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APPLICATION OF ERGONOMICS IN SHIP DESIGN

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ABSTRACT

Reports on shipping casualties show the persistence of a poor maritime safety record and despite the influence of the technical degradation of an ageing fleet, the fact remains that the human factors are responsible for the majority of shipping accidents. Ship designers can play a role in reducing factors that may lead to fatigue and hence human errors in operation of ships and its equipment. Proper ergonomics design of ships is important from safety and comfort aspects. This paper reviews the application of ergonomics; particularly habitability standards in ship design and presents a case study of its implementation on a Malaysian patrol vessel. A patrol vessel was chosen and measurements were made and compared with standard ABS guidelines. The results shows that in most areas, the design of the patrol boat fails to comply with ergonomics design guidelines.

Keywords: human factors, patrol boats, habitability

1. INTRODUCTION

Ergonomics is the study of the interaction of humans and their environment. Many engineering systems, which may not have appropriately considered the human element, have been shown to contain features that can lead or have led to errors committed by humans during construction, maintenance and/or operation. Therefore, it is important to consider the ergonomics aspects when designing the components and systems such as that it is safe for human to construct, maintain and operate. Proper ergonomics design of ships is no exception. Reports on shipping casualties show the persistence of a poor maritime safety record and despite the influence of the technical degradation of an ageing fleet, the fact remains that the human factors are responsible for the majority of shipping accidents.

This paper review the application of ergonomics in ship designs and presents a case study of its implementation on a Malaysian patrol vessel.

2. HUMAN FACTORS IN SHIP DESIGN

2.1 INTRODUCTION

It is often stated that human element accounts for at least 80% of all catastrophic marine casualties [1].

The importance of addressing the human element in maritime safety has been recognised by the International Maritime Organisation (IMO). However, IMO's primary effort so far have concentrated on operations, management and training issues. This has led to the implementation of International Safety Management Code (ISM Code) and the 1995 amendments to the Standard for Training, Certification and Watch keeping Convention (STCW 95) [2].

IMO has also devoted some attention to the human element during design. The sub-committee on Design and Equipment is currently developing the *Guidelines for Engine-Room Layout, Design and Arrangement*. The subcommittee on Safety of Navigation has a correspondence group working on *Ergonomic Criteria for Bridge Equipment and Layout*. However, these efforts are not as comprehensive as those previously devoted to safety management and training [2].

The efforts towards improving working conditions in land-based working areas have been more forth coming. In Malaysia for example, the Occupational Safety and Health Act [3} was promulgated in 1994. Amongst others, the Act stipulates a number of measures that employers must take to ensure safety, health, comfort and welfare of their employees. However the law does not apply to ships in operation.

2.2 Human Fatigue

Human fatigue has been identified as the primary cause and a major contributing factor of numerous maritime mishaps, such as *Exxon Valdez* and *Herald Of Free Enterprise* [2]. Unfortunately, most of ship design and construction rules, such as those published by classification societies, do not adequately address this human element. The guidelines allow for harsh shipboard environments that are noisy, dimly lit, and have high levels of vibration. These conditions disrupt sleep, cause fatigue and intensify its effects.

Adequate sleep is important for operational effectiveness of the crew. Unfortunately, most shipboard operators are not able to get this much sleep. According to Ref. [4], almost 50% of Australian seafarers, while underway, only had four to six hours of sleep a night. Consecutive nights of short sleep duration results in the development of a cumulative sleep debt. This condition lowers initial energy levels and increases the effects of fatigue felt throughout the day, sometimes leading to human errors with disastrous consequences. A proper sleeping environment is critical in ensuring that sleep is restorative. The design of the shipboard sleeping environment is directly controlled by naval architects and marine engineers and as such, they have a great role to play.

3. FACTORS FOR ERGONOMICS SHIP DESIGN

By far, the most comprehensive guidelines for ergonomics design is that recommended by American Bureau of Shipping (ABS) [2]. The guidelines cover such aspects as proper design and layout of the workspace and creation of a conducive working and living environment for the crew. Details regarding habitability standards are given in [5].

