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1. ANEP-17, Supplement 3 to STANAG 4154 - Ad Hoc Criteria for Hydrofoil Vessels Seakeeping Performance Assessment is a NATO UNCLASSIFIED publication.

2. ANEP-17 is effective NATO-wide upon receipt.

3. ANEP-17 contains only factual information. Changes to this publication are not subject to ratification procedures and will be promulgated as necessary by AC/141(IEG/6)SG/5.

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Major General, NOAF
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RECORD OF CHANGES

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FOREWORD

1. STANAG 4154 gives the agreed requirements for determining the General Criteria and Common Procedures for Seakeeping Performance Assessment.

2. STANAG 4194 is the agreed Standardized Wave and Wind Environments and Shipboard Reporting of Sea Conditions.

3. This Allied Naval Engineering Publication Number 17 has been prepared by AC/141(IEG/6)SG/5 on Seakeeping for use with STANAGs 4154 and 4194. It should be noted that this document is not an agreed standard, but is circulated for information and to provide guidance to those involved in ship design.

4. It should be noted that this is one of a series of ANEPs, to be used in conjunction with STANAG 4154.

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Related documents

1. STANAG 4154: General criteria and common procedures for seakeeping performance assessment.

2. STANAG 4194: Standardized wave and wind environments and shipboard reporting of sea conditions

3. International Towing Tank Conference (ITTC) Dictionary

Aim

1. The aim of this Working Paper is to establish ad hoc criteria for the operability and habitability aspects of seakeeping of hydrofoil vessels to be used in the assessment and evaluation of seakeeping qualities in the design phase in order to ensure satisfactory seakeeping qualities.

General

2. Annex I describes the general problems of hydrofoil operations affecting seakeeping. Annex II formulates ad hoc criteria for hydrofoil seakeeping which enable satisfactory design decisions under the present state-of-the-art. Annex III identifies recommended computational and experimental procedures for assessment of ship seakeeping characteristics in the design process. Annex IV provides examples of the procedure described in Annex III . Definitions are given in Annex V, and references in Annex VI.

ANNEX I

GENERAL PROBLEMS OF HYDROFOIL OPERATIONS

1. The predominant feature of hydrofoils, which make this type of vessels very attractive from the seakeeping point of view, is their ability:

- When hullborne at low speed, to experience smaller motions than those of a conventional craft of similar size. This is due, mainly for the surface piercing hydrofoils, to the damping effect of the foil and strut system when they are submerged.

- When foilborne, to maintain speeds higher than those attainable by conventional craft of similar size. This is due to the fact that the hull of a foilborne hydrofoil is supported above the water surface, thereby reducing the vessel drag and minimizing the influence of waves. The limit of foilborne operations with a specified sea state is dependent on the clearance between the hull and the sea surface, and consequently, on the hydrofoil's size.

- When foilborne, mainly for submerged foil hydrofoils, to maintain a very high manoeuvring capability both in course stability and in turning ability.

2. As already anticipated, hydrofoils can be operated in two different modes:

- Hullborne, with the weight of the vessel being supported by buoyancy, with foils and struts either down in the water or raised above the water (if a foil retracting system is installed).

- Foilborne, with the weight of the vessel being supported dynamically by the foil system.

3. Hydrofoils can perform their manoeuvring capabilities in two different modes:

- "Flat" turns when the vessel is maintained by lift system parallel to the calm water surface.

- "Banked" or "fully coordinated" turns, when the vessel is inclined to keep the resultant force applied to center of gravity always at right angle with the deck.

4. Foil system may be of two main different types:

- Surface piercing, the lifting surfaces cross the free surface of the water. The system is self stabilizing, since the deviations from equilibrium position bring a change in the wetted lift-producing foil area, thus creating the restoring force.

- Fully submerged, the lifting surfaces are completely underwater, and are connected to the hull by means of struts. The fully submerged foil system is not inherently stable, and an automatic lift control system is necessary to maintain flight control. As this foil system is completely independent from the sea surface, in moderate sea state, better seakeeping performances can be achieved compared to the surface piercing ones. In high sea states the latter type shows better results than the former.

