
**Large yachts — Quality assessment of
life onboard — Stabilization and sea
keeping**

*Grands yachts — Évaluation de la qualité de la vie à bord —
Stabilisation et tenue en mer*

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Contents

Page

Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Waves	2
4.1 Irregular waves.....	2
4.2 Equivalent scatter diagram, wave height and wave periods.....	3
5 Heading	3
6 Speeds	3
7 Definitions of the areas on board	3
8 Calculation of MSI and EGA	3
8.1 General.....	3
8.2 Weighting factor.....	4
9 Stabilization systems	5
10 Calculation of the ship motions (EGA and MSI)	5
Annex A (normative) Definitions and descriptions	6
Annex B (informative) Guided example	12
Bibliography	16

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 12, *Large yachts*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The lack of standards and criteria for the assessment of the ship-motion related to the risk of discomfort onboard of large yachts was reported to be an important issue for the industry, brokers, owners and representatives. There was not a recognized and accepted procedure, criteria and rating that can be used to compare yachts among each other and evaluate the impact of stabilization systems in the improvement of the comfort onboard.

The increased demand for comfort onboard of large yachts led to the development of several types of stabilization systems and to design large yachts with ship motions in mind. The intention of this document is to define an objective scale for comparison of different levels of comfort at several areas onboard of a large yacht in transit and at zero speed (DP or at anchor).

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Large yachts — Quality assessment of life onboard — Stabilization and sea keeping

1 Scope

This document provides a comparative scale (no judgement) of motion-related comfort onboard yachts to be used for technical and commercial benefit. The scale consists of a maximum number of 5 stars, the higher the amount of stars, the higher the comfort onboard. It allows the selection of the most suitable yacht for a specific purpose, evaluates the impact of stabilization systems, compares designs and identifies the most comfortable position onboard.

The methodology, work flow and criteria proposed in this document are subject to possible improvements and do not take into account certain important aspects that influence the comfort onboard.

The following aspects are not covered in this document: jerk, the method to derive roll damping, stern quartering seas, risk of parametric roll, the influence of the steering devices, green water and waves impacts, compensation for yacht size, gender and age dependency, habituation.

By explicitly listing the aspects that are not covered in this document, the reader becomes aware of them and can improve the assessment with dedicated considerations.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2631-1:1997, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

comfort

<biodynamics> subjective state of well-being or absence of mechanical disturbance in relation to the induced environment (mechanical vibration or repetitive shock)

Note 1 to entry: Many of the factors contributing to a comfortable state for crew and passengers are indicated in [Figure 1](#).

Note 2 to entry: Some of these factors are being assessed and described in existing ISO standards, such as ISO 2631-1 for the vibrations and several others for the noise with respect to human beings.

Note 3 to entry: The comfort factors addressed in the study presented in this document are the ones related to motion, postural stability and the motion sea sickness.

Note 4 to entry: Some of the factors influencing comfort are a function of the extension to the exposure to that specific factor and its intensity, as well as to the gender, age and previous experiences of the subject experiencing discomfort. The mental state of the subjects plays also a very important role.

