Mark Geiger, M.S., CIH, CSP, Alex Ruttenberg, M.S., Chris Parker

Navy Human Factors Engineering/Safety Ship Design Lessons Learned

ABSTRACT

Members of the Naval Safety Center and affiliated support personnel conducted Human Factors Engineering (HFE)/safety evaluations of two in-port Navy ships to assess the vessels' compliance with accepted HFE/safety design standards and HFE/safety 'best practices'. The intent was not to identify parties responsible for any deficiencies, but to translate the surveys/assessments into a user-friendly pictorially-oriented HFE/safety lessons learned design guide based on real world examples for use by both ship acquisition program management and designers for application to existing and future ship programs.

Over five hundred specific HFE/safety design deficiencies were identified during the assessments, along with a number of more general findings. These represent HFE/safety issues that will directly or indirectly impact ship operations, maintenance and crew safety. The type of deficiencies found covered the full spectrum of known HFE/safety shipboard hazards, ranging from insufficient access for maintenance to improper hazard warning labels and operating instructions, from lack of spatial relationships to a lack of consistency in design or placement of identical pieces of equipment in different locations throughout the ship, and in some cases, a lack of safety equipment that presents significant hazards to personnel.

This paper describes the assessment methodology, findings, guidance and recommendations on how to properly address HFE/safety design issues throughout Navy ship acquisition process lifecycle. The incorporation of these lessons learned in current and future programs would significantly improve personnel safety, reduce human error, and improve human and therefore, ship performance. It is important to note that the findings and the corresponding benefits to the identified corrective actions are generally consistent with similar issues found in commercial vessels and offshore platforms.

INTRODUCTION

Human Factors Engineering (HFE) is the specialized engineering discipline concerned with ensuring that systems are designed to match the capabilities and limitations of the personnel, which will operate and maintain them. HFE is one of the critical elements of Human Systems Integration (HSI), which is the U.S. Navy's systems engineering approach, implemented by the HSI Naval Sea Systems Command (NAVSEA) Directorate (SEA 03), that considers the human a critical component of the ship.

HFE combines knowledge of human psychological, physical and social capabilities and limitations with traditional engineering principles and procedures to design ship systems, equipment and software from the user's point of view. Ship system(s)/equipment(s) must be designed with consideration for the personnel that will install, use and maintain them. Failure to do so, can lead to human error, which can result in serious mishaps as well as injuries to the crew, poor maintenance and operation, and crew dissatisfaction.

Studies have shown that the most prevalent cause of accidents and other maritime casualties on military and commercial ships and offshore structures is due to human error (Rothblum 2000, USCG 1995, Bryant 1991). A high fraction of such events have been associated with environments and design configurations that increase the potential for error or fail to mitigate its consequences (Reason 1990, Dekker 2000).

DOD, Navy and commercial acquisition program requirements and design criteria/guidance have increasingly stressed the integration of HFE into the systems engineering and design processes for military ships. The U.S. Naval Research Advisory Committee (NRAC) has estimated that including human elements in the initial design phases of ships and equipment could improve their effectiveness and availability by 30%, survivability by 15% and reduce the number of casualties by 10%, while reducing personnel by 20%. Concurrently, the Secretary of Defense has issued policy memoranda establishing initial and subsequent objectives of reducing DOD-wide mishaps by 50 and then 75 percent (Chu 2003, SECDEF Memo 19 May 2003). While the principal benefit of the incorporation of HFE/safety design requirements and best practices is the reduction of human errors and improved crew safety, the application of HFE/safety principles has the potential of creating significant life cycle cost savings for the ship program office.

In an effort to determine if Navy HFE requirements and guidelines have been effectively translated to operational ship design and to assess opportunities to achieve the DoD's stated mishap reduction goals, CNO 09FB Navy's Safety Liaison Office conducted a series of HFE/safety assessments of in-service Navy ships. Drawing upon over 40 years of combined HFE/safety and ship acquisition experience in the design and operation of military and commercial ships, in 2005 the authors conducted an on-site HFE/safety design review/assessment on two (2) in-port amphibious assault ships (L-Class). Using both Navy HFE/safety design requirements and established best practices, the HFE/safety assessments identified issues directly attributable to design that were likely to cause or contribute to human induced errors; inefficiencies that could cause injury or death to ship personnel; reduce operational efficiency; damage to equipment, furnishings or the ship itself; cause environmental pollution; all of which have the potential to reduce the ship's mission capability.