5. Foil area distribution along the hull may be of three different types mainly depending on the weight distribution:

- canard, the larger part of the lift is generated by the aft foil(s) (about 1/3 forward and 2/3 aft);

- tandem, the lift is generated by the forward and aft foil(s) in equal parts (about 1/2 forward and 1/2 aft);

- conventional (or airplane), the larger part of the lift is generated by the forward foil(s) (about 2/3 forward and 1/3 aft).

Furthermore, forward and/or aft foil surfaces can be in a "split" or "non split" configuration.

6. Seakeeping performances of fully submerged type hydrofoils are only slightly affected by the foil system configuration, the major importance being on the automatic lift control system.

7. Hydrofoils high speed and superior seakeeping allow them to be successfully operated in all "strike" or "sprint and drift" missions such as:

Navy type missions:

- ASW;

- trailing and shadowing of high interest shipping, and deception and decoy of hostile forces;

- delivery and retrieval of commando type special force units;

- quick reaction to unforeseen application of opponent's strength;
- coverage of wide areas in search or defensive barrier operations;
- quick and unexpected projection of offensive capabilities.

Coast Guard type missions:

- search and rescue;
- enforcements of Law and Treaties;
- marine environmental protection;
- fisheries support;
- Exclusive Economic Zone (EEZ) protection.

8. Foilborne operations in rough weather can be conducted either in "contour" mode when the vessel is always maintained, by the lift control system, parallel to the wave profile , or in "platform" mode when it is maintained parallel to the calm water surface. The choice of one of them may depend on mission requirements and on external constraints such as the wave length, slope and height. In heavy seas, compared to the hydrofoil's size, only the "contouring" mode can be performed.

9. The seakeeping phenomenon of major concern is the ability to take-off in a seaway at the design speed and sustain a high speed in rough weather. Other seakeeping phenomena of concern are: motions and accelerations, wave impact on the forward part of the hull, foil broaching and, when hullborne, slamming and deck wetness. The seakeeping phenomena influence adversely the crewand the ship's various systems as well as the ship's performances. These detrimental effects may be grouped under four main headings:

(a) Crew: performance degradation, fatigue, motion sickness, work restrictions, injury, loss overboard;

(b) Structure: damage from crash landing, damage from inertial loads, damage from wave impact, damage from fatigue, damage from hydroelastic instability;

(c) Equipment: performance degradation of weapons and sen sors, loss of on-board system, strain and damage on equipment, increased corrosion;

(d) Ship manoeuvring capabilities: decrease in course stability and turning rate.

10. These effects could individually or collectively stimulate a decision to modify or cancel operations. The aim of giving due consideration to seakeeping in the design process is to reduce the severity of these effects to an acceptable level so that the ship can carry out her mission at the design sea state.

11. Under the present state-of-the-art, it is impossible to evaluate rigorously performance degradation of the crew and the ship's systems, and hence formulate an overall performance index as a function of ship's motions. Present knowledge does, however allow the formulation of ad hoc criteria for the seakeeping phenomena. Furthermore, these criteria are compatible with existing procedure for predicting seakeeping behaviour, and are therefore suitable for use in the design process.

12. In the design process, seakeeping qualities are established by attention to:

(a) overall and local structural strength;

(b) weight distribution and radii of gyration;

(c) underwater hull form and deadrise in the middle and forward part;

(d) lift and stabilization control system and foil configuration;

(e) arrangements (lay out of crew accommodation and working spaces).

13. Under the current state-of-the-art, the effects of the seakeeping phenomena on the crew, structure and equipment are addressed in the design process by specifying acceptable levels of the ship motions at the design sea state and the intended missions, and designing to meet these limits. A minimum set of specification, grouped according to the major design parameters of paragraph 12, is:

(a) (1) frequency and severity of bow impact on waves;

(2) frequency and severity of bottom slamming;

(3) foil broaching;

(b) (1) roll;

(2) lateral acceleration at a number of locations;

(3) a measure of ride quality which accounts for the effect of lateral motions on crew performance;

(c) (1) pitch;

(2) surge;

(3) vertical acceleration at a number of locations;

(4) a measure of ride quality which accounts for the effect of vertical motions on crew performance;

(5) propulsive plant performance degradation;

(d) (1) take off and cruising power.

