1 Module 5 contains practical information intended for the Naval Architect/Ship Designer for improving the ship design conditions on ships. Module 1 (Fatigue – Causes and Consequences) should be read prior to going through this module.

Why do ship designers need to know about shipboard fatigue?

2 The International Maritime Organisation (IMO) has taken steps to publicise the role that human fatigue is increasingly recognised to play in Maritime Accidents, e.g. MSC/Circ.565. Crew Fatigue jeopardises ship safety and can cause accidents [1, 2] when it leads to human error. Human error is believed to be the major cause of accidents across many industries (Donaldson, 1994). Evidence for the role that it fatigue plays a part in maritime accidents has been provided by recent submissions to IMO, e.g. those made by Japan (MSC 71/INF.8; MSC 69/INF.16); and Finland (MSC 68/INF.15). In addition to accidents, human fatigue also affects the potential for operational problems, system breakdowns and near miss-accidents. Fatigue can detrimentally affect factors such as decision-making, which ultimately leads to undesirable situations and international studies [3-8]. Whatever the cause, the effect of fatigue on performance is serious, threatening safe operations which rely on alertness and concentration. In addition to the threat of to safe and secure operation of a ship, shipboard fatigue can jeopardise negatively affect seafarers' physical and psychological health, at a high cost to the individual and the industry.

3 Fatigue can result in long term effects on health and clinical illnesses, increasing the risks of pain, stress, obesity, coronary heart disease, gastrointestinal disorders and diabetes. Long term effects also point to mental health problems such as negative mood states and depression. Seafarers work in a physically demanding environment that requires a high degree of alertness and concentration. Exhausted seafarers are also more vulnerable to the many hazards on-board ships, resulting in slips, trips and falls, strikes by falling objects, burns, body strains and other injuries. Injury claims from P&I Club statistics illustrate how much these hazards cost the industry, in addition to lost time and vessel delays.

4 As highlighted in Module 1, fatigue can arise from a range of factors but is primarily affected by inadequate restorative sleep, excessive wakefulness, work/sleep at inappropriate times of the body clock (circadian cycle) and demanding mental and/or physical work (including keeping balance in heavy sea states). Even the boredom of watchkeeping in the still of the night can cause fatigue. Inadequate restorative sleep (duration and quality) deprivation is among the main causes of seafarers' fatigue but it is not the sole cause. Crew also become fatigued as a result of amongst others, sleep is affected by the living and working environment onboard [9, 10]. This module will concentrate on guidance for improving the ambient environmental conditions onboard ship, as this is the main area where class rules and guidance can be used to alleviate fatigue. However, there is a limit on what can be achieved through design intervention with regards to the ambient environment. In light of this, the working environment and the working practices should be designed to reduce or compensate for crew fatigue. This module deals with design impacts and should therefore be read in conjunction with the other modules.

5 Reducing shipboard fatigue will require orchestrated action by many groups, including flag states, shipowners and operators companies, seafarers and administrations. Naval architects and ship designers need to make their unique contribution by improving the
design of shipboard conditions and incorporating 'fatigue proofing' into ship and equipment design to reduce potential to cause fatigue. Improving the design of shipboard conditions.

HOW DOES FATIGUE AFFECT CREW PERFORMANCE?

6 Fatigue can arise from sleep-deprivation, from physical or mental exhaustion: even from the boredom of watchkeeping in the still of the night. Whatever the cause, the effect of fatigue on crew performance can be crippling, bedevilling safe operations which rely on alertness and concentration. Fatigue affects crew performance in a number of detrimental ways:

1. Causes drowsiness
2. Impairs perception (e.g. causing failure to detect visual or auditory stimuli)
3. Clouds judgement
4. Slows reactions (physical and mental)
5. Reduces motivation, encouraging apathy

7 The effect fatigue has on seafarers' performance is now well-understood thanks to comprehensive studies which were undertaken on the subject:


3. Seafarer fatigue: Wake up to the dangers. Submitted to IMO by the International Transports Workers' Federation. (IMO MSC 69/INF.10.).


8 The first two studies were conducted on behalf of the Australian and United States administrations respectively, whilst the third study, undertaken by the International Transport Workers' Federation, analysed the views of seafarers all over the world:

9 "Based on responses from 2,500 seafarers of 60 different nationalities, serving under 63 different flags, the report demonstrates the disturbing extent of excessive hours and fatigue within the industry." (IMO MSC 69/INF.10.).