This systematic assessment highlighted existing HFE/safety best practices and identified configuration deficiencies whose correction should be incorporated into existing and future ship designs. The assessment also provided the evaluated ship with feedback on immediately-correctable identified design deficiencies. The intent of this project was <u>not</u> to identify parties responsible for any deficiencies, but rather the goal was to conduct a series of surveys/assessments and develop a user-friendly, pictorially-oriented HFE/safety lessons learned design guide based on real-world examples for use by both existing and new ship programs as well as ship and system designers.

EVALUATION PROCEDURE/METHODOLOGY

Pre-Ship Evaluation

In order to prepare for the shipboard assessment, ship-specific data were obtained and evaluated including the layout of the entire ship (with ship alterations made) to gain an understanding of the current ship configuration and equipment to be evaluated as well as to solidify the strategy for the evaluation process.

Naval Safety Center mishap data for amphibious class ships were obtained and analyzed for potential root-cause design issues. The incidents and accidents were categorized and the location/equipment involved were also documented. This information was then used to assist in the prioritization of the ship spaces for the assessment (those ship spaces that had the greatest potential for HFE and safety impacts in terms of frequency and severity).

Personnel using the spaces were requested to participate to facilitate the identification of HFE/safety issues. Ship safety staff was also asked to be available during the evaluation as needed (every effort was made to minimize the impact of the evaluation on ship operations and crew performance of daily duties).

A pre-evaluation meeting with the Commanding Officer (CO) and Executive Office (XO), pertinent members of ships crew, Safety Center representatives and the assessment team was conducted to explain the purposes of the evaluation and its non-attributional intent. A meeting with safety officer, Naval Safety Center liaison, and sequentially with ship department representatives was held to introduce the objectives of the evaluation, review areas of potential concern and systematically elicit fleet/operational input to the evaluation process.

Ship Evaluation

The assessment looked at, to the extent practicable given space accessibility, personnel availability, and time constraints, a wide range of ship spaces and associated system(s)/equipment(s), evaluating compliance with HFE/safety design standards and accepted best practices. Optimally, the assessment would have been conducted during all ship operating conditions to reflect the crew's responsibilities and tasks as well as system and equipment functionality under representative operating conditions; however, the team was only able to conduct pier-side assessments.

The assessment team consisted of two (2) educated and trained human factors engineers and two (2) Navy acquisition safety experts and occurred over two evaluation periods in May and July of 2005.

The assessment team attempted to evaluate each space following a consistent procedure. Each space/compartment was divided into quadrants, with the review starting in the Port-FWD corner, scanning the overhead, followed by the bulkhead and then the floor. The team proceeded through the compartment and repeated the review in the other quadrants. If the quadrants were too large, it was divided further into manageable sections. The estimated time required for each space ranged from one hour for each large complex space, such as the main and auxiliary machinery compartments to 15 minutes for smaller spaces.

The assessment began with the ship spaces that had the greatest potential for HFE and safety impacts (in terms of frequency and severity). Compartments were prioritized based on analysis of ship class specific Naval Safety Center mishap data and general research on known HFE/safety shipboard hazards locations. The general sequence of spaces evaluated included:

- Machinery Space (including associated systems and control stations, work shops, filter rooms as well as Auxiliary Machinery spaces)
- Bridge
- Flight Deck/ Topside
- Communications Spaces
- Air Traffic/Flight Deck Control
- Medical Spaces/Dental
- Weapons
- Well Deck

During the course of the HFE/safety assessment, the following design aspects were reviewed from the perspective of operations, crew safety, systems maintainability, task complexity and overall human performance:

- Stair/ladder design, orientation, location, size and type.
- Layout, orientation and design of operator consoles, control panels, displays and alarms.
- Location, orientation and access to valves and valve handles.
- Placement of equipment removal assisted lifting devices.
- Location or orientation of equipment, furnishings, and structures.
- Accessibility to equipment for operation, maintenance or removal.
- Personnel and material movement for normal and emergency conditions.
- Equipment labeling, signage (instructional and warning), and alarms.
- Passageway/walkway clearance and flow.

