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HABITABILITY AND PERSONAL SPACE IN SEAKEEPING BEHAVIOUR

J. M. Riola[1], M. García de Arboleya[2]

ABSTRACT

The comfort and the well being on board from small sailing boats to huge passengers ships is the focus of this article that describes the factors directly relationated with the assessment of seakeeping performance of a ship in a specified sea environment. In a recent reference is estimated that nearly 10 million people travel each year on more than 230 cruise ships worldwide. So, the increase of comfort level is one of the naval architecture main tasks.

Figure 1. Sailing boats.

Figure 2. HSC.

In recent years the development of high-speed craft HSC has been significant. Not only are the dimensions of the vessels increasing, but also service speeds and expectations of performances tend always to increase. Furthermore, it becomes also more common that HSC operate along routes with harsh weather conditions.

Therefore, the issues of operability, hydrodynamic loads and comfort are very important in the research being carried out in the HSC area. The construction of a new modern HSC is a huge investment for the ship owner; he needs to be sure about the passengers comfort level. The assessment procedure requires the pre-

[1] Doctor Ingeniero Naval, Universidad Politécnica de Madrid (josemaria.riola@upm.es), Nuestra Señora de la Almudena 5, 28250, Madrid, Spain. [2] Psicopedagoga, RGA Psicopedagogía (Myriam@rga-psi.es), Puerto de los Leones 2, 28220, Majadahonda, Spain.

diction of transfer functions for different speed and headings for each ship response. These transfer functions are combined with the appropriate spectral formulation based on the sea characteristics. Also the paper emphasizes in the main psychological problems of the passengers on board due to the fatigue and sickness. This study is based on the ship experience and model tests carried out at Ship Dynamics Laboratory in Canal de Experiencias Hidrodinámicas de El Pardo, CEHIPAR (Riola, 2004).

Keywords: *Seakeepiong, Habitability, Motion Sickness, Assessment, Ship Design*

INTRODUCTION

Anacharsis, brother of Caduides the king of the Scythians, was a philosopher who travelled around the East Mediterranean and Black Sea in the 6th century BC. Their contemporaneous Greeks wrote that he exhorted moderation and good criteria in everything he said. As a seaman, he travelled in different sea conditions and he had the best reference about seasickness "people may be divided into three classes; the living, the dead and the seasick".

Many years from then, Luis Llobera de Avila (Llobera de Ávila, XVI Century), an Emperor Carlos I medicine doctor in the XVI century, accompanied the Spanish king in all their sailings and due to his experience, he advises to avoid sickness problems "to eat little and to smell some days seawater but without seeing it". Avoiding discussions about Llobera's remedies, focussing on the unpleasant experiences on the people on board due to ship motions, this is one of the task performances more delicates to the actual naval architecture designs. Bad weather experiencies (Piñero et al, 2004) are normal in all types of ships but this task is mainly imprtant in the pasenger vessels world. As the philosopher Publiano said "*Improbe Neptunum accusat, qui iterum naufragium facit*" but inherent to the sealife is the unpredictability of weather conditions and the subsequent induced motions at sea.

The stressor crew conditions can be divided in the physical environment ones and the conditions of the task itself. Physical stressors include noise, extremes of temperature, vibration, physical isolation, threat of failure or injury, etc. Stressful task conditionds include time pressure, multiple demands, sleep deprivation and fatigue.


Figure 3. Merchant ship in rough sea.

The seakeeping habitability assesment can be used to improve ship and equipment design and lead to enhanced vessel effectiveness, performance and mainly the safety on board. The ship motions limit not only the passengers, the crew is affected to perform essential functions or not essential but as important as the food preparation and the comfort on board (Riola et al, 2004) is a complex topic the human responses will determine the vessel reputation. Designers always pay attention to feedback provided by operators of exinting ships because these experiences can be considered as important lessons learnt for future designs.

But every effect in ship design is related to other one, for example larger vessels are more comfortable than smaller ones of similar configuration due to the the waves become relatively smaller (Riola et al, 2004). Basic to any seakeeping discussion is the contradictory betwen the roll period and the initial intact stability, so the greater stability, the faster roll will appear and a vessel with dangerously low stability will feel very comfortable but it is the main cause of many disasters yearly, so the architecture design has foccused on determining the acceptable stability in order to achieve the slowest roll period.

A normal passenger ship has a natural rolling period that tends to be the same as the period of waves developed by winds in the range of 20 to 30 knots. The main objective of the naval architecture designer should be to minimise the ship degradation and ensure the safety of passenger on board.

