the required maintenance tasks to support the design. This will help the designer to think through, in steps, how and where the maintainer will need to gain access to the vehicle system, and what tasks he will need to perform – particularly in arduous environment conditions.

H.1.3 The designer should aim to integrate all required maintenance procedures into the design in a practical manner, so that the relevant maintenance and servicing tasks can be performed easily and rapidly, using the most appropriate resources. Consideration should also be given to the frequency of servicing tasks and to operational implications of how and when the maintenance tasks need to be carried out, e.g. at sea and at night.

H.1.4 The benefits of designing with maintenance requirements in mind include significant reductions in servicing times. For example, the UK RNLI were able to achieve a significant saving in 'yard-time' when replacing an engine on the Tamar class lifeboat, over previous designs, such as the Severn, by integrating maintenance and repair requirements into the design.

H.1.5 The designer needs to take account of the variations in human body dimensions and strength when planning procedures for carrying out maintenance tasks.

H.1.6 The designer will need to ensure that any Health and Safety at Work regulations specified are complied with when designing the maintenance tasks.

H.1.7 ***Space for Access –*** The designer shall provide sufficient space and clearances to allow access for maintenance tasks to be performed easily and quickly. This is to include clearances for protective clothing and the operation of maintenance tools.

H.1.8 ***Visual Access –*** The designer shall ensure that the maintainer can see what he is doing when carrying out his tasks. This is both a line-of-sight and illumination issue.

H.1.9 ***Physical Access –*** The designer shall ensure that the tasks to be carried out during maintenance are within the physical capabilities of the maintainer, and that lifting and manoeuvring aids are provided where necessary.

H.1.10 ***Vessel maintenance/adjustment tasks –*** Access to hatches and covers provided for crew maintenance and items to be maintained shall have correctly designed handles, opening devices and handling surfaces. They shall be positioned to allow safe and posture-acceptable operation, preferably by one man, but if not then by two.

H.1.11 The designer should make optimal use of capture fasteners so as to prevent their loss due to ship motion or a fatigued maintainer.

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H.1.12 The maintenance tools required should be kept to a minimum (i.e., a single Allen-key wrench fits most situations). In the US Comanche helicopter design program, this type of HFE design consideration reduced the number of maintenance tools from 256 to 11. Other examples of designing for maintenance include endurance racing cars (e.g. LeMans 24 hour motor race) where the majority of the cars components can be replaced in the minimum amount of time.

H.2 INPUT TO DESIGN PROCESS

H.2.1 Feasibility Design

a *Preliminary General Arrangement (Design Step 5): Access of service items* **–** The designer should ensure that sufficient clearance is maintained around serviceable items. Additionally, serviceable items may need to be raised to provide maintained good access at a convenient working height (e.g. not working on serviceable items from above).

H.2.2 Main Design

a *General Arrangement and Systems (Design Step 12): Maintenance space access details* **–** The NA can consider the exact nature of the maintenance tasks in terms of weight of items (for assessing whether it constitutes a one or two-man lift, or indeed needs specialist lifting gear, and taking account of whether the HSC is at sea or at a maintenance facility). The Designer also needs to identify which items need most frequent servicing or replacement[1], and prioritise these accordingly for optimal accessibility.

H.2.3 End Design

a *Interior Layout Details (Design Step 16), and Detail Design (Design Step 17):* Having located the main items, the Designer must consider the implications of the connecting systems and access to them, e.g. pipework, hydraulic hoses, electrical supply and connectors, access to wiring looms. The NA should aim to minimise instances where large items need to be removed in order to replace damaged or worn connecting items.

H.3 EXAMPLES

H.3.1 Engine maintenance

H.3.1.1 Good maintenance access

Although it may not appear to be directly related to the operational effectiveness of a HSC, poor maintenance access can have a direct affect on it's operational readiness and the ability to undertake repairs during an operation. Examples of good maintenance access are shown below in Figures H-1 and H-2.

Figure H-1 Example of good access to service components, e.g. fuel filters
Image copyright: RNLI

[1] From collating lessons learnt and operational experience in understanding and specifying the context of use (See Section 5), and consultation with maintainers.

Figure H-2 Examples of good access around engines – RNLI Tamar Class Lifeboat (left) and USN SEALION-I Technical Demonstrator (right).
Image copyright: RNLI and US Navy

H.3.1.2 Poor maintenance access

The design requirements of HSC often demand that their size is constrained whilst the engine power is maximized. This will often result in their being minimal space around the engines to allow maintenance tasks to be undertake. An example of how this lack of space impinges on the ease of maintenance can be seen below in Figure H-3.

Figure H-3 Example of poor access to engine components
Image copyright: Powerboat P1

H.3.2 HSC husbandry

All HSC require continual maintenance, servicing and cleaning. To assist the crew and maintainers with these tasks the Designers should include features that make these tasks easier. Examples of these design features can be seen here in Figure H-4.

Figure H-4 Storage solutions developed by the RNLI for holding maintenance equipment.
Image copyright: US Navy

SECTION I
Design review

FORMAL REVIEWS ARE AN ESSENTIAL PART OF THE DESIGN PROCESS. IT INCLUDES THE USE OF CAD DRAWINGS, CAD MODELS AND MOCK-UPS.

I.1 GENERAL

I.1.1 A formal review procedure is an essential part of the HSC design process. The inclusion of the appropriate number of reviews steps will keep the customer informed of the design decisions, and ensure that there are no surprises when the final product is delivered. Traditionally HSC design reviews are often conducted relatively informally. This may be acceptable in some situations but a degree of formality can make the process more successful and help ensure that all operational conditions and eventualities are covered. Different stakeholders may be required at different points of the design review processes. Capability managers will be more concerned with Feasibility Design decisions, whereas end-users are often more concerned with the Main and End Design phases.

I.1.2 Review Tools

a *Computer Aided Design (CAD) Drawings:* These provide the first step in the review process. Designers and Engineers will be able to comprehend the design from 2-Dimensional drawings, but end-users, who will generally not have formal engineering training, will gain a better comprehension of the design if it is shown using 3-Dimensional images. Examples of 3-Dimensional CAD images of a RIB are shown in Figures I-1 and I-2.

Figure I-1 (Left and below left) Examples of 3D CAD images that may be used for reviewing both the overall HSC design concept and some aspects of the Main design phase.
Image copyright: VT Halamtic

Figure I-2 (Below) Example of a 3D CAD image of a HSC crew workstation demonstrating how the overall cockpit concept may work.
Image copyright: VT Halmatic

b *CAD Modelling:* The increasing ability to animate the design within the CAD environment gives a greater insight into the design, particularly where the crew and passengers can be illustrated interacting with the HSC systems. An early example of such modelling is shown in Figure I-3. The animated CAD environment that can demonstrate how an individual may interact with an engineering system (refer to Figure I-4), provides the Designer, end-user and procurement personnel with a greater insight into the design of the HSC at an earlier point in the design process than was previously possible. As CAD modelling enhances and becomes more sophisticated the ability to allow the reviewer to interact with the design will increase. This should not be seen as a replacement for the use of mock-ups.