10 These reports provide clear evidence to the extent of the problem and the ways in which fatigue is detrimental to performance. The third report contains a number of recommendations for improvements, the most pertinent for naval architects and ship designers being (a)

11 In controlling and managing the risks of fatigue at sea the consideration of shipboard ergonomics and the improvement of conditions on board are important considerations ability in ensuring seafarers are provided with the best opportunity to:

1. gain an adequate quality of sleep onboard; and
2. maintain safe levels of alertness and performance during duty periods. the improvement of shipboard conditions,
Before examining the relationship of ergonomics to fatigue, some discussion will be given to those aspects of fatigue that can be influenced by the application of ergonomics.

**What elements of fatigue can be influenced by design?**

There are various aspects of seafarers' fatigue that can potentially be influenced by the design of the living and working environment. Excessive heat or cold, too much or too little humidity, poor air exchange in enclosed spaces where people live and work can cause fatigue. Fatigue that results from the working and living environment can be alleviated by design improvements to the design of the living and working environment. The following aspects should be considered in design [9]:

**14 Sleep area (Design for sleep)**

.1 Cabin, cool, ventilated, quiet and dark
.2 Bunk design and layout, add sofa – different orientation
.3 Mattress, bedding
.4 Insulate and/or isolate sleeping areas

**15 Ship seakeeping – minimise in living and working spaces**

.1 Ship movement
.2 Vibration
.3 Noise

**16 Accommodation spaces and layout (Design for personal needs and comfort)**

Crew accommodation is usually located in a far from ideal location. It is built around the operation of the ship, being placed directly over the engine room. This area does not give the best quality of ride. In addition, it can be noisy.

Acoustic insulation could be used to reduce noise in this area, but it must also be considered in conjunction with measures to increase sleep disturbances to sounds that must be heard, i.e. fire alarms. Consideration could be given to ensure that the accommodation area is restful and that it aids in recovery from fatigue, e.g. in terms of decor, easy to tidy and clean. The following should be considered:

.1 Design for minimal crew flow in sleeping quarters;
.2 Consider laundry, changing, hygiene, privacy;
.3 Insulation or isolation from cargo, engine, other disturbances (noise and vibration);
.4 Lighting/dimmers (design for sleep);
.5 Ventilation/air exchange;
.6 Temperature and humidity (design for sleep);
.7 Design for natural light access;
.8 Galley & mess room/s;
.9 Design of napping stations;
.10 Appropriate medical facilities.

**A. Workplace design (Design for alertness and performance)**

Workplace design, particularly those that require unnecessary sustained exertion (physical or mental), can be offset by better design of the workplace or by better upkeep of the original condition of the ship. Aspects to consider include:
1. Layout of workspaces for efficient work;
2. Natural light access;
3. Design for workflow;
4. Working position (seated/standing, height, flooring material (shock and balance));
5. Lighting (design for alertness) [11];
6. Ease of access to all controls and reading of displays (incorporate human machine interface principles);
7. Ventilation/air exchange;
8. Exposure to chemicals;
9. Noise and vibration;
10. Temperature and humidity (design for alertness).

Additionally, design control centres such as machinery control room layout, cargo control room layout, etc., should consider the integration of people with equipment and systems to reduce mental overload and boredom.

1. **Recreation and recovery**
   a. Privacy and social life;
   b. Minimal "housekeeping";
   c. Gym/training facilities;
   d. Library, media rooms.

2. **Harsh ambient environmental conditions**
   a. For example, too much noise, excessive vibration, inadequate ventilation, poor lighting, excessive heat or cold, too much or too little humidity, poor air exchange in enclosed spaces where people live and work can cause fatigue.

3. **Boredom**
   a. This particular boredom is due to little change in the environment during work tasks or loads. These states include monotony, reduced vigilance and mental satiation. While most of the solutions for these conditions might be related to modifying work practices, others might involve the innovative use of the following (all can be used to stave off fatigue through lack of stimuli):
      ______ Lighting
      ______ Temperature
      ______ Sound
      ______ smell

4. **Onboard facilities**
   a. Recovery from fatigue can be assisted or hampered by favourable or unfavourable crew onboard facilities, including the design of features within:
      ______ accommodations
      ______ recreational facilities
      ______ galleys, mess rooms, food preparation and storage areas
      ______ hygiene facilities
      ______ medical facilities

5. **Ship motions**
   a. Fatigue results from ship motions or seakeeping provisions relating to weather and sea states.
20 General *ergonomic* principles should be used and have been developed to aid designers. These are examined in the next section.