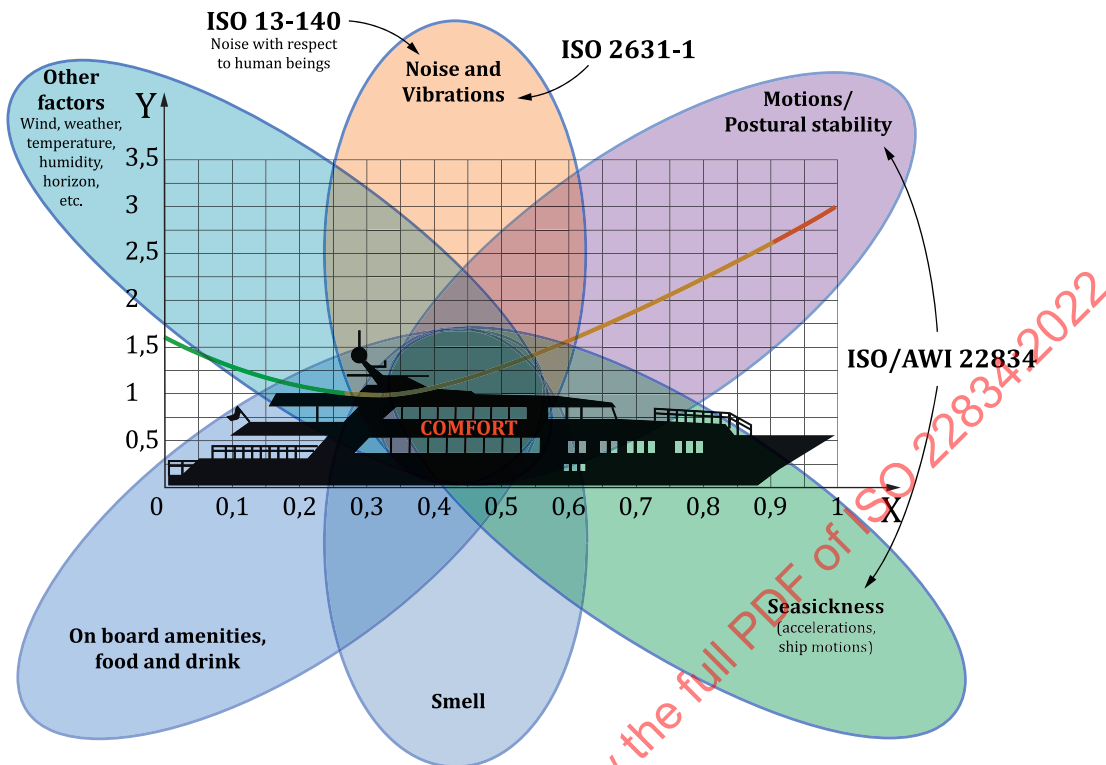


Figure 1 — List of elements contributing to comfort onboard

3.2 effective gravity angle EGA

angle between the transversal acceleration and the sum of the vertical acceleration and the standard gravitational acceleration containing the static roll angle and also the dynamic components

Note 1 to entry: The EGA is the direct measure of the need to look for support for standing persons, but also for tipping or sliding of objects.

3.3 incidence of motion sickness MSI

simple and concise statistically-based measure for predicting the incidence of motion sickness by exposure to vertical accelerations

Note 1 to entry: MSI expresses the percentage of people on board that suffer from sea sickness after a certain exposure time. For passengers vessels, a percentage of 10 % seems to be reported in literature.

Note 2 to entry: The duration of exposure is of one hour.

4 Waves

4.1 Irregular waves

Long crested irregular waves with a Jonswap wave spectrum shall be applied.

4.2 Equivalent scatter diagram, wave height and wave periods

The combined equivalent scatter diagrams of the western Mediterranean (area 47 of the global waves statistics GWS) and Caribbean seas (area 26 GWS) with a significant height between 1 m and 2 m and the periods indicated in [Table A.3](#) and [Figure A.3](#) shall be used.

5 Heading

A right-handed coordinate system shall be used. The 135° heading (bow quartering) shall be used.

[Table A.2](#) and [Figure A.4](#) indicate the heading convention and reference system.

6 Speeds

The two following speeds shall be used separately:

- 0 knots;
- 12 knots.

7 Definitions of the areas on board

Independently on where they are located onboard, the following five areas shall be used as a minimum:

1. owners cabin (OC)
2. dining area (DA)
3. wheel house (WH)
4. crew area (CA)
5. beach club (BC)

The coordinates of the selected areas shall be obtained by considering the geometrical centre of these areas with respect to the origin. The origin shall be reported. The Z-coordinate (vertical plane) shall be determined by considering the deck height of the corresponding area, adding 1,2 m to this height.

When the areas are distributed in a non-symmetrical way, the assessment shall be done for the area itself but also for the mirrored area with respect to the longitudinal ship's plane as well. In this way, the assessment is done for both the windward and leeward side of the non-symmetrical area.

When the destination of the areas onboard is not defined yet, at least five areas without name but uniquely identified (area 1, area 2, etc.) shall be used for the assessment of the comfort onboard following the procedure indicated in this document.

