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INVESTIGATION OF HABITABILITY INDICES OF YTU GULET SERIES IN VARIOUS SEA STATES

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Summary

This paper presents habitability indices of gulet-type boats for the vertical plane motions in specified sea states. Gulets are commonly used in the Mediterranean and the Aegean Sea as pleasure boats. Therefore, it is very important to obtain their habitability indices. Thus, 21 different gulet forms developed as a result of iterative studies are used for analyses. The ISO 2631 standard that defines the effect of different levels of vertical accelerations on humans is used as the first seakeeping criterion. Other seakeeping criteria are obtained from NATO Standardization Agreement (STANAG) documents for pitch motion. Seakeeping analyses are carried out by using commercial software which is based on the strip theory and statistical short term response prediction method. The effect of displacement forces, selected criteria and sea conditions on habitability indices is presented.

Keywords: *Motion on vertical planes; Habitability; Seakeeping criteria; Strip theory;*

1. Introduction

Existing gulets are generally used for pleasure trips and today they are often referred to as Turkish gulets. A systematic series of gulet hull forms with cruiser stern has been developed by Aydın in order to investigate the overall performance of this type of boats. Geometric block coefficient (C_{Bo}) is selected as a main parameter determining the gulet hull forms [1]. The gulet forms from the series and the present gulets with cruiser stern in Turkey are given in Table 1 with their main dimensions, some of the hydrostatic coefficients and displacement forces.

The geometric characteristics of the gulet forms in the series are given in Table 2. Displacement values range between 210.91 - 1825.64 kN, as can be seen in the given tables.

Important step in design phase is hull form optimization. This optimization is usually based on stability, resistance and propulsion. However, it is important to obtain the responses in irregular waves because of the complexity of sea surface. The shipmaster might decrease speed voluntarily or involuntarily due to sea conditions. On the other hand, seasickness phenomenon forces engineers to design more sea kindly ships. A reformation in responses can definitely advance the comfort and safety of the passengers.

Table 1 A comparison between existing gulets and YTU Gulets with cruiser stern

	Present Gulets with Cruiser Stern	**YTU Gulets with Cruiser Stern**
L_{OA} [m]	18 – 33	15 - 35
B_{OA} [m]	5.4 - 7.8	4.839 - 7.543
D [m]	2.35 - 4.1	2.634 - 4.556
T [m]	1.65 - 2.76	1.558 - 2.665
C_B	0.230 - 0.315	0.256 - 0.334
C_{WP}	0.705 - 0.810	0.738 - 0.823
C_P	0.646 - 0.730	0.654 - 0.689
Δ [kN]	343.35 – 1520.55	210.91 – 1825.64

Table 2 Geometric characteristics of YTU Gulets with cruiser stern

Gulet No	**L_{WL}/B_{WL}**	**B_{WL}/T**	**$L_{WL}/\nabla^{(1/3)}$**	**C_{WP}**	**C_P**	**C_{VP}**	**L_{CF}/L_{OA}**	**L_{CB}/L_{OA}**	**k_{yy}[m]**	**Δ [kN]**
G1	2.729	2.817	4.343	0.738	0.654	0.347	0.492	0.509	$0.25*L_{OA}$	210.86
G2	2.795	2.836	4.389	0.731	0.650	0.358	0.491	0.505	$0.25*L_{OA}$	247.97
G3	2.860	2.850	4.432	0.725	0.647	0.369	0.484	0.497	$0.25*L_{OA}$	288.74
G4	2.924	2.789	4.460	0.720	0.646	0.373	0.481	0.491	$0.25*L_{OA}$	336.30
G5	2.987	2.804	4.501	0.717	0.644	0.383	0.478	0.487	$0.25*L_{OA}$	384.91
G6	3.049	2.817	4.540	0.715	0.643	0.392	0.476	0.484	$0.25*L_{OA}$	437.53
G7	3.110	2.763	4.565	0.714	0.644	0.393	0.473	0.480	$0.25*L_{OA}$	498.11
G8	3.170	2.776	4.602	0.714	0.644	0.401	0.472	0.479	$0.25*L_{OA}$	559.26
G9	3.228	2.788	4.636	0.716	0.645	0.407	0.470	0.476	$0.25*L_{OA}$	624.76
G10	3.286	2.739	4.659	0.718	0.647	0.407	0.469	0.475	$0.25*L_{OA}$	699.52
G11	3.342	2.753	4.692	0.722	0.648	0.412	0.468	0.475	$0.25*L_{OA}$	774.27
G12	3.396	2.766	4.723	0.727	0.650	0.416	0.467	0.476	$0.25*L_{OA}$	853.73
G13	3.450	2.723	4.743	0.734	0.654	0.414	0.464	0.476	$0.25*L_{OA}$	943.82
G14	3.501	2.737	4.773	0.741	0.657	0.416	0.464	0.477	$0.25*L_{OA}$	1033.28
G15	3.552	2.751	4.801	0.750	0.660	0.418	0.468	0.479	$0.25*L_{OA}$	1127.81
G16	3.601	2.713	4.819	0.759	0.665	0.414	0.465	0.481	$0.25*L_{OA}$	1234.48
G17	3.648	2.728	4.846	0.770	0.668	0.414	0.470	0.484	$0.25*L_{OA}$	1339.79
G18	3.694	2.742	4.871	0.782	0.673	0.414	0.471	0.487	$0.25*L_{OA}$	1450.56
G19	3.739	2.709	4.888	0.794	0.679	0.408	0.473	0.490	$0.25*L_{OA}$	1575.08
G20	3.782	2.726	4.912	0.808	0.684	0.407	0.475	0.494	$0.25*L_{OA}$	1697.44
G21	3.823	2.743	4.935	0.823	0.689	0.405	0.477	0.498	$0.25*L_{OA}$	1825.64