T e seakeeping performance can be defined from the habitability point of view of motions and accelerations are below specified levels (Girón et al, 2004). Sample wave statistics are shown in the next figure for the winter season averaged over the North Atlantic. The relation is between significant wave high to occurrence per cent.

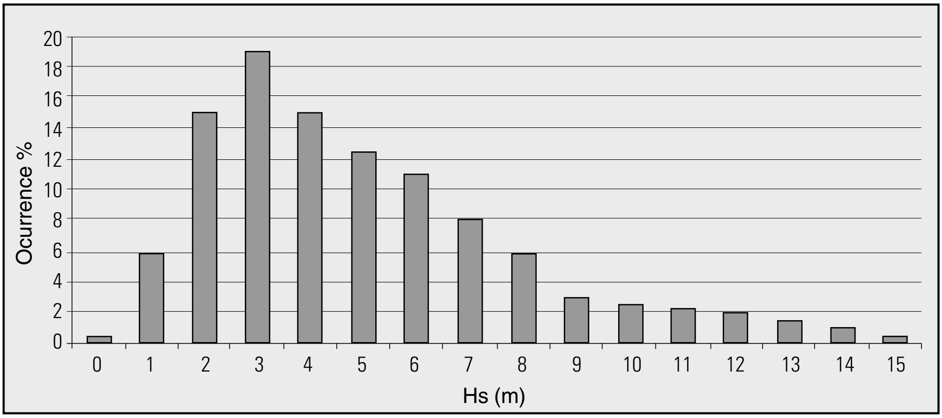

Figure 4: Hs versus occurrence.

PHYSIOLOGY

Three main planes to indicate head and body orientation are used: the coronal, sagittal and transverse planes. The intersection of the mid-sagittal plane and mid-coronal plane forms the spinal axis, yaw is the the rotation about this axis. The rotations about the intersections of the mid-frontal plane and mid-sagittal plane with the mid transverse plane are called pitch and roll. These three rotations are the references of the human body.

In humans, movement through the environment is inferred by three principal sensory systems: the visual sense and the two components of the vestibular system of the inner ear. The human vestibular system is the inertial system that detect and measure the six d.o.f., and it is located in the labyrinth at each inner ear and consists in two main organs, the semicircular canals for detecting angular acceleration and the otolith organs.

Figure 5. Wave impact.

The vestibular apparatus has two otolith organs called utricle and saccule, both with a two layer structure and a sensory cell base, so the otoliths provide linear motion sensation. The main tasks of this system are to enhance the perception of spatial orientation and self-motion, the posture control and to minimize the retinal motion during the head movements.

Motion sickness or kynetosis in the sickness associated to motion, is a term to describe the discomfort and associated emesis, breathing irregularities, warmth, disorientation, pallor and vomiting. According to the mismatch theory, the cause of motion sickness is that the vestibular apparatus provides the brain with information about self-motion that does not match the sensations of motion generated by visual system. Receiving contradictory information or conflicting inputs from two different organs; eyes, the vestibular system and the proprioceptive receptors in the tendons and muscles joints.

Motion sickness is induced by body vibrations at the frequency range between 0.1 to 0.5 Hz. The vertical oscillations are the principal provocative stimulus at sea and their effects are greatest between 0.125 and 0.25 Hz. Due to the verti-

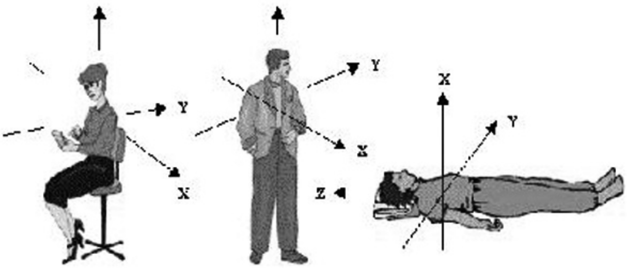

Figure 6. Human axis

cal acceleration in many ships is closer to 0.2 Hz or a roll rate of 5 seconds, this is the sensitivity problem to avoid. Of course, and dependig of the susceptibility individual characteristics, multiple factors have influence in the motion sickness; frequency, intensity, direction and motion duration, activity, food, smell and ambient conditions. Children younger than 2 years are rarely affected but susceptibility rapidly increases peaking between 4 and 10 years old and then gradually declining. Females tends to be more susceptible. Recent ingestion of food, particularly dairy products and foods high in sodium, protein or calories has been associated with increased susceptibility.