8 Calculation of MSI and EGA

8.1 General

For each of the five areas, the MSI and EGA shall be calculated and assessed in accordance with ISO 2631-1:1997, Annex D.

The EGA shall be calculated using Formula (1):

$$EGA(t) = \arctan \left(\frac{a_Y(t)}{a_Z(t) + g} \right) \quad (1)$$

where

- a_y transversal acceleration in $[m/s^2]$;
- a_z vertical acceleration in $[m/s^2]$;
- g standard gravitational acceleration in $[m/s^2]$.

NOTE The EGA contains not only the static roll angle but also the dynamic components [see [Figure 2](#) and Formula (1)]. The EGA is a direct measure of the need to look for support for standing persons, but also for tipping or sliding of objects. Tipping occurs when the EGA is pointing outside the base of the subject. Sliding is dependent on the friction between the subject and the surface on which it is standing.

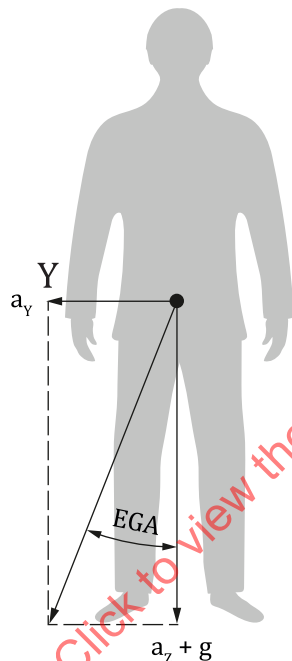


Figure 2 — Determination of the EGA

The assessment of these two quantities (MSI and EGA) is done by verifying the simultaneous fulfilment of the following criteria:

- The root mean square (RMS) of the EGA shall be lower than 2° ;
- The MSI shall be lower than 10 %.

As indicated in [Table B.2](#), there is a relation between the results of the calculations of MSI and EGA at the indicated conditions (the ship's speed, heading, wave height, periods, etc.) and the amount of stars. The fulfilment of the criteria is given as percentage of time: the up-time. This term is also known as workability.

8.2 Weighting factor

The equivalent weighting factors given in [Table A.3](#) shall be used for each of the five areas onboard.

When there is the need to calculate the comfort on more than five areas onboard, equivalent weighting factors shall be used.

9 Stabilization systems

The calculation process shall be performed both with an active stabilization system and without a stabilization system, but not with a passive stabilization system. When a yacht is equipped with passive stabilization systems with elements that remain outside the hull, such a stabilization system contributes to the generation of damping like a bilge keel. The system is excluded when considering the “without” stabilization case. One of the purposes of the entire calculation process is to indicate the improvement in comfort obtainable by adopting a stabilization system with respect to the yacht without any system. The result is the number of stars per area onboard of the yacht without stabilization, and the number of stars per area onboard obtainable with an active stabilization system. The difference in the number of stars is owing to the contribution of the stabilization system to the comfort onboard.

10 Calculation of the ship motions (EGA and MSI)

There are several ways to calculate ship motions and the corresponding EGA and MSI: empirical methods, computer programmes and physical model testing. Since the star system proposed in this document is based on the calculation of two quantities (EGA and MSI) and the fulfilment of the related criteria, the same methodology shall be used to calculate these two quantities.

The fulfilment of the criteria is weighted with the percentage of the relevance of the peak periods.

Together with the results, the methodology used for the calculation shall be reported.

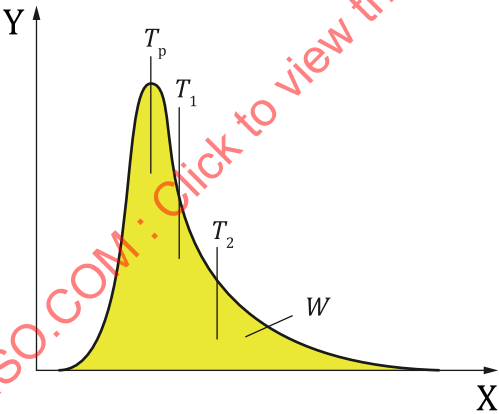
Annex A
(normative)

Definitions and descriptions

A.1 Irregular waves

A wave spectrum is characterized by the significant wave height and information on the wave period, T . The period can refer to the peak period of the spectrum (T_p), to the average value from the spectrum (T_1) or to the average time between two surface elevation zero up-crossings (T_2). Their mutual relations are given in [Figure A.1](#) for a Jonswap wave spectrum.