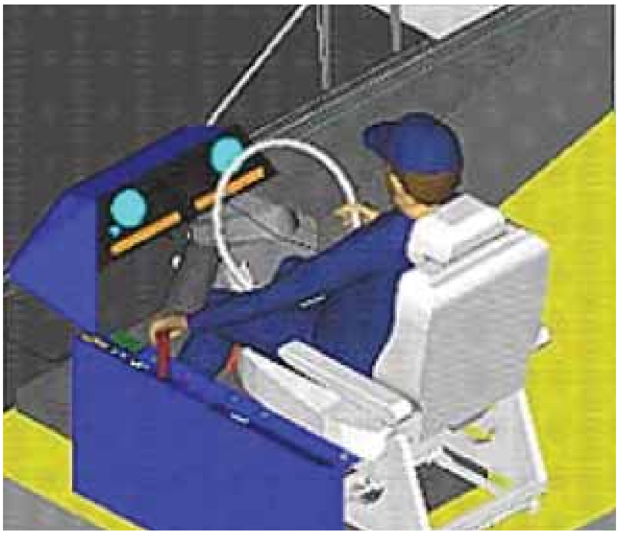

Figure I-3 **An early CAD model of the USN MkV Special Operations Craft Coxswain workstation.**
Image copyright: US Navy

Figure I-4 **An example of how CAD modelling can be used to assess the interaction between the HSC systems and the operator/maintainer.**
Image copyright: US Navy

c *Mock-ups/user-trial:* The pictorial representations, on paper and within a computer, cannot provide a total understanding of the design at its various stages. Mock-ups are a recognised methodology[1] for assessing the interaction of the crew and passengers with the HSC. The level of detail required (i.e. fidelity) of the mock-up are different at the various stages of the design process, and so the representation of the human interfaces should reflect this[2]. The designer/manufacturer should not see this as an unnecessary additional design process cost – rather it is an integral part of the process. Importantly it allows for the assessment of issues such as lines-of-sight, lighting and emergency procedures.

i The mock-up should be produced so that operators and passengers can perform a User-Trial of both routine and emergency procedures under a range of simulated environmental conditions. Two examples of this assessment include the effectiveness of lighting/vision systems (i.e. natural, artificial, NVG), and the ability to operate within the HSC wearing a range of operational/PPE clothing and equipment. This user-trial will allow the HSC design can be modified and optimised prior to the design being finalised/frozen. Advice is available on the prototyping of mock-up human interfaces[3] to help ensure the effectiveness of the review process.

ii The detail, or fidelity that is included in a mock-up is described under three classifications:

Class 1 – Low fidelity; used to evaluate approximate work/accommodation shape, space, external vision and new ideas.

Class 2 – Good fidelity; produced to be close to the craft drawing dimensions, used for the assessment of detail design, crew station configuration, passenger space, maintenance access, ability to undertake emergency procedures, etc.

Class 3 – High fidelity; constructed with production materials and to production tolerances, used to determine Man-Machine Interface details, task lighting, layouts of wiring, plumbing, etc.

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[1] ASCC Air Standard 61/116.9B, Aircraft Mock-Up Inspection Techniques

[2] ASCC Air Publication 61/116/20. Human engineering requirements for rapid prototyping for operator/maintainer interfaces

[3] ASCC Air Publication 61/116/20. Human engineering requirements for rapid prototyping for operator/maintainer interfaces

iii The mock-up evaluation process should include the following:

a Crew tasks and workload.

b Crew motion envelopes.

c External vision envelopes.

d Lighting measurements and observations.

e Maintenance activities.

f Passenger activities.

iv Prior to the User-Trial/mock-up review by operators and SMEs the appropriate information and data should be disseminated so that review attendees understand what the review is to cover, how it will be undertaken, and how feedback is to be made. Wherever possible the feedback should be objective rather than subjective comments. It should be noted that it is essential to capture the results of the User-Trial/review so that future design iterations are based on the recorded feedback. For this process the following activities are required:

a Mock-up and User-Trial review plan.

b Information/data required at mock-up/User-Trial.

c Framework for development of mock-up/User-Trial review checklists.

d Mock-up/User-Trial review recording and reporting procedures.

e Mock-up/User-Trial approval procedure.

v For further information refer to the ASCC Air Standard 61/166.9B Aircraft Mock-Up Inspection Techniques.

I.2 INPUT TO DESIGN PROCESS

I.2.1 Feasibility Design

a ***Design Review – Class 1:*** Formal stakeholder & end-user consultation to agree the Feasibility Design (e.g. CAD drawings) and agreement to proceed to the Main Design Phase. The review will include the use of a low fidelity mock-up (Class 1) to evaluate work/accommodation space and shape, external vision, etc.

I.2.2 Main Design

a ***Design Review – Class 2:*** Formal stakeholder & end-user consultation to agree the Main Design (e.g. CAD drawings and modelling) and agreement to proceed to the End Design phase. The review will include the use of a good fidelity mock-up (Class 2) to evaluate detail design, crew station configuration, passenger space, maintenance access, ability to undertake emergency procedures, etc.

I.2.3 End Design

a ***Design Review – Class 3:*** Formal stakeholder & end-user consultation to agree the Interior Layout Details (Design Step 16) (e.g. using CAD drawings and modelling) and agreement to proceed to the Systems and Detail Design (Design Step 17). The review will include the use of a high fidelity mock-up (Class 3) to evaluate Man-Machine Interface details (see Section F), task lighting, etc.

FURTHER MORE DETAILED INFORMATION FOLLOWS IN SECTION I.3

SECTION I

I.3 ADDITIONAL INFORMATION

I.3.1 EXAMPLES OF HSC MOCK-UPS

I.3.1.1RNLI Tamar Class Lifeboat

The RNLI used a mock-up (Class: ~1-2, refer to Section I-1.2c) of the wheel house during the design of the Tamar class lifeboat. External and internal views of the mock-up are shown below in Figure I-5. Note that the original KAB seating was used rather than the new RNLI/FNC design[1]. It can be seen that the window sizes and locations can be assessed for external situational awareness, and the space between the seats examined for clearance.

Figure I-5 Example of RNLI Mock-Up used during the design review process.
NOTE: Mock-up Class: ~1-2
Image copyright: RNLI

[1] Cripps, R., Rees, S., Phillips, H., Cain, C., Richards, D. and Cross, J. (2003) Development Of A Crew Seat System For High Speed Rescue Craft. *Conference proceedings, FAST 2003*, Naples, October 2003.

Cripps, R., Cain, C., Phillips, H., Rees, S. and Richards, D. (2004) Development of a new crew seat for all weather lifeboats. *Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft.* RINA, London UK.