Nausea and vomiting are the most common complaints of motion sickness and are mediated by central neurotransmitters. In response to visual and vestibular input, increased levels of dopamine stimulate the medulla oblogata's chemoreceptor trigger zone, which in turn stimulates the vomiting center within the reticular formation of the brain stem. Te vomiting center is also directly stimulated by motion and by high levels of acetylcholine. Therefore, most drugs that are used to prevent or ameliorate motion sickness target these neurotransmitters. Commom drugs fall into three classes: antidopaminergics, anticholinergics and antihistamines.

Alternative medicine remedies are becoming popular, so the most popular herbal preparation for nausea is the ginger root in capsules or tea infusion, but other remedies with apricot juice, carrot juice, unroasted pumpkin, parsley or peppermint tea are recommended too. In a recent trip to Asia learn that the oriental non pharmacologic remedies are based on the acupressure. So the pressure is applied to the P6 acupunture point on the pericardial meridiam, located about 3 centimeters from the distant palmar crease between the palmaris longus and flexor carpi radialis tendons. My experience did not find the preventing evidence, perhaps due to an insufficient pressure stimulation of the P6 point or simply this remedy is a placebo. Researchers and surveys have found that up to 100% of ship passengers become seasick under rough conditions.

PERSONAL SPACING

The anthropologist Edward T. Hall was the precursor of the personal distance studies, the relations between the person and the bubble space surrounding us into which another may not introduce without causing arousal and anxiety. He describes (Hall, 1966) how this space can be used and affect our behavior in a public location. The way to use the personal spacing has an enormous influence in the capacity to relationship with others.

Each person has his own territory zones and react of different way in case of invasion. Our manner to defense our space and entering in the others are an integrative part of our relationship mode. Into a crowd, as occurring in many transports, this space is invaded continuously, as example in a underground top hour.

Hall is normally associated with "proxemics", the study of the human use of space within the context of culture and developed a theory arguing the human perceptions of space, although derived from sensory apparatus that all humans share but molded and patterned by their culture. So, differing cultural frameworks defining and organizing space, which are internalized in all people at an unconscious level, can lead to serious failures of communication with different behaviors that initially expected by crew members.

All we have territorial necessities and it is possible to define them in four areas that grow up in the same way that our privacy is decreasing; the intimate, personal, social and public:

— The intimate space is the closest bubble of space surrounding a person. Entry into this space is acceptable only for closest friends and intimates. This distance goes until 30 or 45 cm. At this distance, we are conscious about the others presence, so if this proximity is not waited, the result is a uncomfortable situation.
— The personal distance goes from 45 cm to 120 cm, where is the physical domination limit. This area is the normal one in personal conversations.
— The social distance, 120 to 210 cm, is used in the most used in commercial transactions and the main contact is the visual. This distance permit us certain protection.
— The public distance, 3 m and more, is the maximum extension of our territorial limits. It corresponds with conferences, speeches, low formal meetings, etc.

The naval architecture needs to project taking in account the personal spacing as a normal factor into the habitability passenger study and in ferry ships, in special, the cross-cultural passenger characteristics. Of course, we can not forget that in rough weather conditions the passenger behavior is almost degraded and the personal spacing sensitive is completely affected.

SEAKEEPING PERFORMANCE ASSESSMENT

The seakeeping performance assesment of a ship is mainly related to the weather conditions, the manoeuvring and navigation conditions, the wave responses of the ship and the required seakeeping criteria for the safety and well being of passengers and crew (Girón et al, 2005). Lateral and mainly the vertical accelerations are the most important factors in the seakeeping performance (Girón et al, 2001). The effect of the vertical accelerations on human bodies is the main cause of sickness and the International Standard provides discomfort boundaries as a function of acceleration levels, frecuencies and duration of exposure. To date of seaway performance calculations, human performance is often defined by parameters and it is a good start for comparisons between designs. Our side needs a research continuation into a fuller definition of human performance that includes, fatigue effects and cognitive performance. Shipboard tasks cover a wide range from those that are mainly manual to those that are mainly mental, and are thus defined by different combinations of all factors. The election of a criteria to know the ship seakeeping performance can vary vastly depending of the ship type but looks logic that in a passenger ship the low porcentage of passengers getting seasick is the main comfort objective. But its more critical to know the crew operatibility due to the lack of safety. In the next table a limited criteria for vertical acceleration is presented.