	Jonswap
T_p/T_2	1,285
T_p/T_1	1,198
T_1/T_2	1,072



- Key**
- Y spectral density [m^2/s]
 - X wave freq. [rad/s]
 - T_p peak period [s]
 - T_1 mean period [s]
 - T_2 mean zero up-crossing period [s]
 - W wave energy

Figure A.1 — Jonswap wave spectrum

Long crested irregular waves with a Jonswap wave spectrum are applied in this document.

A.2 Equivalent scatter diagram, wave height and wave periods

The typical wave heights and periods encountered in different parts of the world are not the same and therefore a vessel can operate better in one area as compared with other areas. By monitoring the

automatic identification system (AIS) of yachts sailing around the world over a large period of time, it is possible to conclude with a reasonable certainty that the majority of large yachts operate in the western Mediterranean and Caribbean seas^[1]. These two areas are considered for the development of this document.

One of the most used and accredited source of data for the scatter diagram is the global waves statistics (GWS)^[4] illustrated in [Figure A.2](#), [Table A.1](#) and [Table A.2](#).

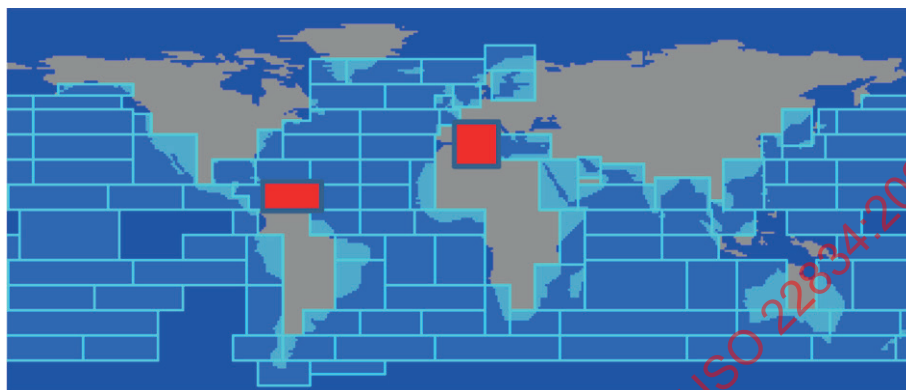


Figure A.2 — GWS area 26, the western Mediterranean, and GWS area 47, the Caribbean

Table A.1 — GWS annual scatter diagram of area 26, the western Mediterranean

Western Mediterranean Area 26 GWS								Annual, all directions				
H_s^a (m)	65	260	346	218	82	23	4					998
> 14												
13-14												
12-13												
11-12												
10-11												
9-10												
8-9												
7-8				1	1							2
6-7			1	2	1	1						5
5-6		1	3	5	3	1						13
4-5		3	10	12	7	3	1					36
3-4	1	9	27	28	14	5	1					85
2-3	3	32	72	58	24	7	1					197
1-2	13	95	145	83	26	5	1					368
0-1	48	120	88	29	6	1						292
	< 4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	> 13	T_2^b (s)
^a Significant wave height (m).												
^b Mean zero up-crossing period (s).												

Table A.2 — GWS annual scatter diagram of area 47, the Caribbean

Caribbean seas Area 47 GWS							Annual, all directions						
H_s^a (m)	10	84	247	308	211	96	32	9	2				999
> 14													
13-14													
12-13													
11-12													
10-11													
9-10													
8-9													
7-8						1							
6-7					1	1	1						3
5-6				2	3	3	1	1					10
4-5			3	9	11	8	4	1					36
3-4		2	14	35	38	22	9	3	1				124
2-3		10	59	104	82	38	12	3	1				309
1-2	2	37	125	135	70	22	5	1					397
0-1	8	35	46	23	6	1							119
	< 4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	> 13	T_2^b (s)	
^a Significant wave height (m). ^b Mean zero up-crossing period (s).													