Proper design of workstation, recreational, work and sleeping environment will contribute towards alertness on watch and reduction of fatigue. For that purpose, four design factors must be considered viz. lighting, noise, vibration and indoor climate [2]. Ref [4] added ship motion as a factor whilst this is already considered as the low-frequency part of whole body vibration described in ABS guidelines [2,5]

3.1 Noise

Noise is present in most compartments of a ship and it is difficult to avoid. Noise comes from numerous sources including engines, generators, pumps, and air conditioners. Mariners working in a noisy environment tend to be moody, irritable, and unable to effectively deal with minor frustrations. Noise causes blood pressure to go up, increases heart and breathing rates, accelerates the metabolism, and a low-level muscular tension takes over the body ("fight or flight" effects). If the noise continues for long periods, the factors compound and it becomes harder to relax. The factors increase as the noise levels increase [4].

The effect that noise has on sleep challenges designers of shipboard general arrangements. Finding the optimal location for sleeping quarters and crew recreation compartments is critical. The levels recommended by American Bureau of Shipping (ABS) [2] are shown in Table 1.

3.2 LIGHTING

Shipboard operators work in a 24-hour environment. Watch schedules frequently change and individuals work under incandescent or florescent lighting throughout the night. Unfortunately, the lighting that is typically installed aboard ships is not stimulating and fatigue settles in during the early morning hours [4].

Illumination is the measure of light (luminance flux) falling on a surface. It is measured in lumen/m^2, which equals one lux or 0.093 foot-candles (ft-c).

Table 1 ABS Permissible Noise Levels [2]

Space	Maximum dB (A)
Machinery space (continuously manned)	90
Machinery space (not continuously manned)	110
Machinery control rooms	75
Workshops	85
Non-specified spaces	90
Navigation Bridge and chartroom	65
Listening post, including bridge wings and windows	70
Radio rooms	60
Radar rooms	65
Cabins and hospitals	60
Mess rooms	65
Recreation rooms	65
Open recreation areas	75
Offices	65
Galleys	75
Serveries and pantries	75
Spaces not specified	90

Current design standards and guidelines on illumination levels in ship compartments are inadequate for maintaining watch-stander alertness and do not mitigate fatigue. ABS guidelines for lighting provide recommended illumination levels for all the types of compartments on a ship.

3.3 Vibration

Mariners experience shipboard vibrations caused by machinery, marine equipment and the ship's response to the environment. Vibrations resonate throughout the hull structure and the entire crew can be affected. The propagation of these vibrations along the decks and bulkheads subject the crew to whole body vibration and noise [6].

Short-term exposure can lead to headaches, stress, and fatigue. Long-term exposure leads to hearing loss and causes constant body agitation. Maritime vibration guidelines keep levels low enough to prevent bodily injury but the recommended levels can cause fatigue and disrupt sleeping patterns. ABS Guidelines [5] give maximum weighted root-mean-square acceleration level in the frequency range 0.5-80Hz as 0.4 m/s and 0.315 m/s for task-performance and comfort criteria respectively.

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4. CASE STUDY BACKGROUND AND METHODOLOGY

For the purpose of this ergonomics case study, a fast patrol craft belonging to one Malaysian Government agency was chosen to be the subject, Figure 1. The craft is 22.5 metre Aluminium Fast Patrol Craft built in year 2001.

In conducting the case study, measurements were conducted onboard the ship to measure all the environmental condition i.e. lighting level, noise level, vibration level, and thermal condition when the ship was cruising at its normal operating speed.

The equipment used for the measurement is shown in Table 2.

Measurements were made on 18th January 2002 when the patrol boat was on a regular patrol duty in Malaysian waters. The duration of the study was five hours.

5. RESULTS AND DISCUSSION

5.1 Lighting

Results for lighting survey is shown in Table 3. All the shipboard operators of the patrol boat are working in the 24-hour environment and thus the luminance level should be enough to stimulate the body and help to maintain crew alertness. Looking into the comparison between average lux and minimum lux standard from Table 3, it is found that almost all of the average lux values do not even reach to the minimum lux requirement of ABS standard. This situation is considered poor since the duty on watch at night especially need high alertness of officers but the average lux at the wheelhouse is so low that may not help to maintain crew alertness. As for the other areas, the lux levels are markedly quite low as well. Although this is not critical from the safety aspect, the need for comfortable working environment is not fulfilled.

As a result, the lighting design of this craft can be said not ergonomic and there are rooms for improvement.