(2) hull clearance;

(3) foil broaching;

(4) strut and foil system hydroelastic instability;

(5) lift control capability;

(6) dynamic stability and directional stability;

(e) (1) vertical and horizontal acceleration at a number of locations.

Specifications (a)(2), (b), (c), (d)(1) and (e) apply to hullborne condition. Specifications (a)(1)(3), (b), (c) and (e) apply to foilborne condition.

14. For hydrofoil vessels, the seakeeping performance assessment must be considered not only as a design tool, but also as a mean to provide detailed informations to the commanding officer to fully exploit the ship's capabilities without undue risk for crew, equipment and structure.

15. Formulation of ad hoc criteria and guide lines for each of the above aspects of seakeeping is discussed in Annex II.

ANNEX II

AD HOC CRITERIA FOR HYDROFOIL SEAKEEPING

1. The effects of seakeeping on crew, structure and equipments are addressed in the design process by specifying acceptable levels of ship motions and related phenomena for specified environmental and operational conditions, and designing to meet these limits. Criteria and limits depend on the intended missions/tasks and equipment sensitivity. Design criteria should also consider the possible future requirements of interoperabilty of ships which are expected to participate in joint NATO operations.

2. A minimum set of seakeeping phenomena which must be considered in a hydrofoil design process, with regard to hydrofoil operations, and the factors governing definition of criteria for each of these aspects of seakeeping are listed below:

Phenomenon	Factor governing criteria
Impact of bow, slamming, foil broaching	- primary and local structure strength - hydroelastic instability - material fatigue - crew tolerance to impact
Ride quality	- crew performance degradation - fatigue and motion sickness - work restrictions
Pitch, surge, roll, vertical and lateral motions	- equipment specifications
Lift system	- cavitation, increased resistance, saturation
Propulsive performance degradation	- propulsion machinery specifications - foil and strut configuration
Take-off power	- increased resistance, involuntary speed reduction

3. It is emphasized that seakeeping criteria must be given in a form which recognizes the stochastic nature of the wave environment. For example, a roll limit may be expressed as the maximum allowable RMS roll, but not as a limit on the maximum roll angle.

4. In the seakeeping assessment process a range of operational conditions must be considered, which are defined by:

Ship condition	-	displacement, metacentric height, trim;
Environment	-	wave and wind conditions, long or short crested sea;
Mission objective	-	task, speed, mode of operation, heading to wave and wind.

5. General criteria, hullborne or foilborne condition as indicated, for each of the above seakeeping phenomena are described below.

6. Bow impact, slamming, and foil broaching criteria are derived from consideration of hull and/or foil system damage risk and operability. Structural design criteria for the hull structure, the struts and foil systems, have to be established considering the intended mission profile, the design sea state, and the operational area. These criteria must consider overall and local maximum loads, fatigue as well as hydroelastic instability (divergence and flutter) of foils and struts. Limiting conditions criteria depend from:

(a) hullborne condition

- local loads on the forward hull and inertial loads to equipments due to slamming;

(b) foilborne condition

- local loads on the forward hull, inertial loads to equipments and hull due to bow impact consequent or not to foil broaching;
- material fatigue in the struts supporting areas of the hull and in the foil system components;
- hydroelastic instability of foil and strut systems;
- crew tolerance to bow impact, which may be formulated by comparing the new design's characteristics with those of an hydrofoil known for its superior behaviour.

(c) intermediate conditions taking/landing

- localized impact loads on the forward and bottom structure during taking off or landing.

7. Ride quality criteria are derived from operability considerations in the foilborne condition and habitability considerations in the hullborne conditions, taking into account the human body behaviour in the presence of the ship motions. Criteria must consider that hydrofoil missions are shorter but with higher responses at higher frequencies than other type of vessels. In foilborne condition roll can be considered as a minor concern parameter for both type of hydrofoils. In hullborne condition the foil/strut control system can be used as a roll stabilization device. The least complex criterion would take the form of limits on vertical/lateral accelerations at specified locations along the ship.

8. Pitch, surge, roll, vertical and lateral motion criteria are derived from operability considerations in foilborne condition. Limits are set on the motion amplitudes taking account of the operational mode: "contour" or "platform", thus primarily considering the sea state. Limiting values on motion amplitudes are derived from equipment specifications. In the hullborne condition this criteria can be regarded as the ride quality criteria.