Limiting criteria for vertical acceleration (RMS)	
0.02 g	Passengers on a big cruise liner
0.05 g	Passengers on a ferry
0.10 g	Normal work for the crew
0.15 g	Heavy work for adapted crew
0.20 g	Ligth work for adapted crew
0.275 g	Simple works

Figure 7. Work limiting criteria.

The International Standard ISO 2631-1 "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration" (ISO Standard 2631-1, 1997) defines methods of quantifying whole-body vibration in relation to human health and comfort, the probability of vibration perception and the incidence of motion sickness.

The standard defines a motion sickness dose value MSDV such that higher values to a greater incidence of motion sickness where there are two alternative calculating methods depending of the exposure period. If the motion measurements are approximately constant in a short period, where a_w is the square of the measured root mean square z-axis acceleration and T_0 is the exposure register duration, the used formula to obtain the MSDV is:

$$MSDV_z = a_w \; T_0^{1/2}$$

If the motion measurements corresponding to the full period or close, a_w is the frequency-weighted acceleration in the z direction and T is the period, the MSDV can be obtained with the following expression:

$$MSDV_z = \left\{ \int_0^T [a_w(t)]^2 \, dt \right\}^{0.5}$$

Of course, the reactions depending of many factors as human propension, type of activity on board, if reading, etc. The percentage of people who may vomit can expressed by:

$$PV = K_m \, MSDV_z$$

Where K_m is a constant which vary according the exposed population. The following table presents the comfort habitability sensations respect to the exposed accelerations:

Habitability accelerations (RMS)	
< 0.315 ms^{-2}	Not uncomfortable
0.315 – 0.63	A little uncomfortable
0.5 – 1.0	Fairly uncomfortable
0.8 – 1.6	Uncomfortable
1.25 – 2.5	Very uncomfortable
> 2 ms^{-2}	Extremely uncomfortable

Figure 8: Habitability comfortable

The ship motions effects on human performance could be defined in terms of these five factors:

— MII: Motion Indiced Interruptions
— MIF: Motion induced fatigue
— Cognitive performance
— MSI: Motion Sickness Incidence
— Habituation

But usually the main useful parameters refered to motion are the MSI (O'Hanlon and McCauley, 1974) and MII (Graham, 1990). Their definitions have evolved since the 1970s. A mathematical model of MSI was found, as expressed in the following equation:

$$MSI = 100\left[0.5 \pm erf\left(\frac{\pm \log_{10}\frac{a_z}{g} \mp \left(-0.819 + 2.32\left(\log_{10} w_e\right)^2\right)}{0.4}\right)\right]$$

Where *erf* is the error function, a_z is the vertical acceleration averaged over a motion cycle. There is a frequency around 0.167 Hz (1 rad/sec), where the MSI presents a maximum sensitive value.

A Motion Induced Interruption MII is defined as an incident where ship motions become sufficiently large to cause a person to slide or lose balance unless they temporarily abandon their non-seated task to pay attention to keeping upright. The sudden changes in vertical acceleration have a seriously adverse effect on crewmembers to maintain postural stability and carry out their functions whatever they may be. MII is focussed on stumbling, sliding and lift-off, but as general idea it predicts a man will lose balance when the tipping moment exceeds the righting moment provided by the separation of the man's feet. Tipping coefficient is the ratio of the half-stance width to the center of gravity height and it is used to evaluate the probability of tipping per minute. Longitudinal, lateral and vertical forces per unit mass and the sliding, lateral and longitudinal tipping phenomena moments are predicted using the following formulas:

$$F_{longitudinal} = -\ddot{D}_{surge} + g\,\eta_{pitch}$$

$$F_{lateral} = -\ddot{D}_{sway} + g\,\eta_{roll}$$

$$F_{vertical} = -\ddot{D}_{heave} - g$$

$$S = (\ddot{D}_{sway} + g\,\eta_{roll}) - c_f\,\ddot{D}_{heave} \qquad S > c_f\,g$$

$$T = (-\frac{1}{3}h\,\ddot{\eta}_{roll} + \ddot{D}_{sway} + g\,\eta_{roll}) - \frac{1}{h}\ddot{D}_{heave} \qquad T > \frac{l\,g}{h}$$

$$T = (\ddot{D}_{surge} + \frac{1}{3}h\,\ddot{\eta}_{pitch}) - \frac{d}{h}\ddot{D}_{heave} \qquad T > \frac{d\,g}{h}$$

Where *S* is the sliding function, *D* is displacement, h is motion, cf is the frictional coefficient, l is the half-stance width, d is the half-foot length and h is the height of the center of gravity. *STANAG 4154* recommends 35% MSI in two hours or 20% in four, a interruption per minute and a vertical acceleration with a quadratic medium value of simple amplitude of 0.2 g, as operative limits.

