Critical Significance of Human Factors in Ship Design

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Human Factors

- Branch of engineering optimizing the interaction between technology and the human operator
- Often aimed at the highest level of technology, yet required at all levels to insure maximum efficiency
- Human factors input required in ship design
  - Human-technological interaction of man, machinery, and equipment
  - Additional demand of operating and controlling equipment and systems on a moving platform

Maximizing Shipboard Human Performance

- Operator-technology interaction is continually affected by the ship environment: provocative motion, fatigue, work and rest space design, motion sickness, vibration, noise and temperature
- Human performance is degraded on a moving platform
  - By purely physical limitations such as standing, walking and working while undergoing whole body motions imposed by heavy seas
  - By fatigue, motion sickness and degradation of mental performance, increasing the potential for task inefficiency and personal injury

Seakeeping

- Seaworthiness includes all of the features of the design of the ship that affect its ability to remain at sea in all conditions and carry out its preplanned operational mission, such as:
    - strength
    - ability
    - response to wave action
- Effects of provocative motions on crewmember performance (Brown, 1985)
    - Task becomes more difficult
    - The individual performs less well

Seakeeping (contd.) - Correlation of Wave Height and Wind Speed

Sea State	Wave Height (m)	Beaufort No.	Wind Speed (kts)
1 – 4	Up to 2.5	0 – 5	Up to 21
5	2.5 – 4	6	22 – 27
6	4 – 6	7	28 – 47
7 and over	7 and over	8 and over	Over 48

(Brown, 1985)

Seakeeping (contd.) – Loss of Fighting Effectiveness, 3000 – tonne Frigate (108 m)

Sea State	Wave Height (m)	Effect
1 – 4	Up to 2.5	Nil
5	2.5 - 4	Inconvenience, work takes longer. Some effect on sensors. RAS difficult.
6	4 – 6	Up to ½ crew sick. Sleep difficult. All are tired, some exhausted. Helicopter operation difficult (quiescent period only). Many weapon systems degraded.
7 and over	Over 6	Ship is ineffective as a fighting unit.

(Brown, 1985)

Seakeeping (contd.) – Percentage Loss of Fighting Effectiveness, 3000 – tonne Frigate

Sea State	% Loss
5	10
6	30
7 & Over	95

(Brown, 1985)

Seakeeping (contd.) - Effective Days Lost. *Leander*, North Atlantic

Sea State	% Year	No. of Days (out of 150)	% Loss of Effectiveness	Lost Days
1 – 4	62	93	0	-
5	22	33	10	3
6	11.5	17	30	5
7 and over	4.5	7	95	7
Total				15

(Brown, 1985)

Whole-Body Vibration

- Affects subjective comfort, working efficiency, health and safety
- Affects the stability of objects in the operator's field of vision, causing blurred vision and difficulty of interpretation
- Can be either low frequency motion induced by sea conditions (motion sickness), or high frequency vibrations originating from onboard machinery
- Can also result from hull responses following severe slamming in heavy seas

Whole-Body Vibration (contd.)

- High frequency vibration originating from onboard machinery affects subjective comfort, working efficiency, health and safety
- Whole-body vibration from 2-12 Hz can affect human performance
- Significant manual control problems occurred during simulated ship motion in the range of 0.02-0.2 Hz
- There is no one predictor of performance for all operators in all settings
- Can cause performance deficits, fatigue, accident-proneness and health hazards

Motion-Induced Sickness

- More than half of the population are susceptible to motion sickness and practically everybody can be made sick if provocative motion is severe enough
- Even after adaptation has taken place people can still become seasick under appropriate conditions
- Competence on primary tasks is maintained during a brief bout of motion sickness, but not “secondary maintenance tasks” (Birren, 1949)
- Individuals may make an extra effort to conduct their primary task during short exposures
- Motion sickness is no different: at sea, in the air, etc, and can be provoked by visual motion alone

Motion-Induced Sickness (contd.)