Every wave condition (lasting for a few hours) is counted as one observation. Observations gathered around all the year are then counted and brought back to thousands. With 250 observations, it means that such period would occur 25 % of the time per year.

Out of 1 000 observations presented in the scatter diagrams, the biggest group is represented by waves having a significant height between 1 m and 2 m. It is therefore representative to focus on this group of waves as they represent the most probable waves a yacht encounters. Waves with a significant height of 2 m are considered very challenging for yachts just above 25 m of length.

A yacht that has a natural peak period of roll of about 8 s, or shorter, has a higher probability of encountering waves that lead to a resonant situation. Table A.1 and A.2 (scatter diagrams) show that waves with a zero up-crossing period between 5 s to 7 s are the most common ones in the western Mediterranean and are also very common in the Caribbean sea. When considering ship motions, the term peak period is used, while in the scatter diagrams, the zero up-crossing periods are plotted instead. The relations between one and the other are known, they depend on the peak enhancement factors as indicated in 4.1. In this document a Jonswap wave spectrum is used and the corresponding enhancement factor is 3,3: a peak period of 8 s corresponds to a zero up-crossing period of 6,2 s.

Yachts that have a longer natural period than 8 s have a lower probability of encountering waves that lead to resonant conditions.

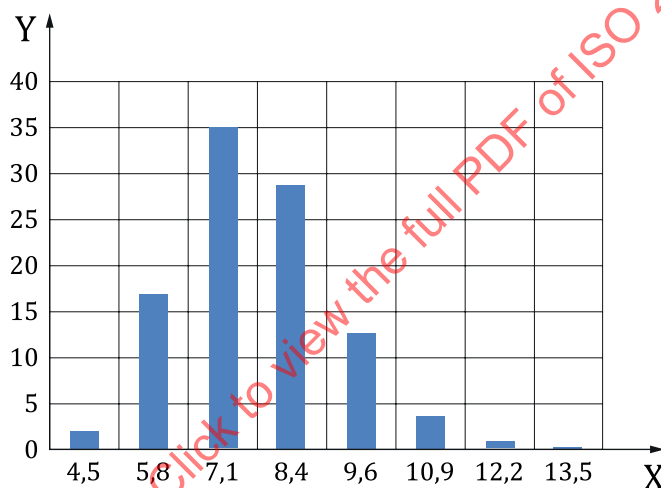
When a yacht is sailing at a certain speed, the wave-encounter frequency becomes the one to consider, which is a function of the relative speed between the vessel and waves and its heading. The longer the natural period of a yacht, the smaller the roll response is.

An equivalent scatter diagram made by combining all waves of the indicated areas with a significant height in the range of 1 m to 2 m and all periods is given in Table A.3 and Figure A.3.

Table A.3 — Zero up-crossing period of the selected areas with average and percentages

	T_2^a											No. ^c	AREA GWS
H_s^b (m)	< 4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	> 13		
1-2	13	95	145	83	26	5	1	0	0	0	0	368	47
1-2	2	37	125	135	70	22	5	1	0	0	0	397	26
averaging	7,3	64,9	134,6	110,0	48,8	13,8	3,1	0,5	0,0	0,0	0,0	383,0	-
% of total	2 %	17 %	35 %	29 %	13 %	4 %	1 %	0 %	0 %	0 %	0 %	100 %	-

^a Mean zero up-crossing period (s).
^b Significant wave height (m).
^c Total number of observations with waves having a significant height between 1 and 2 m across all periods (-).

**Key**X T_p [s]

Y Occurrence [%]

Figure A.3 — equivalent scatter diagrams for comfort assessment

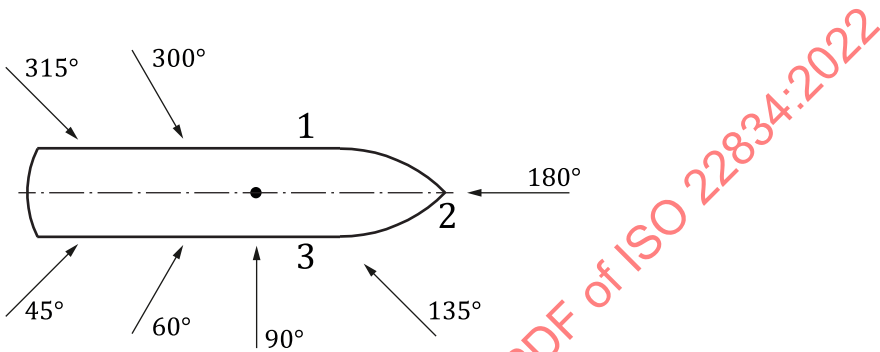
Between the data presented in [Table A.3](#) and the data illustrated in [Figure A.3](#), there is a conversion from zero up-crossing to peak period.