9. Lift and stabilization control system criteria are derived from operability considerations in foilborne condition. It must be ensured, at the design sea state, with ship motions and seakeeping phenomena being below limiting values, a convenient safety factor to electronic, electrical, and hydraulic components in order to avoid overload or saturation. Furthermore it must provide quick reaction in order to avoid foil cavitation and increased resistance due to large angles of attack and reduce the inherent response to rough water.

10. Propulsive performance degradation criteria are derived from operability considerations for the propulsive machinery mainly in the presence of a water jet propulsion system in foilborne condition, "platform" mode, and in the take-off phase, in order to avoid pump cavitation. Limits are set up by propulsive plant specifications.

11. Take-off and cruising power criteria are derived from operabilty considerations. The propulsive plant performances must ensure the necessary power to take-off at the design speed in the design sea state. Augmentation lift devices to reduce take-off power can be used.

ANNEX III

RECOMMENDED COMPUTATIONAL AND EXPERIMENTAL PROCEDURE FOR HYDROFOILS SEAKEEPING PREDICTIONS

1. This Annex identifies recommended computational and experimental procedures for prediction of hydrofoil vessel's seakeeping qualities in the design process and for guidance on the capabilities of existing vessels.

2. The procedures are grouped into eight categories which will be addressed individually in hullborne and foilborne conditions:

(a) Specification of sea spectra;

(b) Hydrofoil motion response;

(c) Bow impact;

(d) Slamming;

(e) Ride quality;

(f) Propulsive performance degradation;

(g) Take-off and cruising power;

(h) Lift and stabilization control system.

3. Specification of sea spectra. Definition of seaway, wind state and areas of operation is of paramount importance. For each area of operation a range of wave spectra must be identified by the use of related document 1 and its associated source documents; references 16, 17, 18 contain further informations. It is emphasized that a minimum of two parameters (significant wave height and wave modal period) must be used in specifying seaway spectra. Further, at a given height, it is important to cover a realistic range of characteristic wave periods as some aspects of seakeeping or the mode of operation, i.e. "contour" or "platform" are very sensitive to wave period. Documents should be consulted to obtain the proper statistical distribution of wave period with wave height for the areas of operational interest. It should also be recognized that seas are usually short crested to some degree, and therefore a spreading function should be selected for this purpose.

4. Hydrofoil motion response. In foilborne and hullborne conditions computational procedures show a very good accuracy for motion prediction of fully submerged foil systems. This is due to the knowledge of foil systems performances in a seaway and to the knowledge of motions of ships fitted with or without appendages. It must be recognized that the motion

prediction of surface piercing crafts in foilborne condition is much less accurate. Ref. 6 contains a general overview on conventional and unconventional craft seakeeping. In foilborne conditions motion simulation equations must be used and they have to consider all the parameters involved, see ref. 25, 29. In hullborne conditions a linear strip theory based program can be used applying the superposition principle to the regular waves induced motions, see ref. 5, 14, 15, 20, 21, 22. The program must consider the presence of appendages and non-linear components in roll damping arising from viscous effects on them, ref. 19. Surge is of major concern only under foil broaching conditions. Model tests in regular and irregular waves are a good method of prediction and can therefore be used with great confidence for both conditions, see ref. 2. It must be noted that in order to ensure supercritical Reynolds number to the propeller and to the foil system, model sizes may become too great and too fast for most of the test capabilities, and therefore, in some cases, an experimental manned boat is required. Useful data and overviews on this topic are contained in ref. 9, 10, 11, 31, 32. The following procedures are recommended for motion prediction in the design stage:

(a) Motion simulation equations in foilborne condition;

(b) Strip theory-based computer programs for ships with fairly normal hull form in hullborne condition;

(c) Model tests in regular and irregular waves in both conditions.

5. Bow impact. A method which recognizes the probabilistic nature of this phenomenon must be used. It has to take account of mode of operations: "contour" or "platform", hull clearance, relative motions, short or long crested sea and wave profile,lift control system characteristics, foil broaching. The determination of hull-girder loads and hydrodynamics impacts arising from this event can be performed with a method such that indicated in ref. 27; a further investigation on slamming pressures can be done by using ref. 28. In order to have an estimate of this phenomenon occurrence probability, model tests in regular and irregular waves are at present the only reliable source of data. In conclusion, the following procedures are recommended:

(a) Model tests in regular and irregular waves in foilborne condition;

(b) Analytical methods for primary and local loads.