- Best solution to motion sickness is adaptation, a "rational treatment" (Hill, 1936)
- Incidence of motion sickness is due to
  - Frequency, duration, intensity and direction of the stimulus, with frequencies around 0.2 Hz being most provocative
  - Susceptibility of the operator
  - Operator's level of activity at the time
  - Food, ambient air temperature and certain odors
  - Relationship to displacement weight of ship

The Predicted Incidence of Seasickness Related to the Displacement Weight of Ships

Displacement Weight of Ships (tons)	Predicted Incidence of Seasickness
200	67%
1,000	62%
3,000	55%
5,000	50%
10,000	41%
15,000	35%
20,000	29%
30,000	22%

(Pethybridge, 1982)

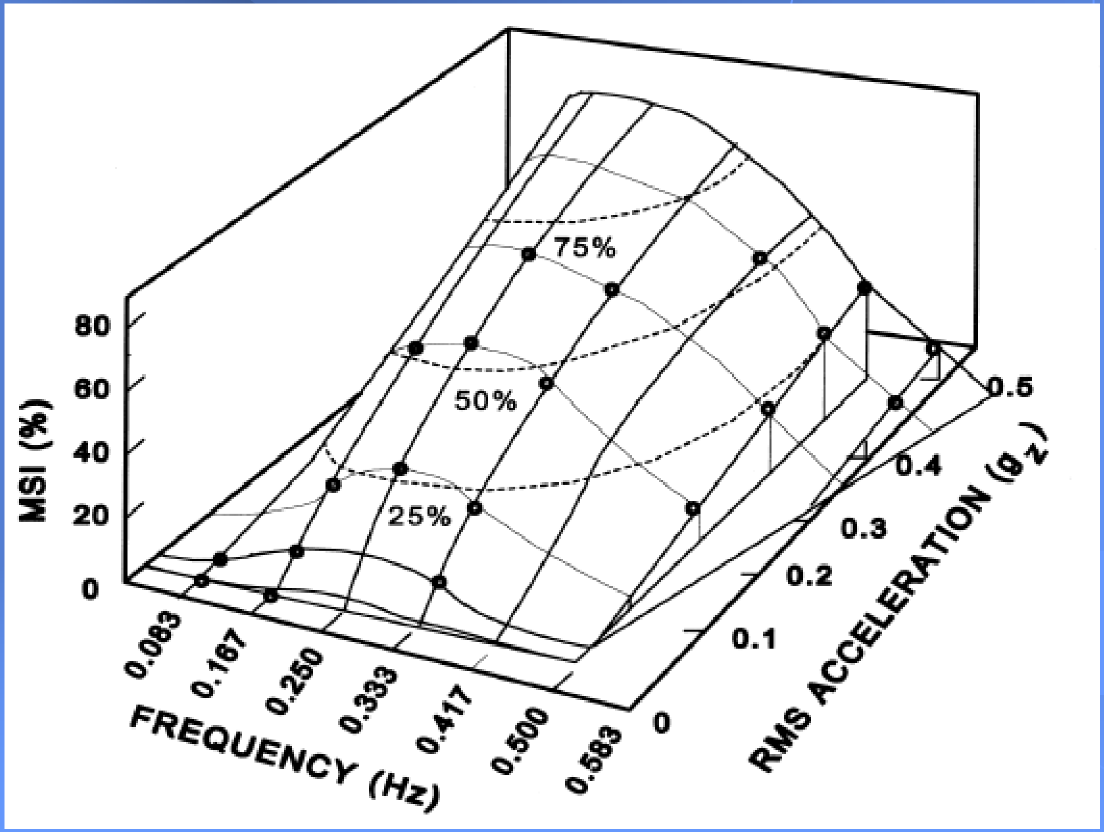
Management and Prevention of Motion Sickness

- Behavioral desensitization may be best solution for operators working regularly in provocative motion environments (Dobie, 1963)
- Suited to occupational situations requiring skilled or hazardous tasks
- Cognitive-behavioral therapy teaches individual to control the focus of cognitive processes long enough to allow habituation to occur
- Technique is highly successful, and affords protection for several years, even indefinitely (Dobie, 1974)

Provocative Motion

- No frequency is adverse unless there is motion of some amplitude at that frequency
- In some instances, even with motion, a particular frequency may not be of concern because of insignificant acceleration levels.
- Problems arise when motion and accelerations of significant amplitudes act at particular frequencies and cause a reduction in crew performance
- “Moderate accelerations at frequencies near 0.2 Hz should be avoided as these produce the highest incidence of motion sickness” (O’Hanlon and McCauley)