A.3 Heading

The heading (μ) of the vessel is given in a ship coordinate system; it is defined as the angle between the direction of the wave propagation and the direction of the vessel's bow. The sign conventions given in [Table A.4](#) and [Figure A.4](#) apply for the heading and reference system for positions.

Table A.4 — Heading convention and reference system

Ship heading convention		Reference system	
180°	head seas	X = 0	at aft perpendicular and positive forward
135°	bow quartering seas over starboard	Y = 0	at centreline and positive to portside
90°	beam seas over starboard	Z = 0	at base line and positive upward
45°	stern quartering seas over starboard		
0°	following seas		



- Key**
- 1 portside
 - 2 bow
 - 3 starboard

Figure A.4 — Heading convention and heading of 135 degrees, bow quartering

Certain directions lead to dominant ship responses. Head waves lead to pitch response with no roll. A beam sea induces mainly a heave response with roll depending on the wave period. Stern quartering seas lead to a combination of yaw and roll.

The maximum ship responses occur at similar headings, but each vessel is unique and has the maximum responses at headings that are specific for that design of ship, metacentric height (GM) and weight distribution.

It is very difficult to identify a unique heading that represents an objective condition for a fare comparison among yachts.

A heading that generally leads to a combination of motions and rotations is the 135°, bow quartering. When exposed to waves coming from this specific direction, yachts generally react with considerable pitch, roll, yacht, heave, surge and sway.

When at anchor, most yachts use one anchor only and find a balance between the forces exerted by the wind on the superstructure and the ones induced by current and waves on the underwater part. Often this balance leads to having yachts at a heading between 170° and 120°.

The 135° heading is used in this document.

A.4 Speeds

Yachts spend a large part of their operational life either at anchor or at cruising speeds (see Reference [1]).

Two speeds for the stabilization and seakeeping assessment of yachts are used: 0 knots and 12 knots.

A.5 Definitions of the areas onboard

A.5.1 General

If the method and criteria for the stabilization and seakeeping of yachts generates only one number for the assessment of the entire yacht, this is not entirely correct. Two identical sister ships can have different general arrangements. For example, in one case the owner cabin is positioned at the most forward part of the yacht (monohull) and in the other case at 1/3 of the ship's length, measuring from the stern. Even if the two yachts encounter exactly the same waves, the owner with his/her cabin at the most forward part is exposed to much higher accelerations and has a much higher risk of motion-induced sickness.

Similar considerations can be made for other areas onboard: their position in length and in height is relevant and has an influence in the assessment.

This method can also be used in the preliminary design phase to highlight the most comfortable areas onboard and to assist in the development of the general arrangement, or at least to inform and generate awareness among the parties involved in the yacht's design process.

A.5.2 Weighting factor

The weighting factors to assess the comfort on the five different areas onboard, and their influence on the final result, have to consider the areas where guests spend most of the time (OC, DA, BC). Certain crew operations are equally important for safety and comfort onboard (WH, CA, BC).

The weighting factors proposed are equivalent for each of the five areas onboard, as indicated in [Table A.5](#).

Table A.5 — Weighting factors for the five areas onboard

Weighting factors		
Area	Abbreviation	Contribution
owners cabin	OC	0,2
dining area	DA	0,2
wheel house	WH	0,2
crew area	CA	0,2
beach club	BC	0,2

A.5.3 Calculation of the ship motions, EGA and MSI

Many suppliers and some designers have collected sea trial data and base their calculations on statistical regressions. This method offers the lowest level of accuracy but is quick. Some designers and shipyards make use of numerical tools that can differ in complexity and accuracy: strip theory based, panel codes, semi and fully viscous computation fluid dynamics tools. The most accurate way possible to predict ship motions and the relevant parameters is still by model testing. Full scale measurements are of course the way to prove that the predictions are done accurately, but it is difficult to control the environmental forces in play and to accurately measure them for reference purposes.