I.3.1.2USN RIB prototype suspension seat

A prototype semi-active suspension seat was designed for the USN 11m RIB by ActiveShock Inc (refer to Figure A-7). because of the seats displacement the crew member is placed higher from the RIB deck and therefore the RIB controls were longer in the correct position to be used by the helmsman. Therefore the console and the location of the controls needed to be redesigned to provide the helmsman with effective and comfortable operation of the RIB. Figure I-6a shows the mock-up(Class: ~2, refer to Section I-1.2c), including the first prototype seat being used by the operator to identify the new position of the steering wheel, thus demonstrating the use of the guidance provided in Section F of this Guide. The design solution for the suspension seat and RIB controls was subsequently successfully trialled at sea (refer to Figure I-6b).

Figure I-6a Example of Helm console mock-Up being used to develop the MMI to work with a prototype suspension seat.
NOTE: Mock-up class: ~2
Image copyright: US Navy

Figure I-6b Prototype suspension seat and modified coxswain helm position undergoing Test & Evaluation on a USN 11m RIB.
Image copyright: US Navy

I.3.1.3USN MkV Special Operations Craft

The USN MkV SOC was designed using a wheel house mock-up (Class: ~1, refer to Section I-1.2c) to assess the accommodation of the crew seating. Figure I-7a shows the mock-up with four Stidd seats being used to assess space allocations, lines-of-sight and external view. Figure I-7b shows the resulting production MkV SOC being operated by the crew.

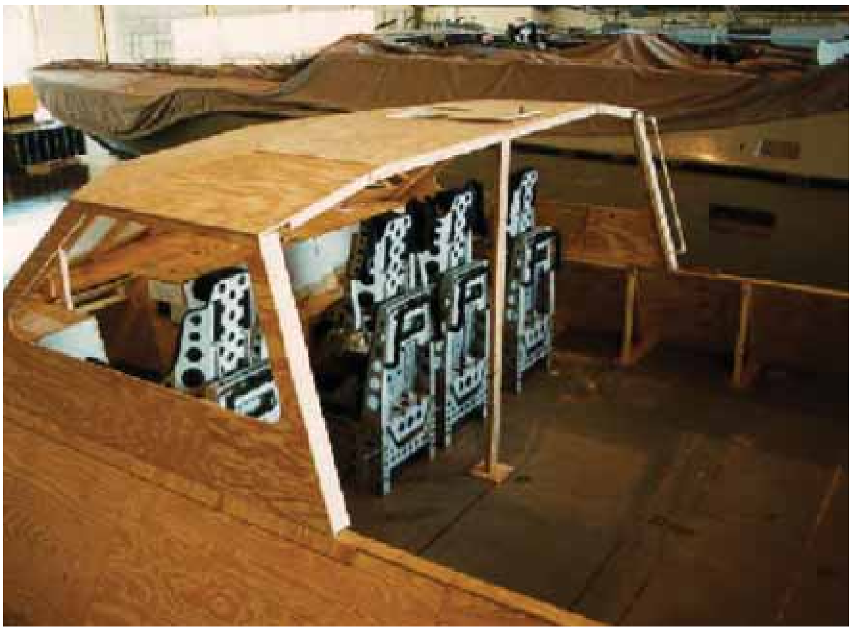

Figure I-7a Mock-up of USN MkV SOC being used to establish locations and spacing of crew seats, external view, etc.
NOTE: Mock-up class: ~1
Image copyright: US Navy

Figure I-7b A view of the resultant layout of the USN MkV SOC
Image copyright: US Navy

I.3.1.4 UK MOD Fast Transit Craft

The design of a Fast Transit Craft involved addressing HF issues at the drawing design phase (refer to Figure F-7) and during the assessment of the coxswain workstation mock-up (Class: ~1-2, refer to Section I-1.2c) by end-users. Figure I-8a shows the mock-up from two perspectives and gives an indication of the relationship between a tall coxswain and the HSC MMI. The final design can be seen in Figure I-8b.

Figure I-8a mock-up of a UK Fast Transit craft helm position being used to establish locations and spacing of crew seats, external view, control locations and instrumentation layout etc.
NOTE: Mock-up class: ~1-2
Image copyright: Human Sciences & Engineering Ltd

Figure I-8b A view of the resultant layout of the UK Fast transit Craft Helm position
Image copyright: Human Sciences & Engineering Ltd

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SECTION J
Test & Evaluation

THE PERFORMANCE OF THE HSC SYSTEM SHOULD BE ASSESSED IN ACCORDANCE WITH THE URD AND SRD. THE RESULTS WILL FEED INTO THE DEVELOPMENT OF THE CRAFT'S OPERATING PROCEDURES AND CREW TRAINING REQUIREMENTS.

J.1 GENERAL

J1.1 It should be assumed that a formal assessment[1] of the HSC will be conducted by the customer against the design specification and/or URD/SRD. This is often accomplished by constructing a compliance matrix that may for part of the SRD. Whilst it is difficult to pre-empt the conclusions of subjective methods of assessment (although end-user input during Design Reviews can provide a good indication), more objective criteria will be used by the customer whenever possible. These should be available to the Designer, and could assist in evaluating the HSC design prior to the formal Test & Evaluation (T&E).

J.1.2 The Design Review activities previously described (see Section I) form part of the overall assessment of the HSC and should address many of the design requirements prior to the building of the [prototype] HSC. If the Design Review process is successful the trials of the prototype/First of Class HSC should be relatively straightforward.

J.1.3 There are specific guidelines for assessing HF during the T&E[2] phase. The Designer may consider it prudent to use/adapt these for use during the Design Reviews.

J.1.4 The Prototype HSC will be assessed to the full range of its operational envelope. In particular, the HSC will be tested under taxing conditions including:

a Night/dark conditions

b Rough sea conditions

c Cold and hot environments

d Emergency conditions

J.1.5 Where these conditions are considered to present too great a risk to crew and passengers, the customer may use simulation techniques instead; however the intention will be to simulate these conditions as accurately as possible. It is important to note that the use of human participants within T&E activities is closely regulated in most countries, particularly where the military is concerned. In the US Navy the Test Director must receive approval to test from an Institutional Review Board[3] (IRB). This requirement comes from SECNAV INSTRUCTION 3900.39D, Human Research Protection Program, which references higher level DoD directives, in particular, Protection of Human Subjects and Adherence to Ethical Standards in DoD Supported Research. The scope of this guidance includes tests within which operators (including military operators performing their normal duties) are exposed to experimental conditions (i.e., an experimental seat) that could result in injury. An IRB is a separate additional requirement from the traditional test plan review panels convened by most US Navy labs.

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[1] For the UK MOD this is the Integrated Test, Evaluation & Acceptance Plan (ITEAP).

[2] NATO RTO-TR-021. Guidelines on Human Engineering Testing and Evaluation. ISBN 92-837-1068-1. May 2001.

ASCC Advisory Publication 61/116/12, Crew Performance Measurement.

ASCC Advisory Publication 61/116/18, Human Engineering Test and Evaluation Procedures for Systems, Equipment and Facilities

[3] In the UK this is known as an Ethics Committee.