**What does ergonomics have to do with shipboard design?**

21 The discipline of ergonomics is founded on the belief that good design supports human performance and is not limited to aesthetic qualities. A well-designed work system or piece of equipment, from an ergonomics viewpoint, takes advantage of human capabilities and minimizes the impact of human limitation while ensuring that the equipment or system is fully functional and safe (i.e. designed for human use and meets operational requirements safely). Ergonomics has been defined as:

22 "The scientific discipline concerned with the application of validated scientific research about people, their abilities, characteristics and limitations to the design of systems they use, environments in which they function and interact, and jobs they perform to improve health, safety, well-being and overall system performance."

Ergonomics produces and integrates knowledge from the human sciences to match jobs, systems, products and environments to the physical and mental abilities and limitations of people. In doing so, it seeks to improve health, safety, well-being and performance."

23 Ergonomically designed work systems enhance safety, effectiveness, and efficiency. They should also support the shipboard tasks done by officers and crewmembers under all conditions, including situations where people may be fatigued.

24 The ergonomics approach to design is human-centred. This means that all designable components (ship, ship's systems, equipment, service, etc.) are fitted to the characteristics of the intended users, operators or workers (e.g. seafarers, maintainers, etc.) rather than selecting and/or adapting humans to fit the system and/or product. This should be done by consideration of:

.1 the intended target population;
.2 the task, goal or intended outcome of the system, product or service; and
.3 the environment in which the design is to function.

25 Below is a set of general *ergonomic principles* designed to reduce fatigue by adapting working conditions to the anatomical, physiological and psychological characteristics of people in relation to their work environment, should be employed.

.1 The design of the workspace and work equipment shall take into account constraints imposed by body dimensions, with due regard to the work process.

.2 The design of the work shall be such as to avoid unnecessary or excessive strain in muscles, joints, ligaments, and in the respiratory and circulatory systems. Strength requirements shall be within physiologically desirable limits. Body movements should follow natural rhythms. Body posture, strength exertion, and body movements should be in harmony with each other.

.3 The work environment shall be designed and maintained so that physical, chemical and biological conditions have no noxious effect on people but serve to ensure their health, as well as their capacity and readiness to work. Account
shall be taken of objectively measurable phenomena and of subjective assessment.

4 The design of the work process shall safeguard workers' health and safety, promote their well-being, and facilitate task performance, in particular by avoiding overloading and underloading. Overloading and underloading will result in transgressing, respectively the upper or lower limits of the operational range of physiological and/or psychological functions, such as physical or sensory overloading produces fatigue. Conversely, underloading or monotonous work will diminish vigilance.

26 These general principles can be refined into a collection of more specific criteria, which are context-dependent. For example, the first principle (consideration of body dimensions) could be refined in terms of criteria for work-surface height, seating arrangements, space, range for controls, handles etc. The vast majority of ergonomic standards give specific guidance at a low-level of detail. Many of these are tailored for specific industries, some for marine.

27 Those affected by the design (the seafarers) should be involved throughout the whole design process, including evaluation. This will help to optimize solutions (e.g. by providing specific experience and requirements). Their early and continued participation and involvement is regarded as an efficient design strategy within ergonomics since, in addition to improving the design, it reduce late-stage re-work and increases user acceptance.

28 Task-oriented design also takes into account differences that can be observed between the designed task and the way the task is actually performed. Activities in performing a task are affected by variations and changes in, for example, context, procedures, equipment, products or materials.

29 The relations between the conditions and demands placed on the seafarer and their response to being exposed to such conditions and their effects need to be considered in the design of ship systems, services, products and tasks in order to avoid impairing effects on the individual. The response to conditions and demands are dependent on individual characteristics (e.g. body size [12], age, capacities, abilities, skills, etc.).

30 Appropriate standards are referenced throughout the following sections. A few standards give guidance on how to incorporate ergonomics into the design process [i.e. [13]], e.g. ergonomic principles in the design of work systems. The remaining sections also look at specific help that is available to the ship designer's wanting to reduce seafarer's fatigue to incorporate "fatigue proofing" strategies into design. This "help" takes the form of tools, guides, standards, regulations and rules.

What tools are available for designing/building fatigue resistant ships?

31 Unfavorable environmental conditions can be instrumental in causing fatigue. Environmental conditions include noise levels, vibration, ship motion, seakeeping qualities of the ship, lighting, temperature and ventilation. These environmental conditions affect crewmembers within their workplace (bridge, engine room, etc.) and accommodation quarters, (including dining, food preparation and storage areas, hygiene and medical support areas.)