Crewmembers were asked information about specific tasks in their shipboard workspaces. Following are the "Big Seven" questions that were either specifically asked of or generally referenced in discussions with the crew:

- What are the specific tasks required of the ship’s crew to both operate and maintain the overall system of each piece of equipment?
- Who will be the user/maintainer (e.g. male or female or both, rate/rank, etc.)?
- What is the operating environment at each work site (i.e., temperature, motion, humidity, noise, lighting)?
- What level of training will the users possess?
- What is the worst case under which the equipment or system might be used?
- What types of human errors could be anticipated with the equipment or system?
- What consequences would result from those human errors (e.g., loss of equipment, personnel injury, degradation of ship mission)?

The following summarizes the typical identifiers of HFE/safety design issues used by the assessment team:

- Spatial Relationships of controls and displays: Users making incorrect associations between the arrangement of presented information and the actual system(s)/equipment(s) that it represents may lead to incorrect assumptions and result in human error.
- Shortcuts: Users tend to find the 'easy’, often unintentional, means to complete a task even if it includes unsafe behavior. Providing the user with the correct tools to complete the task as well as eliminating options for doing otherwise can significantly reduce risks that result. Additionally, the common existence of 'shortcuts’ may be used to help identify design deficiencies or maintenance issues requiring corrective action.
- Consistency: Human performance can be significantly improved through the use of pattern recognition in terms of consistent orientation, location, color and even abbreviations used on human interfaces.
- Access/Accessibility: Design of systems should ensure that there is adequate space for the body (or body part) to complete tasks required while wearing appropriate gear and carrying appropriate equipment for the full range of user anthropometry (sizes and capabilities).
- Feedback: Human-Machine Interfaces require instant, constant and relevant feedback of system (as well as interface) status.
- Personnel and Materials Movement: Safety considerations based on arrangements of equipment such as ladder angles and configurations; availability and effectiveness of materials handling equipment. Evaluation of the safety and efficiency of current designs and practices including the work-around such as loading/unloading parties involving dozens of crewmembers.
- Habitability: Quality of life and quality of work become safety and health concerns including ventilation, heat and noise stresses that impact physical safety and well-being.

When an HFE/safety deficiency, or conversely a 'best practice’, was identified, the location and nature was documented:

- For each deficiency identified, a detailed description of the ‘issue’ was documented, the potential impact noted and a proposed design and/or operational solution(s), as appropriate, were outlined.
- For each best practice identified, a detailed description of the best practice was documented.

Where possible, photographs were taken to accurately capture issues/best practices identified. Additionally, physical measurements were taken to further illustrate the characteristics of issues identified.

FINDINGS

There were over five hundred specific HFE/safety deficiencies identified during the assessments, along with a number of more general findings. Many of these represent HFE/safety issues that directly impact ship operations and crew safety. Locations of these deficiencies ranged from berthing (living) spaces to machinery rooms, from food preparation facilities to cargo holds, and from offices and workshops to electrical equipment rooms. The type of deficiencies found covered the full spectrum of known HFE/safety shipboard hazards, ranging from insufficient access for maintenance to improper hazard warning labels and operating instructions, from lack of spatial relationships to lack of consistency in design or placement of identical pieces of equipment in different locations throughout the ship.

Due to the nature of the assessment – not a comprehensive assessment of all ship spaces – no effort was made to conduct any statistical assessment of the evaluation findings. The objective was to develop a 'lessons learned' document, in a format that described issues captured (pictorially, if possible) with recommendations for elimination or mitigation of identified deficiencies, and where captured, pictorial examples of best practice design characteristics as well as reference to the applicable requirement from HFE/safety guidance documents. The findings will be used to illustrate points outlined in HFE/safety requirements documents, design guidance materials, and accepted industry best 'best practices' for use by ship acquisition professionals, the NAVSEA ship design community, and the evaluated ships for potential immediate corrective action.