If we are designing warships or similar forms a STANAG 4154 is a good tool for seakeeping and habitability characteristics. The majority of the research on human behavior and his consequent parameters of sickness and efficiency on board was carry out by governmental institutions related to the navies and warships. Most of these data are directly applicable to the HSC, so all the obtained highlights are needed in the actual ferry designs.

In the early 1980s, Baitis et al (Baitis, 1984) used a newly developed lateral force estimator LFE to compute motion induced interruptions MII of flight deck crew operations. And in reference (Graham, 1990) in 1990, Graham developed a general lateral force estimator (GLFE) to compute motion induced interruptions MII at any location on the ship. An ad hoc working group of four nations (ABCD) was formed to plan and guide human performance research, starting with series of experiments in the US and UK to measure MII for a range of manual tasks. Crossland and Rich (Crossland, 2000) thus refined the algorithms and criteria for MII. Colwell (Colwell, 2000) reported on the results of shipboard surveys to qualitatively assess a range of effects on performance of a variety of shipboard tasks.

A total of 1,700 booklets of questions were handed to sailors on seven ships in maneuvers off Scotland in February 1997. The sailors were to initially answer a few questions about their specific shipboard assignments. Then at the end of each watch they were to answer questions on the next two pages in the booklet; the first of which addressed symptoms of fatigue and motion sickness and the second, other effects on task performance. At maneuvers ending, an approximate 60% of the booklets were returned. So over 16,000 survey responses to correlate ship motion effects on human factors. Comparisons were made between crewmembers that were susceptible to seasickness and those that were not and between crewmembers that were doing manual tasks and those that were doing cognitive tasks.

A good seakeeping crew reference is the NATO STANAG 4154 on Common Procedures for Seakeeping in the Ship Design Process with the following data criteria:

Recommended criteria
— 20% MSI in 4 hrs
— 1 MII per min
— 35 knots relative wind

Default criteria
— 8º SSA roll
— 3º SSA pitch
— 0.4 g SSA vertical acceleration
— 0.2 g SSA lateral acceleration

Papers given in 2004 in the AVT-110 Symposium on Habitability of Combat and Transport Vehicle began to point the way toward application of human performance models in the design of high-speed vessels. Riola, Esteban y Girón (Riola et al, 2004) introduced the concept of motion filters to address the effects of seasickness.

Vibration as a limit on human performance is also cited in ISO Standard 2631 (ISO Standard 2631-1, 1997). The human body is susceptible to seasickness in the frequency range of 0.05 to 1 Hertz, the range in which ship motion occurs for low to moderate speed ships and vessels. The human body experiences what the ISO standard cites as fatigue decreased proficiency in the frequency range of 1 to 80 Hertz, often the result of structure borne slamming responses and machinery vibration. Miller and French (Miller and French, 2005) reported on a Physiological Stress Index PSI model they developed to estimate the impact of exposure to physical stressors, specifically extreme temperatures and fatigue related to insufficient sleep.

The first step in the seakeeping assesment is to know the hydrodynamic vessel responses related to speeds and headings (Esteban et al, 2005) to the wave excitation loads. The second is to obtain the wave spectra of the operational area to know the motions magnitude. So, the habitability can be obtained based on the probability of motions at acceptable levels. The operational seaway for the ship is decribed by a statistical model, in which the area wave characteristics is known in terms of wave height and wave energy related to frequencies and headings (Recas et al, 2004). In order to compute the motions, first we must compute the forces from any adequate equation.

Normally compute the excitation force, the added mass, and the radiation damping for a vessel as a function of frequency and heading. When the equations of motions are solved for a unit amplitude wave, we obtain a set of quantities called Response Amplitude Operators, or RAOs. These so-called RAOs are the key elements of the seakeeping analysis and they are transfer-function-like operators that give the frequency vessel motion response to the wave amplitude as a frequency function.

Having these RAOs, it is possible to combine them with the sea spectrum to obtain the power spectrum of the ship motion components: surge, sway, heave, roll, pitch and yaw.