J.1.6 Operational system testing is performed on a fully functional prototype (or First of Class) using trained end-users conducting representative missions in realistic conditions (including the taxing conditions outlined above). End-users will be required to adhere to all operating and maintenance procedures, including the use of manuals[4] where appropriate, and therefore the Designer may wish to ask end-users to conduct these documented procedures during the latter Design Reviews using the appropriate mock-up. Operational testing of the HSC's individual system components may also be conducted where their use constitutes a meaningful division of a crewmember's duties, for example, tests of integrated electronic chart display systems using coxswains and navigators.

J.1.7 This Guide does not specifically cover crew training requirements. These are both general and specific to the operation of the HSC be designed. Some training aspect will need to be considered if the T&E of the prototype HSC system is to effective. An appropriate Training Needs Analysis should be undertaken, this will be related to the Task Analysis that is undertaken as part of the HSC Specification Process, and a crew training programme for the new HSC devised and validated.

J.2 EXAMPLES OF HSC SYSTEMS TEST & EVALUATION

J.2.1 Computer Systems Operation

J.2.1.1 The development of computer workstation peripherals suitable for use on a HSC involved several iterations of laboratory and sea testing, each resulting in improvements to the overall design. The USN started with a variety of potential Commercial-Off-The-Shelf (COTS) and Government-Off-The-Shelf (GOTS) solutions[5], most of which were down selected during laboratory usability testing.

Figure J-1 Examples of computer input devices evaluated for use onboard a HSC.
Image copyright: US Navy

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J.2.1.2 To adequately address all requirements identified during the Mission Task Analysis (MTA), new devices had to be prototyped and tested. Although USN MkV SOC operators were involved in both the lab and sea tests, quantitative analysis more than qualitative analysis dictated the final design iterations. Although user feedback is important in determining cultural differences and mission essential tasks that may have been missed by the MTA, users generally do not have engineering qualifications and their opinions can vary significantly. Design decisions must ultimately be driven by quantitative (measurable) criteria that ensure compliance with HSC system requirements and relevant HF interface standards. In developing a cursor

[4] Specifications for the content of HSC documents and manuals can be found in ISO 10240:2004, Small craft – owners manual

[5] GOTS;1-3, Specific project prototypes; 4-6, COTS; 7-10.

control device for the USN MkV SOC computer workstation, the USN also developed software that allowed operator efficiency (as determined by speed and error rate) to be recorded while conducting a series of clicking, scrolling, highlighting, cut/paste, and typing tasks over a range of sea states. In the end, this quantitative analysis demonstrated that one design (refer to Figure J-1; 5) far outpaced the others, permitting continuous use in high sea states (6-8 foot, occasional 10), with the lowest error rate.

Figure J-2 An example of laboratory-based (left) and at-sea testing (right) of prototype computer input devices.
Image copyright: US Navy

J.2.1.3 It should be noted that one engineering solution does not necessarily fit all situations. The computer workstation developed for the USN MkV SOC was optimized for the tasks conducted by a particular operator type seated at a particular onboard location. The solution needed, in this instance, to include a seat mounted monitor given that the operator spends 75% of their time monitoring the display. While the seat mounted cursor control device and keyboard tray are now migrating to the navigator and Boat Commander work stations, providing these particular operators with a seat mounted display could actually hinder some of their primary tasks (i.e., obstacle avoidance) by blocking their view outside the craft.

J.2.2 Operator subjective assessment of Computer System and Man Machine Interface

J.2.2.1 As described above (Section J.2.1) the HSC system computer can incorporate software to rate the crew members ability to successfully operate the system. In addition to this quantitative assessment it is important to obtain the users feedback on their perceptions of the systems design and operation, as the inability to operate the system simply and effectively is linked to frustration and morale, and therefore operational effectiveness.

The RNLI, as part of the Test & Evaluation of the Tamar class lifeboat recorded data from crew members on their experience of the new SIMS (refer to Section F.3.2.4.2) compared to previous legacy system[6]. They were asked to rate, on a scale of one to five their perception of the new system compared to the legacy system, for a number of functions and attributes. The results of this evaluation are shown below in Figures J-3 and J-4. Figure J-3 indicates how the experienced lifeboat crew-members rated the SIMS as being better than the legacy system. Note the lower score for the ‘Radar work’, this is considered to be because the SIMS uses the some generic radar display as the legacy system. Similarly J-4 indicates the subjective ratings from the crew-members of the SIMS performance, note that the crew members ‘Confidence before trials’ was low compared to the high scores that they gave the SIMS following the Test & Evaluation.

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[6] Nurser, J. and Chaplin, N. (2004) Development of integrated electronic system and human-machine interface in a new class of lifeboat. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

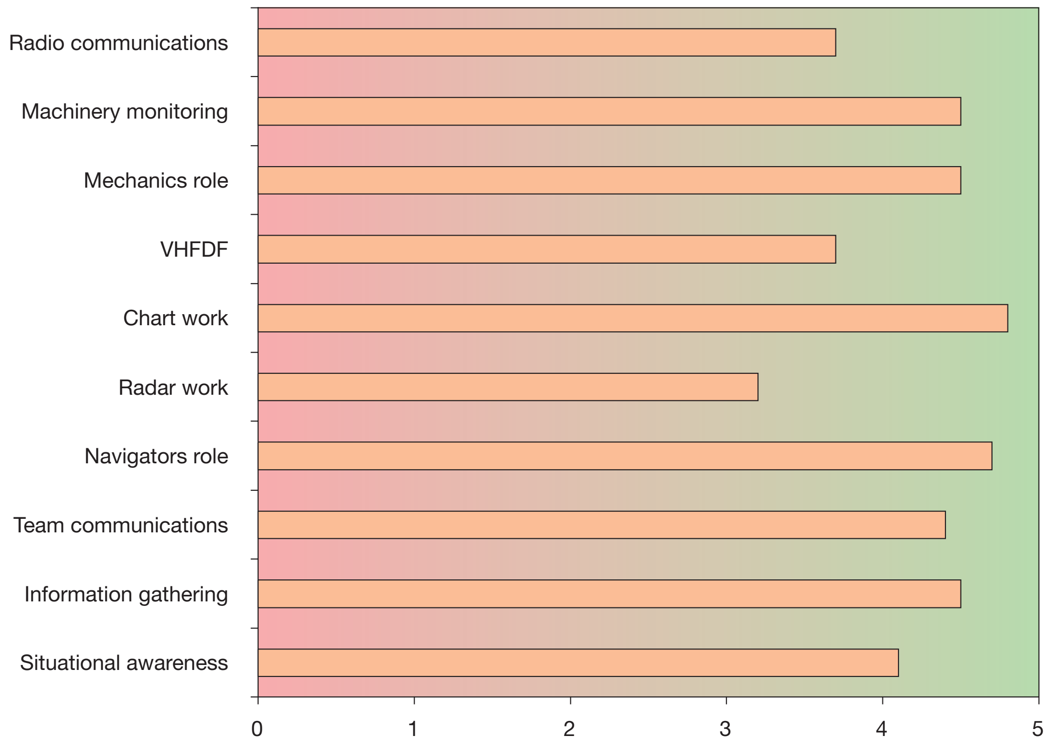

Fig J-3 Subjective comparison of the RNLI SIMS with the RNLI legacy system by experienced crew members.