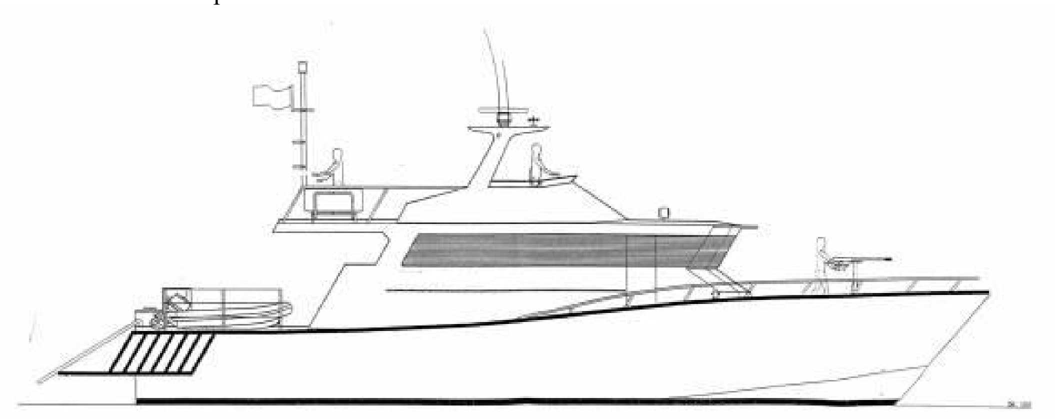

Figure 1:Outboard profile of the Patrol Craft

Table 2 Measuring Equipment

Parameter	Equipment
Noise	Bruel Kjaer Model 2233 Sound level meter
Lighting	Lutron LX102 Light meter
Vibration	SKF Micrology
Humidity	Hygrometer

Table 3 Luminance Level

		Boat	ABS	
	Area	**Lux**	**Min**	**Pref**
1.	Control consoles (panels, switch board, gauge boards)		325	540
	L1	115		
	L2	100		
	L3	107		
2.	Control rooms (engine room, boiler room, generator, steering room, switchboard room)		220	540
	L4	97		
	L5	143		
3.	Inspection tasks (Rough)		325	540
	Radio room L6	119		
4.	Corridors, passageways, stairways		110	210
	L7	128		
	L8	84		
5.	Galley L9	214	540	755
6.	Offices ordinary task (desk work, reading)		430	540
	Radio room L10	134		
7.	Sanitary spaces (General) L11	135	325	-
8.	Sanitary spaces (Mirrors) L12	160	540	-
9.	Storage L13	87	55	110

5.2 Noise

Results shown in Table 4 indicate that every reading of noise level (dB) has exceeded the maximum level of ABS Standard. Some significant high noise levels from Table 5 are, about 80 dB at wheelhouse, 77 dB at radio room, 102 dB at stern deck, and 120 dB at engine room. These are the main areas where the crew spends most of their time, except engine room that is not continuously manned.

Exposure to such high noise level over a period can produce pathological side effects and thus can comprise a health hazard. The excessive noisy environment has provoked crew awareness. Surveys by Lim in Ref [6] indicated that the crew were unhappy and wished that noise level should be decreased particularly at the radio and engine rooms.

Table 4 Noise Level

		Boat	ABS
	Area	**Average dB(A)**	**Max dB(A)**
1.	Navigation Spaces		
	N1	80.3	65
	N2	80.6	
2.	Radio room N3	76.7	60
3.	Officer Cabin		60
	N4	75.2	
	N5	76.5	
4.	Galley N6	79.4	75
5.	Non specific work space		
	Machine control room	101.7	90
	Upper deck N8	96.6	
6.	Crew Cabin		
	N9	78.3	60
	N10	79.9	
7.	Mess Room	82.0	65
9.	Machinery space (not continuously manned)		
	N12	119.6	110
	N13	119.4	
	N14	117.1	
10.	Normally unoccupied spaces		
	Provision Store N15	79.8	
	Passageway N16	82.3	
	Fwd deck N17	115.6	90
	Port deck N18	105.1	
	Starboard deck N19	100.4	
	Stern deck	101.5	

5.3 Thermal comfort

The thermal environment is determined by four physical factors: air temperature, humidity, air movement, and temperature of surfaces that exchanges energy by radiation [7]. The combination of these factors determines the physical conditions of the climate and our perception of the climate. According to ABS ergonomics guidance notes [2], the optimum range of dry-bulb temperature for accomplishing light work while dressed appropriately is 21-27 degrees C (70-80 degrees F) for warm climate. The optimum comfortable temperature is 22 degrees C. Meanwhile the humidity should be maintained between 20% ~ 60% with an optimum relative humidity of 45% at 21 degrees C (70 degrees F) if possible.