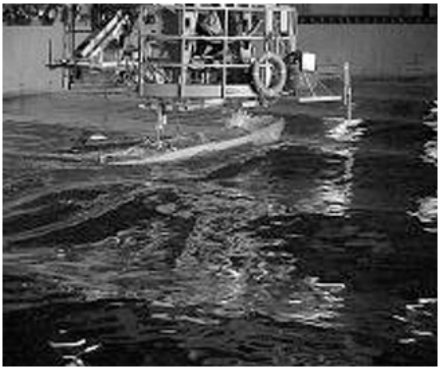

Figure 9. Seakeeping basin.

From the motion components spectrum all the necessary ship motion statistics are obtained and the seakeeping analysis performed.

Using spectral methods we assume that the sea surface is an ergodic, Gaussian random process with zero mean. And the ship can be represented by a linear system that allows the spectral density of any given response to be found by multiplying the incident wave spectrum by the square of the RAO.

The best way to obtain the response amplitude operators RAOs is to carry out model tests in a basin. The amplitudes and phases in the frequency domain and define the response amplitude due to a wave excitation. The tests must be performed with regular wave tests at different headings. The responses of the wave excitation are obtained by superposition of the RAOs and wave spectral density function (Recas et al, 2004). The results must be carried out for a complete set of headings in each ship condition. The amplitudes and phases can be obtained by harmonic analysis using a least squares procedure. The RAOs themselves are of limited use because in reality, the sea is confused with peaks and valleys all over the place. Thus, a sea is normally specified by a spectrum, a function of frequency and heading which gives a measure of the square of the amplitude of a sine wave of this frequency and heading in the sea. So, irregular long crested wave tests must be carried out in order to know the ship behaviour. For the Mediterranean Sea, a JONSWAP wave spectra corresponding to sea state number 3 to 5 with a peak periods from 6 to 8 seconds can be chosen.

Respect to the motions of the six degrees of freedom, the heave, pitch and roll are the most interesting from the seakeeping point of view due to their natural response periods and resonance phenomena. The last necessary step from the motion sickness point of view, is to obtain the vertical and lateral accelerations to obtain parameter comfort data.

HABITABILITY ASSESMENT

The goal of this knowledge of the seasickness is to transfer the information on sailing time to the master on screen to comfort the passengers. According with test data and the experience on ships at sea, people have less tolerance to vertical motions and accelerations in the range of 0.1 Hz to 0.25 Hz o their equivalents in seconds, with a fast sensitivity reduction with higher or lower values.

In the figure 10 can be shown how the master how to reduce the sickness index, in a particular place, slightly modifying the speed or heading of the ship. The two white lines show how the MSI changes when the speed or heading is modified. Of course, this highlight of the results agrees with the real practice because the heading is most influent variable on sickness.

A good presentation to this effect is a polar diagram due to the easy way to control the effect of the speed and headings. A polar diagram is a good assesment for seakeeping performance.

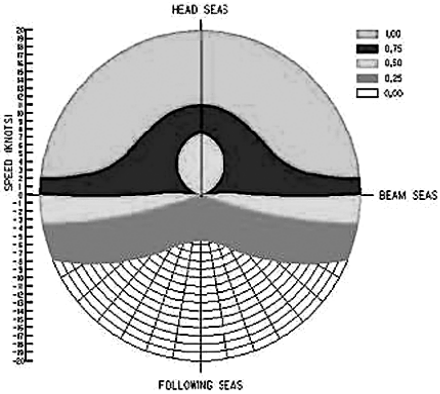

Figure 10. Polar diagram.

This diagram type gives maximum values for each combination of speed, heading and sea state, limiting the area where the ship with this speed and heading can be sailed without exceding any limiting criteria. In the figure 3 is presented a case in the bridge of a passenger ferry in a medium speed in a sea state 4. With the combinations of headings and speeds, a complete manoeuvring set can be obtained and the consequent seakeeping criteria are available in the different sea states of the ship.

CONCLUDING REMARKS

The assesment of the ship seakeeping performance in a operational area requires the prediction of transfer functions for speeds and headings for each response. The transfer functions are then combined with an spectral sea area.

Some evaluation parameters can be used for to developed a seakeeping criteria. A presentation of MSI, MII, ISO2631, GLFE were made. Most of these type of parameters are complementaries and can be appropiated for passenger and crew.

The results must be presented in a esay diagrams to facilitate the cmaster decissions. A good example is the polar one in order to obtain the habitability values for each speed, heading and sea state.

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