Relationship between the incidence of motion sickness: percent emesis within two hours, wave frequency and average acceleration during each half-wave cycle, for vertical sinusoidal motion



(O'Hanlon & McCauley, 1974)

Approaches to Preventing or Mitigating Adverse Effects of Ship Motion on Crew

Approaches	Methods
A. Ship design and systems engineering	1. Hull design 2. Ship arrangements 3. Operation and maintenance of machinery and equipment 4. Motion attenuation devices (e.g. fins) 5. Vibration isolation and damping treatments 6. Isolation of special stations

(Bittner & Guignard, 1984)

Approaches to Preventing or Mitigating Adverse Effects of Ship Motion on Crew (contd.)

Approaches	Methods
B. Human factors engineering (Bittner & Guignard, 1984)	1. Arrangement and designs of crew space 2. Location and orientation of crew stations 3. Work and task design 4. Display control design and placement 5. Optimization of ship environmental factors 6. Individual anti-vibration devices

Summary of Motion Response Mitigation

- Level of provocative motion to which the operator is exposed should be reduced where possible
- Design of vessels can minimize exposure to (0.2 Hz) accelerations causing highest incidence of seasickness
- Key workstations can be located near ship's center of rotation or along the main axes of the hull
- Workstation layout should be designed to minimize head movement to reduce vestibular stimulation
- Sleeping quarters located in areas of mild ship motions
- External frame of reference could be provided

Whole Body Motion - Recent Study of MII

- Recent research complements the 1995 MII database (3 DOF) by using motion profiles from current generation ships and includes 6 DOF
- Determines the degradation of human physical performance by ship motion through fatigue and MII
- Develops tolerance models for use by ship designers
- Lack of an external visual reference revealed reliable differences in performance across different headings in sea state 5

Gross and Fine Motor Skills

- Gross motor ability (walking and standing) affected by bodily direction in relation to ship's heading due to postural reactions
- Fine motor skills are affected by the type of task and control used (trackball, mouse, touchscreen) and accommodation (support for controlling arm)
  - Continuous unsupported arm movement very seriously affected
  - Tracking tasks involving fine movements with supported arms affected less so
  - Ballistic task involving digit keying virtually unaffected
- Operator interface aboard ships should be designed around motion-resistant tasks

Cognitive Performance

- Work on ships is more mental than physical compared with many years ago, so the effect of ship motion on cognitive performance must be considered
- Cognitive performance not shown to be significantly degraded in laboratory experiments
- Operators may maintain accuracy of primary task during initial exposure to provocative motion, but not for longer duration
- Time course of performance decrements - step function, not a slope function
- Sapov & Kuleshov (1975) reported degraded cognitive tasks during early stages at sea; improved later

Motion-Induced Fatigue

- Motion-induced fatigue is a serious naval/maritime performance problem (Colwell, 1989)
- Severe ship motions can raise the crews' energy expenditure significantly as more muscular effort is required to maintain posture as well as perform tasks
- Human response to ship motion characterized by drowsiness and mood changes which cause operator inefficiency and accident-proneness
- Related to sleep disturbances due to ship motions and possibly the sopite syndrome
- Folly to believe that crewmembers can "get used" to coping without sleep and not incur performance penalties - 8 hours of sleep recommended

Effects of Noise

- Non-auditory (stressor) effects of noise are less well-defined than those that affect hearing
  - Intermittent noise more distracting than continuous
  - High pitch noise more distracting than low
  - Non-localized noise more annoying than localized
- Difficult to identify the specific effects of noise in the shipboard multi-stressor environment
- Efficiency of verbal communication is affected at ambient noise levels of 78 db
- Noise is obviated by changing the transmission pathway, reducing exposure or providing protection

Conclusions

- Optimal performance is achieved when the crew component is designed in from day one
- Designers must know as much about what the operator can and cannot do, as for the vessel's capabilities
- Working knowledge of human-technology interaction can optimize the relationship and total ship performance
- Team effort requires input from various disciplines
- Resulting ship design can operate effectively under difficult conditions with a minimal crew complement

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