Results of temperature and humidity measurement are shown in Table 5.

Table 5 Temperature and Humidity

	Region	Temp (°C)		Rel. Humidity
		Dry bulb	Wet bulb	(%)
1.	Wheelhouse T1	26	23.5	80
2.	Radio Room T2	25	23	84
3.	Commander CabinT3	25	23	84
4.	Galley T4	28	24	71
5.	Passageway T5	25	21	67
6.	Provision Store T6	26.5	22	65
7.	Stern Deck T7	28	25.5	81
8.	Cabin T8	27.5	25	81
9.	Mess Room T9	26	24.5	88
10.	Control Room T10	28	24.5	74
11.	Engine Room			
	T11	30	26	72
	T12	39	28	42
12.	Open recreation area T13	26	24	84

The result shows, the range of dry bulb temperature is 25 –28 degrees C and the humidity range is 65% – 88%. Compared to the ABS ergonomics standard, in some cases, the temperature and humidity are higher and do not meet the ergonomic range. It is stated that the humidity should decrease with rising temperatures, but should remain above 20% to prevent irritation and drying of the body. Therefore, in order to have a better thermal comfort, the temperature should be decreased to say 21 – 26 degrees C.

The effective temperature at the engine room was not included in the above discussion since the chart is based on wearing customary indoor clothing and performing light muscular or sedentary work. Although its temperature and humidity is high, it is still in the acceptable zone and it is not critical since the engine room not continuously manned.

In the survey by Lim [6], the crew complains of non-uniform distribution of air-conditioning flow. This parameter is indicated in ABS guidelines as vertical and horizontal temperature gradients. However, system in the cabin was not uniformly distributed and that is why they felt uncomfortable. Thus, the flow of the air-conditioning system should be designed to distribute the flow more uniform.

The issue that needs attention is the high temperature and humidity in the crew cabin since having a good sleeping environment would help improve the working spirit and reduce fatigue.

5.4 Vibration

From Table 6, RMS values of A_Z acceleration are between 0.383 m/s^2 and 1.138 m/s^2. Comparison with the vibration exposure limits in shows that the ship vibration level is not good, particularly at the stern deck and the engine.

Looking into the level to maintain proficiency as an average, it is apparent that the vibration levels at the main working place, wheelhouse and radio room are too high for the crew to maintain proficiency for more than 4 hours. Staying in the engine longer than half an hour is expected to be very uncomfortable.

Table 6 Vibration Measurement Data

Measuring Location	Acceleration (RMS) m/s^2	ABS	Guide
		Max	Pref
Wheel House	0.736	0.4	0.315
Radio Room	0.383		
Upper deck	0.589		
Cabin	0.883		
Mess Room	0.922		
Engine Room 1	1.138		

6. CONCLUDING REMARKS

Measurements carried out on a Malaysian Patrol Craft have indicated many areas that need improvement. The designed lighting system on the patrol boat is not ergonomics. It was observed that one reason is the poor distribution of light that is influenced by the reflectance of the walls, ceilings, and other room surface. The grey coloured wall (except the engine room) reflectance is quite low. Thus in order to contribute to the effective distribution and utilization of light, it is desirable to use rather lighter coloured walls, ceilings, and other surface.

The noise level measured was high, and thus hearing protectors need to be used with noise level greater than 85 dB. Although noise is an unavoidable issue in maritime operations, steps can be taken in the design stages of a ship to decrease noise effects. Post-production measures can also be taken to reduce noise levels.

From the data collected, the humidity in cabin is quite high and may be causing discomfort to the crew. The condition should be improved by reducing the temperature level and directly reduce the relative humidity. The vibration level measured onboard the patrol boat was rather high compared to the ABS Ergonomic Guidance Notes. The source of vibration however has to be identified before applying the solution. Vibrations created by engines, generators, and pumps can be reduced through damping and isolation. The methods used to reduce vibrations are similar to those used to reduce noise.

Work reported in this paper is part of an on-going study on implementation of ergonomics guidelines in the design of Malaysian ships. Further work is being done to study other aspects of ergonomics such as anthropometrics as well as carrying out measurements on other types of ships and boats.

7. REFERENCES

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