32 Ergonomic standards is a major are effective tools for improving the working environment, particularly those that deal with environmental conditions (such as temperature, vibration, ventilation, etc.).
33 Tools that support ergonomic design include the use of computer simulation tools. These are increasingly being used to assess both the impact of environmental conditions as well as work and living design ergonomics. Examples include virtual reality and three-dimensional computer aided design (JACK; SAMMIE; etc.). Use of such simulation tools is encouraged as they allow early and more cost effective evaluation of various aspects of design.

34 Environmental conditions also extend across structural design, propulsion, hull forms and several other aspects of design. Often, constructive solutions may be employed to improve environmental conditions. For example, the transmission of noise can be dampened by the insertion of acoustic insulation; similarly, resilience techniques can be used to alleviate vibration problems.

35 There are a variety of design tools available for this and include recommended guides, prescriptive and evaluation standards. Design software such as Finite Element Analysis (FEA) which can assist the ship designer in ensuring that the specified limits specified by shipowners are not exceeded. These tools can be used for:

1. Calculating noise limits;
2. Calculating vibration limits;
3. Calculating seakeeping qualities/quality of ride;
4. Analysing ventilation flows; and
5. Performing model tests.

What rules and guidance are available for designing/building a fatigue resistant ship?

36 There are a number of rules, regulations, standards and guidelines designed to enhance environmental shipboard conditions, which can be used by the ship designer who wants to reduce seafarer fatigue. As this is a developing area many of the measures referenced here are provisional field and the designer should check for new material.

A Accommodation

37 Some aspects of crew accommodation, for instance minimum size and acoustic insulation, are subject to regulation such as the International Labour Organization (ILO), Maritime Labour Convention (MLC) 2006. The ILO Conventions MLC, 2006 that addresses crew accommodation are as follows in Title 3 (Accommodation, Recreational Facilities, Food and Catering). The purpose is to ensure that seafarers have decent accommodation and recreational facilities on board. Regulation 3.1 – Accommodation and recreational facilities and Standard A3.1 – Accommodation and recreational facilities, incorporates prescriptive requirements for accommodation spaces (i.e. crew will have for example fewer or no cabin mates, a larger cabin floor area and more convenient access to showers, water closets, and lavatories).

38 The MLC, as it relates to habitability, institutes minimum standards of living through the provision of crew accommodation areas that are:

1. free from hazardous levels of noise and vibration;
2. provide appropriate levels of lighting and indoor climatic qualities; and
3. offers improved crew accommodation design.

39 The MLC (2006), Guideline B3.1 (Accommodation and recreational facilities) provides more specific guidelines for ship design, covering the following aspects:
1. Ventilation;
2. Heating;
3. Lighting;
4. Sleeping rooms;
5. Mess rooms;
6. Sanitary accommodation;
7. Hospital accommodation; and

Convention No. 92 concerning crew accommodation on board ship (Revised 1949)
Convention No. 133 concerning crew accommodation on board ship (supplementary provisions)
Convention No. 147 concerning minimum standards in merchant ships
Protocol of 1996 to Convention No. 147
Recommendation 155 of 1976, recommendation concerning the improvement of standards in merchant ships
Recommendation No. 140 concerning Crew Accommodation (Air Conditioning)
Recommendation No. 141 concerning Crew Accommodation (Noise Control)

Crew accommodation is also subject to National Standards such as The Ministry of Maritime Affairs and Fisheries of Korea, Ship Safety Act: Crew accommodation.

B Environmental conditions in crew only in living and working spaces

41 Some Classification Societies have rules, most of them being optional rules, for aspects of environmental conditions (i.e. noise and vibration) for certain ship types.

1. Passenger (e.g. cruise, Ro-Ro ferries)
2. High speed craft (e.g. Surface Effect Ships, wave piercing catamarans, hydrofoil)
   Yachts

42 However, these rules could form the basis for an assessment of any ship type. The variance that lies between the different schemes operated by different classification societies. A number of these Rules assessment criteria include crew-only spaces as well as passenger spaces. Crew-only spaces are defined as the following follows:

1. accommodation spaces (e.g. cabins, corridors, offices, mess rooms, recreation rooms)
2. work spaces
3. navigation spaces

43 These Rules are contained in:
Several IMO developed requirements and resolutions aimed to protect the seafarer from unacceptable levels of noise:

1. SOLAS Regulation II-1/3-12 Protection against noise.
2. IMO Res. MSC. 337(91) Code on noise levels onboard ships (This code is mandatory under regulation II-1/3-12 with entry into force on 1 July 2014).