Reducing motions and accelerations in several sea states is necessary for the sake of passengers. Increasing the habitability index (HI) percentage for the passenger saloon should be one of the designer’s priorities. The seakeeping performance of a vessel in a particular sea environment depends on 4 main factors:

- Response in regular waves (RAO)
- Sea state (SS)
- Vessel's speed and heading
- Standardized seakeeping criteria.

While the behavior of a vessel in regular waves depends on its weight, main dimensions, hull form parameters and weight distribution, the sea state evaluation is based on annual measurements and it might be different for each sea environment. Ship motion amplitudes and vertical plane accelerations in regular waves can be calculated by using 2D strip methods in conceptual design phase.

Seakeeping performance of yachts and pleasure craft has an important impact on boat overall performance and it is related to being below or above the specified seakeeping criteria. Absolute vertical acceleration and pitch motion are two motions important for the comfort of passengers. Sarıöz and Narlı, in their study, claimed that selected criteria directly affect seakeeping performance evaluation of a ship and they calculated HI for the selected criteria for sea states 5 and 6 [2]. In another study, they calculated habitability performance indices of a passenger ship by using wave distribution scatter [3]. In both studies aforesaid motion is vertical acceleration and limiting values are obtained by using the ISO 2631 standard.

In this study, the HI of 21 different gulet hull forms are calculated for absolute vertical acceleration in the passenger saloon and pitch motion according to the selected criteria. Longitudinal position of COG is taken to be the same as that of LCB for each gulet in the analyses. This means that there is no trim at steady condition. VCG is taken as 1.5 meter for G1 and it is directly increased proportionally with D values for all gulets. Gyration radius for pitch motion, kyy, is taken as 0.25*L_{OA} for all gulets. Location of the passenger saloon is shown in Table 3:

Table 3 Location of passenger saloon

Longitudinal distance from aft extreme (m)	L_{OA}*0.4
Transversal distance from centerline (m)	0
Height from carina (m)	D*1.20

2. Seakeeping Performance Assessment

Seakeeping performance is evaluated for all headings and for Fn =0:0.05:0.3 in this paper. Hydrodynamic coefficients are calculated by using Frank Close-Fit method for each gulet section. Cross sections of number 11 Gulet (G11) are shown in Figure 1.

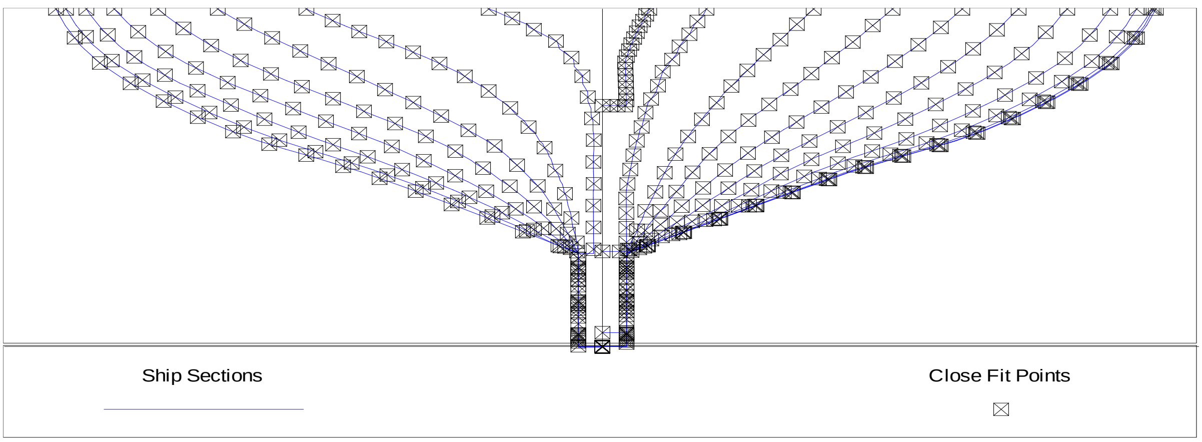

Figure 1 Sections of Gulet and Close Fit Points

The assessment of seakeeping performance of a pleasure craft in a specified sea state is related to the following elements:

- Ship geometry
- Weight distribution on ship
- Transfer functions (RAO) in regular waves
- Wave spectra
  As a result of these interactions;
- Determination of ship responses
- Calculation of HI for the defined limiting values and sea states.

HI can be calculated for each of the gulet forms following this assessment procedure. Interaction of the above given elements will determine HI.