The method and tool to use is not specified in this document, but the assessment should clearly state which methodology has been used to make the assessment.

Annex B (informative)

Guided example

This example uses an arbitrary 30 m displacement motor yacht, monohull.

The coordinates of the five areas onboard, the hydrostatics, GM, and inertia values are known or assumed.

A strip theory-based tool is used. Two separate input files are prepared: one with a set of stabilizer fins and another one without any stabilization system.

The programme calculates the EGA and MSI values at the following conditions:

- heading: 135°;
- speeds: 0 knots and 12 knots;
- long crested irregular waves with a significant wave height of 1 m, Jonswap spectrum;
- all wave periods requested.

In [Table B.1](#), the values of the RMS of EGA below 2° and MSI below 10 % fulfil the criteria. The criteria is satisfied when both the EGA and MSI criteria are fulfilled simultaneously. The fulfilment of the criteria is weighted with the percentage of the relevance of the peak period.

The results show that the example yacht can profit from the installation of a stabilization system.

The criteria, weighting factors and relation to the star system are summarized in [Table B.1](#).

Table B.1 — Example of assessment for a 30 m displacement motor yacht, monohull (1 of 8)

ACTIVE	0 kn								
EGA	owners cabin	0,68	1,43	7,18	1,65	1,30	1,06	0,88	0,74
2	dining	0,70	1,46	6,58	1,38	1,09	0,89	0,73	0,61
	wheel house	0,74	1,52	8,70	1,67	1,33	1,09	0,91	0,77
	crew area	0,60	1,17	4,77	1,43	1,13	0,91	0,76	0,64
	beach club	0,93	1,83	6,53	1,50	1,16	0,92	0,75	0,62
MSI	owners cabin	4,06	6,02	5,09	4,23	3,37	2,75	2,27	1,90
10	dining	2,16	2,97	2,83	2,57	2,11	1,74	1,46	1,23
	wheel house	2,55	3,63	3,25	2,84	2,31	1,90	1,59	1,33
	crew area	4,32	6,43	5,42	4,48	3,56	2,90	2,40	2,01
	beach club	3,77	5,55	4,80	4,03	3,22	2,63	2,18	1,83

Table B.1 — Example of assessment for a 30 m displacement motor yacht, monohull (2 of 8)

	Uptime	STARS
	ACTIVE	0 kn
owners cabin	64,86	****
dining	64,86	****
wheel house	64,86	****
crew area	64,86	****
beach club	64,86	****

Table B.1 — Example of assessment for a 30 m displacement motor yacht, monohull (3 of 8)

W/O stabilization	0 kn								
EGA	owners cabin	0,83	3,60	6,85	5,22	4,19	3,60	3,07	2,62
2	dining	0,94	3,45	6,37	4,74	3,81	3,26	2,77	2,36
	wheel house	1,03	4,18	7,64	5,87	4,79	4,16	3,57	3,07
	crew area	0,62	2,53	5,27	3,94	3,06	2,59	2,18	1,85
	beach club	1,15	3,64	6,35	4,69	3,77	3,22	2,73	2,32
MSI	owners cabin	4,06	6,02	5,09	4,23	3,37	2,75	2,27	1,90
10	dining	2,16	2,97	2,83	2,57	2,11	1,74	1,46	1,23
	wheel house	2,55	3,63	3,25	2,84	2,31	1,90	1,59	1,33
	crew area	4,32	6,43	5,42	4,48	3,56	2,90	2,40	2,01
	beach club	3,77	5,55	4,80	4,03	3,22	2,63	2,18	1,83

Table B.1 — Example of assessment for a 30 m displacement motor yacht, monohull (4 of 8)

	Uptime	STARS
	W/O stab.	0 kn
owners cabin	1,90	*
dining	1,90	*
wheel house	1,90	*
crew area	2,04	*
beach club	1,90	*