Relevant Standards on Noise

3. ISO 717-1; 717-2: 2013 Acoustics - Rating of sound insulation in buildings and of building elements:
   - Part 1: Airborne sound insulation in building and interior elements.
   - Part 2: Impact sound insulation.
   - Part 24: Field measurements
   - Part 7: of airborne sound insulation between rooms Part 5 Field measurements of airborne impact insulation of floors
6. IEC Publication 60651 Sound level meters
7. IEC Publication 60225 Octave, half-octave and third octave band filters intended for the analysis of sound and vibrations
8. IEC Publication 60804:Ed. 2.0 and amendment No.1, 1989 Integrating-average in sound level meters
9. IEC Publication 60942:2003 Electroacoustics Sound calibrators

Other Standards on Vibration

1. ISO 2041:2009 Mechanical vibration, shock and condition monitoring Vocabulary
2. ISO 2631 (Series) Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration
ISO 20283 Mechanical vibration - Measurement of vibration on ships.

- Part 3 (2006): Pre-installation vibration measurement of shipboard equipment

ISO 6954:2000 Mechanical vibration and shock – Guidelines for the overall measurement, reporting and evaluation of vibration with regard to habitability on passenger and in merchant ships

Classification Societies’ Guidelines for Noise and Vibration

45 In addition to the Comfort Notation described above, Classification Societies have guidelines for noise and vibration limits onboard ship, as listed below:

1. NK Noise and Vibration Guideline, July 2011
2. NK Guide to ship noise control, 1982
3. ABS Noise and Vibration control for inhabited spaces, July 2014
4. ABS Guidance notes on ship vibration, April 2006
6. IACS Unified Interpretation SC82 Protection against noise, 1993
7. BV Recommendation designed to limit the effects of vibrations onboard, Guidance note, NI38 A-RD3, 1979
8. VERITEC Vibration control in ships, 1985
9. LR Guidance notes on acceptable vibration levels and their measurement, 1990

46 In addition to the guidelines above, classification societies have guidelines for crew habitability on ships, offshore installations, workboats and mobile offshore drilling units, developed with the objective of improving the quality of crew member performance and comfort by improving working and living environments in terms of accommodation area design as listed below:

1. ABS Guide for crew habitability on ships, July 2012
2. ABS Guide for crew habitability on offshore installations, September 2012
3. ABS Guide for crew habitability on workboats
4. ABS Guide for crew habitability on mobile offshore drilling units (MODUs), September 2012

Working spaces

47 Regulations and standards exist for dealing with improvements to working spaces which may help in reducing fatigue. Some of the standards are still under development. These measures include bridge layout and navigation equipment, engine rooms, and general ergonomics, as follows:

Bridge Layout and Navigation Equipment
Engine-Rooms

.1 IMO MSC/Circular.834, Guidelines for engine-room layout, design and arrangement.

.2 ISO 8861 Shipbuilding – Engine-room ventilation in diesel-engine ships -- Design requirements and basis of calculations. ISO 8861

General Ergonomics


.5 ISO 26800:2011 Ergonomics -- General approach, principles and concepts.


.7 ISO 6385:2004 Ergonomics principles in the design of work systems ISO 6385 (Draft)

3 Standards for equipment design have been included for completion purposes. Really, they are outside of the remit of the ship designer, being items bought-in by the shipyard. However, ship designers are concerned with the integration of the equipment.
.8 ISO 10551:1995 Ergonomics of the thermal environment -- Assessment of the influence of the thermal environment using subjective judgment scales. ISO 10551

.9 ISO 11399:1995 Ergonomics of the thermal environment -- Principles and application of relevant International Standards. ISO-11399


.11 ISO 9241 Ergonomic requirements for office work with visual display terminals (VDTs):
   - Part 5 (1998): Workstation layout and postural requirements
   - Part 6 (1999): Guidance on the work environment

.12 ISO 11064 Ergonomic design of control centres. Part 1 (2000): Principles for the design of control centers

.13 ISO 15535:2012 General requirements for establishing anthropometric databases
References


IMO, MSC 69/INF.15 Human Errors on the Bridge – A study of Finnish Shipping.

IMO, MSC 69/INF.10 Seafarer fatigue: Wake up to the dangers.

IMO, MSC 69/INF.15 Fatigue – Groundings and collisions.


IMO, MSC/Circ.565. Fatigue as a Contributory Factor in Maritime Accidents.