6. Slamming. Few validated computational methods can be recommended for hydrofoil vessels slamming prediction. This is due to the specific hull forms and to the presence of foils and struts. Useful informations can be

achieved only with retracted foils, also considering the low operational speed of these ships in hullborne condition, see ref. 3, 5, 15, 20, 23, 33. The following procedures can provide information:

(a) Strip theory-based computer program for ships having fairly normal hull form;

(b) Model tests in regular and irregular seas.

7. Ride quality. Methods for quantitative assessment of ride quality of naval vehicles are still in the formative stage. The methods which can be used are not completely exhaustive and reliable. They ought to consider one or more parameters derived from the ship motions or accelerations and their resulting effects on the crew working capability. References 8, 12, 13, 24 provide guidance and informations on this topic.

8. Propulsive performance degradation. According to the propulsion system of concern: screw propeller, water jet, a method for the propulsive coefficients decrease computation, which results in an involuntary loss of speed, must be used both in foilborne and hullborne condition. For screw propellers it must take account of added resistance and efficiency decrease due to disturbed flow in a seaway. For water jets it must consider the added resistance and the efficiency decrease due to disturbed flow at the intake ducts. Pump cavitation phenomena can be of considerable effect in this case. No reliable computational methods have been developed at present, hence the following procedure is recommended to obtain figures on the topic:

(a) Model tests in regular and irregular waves.

9. Take-off and cruising power. The required power to take-off at the design speed in the design sea state and at various relative headings must be checked. The power required to maintain the cruising speed shall also be checked. In hullborne condition the propulsive plant performance, considering the degradations outlined in the previous paragraph, must be capable of reaching the needed values. It must be noted that the take-off is a transition phase and that many phenomena are interacting thus enhancing the difficulty of the evaluation. One method which gives a resistance prediction by setting up equilibrium equations, but in calm water only, is indicated in ref. 30. The recommended procedure to investigate into this phenomenon is:

(a) Model tests in regular and irregular waves.

10. Lift and stabilization control system. By using simulation equations the lift system, and the lift control system must be evaluated in order to avoid electric, electronic and hydraulic overload or saturation phenomena at the design sea state. Cavitation or ventilation phenomena, which could result in a foil broaching, have to be controlled. See ref. 25, 26.

11. Examples illustrating the use of the above procedures, in conjunction with the general criteria of Annex II, are given in Annex IV.

ANNEX IV

EXAMPLES OF PROCEDURES FOR HYDROFOIL SEAKEEPING PREDICTIONS

1. This Annex provides examples of the procedures described in Annex III. Postulated criteria are used pending development of the STANAG on criteria. One example has not been worked out in detail, in this edition, due to a lack of available data. It is going to be based upon the ship comparison procedure described below in paragraph 2. Those Annex III procedures which are not illustrated in the example are then briefly treated.

2. Ship comparisons. The compatibilty of NATO ships in joint operations can be assessed by the following procedures:

(a) Specify an operational scenario including the mission to be performed and the range of conditions (seaway, wind and other relevant environmental factors, ship speeds, and ship-to-wave relative headings) under which the mission has to be performed.

(b) Specify the ships which will perform the mission; and in accord with Annex II, the seakeeping-related criteria applicable to these ships for the mission. (Ships and criteria must be jointly specified because criteria can be ship dependent.)

(c) Determine the relevant seakeeping characteristics of each ship considered in accordance with the procedures outlined in this Annex. These characteristics should be determined for the range of conditions specified in (a) and expressed in terms of criteria from (b).

(d) For each ship compare the results of (c) with the criteria specified in (b). Thus, identify the subset of the conditions specified in (a) under which each ship can perform the mission being considered.

(e) Compare the results of (d) for the ships evaluated. This comparison assesses the relative abilities of the ships to perform successfully in the operational scenario specified in (a).