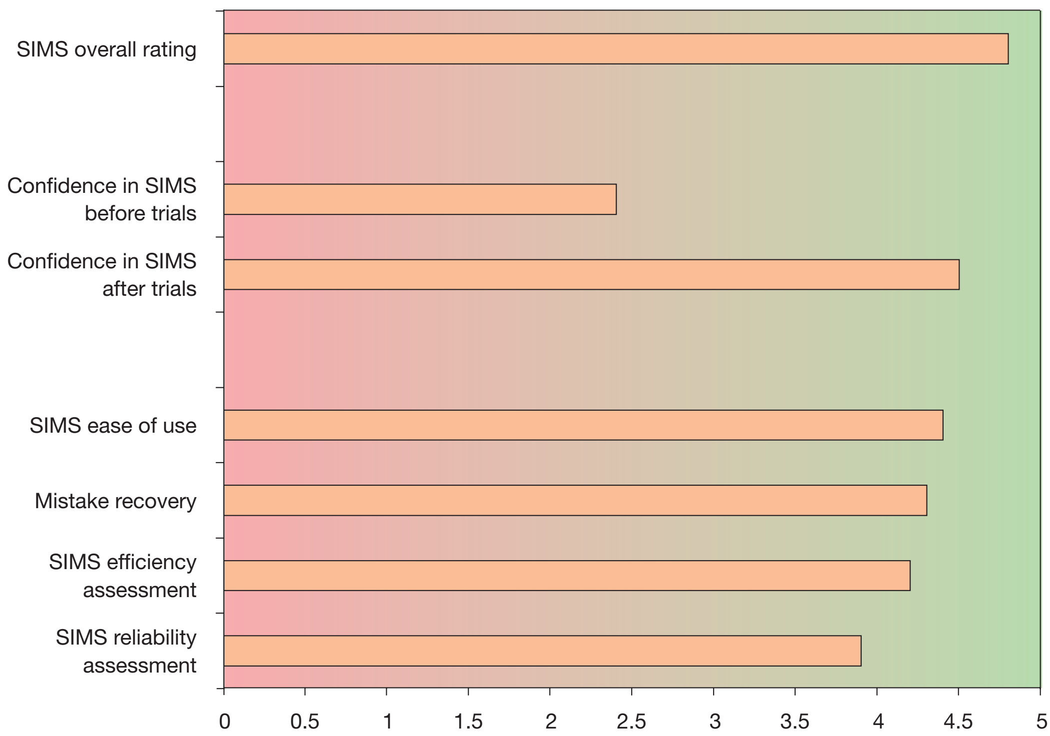

Figure J-4 Subjective rating of the performance of the RNLI SIMS by experienced crew members.

J.2.2 SHOCK MITIGATION SEAT ASSESSMENT

J.2.2.1 Laboratory-based Test & Evaluation

Laboratory tests can be performed as a method of providing a repeatable dynamic environment, e.g. using an impact sled, such as at the University of Virginia Center for Applied Biomechanics Crash Test Facility, where a single high acceleration impact event can be replicated. Such a test provides the ability to evaluate different variations of isolators, seat pads, etc. Also by using instrumented anthropometric crash-test dummies, a measure of the loadings and stresses within the body can be determined. This helps to provide better methodologies for acute injury predictions. However, currently, no known laboratory facility exists to provide multiple random impacts of the magnitude, durations and encounter frequencies typically experienced on an actual HSC.

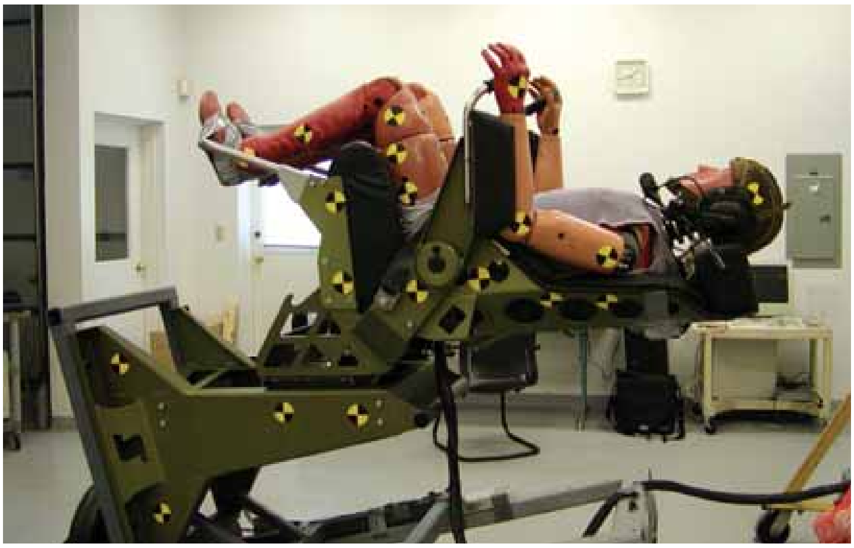

Figure J-5 Example of an anthropometric test dummy being using for the testing of the Stidd/Taylor V5 suspension seats on a deceleration (crash) track.
Image copyright: University of Virginia

J.2.2.2 At-sea Test & Evaluation

J.2.2.2.1 Data from the Stidd/Taylor V5 suspension seat at-sea test on board the USN MKV SOC was used in validating the Madymo7 spine model for use as a replacement for the original ISO 2631 Part 5 neural net. This was an important step in modifying the predictive spine stress dose model for application in higher than 4g environments. 50th percentile male Anthropometric Test Dummies were used to control variables between the two seat variants (V4 - semi-rigid and V5 -suspension). It should be noted that at the time of the test, the MkV SOCs had been refitted with V5 suspension seats and that there was sufficient empirical evidence regarding the improved safety of V5 seats that it would have been considered unethical to use a human test subject in the V4 semi-rigid seat.

Figure J-6 Example of Anthropometric Test Dummies being using for the testing of the Stidd/Taylor V5 suspension seats fitted to the USN MkV SOC.
Image copyright: US Navy

[7] www.tass-safe.com

J.2.2.2.2 The RNLI, for the development of their new suspension seat for the Tamar Class Lifeboat, undertook an extensive design and assessment programme[8]. The prototype seat was initially tested in the laboratory and subsequently underwent a series of sea trials on a RIB. As with the USN suspension seat trials, the RNLI first tested the prototype seat at-sea using Test Dummies before progressing to manned-testing. This testing regime is shown below in Figure J-7.

Figure J-7 Example of anthropometric dummies being used for the testing of the RNLI/Fraser-Nash suspension seats and the subsequent assessment by RNLI personnel.
Image copyright: RNLI

[8] Cripps, R., Rees, S., Phillips, H., Cain, C., Richards, D. and Cross, J. (2003) Development Of A Crew Seat System For High Speed Rescue Craft. Conference proceedings, FAST 2003, Naples, October 2003.