While no statistical analysis of the evaluation findings was conducted, the data collected was organized by issues categorized in order to perform rough trend analyses, and some correlations between the frequencies of issues, location and the categories above were documented to help illustrate significant trends.

The hazards identified were broadly categorized as follows with emphasis on 'Deficiency Category'. HFE/safety deficiencies were categorized into 15 broad categories and approximately 25 sub-categories roughly based on the topic areas of the ASTM F1166 (Table 1).

TABLE 1. HFE/Safety Deficiency Categories and Potential

Category	Sub-Category	Descriptions (Typical design Issues)
Controls	Controls	The controls chosen are often not appropriate for the function, labeling is inadequate or not in the correct location, or controls are not arranged in consistent and safe (cannot be accidentally bumped or engaged) locations.
Displays	Displays (Location, Orientation and Arrangement)	Visual displays often don't conveying information effectively due to labeling, coding, content. Visual (and auditory) displays are often located out of sight or earshot to be read impacting the comprehension of information displayed in terms of time and accuracy. Additionally, displays such as gauges should be located to suggest function, e.g., gauges representing pressure in and out should be IN (left) and OUT (right).
Alarms	Alarms	Content and coding of visual and auditory alarms often do not use design to solicit appropriate behavior including consistent color, labeling, location, response and acknowledgement requirements.
Control, Display and Alarm Integration	Control, Display and Alarm Integration	Controls, alarms and displays are often arranged with no association between functions therein or their position fails to coincide with actual equipment orientation (i.e., spatial relationships).
Anthropometry (dimensional & physical performance "Fit" between personnel & workspace)	Anthropometry	Design of marine systems shall consider the physical dimensions of the user population that will operate/maintain, traditionally, 5^{th} % females to 95^{th} % males. Heights of equipment, for instance often can accommodate the high end or low end of the range, but not both.
Workplace Arrangement	Design for Work Positions	The design of work spaces often does not provide an arrangement that supports safe postures or physical/visual access for operation. This includes mounting heights of controls/displays based on postures (standing, seated, squatting, etc) and dimensions of desks, consoles and workbenches.

Category	Sub-Category	Descriptions (Typical design Issues)
	Consoles and Panels	Console and panels are often physically located and positioned so as to make it difficult to tell which equipment is being operated and how. This includes consistent locations, visual access and spatial relationships with equipment.
	Other equipment	Pumps, strainers, equipment racks and file cabinets are often arranged without proper access for operation or removal, or in the case of file cabinets located FWD/AFT to keep roll from opening drawers.
Access Aids	Stairs	Stairs typically are too steep (should be between 30-35 degrees), too narrow or have tread depths that are too shallow and do not account for adequate overhead clearance (84").
	Ladders	Ladders often impede safe operation in terms of dimensions, angles (incline ladders less than 60 degrees and vertical ladders 90 degrees), handrails and safety devices, if appropriate (cages or fall protection devices).
	Platforms	Platform design often does not provide the correct height or area required for a particular task. Handrails are also usually not adequate for safety to prevent a fall the platform.
	Hatches and Doors	Hatch dimensions are often too small, have a sill too high or top too low to support operation by personnel wearing appropriate clothing. Hatches mounted on horizontal surfaces are often heavy and protrude form the standing surface or are recessed also providing a tripping hazard. Doors often swing into spaces or do not have clearance for full swing.
	Walkways/Passageways	Walkways and passageways often present obstructions in the overhead or along the bulkheads or do not provide the width for the volume of personnel passing especially during emergency situations.
Valve Placement	Valve Placement (Location and Orientation)	Placement and orientation of valves is often out of reach of the operators or does not provide physical clearance in order to generate adequate torque using a safe, ergonomic posture.
HCI	HCI	Computer interfaces do not meet user expectations in terms of behaviors of the interaction (navigation and feedback) and layouts of information presented.
Habitability	Noise	Unsafe noise levels are a major problem, especially in machinery spaces where there is extended exposure to high noise levels and use of hearing protection may be inconsistent.
	Climate	Heating and cooling are not providing a comfortable (and safe) living or working environment. Machinery spaces reach unsafe heat levels and ventilation may not re-circulate fresh air in spaces that have hazardous vapors or gases.
	Lighting	Lighting levels are often too low for a given task, do not consider glare (especially on the bridge) or do not consider specific tasks and situations (i.e. Night Vision Goggles (NVG) compatible).
	Accommodations	Adequate provisions to support shipboard quality of life including berthing, messing, sanitary spaces, lounges, etc. are often reduced. Volume of storage, adequate clearance in and around berthing racks, and lounge facilities are limited and often do not support the quantity of personnel for a given berthing area.
Labeling	Labeling	Labels are often in the wrong format, color or location. Most labels are white letters on a dark background, which should be the opposite. Hazard labels should identify the hazard, how to avoid it and the consequences if not avoided. Labels are also often below controls and displays and should be above.
Material Handling	Material Handling	Systems requiring push/pull, lifting, carrying tasks don't consider design to provide safe postures. For example, handles or lifting aids may be required for safe handling tasks.
Maintenance	Maintenance	Equipment doesn't consider requirements for maintenance in terms of physical access (clearance and covers) and consideration for tools and test equipment
Hazards and Safety	Workplace Hazards	Door swings, protrusions and sharp corners often exist within walk and work areas. Walkways should not have equipment or racks mounted in