2.1 Gulet Response Characteristics

The first step in estimation of the seakeeping performance is to detect the motion response amplitudes and phase lags in the frequency domain for all 6 degrees of freedom. Then RAOs can be determined for each specified response in terms of heave motion, velocity and acceleration. Graph of RAO of G11 is shown in Figure 2 for the case of zero speed and head waves. It should be pointed out that there is a potential for resonance behaviour due to the restoring effect of the heave and pitch motions.

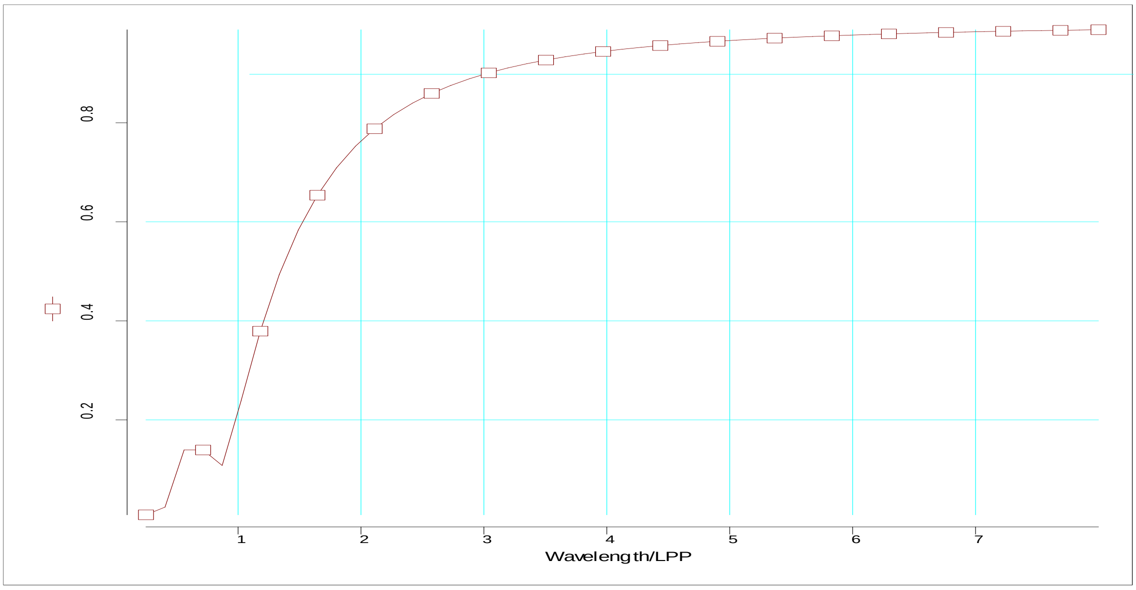

Figure 2 G11, Heave transfer function for Fn=0, μ:180°

2.2 Definition of Seaway

Ship motions in irregular waves should be investigated as the regular waves are seldom present in nature. It is important to get ship motions in random waves because of the complexity of sea surface. Modelling of the seaway is possible by using some statistical methods. Irregular sea can be expressed by using wave spectra that are composed as regards to normal (Gauss) distribution. In order to enter short term statistical parameters, firstly the spectral density function has to be known. This function must fit the characteristics of the sea environment where the gulets will sail. The 2-parameter ITTC wave spectrum (developed by Bretschneider), which is proposed in STANAG 4194 documents, is used in the analyses as the gulet type boats mostly operate in the East Mediterranean Sea. Analyses are performed for sea states 2, 3 and 4. The characteristic wave heights and modal periods for the mentioned sea areas are given in Table 4.

Table 4 Characteristics of the East Mediterranean Sea

Sea State	Characteristics Wave Heights, $H_{1/3}$ (m)	Modal period, T_m (s)
2	0.30	5.00
3	0.88	6.25
4	1.88	8.15

2.3 Prediction of Motions

Predictions of ship's responses in operational sea environment are normally based on 2D and 3D analytical methods. In the short-term analyses the average, observed and most frequent motion amplitudes are obtained with the help of response function curve which is obtained by superposition of RAOs and wave spectrum curves (Figures 3-5 and Eq.1). Response function curve must be plotted for all headings and motions which affect the habitability of the ship. In this paper, maximum Fn is taken to be 0.3, because gulets are a type of displacement boats and Fn is a limiting factor for the strip theory.