Cripps, R., Cain, C., Phillips, H., Rees, S. and Richards, D. (2004) Development of a new crew seat for all weather lifeboats. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

SECTION K
Examples of HSC design utilising an integrated design approach

HUMAN FACTORS ENGINEERING DESIGN PRINCIPLES ARE AN INTEGERAL PART OF THE HSC DESIGN PROCESS.

K.1 CASE STUDY: RNLI TAMAR CLASS LIFEBOAT

K.1.1 INTRODUCTION

K.1.1.1 The RNLI carries out Search & Rescue operations around the coast of the UK and the Republic of Ireland. The RNLI is perhaps slightly unusual within the commercial world in that it designs, operates and for the large part maintains its own fleet of boats, and therefore input into design activities includes input from operational and maintenance activities.

K.1.1.2 This interaction of through life operational and maintenance considerations in the design phase has proved to be beneficial to RNLI lifeboat designs over the years, and this was particularly important in the development of the Tamar Class lifeboat (see Figure K-1).

Figure K-1 RNLI Tamar Class Lifeboat
Image copyright: RNLI

K.1.1.3 The project began with an Operational Requirement (OR) in 1996, a time when there was precious little information available in the public domain regarding regulatory requirements or appropriate guidelines for the consideration of human factors in small craft design. Although the OR did not contain a specific HF requirement, the multi-disciplinary project team called upon the experience of the design, operational and maintenance teams to ensure all users would be considered in the design – accepting that a small boat is always going to be a compromise.

K.1.2 THE TAMAR DESIGN SPIRAL AND HF ISSUES

K.1.2.1 The Tamar design process was based entirely on a first principles approach as RNLI lifeboats are not covered under Merchant Shipping or Class requirements, and this has included the approach to HF issues.

K.1.2.2 Unlike the traditional design process described in this Guide, the size of the Tamar design team facilitated concurrent design processes on a number of fronts, allowing HF issues to be addressed as part of the development of the craft. An example of this process is the wheelhouse shape.

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K.1.2.3 The Tamar's self righting ability is due largely to the buoyancy provided by the geometry of the wheelhouse. However the wheelhouse must also, for example, accommodate crew headroom internally, maintain sightlines externally (whilst also being constrained by a height limitation for boathouse doors), be able to be manufactured efficiently, interface with shore facilities and meet a whole host of other competing requirements. Figure K-2, shown below, illustrates how some of these HF issues were fundamentally included in the wheelhouse design process.

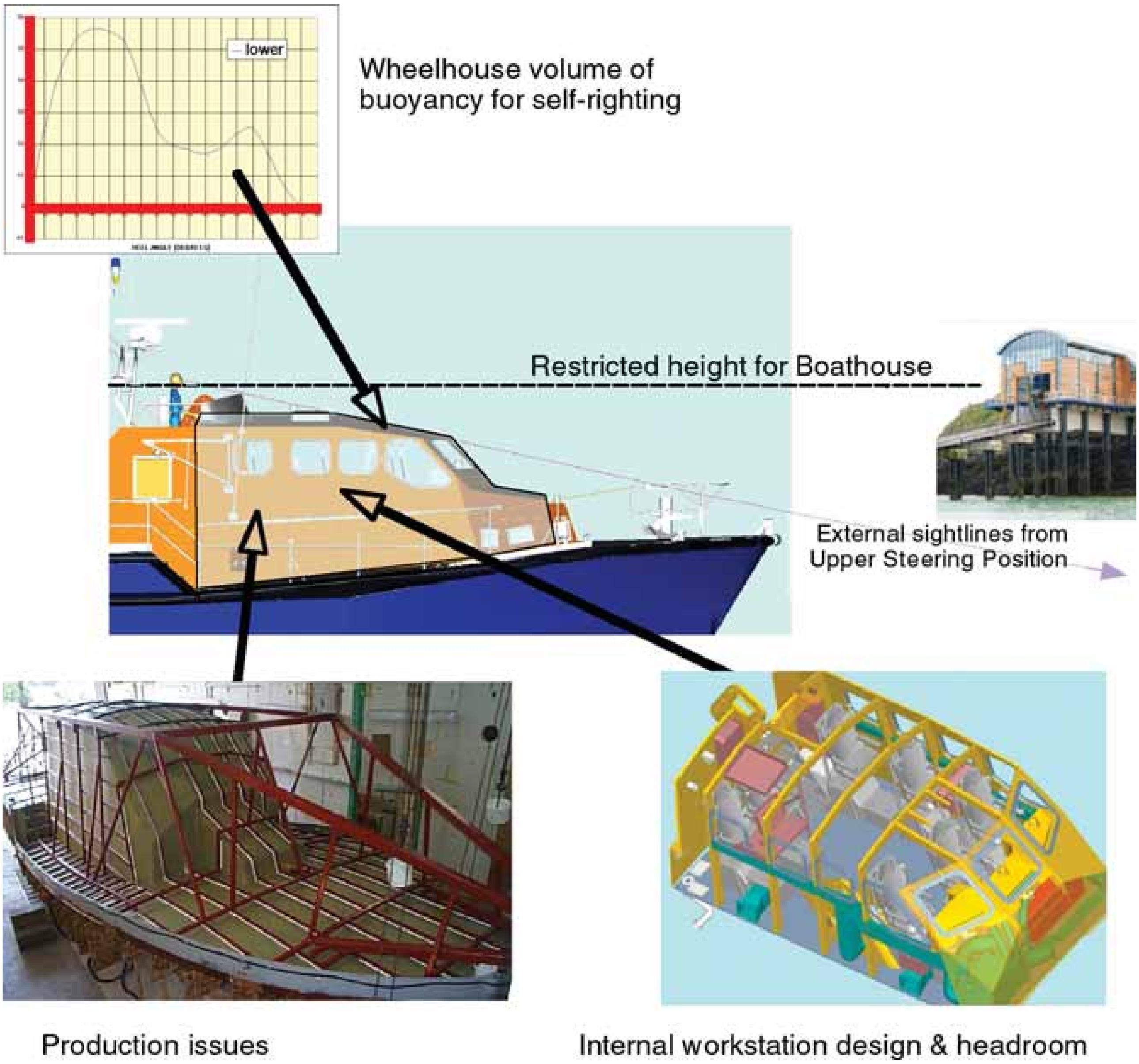

Figure K-2 RNLI design considerations for Tamar Class Lifeboat
Image copyright: RNLI

K.1.3 THE TAMAR HULL FORM

K.1.3.1 It is true to say that motions and other HF issues were not paramount in the consideration of the Tamar hull form. Since a lifeboat is much more than a transit craft taking personnel from one location to another at speed, it must fulfil other criteria apart from the declared speed and range requirements, for example:

a Operation in all weathers

b Self righting

c Stable working platform

d Good towing capability

e Slipway operations

f Operation by volunteer crews

K.1.3.2 The optimisation of the hull form for motion mitigation would have unacceptably compromised the other requirements for the craft, and hence she is a compromise of all factors.