Category	Sub-Category	Descriptions (Typical design Issues)
		the areas between 77” and 52” or below 38” above the deck.
	Equipment/Mechanical/Fluid Hazards	Guards or safety barriers from hazards such as equipment (blades, hot/cold), fluid and electrical hazards are often missing.
	Hazard Marking	Hazards that cannot be eliminated very often do not have appropriate clear, concise signage located such that the hazard is identified with provisions for avoiding the hazard and consequences of not followed.
	Emergency Egress	Emergency egress routes may not be provided or may not be clearly marked in terms of design of doors that are safely and easily operated, clear passageways and signage marking the egress route.
Communications	Communications	Communications systems often do not have technical capabilities for safe and efficient communication given the operating environment. For example, loudspeakers in machinery spaces can be too loud in some parts of compartment, while too quiet in others.

Location/type of space where the deficiency (or best practice) occurred was categorized as follows (Table 2).

TABLE 2. HFE/Safety Deficiency Location Classification

Compartment Type
Berthing/Habitability
Bridge
Flight Deck/Topside
Galley/Mess
Ground (Flight Deck/Hanger Deck) Control
Hanger Deck
Machinery Spaces
Medical Spaces
Office
Passageway
Storage

The majority (over half) of the HFE/safety deficiencies/issues identified fell broadly within following main categories: Workplace Arrangements, Labeling, Maintenance, Hazards & Safety, Access Aids and Controls. The evaluation found that there are certain ship spaces, such as the machinery rooms and accommodation spaces, which required a greater amount of focus. Because there is more crew interaction within these spaces, a greater potential for design-induced human error exists. Correspondingly, the vast majority of deficiencies/issues were found to be located in the machinery spaces, followed by the flight deck/topside, medical spaces and bridge.

The following specific examples are provided to illustrate the deficiency/issue identification and capture methodology, types of deficiencies / issues identified, potential impacts and recommended actions. All of the examples provided are fully representative of the full-range of deficiencies/issues identified during the ship evaluation.

Location/Equipment(s): Passageway – Horizontal Stem Valve
Issue Category: Valve Orientation and Location
Issue(s) Description: Due to the height of this valve, which is in a passageway approximately 7' off the deck, it is inaccessible without the use of a ladder or elevated platform. Also, since this handwheel is greater than 6" in diameter, it should be located for two-hand operation.
Potential Impact: Placing valves in this location will make the valves impossible to reach, especially in emergency situations and if reached with the aid of a ladder, require the dangerous and awkward postures.
Reference Criteria: ASTM F1166, Section 24.6.1, 24.6.6
Recommended Actions: Relocate this valve so that it is between 42" and 72" above the deck surface (for normal operations) or between 45" and 60" above the deck for emergency operations.