$$S_z(\omega_e) = S_\zeta(\omega_e) \times |RAO_Z|^2 \quad (1)$$

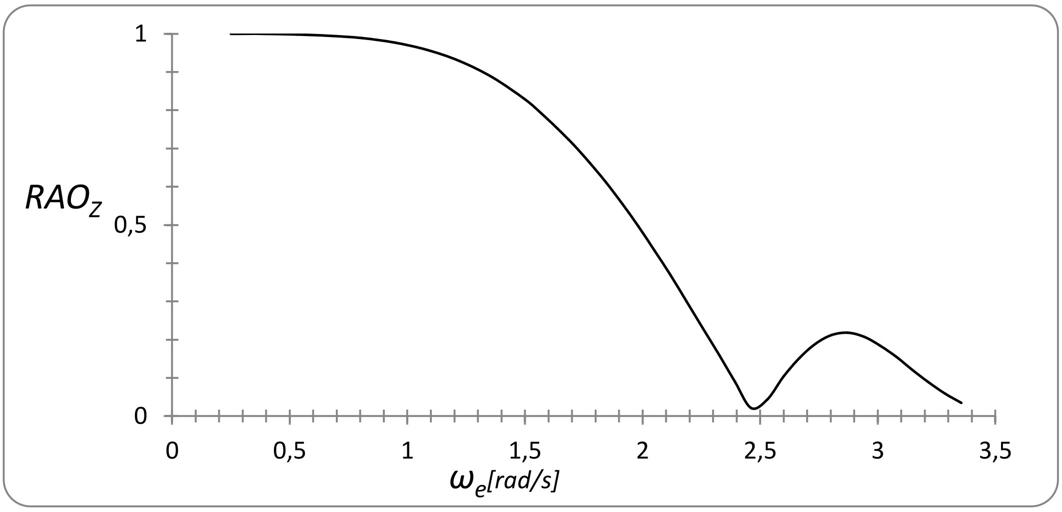

Figure 3 Typical RAO curve

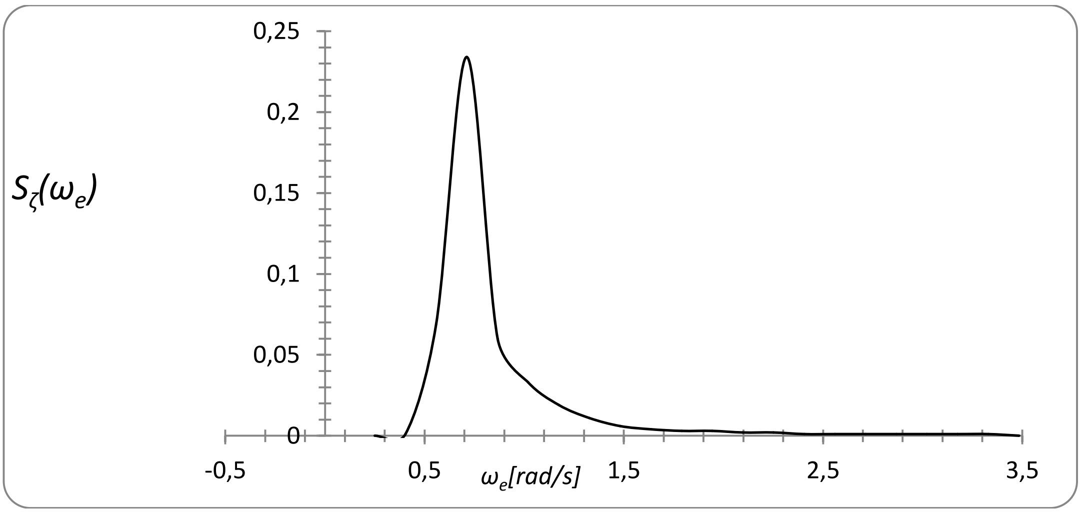

Figure 4 Typical wave spectrum curve

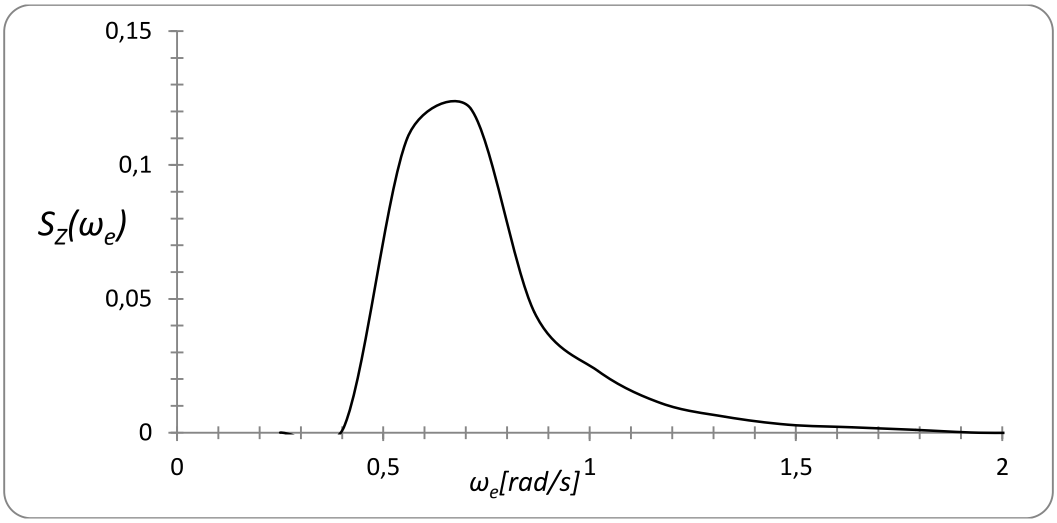

Figure 5 Typical response curve

The passenger saloon Root Mean Square (RMS) absolute vertical accelerations for G11 in sea state 3 are given in Figure 6. These results are based on calculations for a Fn range of 0-0.3 and SS3.