K.1.4 THE TAMAR'S ERGONOMICS

K.1.4.1 As with all operators, the RNLI has a duty of care to discharge to its crews, and therefore research was undertaken into the ergonomic requirements for Tamar.

K.1.4.2 The real key to the success of this work was to consider all aspects of HF together. Therefore work was progressed concurrently on seating, comfort, workstation layout and command and control systems.

K.1.4.3 Since the hull form could not be optimised for motions, the RNLI were aware that there was a requirement for shock mitigation systems. Current seating was known to be limited, but there were few proven shock mitigating seats or other commercially available systems that were either affordable or acceptable from weight and cost considerations. Therefore the RNLI, with industrial and academic partners, undertook fundamental research into vessel motions, human frame capability and shock mitigating seating, which resulted in the development of a new crew seat.

K.1.4.4 At the same time, the RNLI also commissioned an audit and report on the proposed workstation layout (crew wheelhouse positions) to ensure that the seating and information/controls interfaces would produce an acceptable arrangement.

K.1.4.5 Since the new crew seat would aim to improve the safety of crews, it was deemed appropriate to try to keep crews in those seats for as much time at sea as possible. Therefore an integrated electronics system was developed which brings information, operation and control of the boat and its systems to the crew in their seats.

K.1.4.6 This work was undertaken by the Tamar design team supported by industrial and academic partners and specialist consultants in the field of human factors.

K.1.4.7 The Tamar design also features an Air Conditioning (AC) system which enhances crew comfort, however the consideration of the requirements of this system at an early stage lead to the incorporation of the AC power supply be incorperated into the boats hydraulic ring-main design. Again an example of HF issues needing to be considered fully at all stages of the design.

K.1.4.8 The Tamar design team also addressed the maintenance and production aspects of HF in the design to ensure that operational, maintenance and construction staff could carry out their tasks safely, efficiently and effectively.

K.1.4.9 Examples of some key points that arose from these considerations were:

a Engine room accessibility (clear walkways are provided right around both engines).

b Engine removal hatches have minimal fit out.

c The mast is designed to pivot forward to facilitate engine removal with the minimum of disruption to above deck systems.

d Primary fuel filters and changeover valves are easily accessible

e Bilge valve actuator fuses are easily accessible

f All junction boxes are tallied and fuses identified

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g Cable routing through glands is specified such that each cable on each boat passes through the same X-Y coordinate on the same gland.

h Gearboxes can be removed using built in lifting points over the engines

i Cylinder heads can be slung from built in lifting points

K.1.4.10 With increasing operational and maintenance experience, feedback received has been very positive in almost all aspects of the HF considerations. From operation at sea, to major work in boatyards, the inclusion of HF factors throughout the design process appears to be paying dividends for the RNLI.

K.1.5 RNLI PUBLICATIONS

K.1.5.1 The RNLI have published a number of articles and papers relating to the design of the Tamar class Lifeboat. Examples of these include:

Cripps, R., Rees, S., Phillips, H., Cain, C., Richards, D. and Cross, J. (2003) Development Of A Crew Seat System For High Speed Rescue Craft. Conference proceedings, FAST 2003, Naples, October 2003.

Cripps, R., Cain, C., Phillips, H., Rees, S. and Richards, D. (2004) Development of a new crew seat for all weather lifeboats. Conference Proceedings; SURV 6: Surveillance, Pilot & Rescue Craft. RINA, London UK.

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K.2 CASE STUDY: US NAVY SEALION TECHNICAL DEMONSTRATOR

K.2.1 THE SEALION-I CRAFT

K.2.1.1 The SEALION-I is an experimental, modular craft with a lot of opportunities for human factors engineering. Computer-aided design and full-scale mock-ups (see Figures K-3 to K-5) were used in an effort to optimize cockpit ergonomics. Much of the ergonomic design, human interfaces, and maintainability incorporated in this design have resulted from several decades of experience and lessons learnt regarding human factors engineering on boats and craft. An example of a recent lesson learnt that was incorporated is associated with the cockpit re-design for the SEALION-II. This re-design reduces the crew size needed to drive and navigate the craft from three to two. Under logistics transport, a crew of one is possible.

Figure K-3 The US Navy SEALION-I technical demonstrator.
Image copyright: US Navy

K.2.2 THE SEALION-I COXSWAIN'S CONSOLE

K.2.2.1 The Coxswains console was designed using ergonomics, computer-aided design and mock-ups. Nevertheless, after the design was completed and manufactured, room for improvements were found with further human factors studies and incorporated into the SEALION-II console design.

Figure K-4 Images of the SEALION-I Coxswain's CAD Console, mock-up and actual cockpit
Image copyright: US Navy

K.2.3 THE SEALION-I ENGINE SPACE

K.2.3.1 The SEALION-I engine space, shown in Figure K-5, is small due to the crafts volumetric constraints. However, given the space allowed, the engine space was designed and optimized for routine maintenance and operational requirements.

Figure K-5 THE SEALION-I engine room.
Image copyright: US Navy

K.3 CASE STUDY: ACTIVE SHOCK, INC. SEMI-ACTIVE 11M RIB SUSPENSION SEAT

K.3.1 INTRODUCTION

K.3.1.1 It is important to note that the design methods and lessons discussed in this guide are not only applicable to new boat programs, but should be employed whenever equipment is added or modifications are made to HSC. The following case study explains the methodology used in developing a new shock mitigation seat for an existing craft (the US Naval Special Warfare Rigid Inflatable Boat (NSW RIB)).

K.3.1.2 The Active Shock, Inc. (ASI) seat uses semi-active suspension technology to continuously change the damping characteristics by adjusting the electro-mechanical valve inside the absorber. The goal of the design is to automatically optimize the ride quality and provide maximum protection against shock-related injury over a range of seat and craft accelerations. Due to the relatively small design space afforded by the NSW RIB, the seat was designed for operators to ride in a semi-standing/sitting position.

ASI also engineered modifications to the frequently used controls to address changes in crew position and posture resulting from the introduction of the ASI seat. The steering column, bucket and throttle controls were moved closer to the operators. Also, the Navigator position handgrips were extended.

K.3.2 ASSEMBLING THE DESIGN TEAM

K.3.2.1 In developing a suspension seat for the NSW RIB, it was important to assemble the correct Subject Matter Experts early in the design process. Although ASI were uncontested experts in suspension system design, they admitted that designing suspension seats for high speed craft was a new area for them and assembling a design team to ensure nothing was overlooked was a significant step in risk reduction.

The resulting Integrated Product Team included members of:

- The U.S. Naval Special Warfare Group 3 and 4, who provided mission expertise;
- Battelle, who provided expertise in seat ergonomics and anthropometry
- United States Marine, Inc (USMI), who manufacture the NSW RIB
- and the Naval Surface Warfare Center-Panama City Division (NSWC PCD) who provided expertise in shock mitigation and human injury testing.