FIGURE 1. Valve Orientation and Location: Main Passageway

Location/Equipment(s): Flight Deck/Topside: Port Side Troop Walkway – Ladder Hatch

Issue Category: Access Aids – Vertical Ladders

Issue(s) Description:
The design of this ladder that passes through the deck ends at the deck providing an unsafe situation as personnel translate to the deck.

Potential Impact:
Personnel could slip or fall of ladder as they transition from ladder to deck or vice versa.

Reference Criteria: ASTM F1166, Section 31.8.5

Recommended Actions:
Provide rungs or vertical handrails (mimicking the stringers below) on the bulkhead above the deck level in order to provide secure hand support as personnel pass through the deck on to/off of the ladder.

FIGURE 2. Access Aids – Vertical Ladders: Flight Deck/Topside

Location/Equipment(s): Flight Deck/Topside: Port Side Flight Deck Catwalk – Lifeboat Instruction Label

Issue Category: Labeling

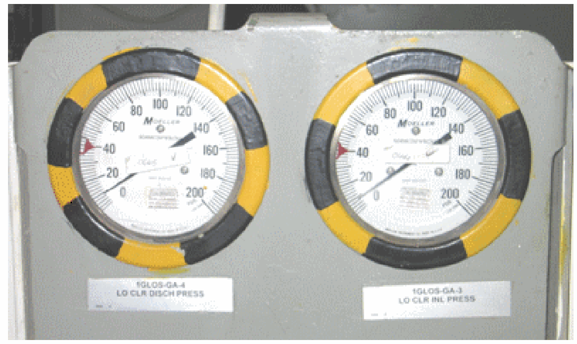
Issue(s) Description:
The location and format of the instruction label for the operation of the lifeboat makes this extremely difficult to read. The label is located behind a handrail and a steel plate and cannot be viewed head-on, only from above, and the format does not follow standard instruction labels, such as black lettering on a white background for improved readability even in low lighting.

Potential Impact:
Incorrect operation of the equipment may result from this faulty instruction labeling especially considering that this is required to be read during high-stress emergency situations.

Reference Criteria: ASTM F1166, Sections 29.4 and 29.7.4

Recommended Actions:
Change the location and the format of the instruction label to a make it more readily visible and readable at eye level. Move the label to the top of the equipment to be visible while standing in front (and remove masking tape). The label should be white letters on a black background and the title should be 50% larger than headings which should be 25% larger than inscription text.

FIGURE 3. Labeling: Flight Deck/Topside



Location/Equipment(s): Machinery Spaces: Auxiliary Machinery Space – L/O Pressure Gauges

Issue Category: Displays (Location, Orientation and Arrangement)

Issue(s) Description:
The LO pressure gauges read INTAKE on the right and DISCHARGE on the left which is the opposite of the convention as personnel read from left to right. Additionally the labels are below the gauges, which are read after reading the gages as personnel also read from top-down.

Potential Impact:
Personnel reading the gages might assume that the pressure reading on the left is IN and DISCHARGE on the right as convention is that information read from left-right, top-down should mean IN-OUT. Data could therefore be erroneously collected and flawed decisions made.

Reference Criteria: ASTM F1166, Section 7.1 and 29.7.4

Recommended Actions:
Swap the location of the gauges and move the gauge labels above the gages so that there is a cue to the user what information will be displayed on the gauges before it is read.

FIGURE 4. Displays: Machinery Spaces - Auxiliary Machinery Space

Location/Equipment(s): Galley/Mess: Bakery – Emergency Escape Scuttle Hatch Key

Issue Category: Hazards & Safety - Workplace Hazards

Issue(s) Description:
Key used to open emergency hatch is hung on a length of angle iron 12" above the deck adjacent to the hatch.

Potential Impact:
The angle iron rack for the key is a tripping hazard due to its height as well as its location approximately 12" away from the perimeter of the work table. Crew expressed that they trip over this regularly while moving through space or while carrying food.

Reference Criteria: ASTM F1166, Section 51.4.4

Recommended Actions:
Remove the angle iron rack for the key and hang it on an adjacent bulkhead or move the rack closer to the work table out of the flow of crew passage.