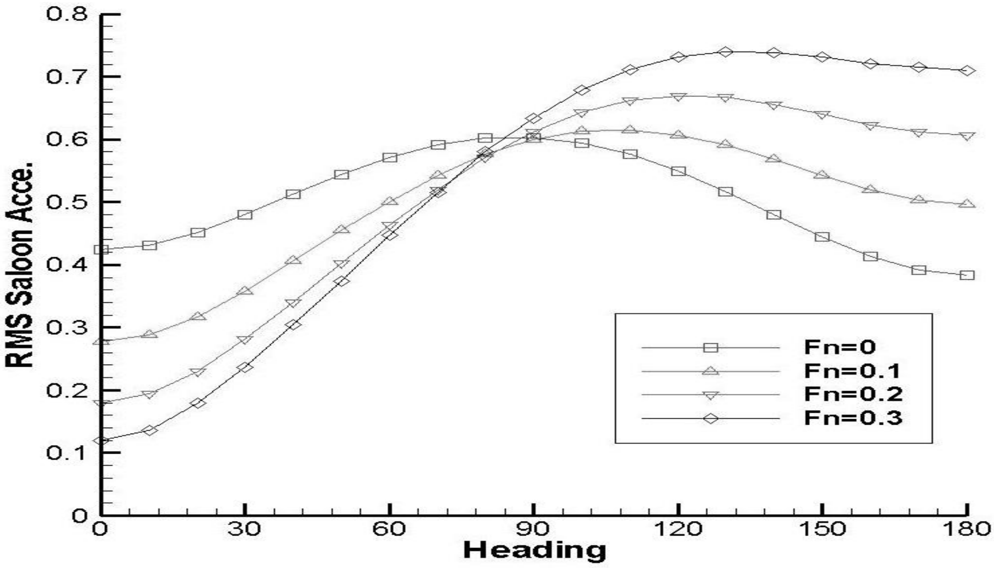

Figure 6 Graph of saloon RMS vertical accelerations for G11 (SS3)

3. Habitability Index

Habitability indices which are available for zero speed to operational speed, at all headings, specified sea conditions and seakeeping criteria can be calculated by using Eq. (2):

$$HI = \frac{1}{2\pi V_0}\int_0^{2\pi} V_{lim}(H_{\frac{1}{3}}, T_m, \mu)d\mu \qquad (2)$$

Limiting seakeeping merits presented in the NATO standard STANAG documents for pitch motion are taken as 1.5° and 2° RMS. These specific criteria are formulated on the basis of surveys which were carried out during voyages on particular US navy ships. The effect of vertical acceleration on human body was researched extensively by International Standard ISO (1985-1987) and proved relative to pitch motion [2, 3, 4 and 5]. Passenger comfort is closely related to vertical accelerations in the passenger saloon and pitch motion. Selected acceleration levels are shown in Table 5 with acceptance time range of gulet trips from 30 minutes to 2 hours.

Table 5 Selected acceleration levels

Exposure time [hour]	RMS vertical acceleration [m/s^2]
2 hours	0.500
1 hour	0.707
30 min	1.000

As it is seen in the polar diagram in Figure 7, the coloured zone is the dangerous zone for G11 when the selected pitch motion criterion is 2° RMS in SS 4. Beam waves are recorded as safer than head and following waves for the pitch motion. Habitability index can be obtained by calculating the rate of the safe zone to all zones and it is calculated as 0.608. This rate is between 0 and 1 in all cases.

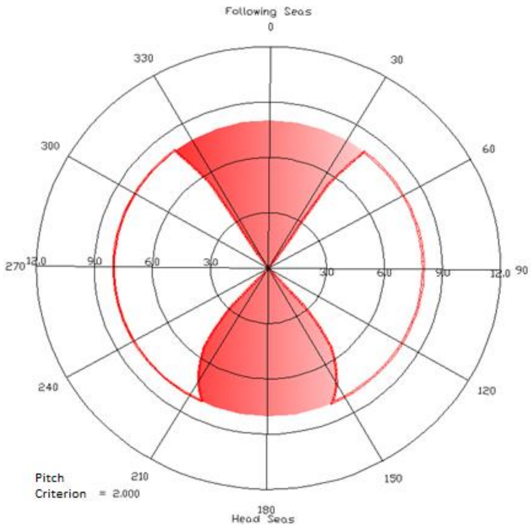

Figure 7 G11, SS 4, pitch motion polar diagram

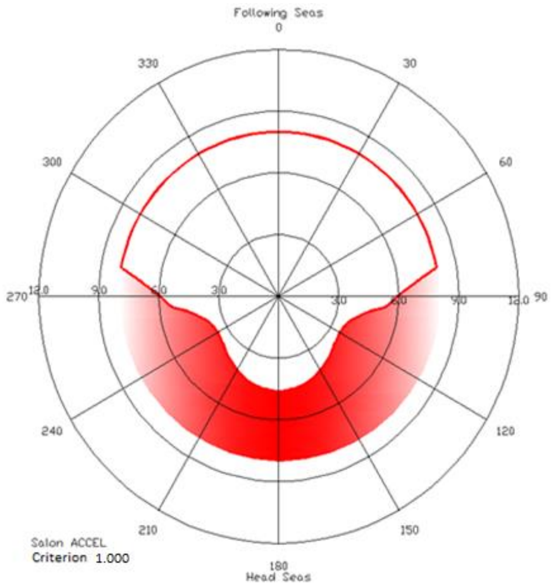

Figure 8 G11, SS 4, passenger saloon, vertical acceleration polar diagram

Figure 8 shows the dangerous and safe zone for G11 when the selected vertical acceleration criterion is 1 m/s^2 at the passenger saloon in SS4. Habitability index can be obtained by calculating the rate of the safe zone to all zones for 30-minute trip and it is calculated as 0.623 by using this method for the case in Figure 8. Head waves are more dangerous for vertical acceleration.