K.3.3 THE DESIGN APPROACH

K.3.3.1 DEFINE THE RIB SPECIFIC PROBLEM
Deck accelerations were collected during a series of NSW RIB missions to characterize the NSW RIB environment. By determining what the expected environmental input is at the base of the suspension unit, ASI was able to design a suspension unit and control algorithm with an acceptable shock mitigating output

at the seat cushion. During this data collection period, the design team conducted a Mission Task Analysis (MTA) with the craft operators. This was used to define the following design constraints:

- ***User Population:*** US Navy Special Warfare Combatant-craft Crewmen (SWCC) & US Navy SEALS, males only
- ***Required Equipment:*** Protective clothing & equipment (added as much as 24 inches to chest circumference)
- ***Structural Change Limitations:*** Deck footprint, line-of-sight, console interface redesign options
- ***Task Integration:*** Access to controls and displays with high frequency of use underway; ingress & egress

K.3.3.2 DESIGN THE SYSTEM USING CONCEPT MODELS/SIMULATION

K.3.3.2.1 MannequinPRO, a Human Figure Modeling Software was used to simulate the targeted operator population. The application contains anthropometric data for US Army personnel. There are no current US Navy anthropometric data available, but studies show broad applicability of Army data to other US military services for gross dimensions. The MannequinPRO model was customized to reflect the clothed anthropometry size increases identified during the MTA. This produced standard mannequins at 5th and 95th percentile stature with remaining dimensions calculated using multivariate regression techniques (percentiles are not additive – no such thing as “50th Percentile Man”).

K.3.3.2.2 Optimal ergonomic postures were modeled using the following criteria:

- Craft accelerometer data defined a resultant force vector – half-cone shape ~12° aft
- The thoracic kyphosis & lumbar lordosis curves of spinal vertebrae had to be maintained
- Intervertebral articular surfaces had to be perpendicular to the force application
- Spine, pelvis & leg relative orientation is critical to maintaining vertebrae in optimal position for injury reduction
- Reach envelopes, lines-of-sight & resultant head position produced by body posture had to be considered
- Space availability for the seat footprint on the deck was limited by the engine compartment and console, and could not be changed

These criteria produced three possible posture options: fully-seated, straddle, and standing. These options were first reviewed in CAD and then in a physical mock-up to determine their feasibility. The fully-seated seat would not fit within deck constraints and risked poor leg-to-spine angles during impacts. The standing posture would have proved too fatiguing during lengthy mission profiles. The straddle posture was chosen as an optimal trade-off.

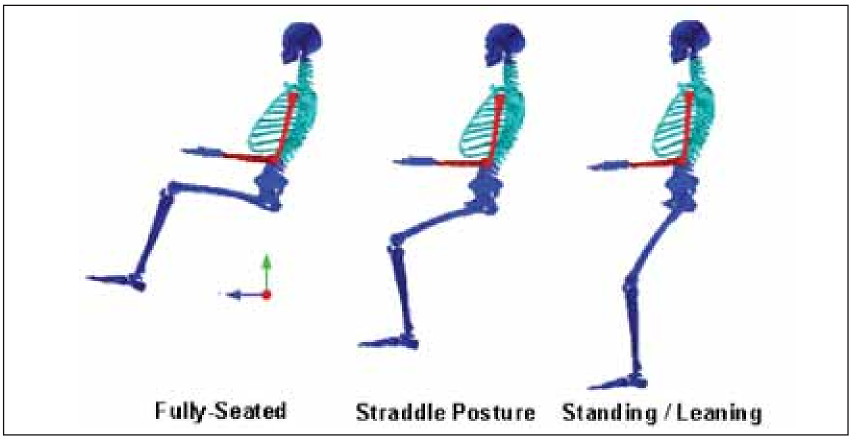

Figure K-6 Skeletal Analysis of Possible Posture Options.
Image copyright: US Navy

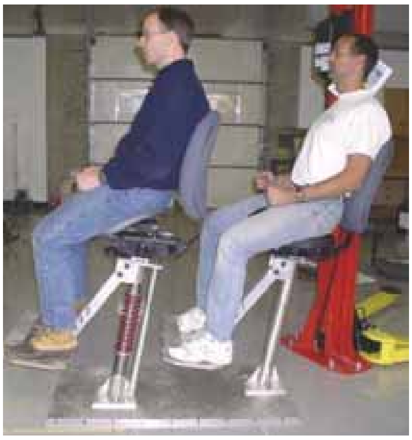

Figure K-7 Physical Mock-up for Evaluation of Proposed Postures.
Image copyright: US Navy

K.3.4 TEST METHODOLOGY

K.3.4.1 A 6-way adjustable physical seat and RIB console mock-up was built using a variety of commercial and purpose built seat pan shapes. A fit test of the multiple seat pan options was conducted using operators wearing their mission essential equipment. The console was raised and lowered to replicate the range of the suspension system's displacement. The mockup was used to:

- Confirm seat footprints fit on deck
- Determine necessary ranges of adjustability for seat components
- Measure reach envelopes, lines-of-sight & ingress / egress in aisles
- Revise final seat geometry, contours & dimensions
- Finalize console interface redesign options

Figure K-8 Seat and NSW RIB Console Mock-Up.
Image copyright: US Navy

K.3.4.2 TOTAL SYSTEM TESTING

The lessons learned from the mockup were fed back into the design of the prototype seats. These were built and installed on an NSW RIB, along with the necessary console modifications. Sea tests were conducted in waves ranging from 2-3 foot to 6-8 foot. Operators wore cold weather gear, which was considered worst case for anthropometric accommodation. The ISO 2631 Part-5 (spine stress dose) was used as a quantitative measure for shock mitigation. Video, audio, survey, and interview data was collected to determine comfort issues (i.e., hot spots), anthropometric accommodation, mission related issues, etc. The analysis from this initial testing led to further optimization of the seat design which was also confirmed via follow-on sea trials.

The resulting seat provided an average 24% reduction in shock at the operators' lower lumbar spine, as compared to the previous standing/leaning bolsters.

Figure K-8 ASI Seats fitted to the NSW RIB.
Image copyright: US Navy

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ASCC Air Publication 61/116/20. H*uman engineering requirements for rapid prototyping for operator/maintainer interfaces.*

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10. Abstract:
This Guide supports the High Speed Craft (HSC) community by providing Human Factors Engineering guidance to enhance the specification, design, evaluation and operation of HSC. It provides guidance on many topics including assisting the designer with the inclusion of features than can reduce exposure to high levels of shock & vibration. This will help to reduce the risk of fatigue, acute and chronic injuries, and therefore enhance operational effectiveness and readiness, and the health & safety of the crew and passengers. The Guide also provides assistance with man-machine interface issues than will enhance situational awareness and therefore safety. The Guide has been produced with the cooperation of the ABCD Working Group on Human Performance at Sea and significant contributions have been received from the UK RNLI and the US Navy.

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