FIGURE 5. Hazards & Safety - Workplace Hazards: Galley/Mess

CONCLUSIONS AND RECOMMENDATIONS

Lack of consistent attention to HFE/safety considerations was apparent in the wide range and high frequency of issues identified during this evaluation. The potential costs in terms of mission effectiveness, crew efficiency, habitability and safety are difficult to quantify, but certainly pose a cumulative impact on force efficiency and life cycle cost management. While some of the issues identified represent fundamental deficiencies in ship design (for example poor layout and design of the bridge), many are immediately correctable. Past experience has demonstrated that correcting these deficiencies will not only result in a safer, healthier, more efficient crew, and operational cost savings, but can also be accomplished with little operational impact and negligible capital investiture. Common opportunities for cost effective retrofits, minor engineering changes and relatively low cost ship alterations (SHIPALTS) may include, but are not limited to, the following:

- Readjusting closure mechanisms of egress doors and hatches associated with emergency escape trunks.
- Performing repairs, routine maintenance and minor improvements on shipboard ladders and handrails.
- Reducing the use of inclined ladders in areas of high material handling.
- Improving access to system(s)/equipment(s) requiring routine (frequent) maintenance.
- Clarifying the hazard condition on labels and signs (warning v. caution), eliminating redundant signage and ensuring consistent label/signage format.
- Using handle extensions or relocating certain of the smaller valves, particularly in the engine room and auxiliary spaces to ensure access for the full-range of user anthropometry.
- Ensuring the use of consistent scales for co-located gauges displaying similar information.
- Changing the piping layout so as to minimize unsafe behavior or personnel standing on pipes to access equipment (Rigid stands above some pipe chases may be needed where piping cannot be moved).
- Eliminating intrusions in passageways and other high traffic areas (tripping hazards, knee-knockers, etc.).
- Ensuring adequate access for material/equipment routing to/from workshops and workspaces.

Information acquired during this ship design evaluation effort will be instrumental in assisting the Navy to design safer, healthier, more operator-friendly and maintainable ships. Efforts are already underway to incorporate the illustrative findings of this review into actions for the next generation amphibious assault ship programs.

A commitment to implementation of existing HFE/safety requirements and updated design guidelines early and often in ship acquisition programs is required to ensure that new naval vessels are designed in accordance with the current standards of practice. It is critical to incorporate these design criteria and practices as early and often in the program lifecycle. However, programs in which such HFE/safety technical support and program oversight has been implemented have achieved significant improvements in design; avoided or remedied common design errors as late as at the 90% design completion program stage (Dalpiaz, et al 2005).

DISCLAIMER

Opinions are the authors' and do not necessarily represent official Navy policy.

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Mark Geiger M.S., CIH, CSP *is the Naval Safety Center's acquisition safety expert in the Chief of Naval Operations Safety Liaison Office,.. His background spans 25 years of diverse experience in the occupational health and safety, industrial hygiene, and environmental fields. He holds Master of Science degrees in Environmental Engineering (M.S.E. Civil Engineering, Catholic University, 1998) and in Environmental Health Sciences (Industrial Hygiene and Occupational Safety from Kettering Laboratory at the University of Cincinnati, 1980). He is certified by the American Board of Industrial Hygiene (CIH 1983) and the Board of Certified Safety*

Professionals (CSP 1991). He may be contacted at Mark.Gegier1@navy.mil

Alex Ruttenberg, M.S. *is a Program Manager at BMT Designers & Planners, Inc., Arlington, Virginia. He is responsible for managing environmental, safety and health support for US Navy ship acquisition programs and supporting research and development efforts. Mr. Ruttenberg holds a Master of Science degree in Environmental Science from Johns Hopkins University. He may be contacted at ARuttenberg@dandp.com.*

Christopher Parker *is educated and practiced in maritime applications of Human Systems Integration (HSI), Human Factors Engineering (HFE), ergonomics and related disciplines for government and commercial maritime clients, including new ship program offices, U.S. Navy research & development programs, in-service engineering agents, and commercial shipyards. He is currently the HFE lead for all Surface assets in the U.S. Coast Guard's Deepwater Program. He holds a bachelor's degree in Psychology and studied Human Factors and Ergonomics at the University of Dayton graduate program. He may be contacted at Cparker@dandp.com.*