4. Results and Discussions

A set of analyses was carried out for 21 different hull forms in order to determine seakeeping characteristics for gulets. Firstly, RAO graphs were obtained in regular waves and then they were superposed with the chosen wave spectrum. In the end, most frequent motions (RMS) were obtained in irregular waves by using statistic methods. HI were calculated for all gulet forms in SS 2, 3 and 4 by using polar diagrams. The ISO 2631 standard for absolute vertical acceleration and the pitch motion standard which is formulated in STANAG documents were used as seakeeping criterion in calculating indices. The obtained results are graphically presented. Figure 9 shows the changing of HI values for vertical acceleration at the passenger saloon for all gulet forms in SS3, while Figure 10 shows the same configuration for SS4. As can be seen in Figures 9 and 10, as the sea state level increases the HI values decrease. Since RMS's in SS2 are within the chosen set of criteria, the habitability index is calculated as 100 % even for the lightest hull form G1. Another outcome is that seakeeping criteria affect HI directly. As the criteria levels increase, the HI values increase correspondingly. Longitudinal position of passenger saloon is about 10% is behind of amidships for each gulet. Increment on L_{OA} from G1 to G21 is the main reason for lack of correlation between displacement forces and HI for vertical accelerations. The reason is that vertical accelerations at the passenger saloon are directly related to the distance to COG (see Equations 3 and 4).

$$Z_s = (\eta_3 + y\eta_4 + x\eta_5)e^{i\omega t} \tag{3}$$

$$A_s = (-\omega_e^2 Z_s)e^{i\omega t} \tag{4}$$

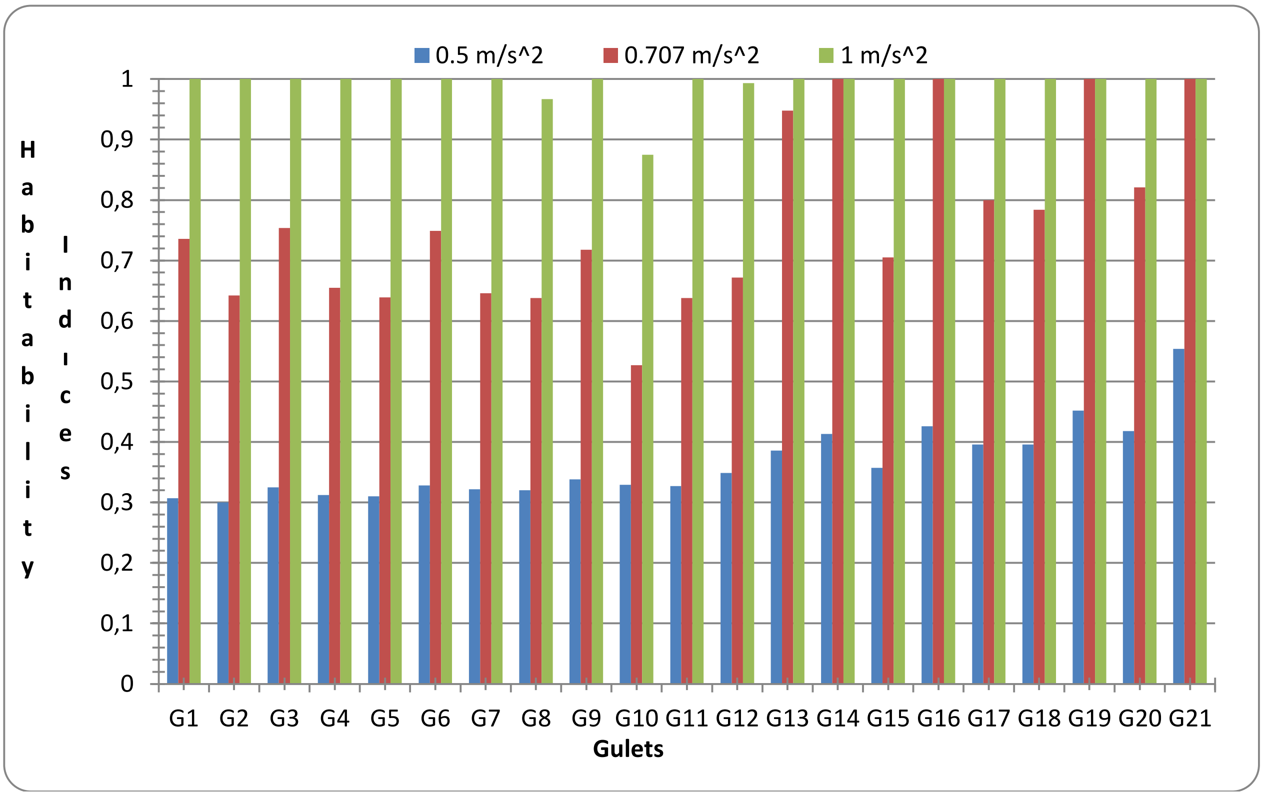

Figure 9 SS3, HI for vertical acceleration in passenger saloon

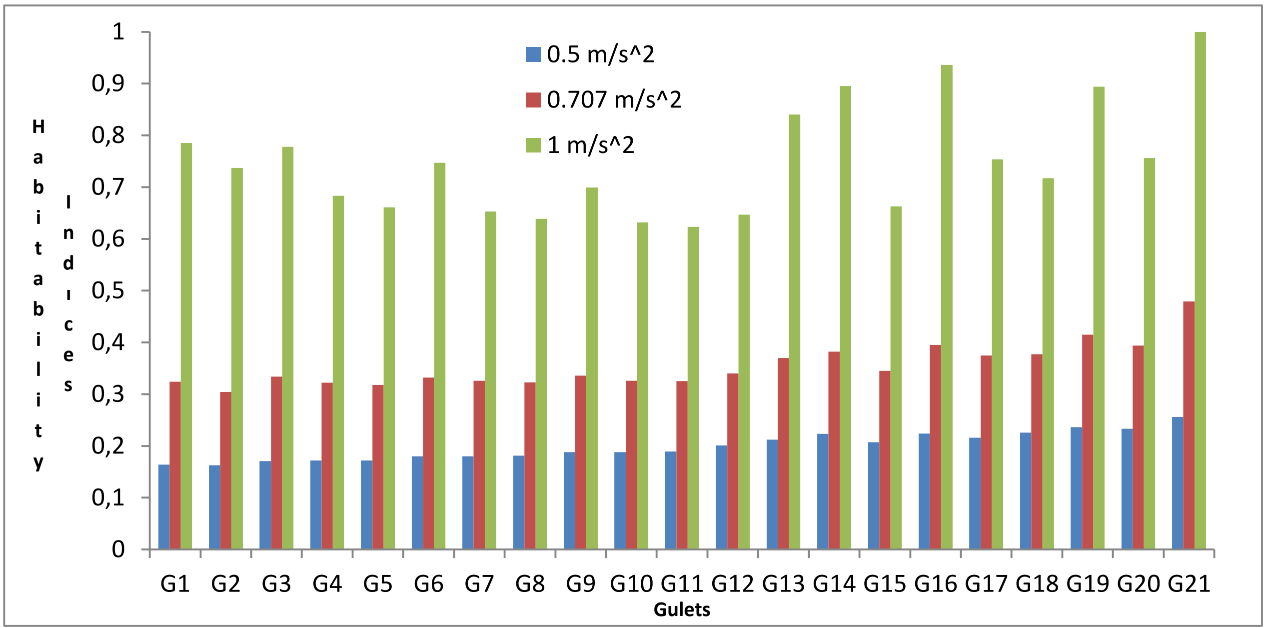

Figure 10 SS 4, HI for vertical acceleration in passenger saloon

It is logical to check Figure 11 and Figure 12 to discover the effect of displacement forces on habitability. Increment of displacement forces of gulets also increases the HI at the specified criteria. All gulets after the gulet G9 reached 100 % habitability rates in SS3 at the 1.5° RMS pitch motion criterion, which can be seen in Figure 11. When SS4 is considered, it is clearly seen that HI are very low for the hull forms G1-G9. The form G21, the heaviest one, has nearly 51% habitability index in SS4 at the 1.5° RMS pitch motion criterion. In the conditions of 2° RMS pitch motion criterion, the HI values are increasing with noticeable change. While all gulets have 100% habitability rate in SS3, the rate is decreasing in SS4, which can be seen in Figure 12. The form G1, the lightest one, has nearly 44% habitability index in SS4 at the 2° RMS pitch motion criterion.

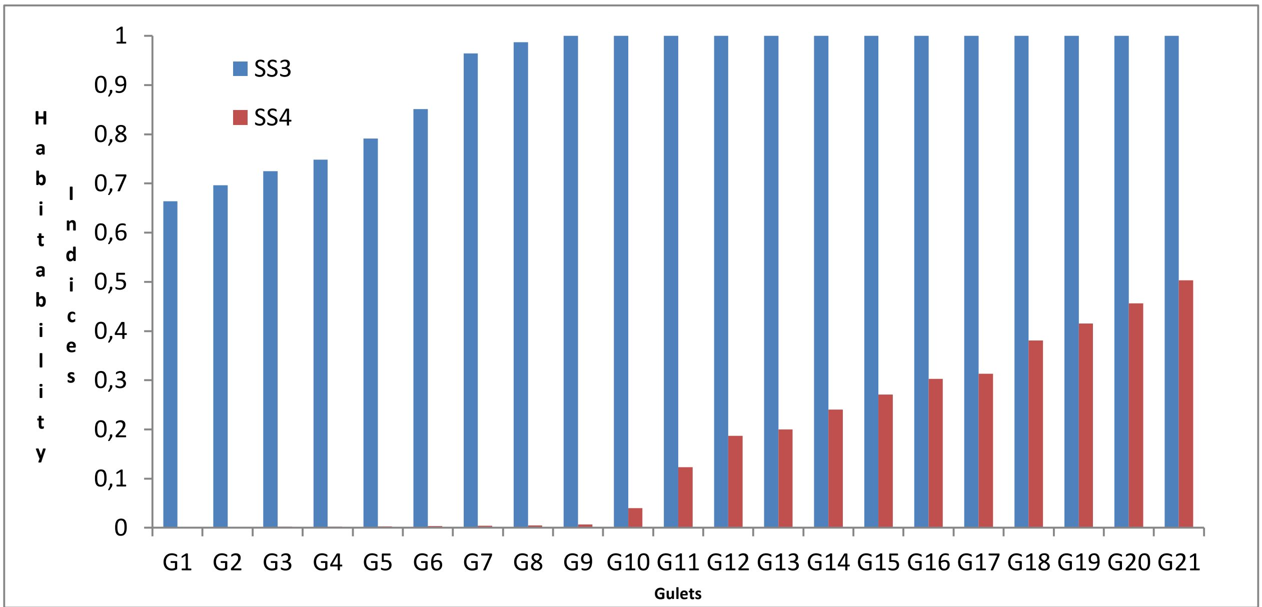

Figure 11 HI for pitch motion at chosen criterion (1.5° RMS)

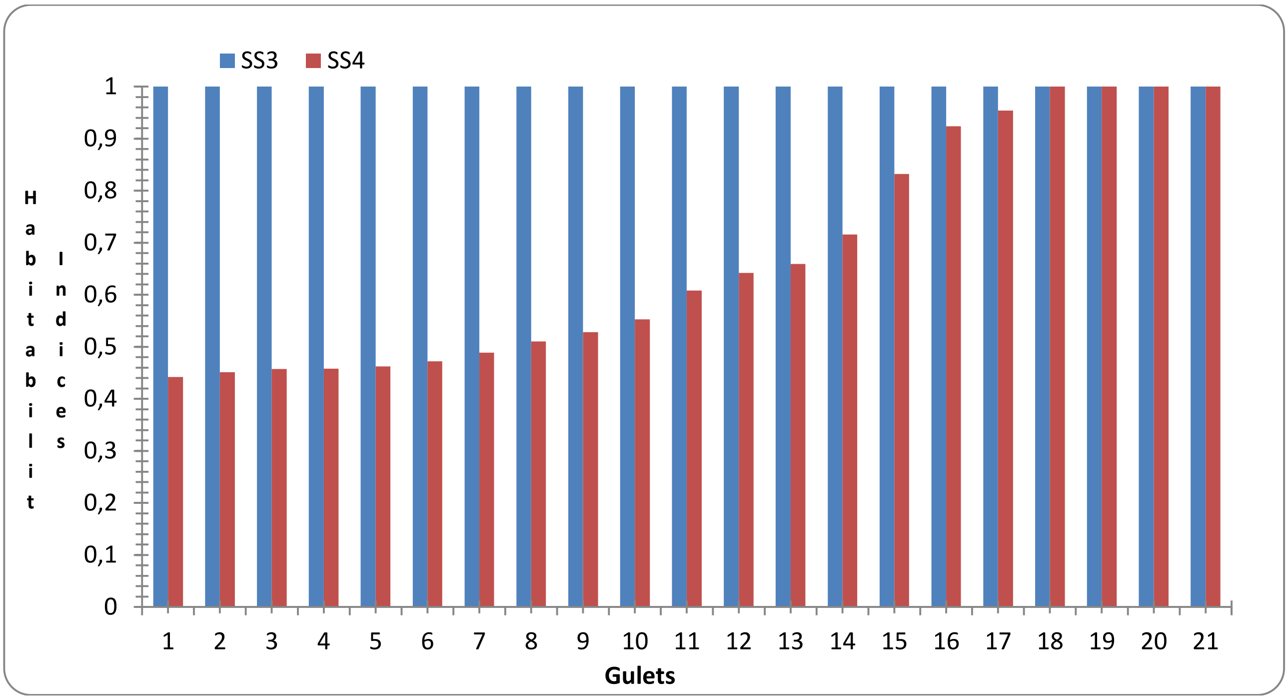

Figure 12 HI for pitch motion at chosen criterion (2° RMS)

5. Conclusions

The evaluation of seakeeping performance of gulets in the specified sea states is the main output of this paper. Mission definition has to be turned to operational success because gulets are pleasure boats. It is possible to obtain habitability percentage of gulets for the given operational sea area. It is shown in the study that habitability percentage of gulets strongly depends on the selected seakeeping criteria and sea state. It also strongly depends on displacement forces of gulets. Therefore, the graphs presented in this study should be studied prior to potential gulet building. Designers should be careful at the conceptual design stage regarding passenger demands in terms of comfort, safety and seasickness phenomenon.

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