3. Ship comparison example for search and rescue mission. Not available, in this edition, due to a lack of data.

ANNEX V

DEFINITIONS

Added resistance	In calm water, at a given speed, a certain resistance to forward motion is experienced by the ship. In waves this resistence increases and the difference is termed added resistance.
Amplitude	The difference between the mean value and individual peak (or trough) of an oscillatory record.
Banked turn	When the vessel is inclined to keep the resultant force applied to center of gravity always at right angle with the deck.
Bow impact	In foilborne condition, phenomenon occurring when the hull forward body slams in the oncoming wave.
Canard	Configuration of foil surfaces: approximately 1/3 lift generated forward and 2/3 generated aft.
Cavitation	Phenomenon occurring on a surface in a flow when the local pressure becomes lower than the vapour tension of the fluid at that temperature.
Contour	Mode of operation of hydrofoil following the wave profile. It can easily performed in long-crested seas.
Conventional	Configuration of foil surfaces: approximately 2/3 lift generated forward and 1/3 aft.
Crash landing	Slamming into the sea surface when a sudden loss of lift occurs.
Cresting	Hull contact with wave crests without high local loads values.
Divergence	Deflection under loading increasing without oscillations in the struts and foils systems at high speeds.
EEZ	Exclusive Economic Zone. Surface and depth sea areas where governmental exploitation rights have been established.

Flap	Movable control surface fitted at the trailing edge of a foil surface.
Flat turn	When the vessel is maintained by lift system parallel to calm water.
Flutter	Unstable oscillation arising in the struts and foils system at critical speeds.
Foil	Wing area generating dynamic lift.
Foilborne	Sailing condition with the weight of the vessel supported by dynamic lift.
Foil broaching	Sudden loss of lift due to disturbed flow, cavitation, ventilation.
Fully coordinated turn	See banked turn.
Fully submerged	Configuration of foils and struts systems: in calm water, foilborne condition the sea surface is not pierced by the lifting areas.
Heading	Ship's course relative to predominant direction of travel of waves or wind. 0 degrees = following 45 degrees = quartering 90 degrees = beam 135 degrees = bow 180 degrees = head
Heave	Oscillatory vertical motion of ship's centre of gravity.
Hullborne	Sailing condition with the weight of the vessel supported by buoyancy.
Hull clearance	In foilborne condition the minimum distance between the hull bottom and the calm water surface.
Hydroelastic instability	Phenomenon occurring on high aspect ratio structures moving at high speeds in a viscous flow. See divergence and flutter.

Involuntary speed loss	For a given output of engine power, a ship achieves a lower speed in a seaway than in calm water. This reduction in speed is the involuntary speed loss.
Irregular waves	A wave system having heights and periods which are not constant. It is "long" or "short" crested depending on whether the wave energy is uni-directional or multi-directional, respectively.
Lift and stabilization control system	All the electronic, electric, hydraulic and mechanical components which are necessary to provide continuous control of the foil system and hydrofoil during take-off, landing and foilborne operations.
Local structure	The hull structure close to the parts of the hull which supports concentrated loads.
Metacentric height	The vertical distance between the center of gravity and the metacenter: the parameter which governs the "stiffness" of the ship in roll.
Pitch	Oscillatory angular motion about a horizontal transverse axis.
Platform	Mode of operation in which the hydrofoil keeps the deck horizontal. It can be easily performed in short-crested sea.
Primary structure	The main structure of the hull.
Regular wave	Waves with constant height and period. Such wave exists only in theory and towing tanks.
Retracting system	All the electric, electronic, hydraulic and mechanical components which are necessary to raise the foil and strut systems above the sea surface.
Ride quality	A measure of ship motions in terms of the comfort of the ship's crew and their capacity to maintain calm sea performance levels.
Rms	In the context of seakeeping, Rms (root mean square) is used for standard deviation of a signal relative to its mean value. This is only precisely correct for signals of zero mean.

Roll	Oscillatory angular motion about a horizontal longitudinal axis.
Saturation	Condition occurring when a device reaches its maximum performance.
Sea state	Generic term describing the roughness of the sea. It has no precise definition but scales of sea state number and significant wave height have been proposed.
Significant wave	If all the wave heights (peak to trough) of a wave record are measured, the significant wave height is the mean value of the highest one-third of all the wave heights. It is approximately equal to the wave height estimated by an observer.
Slamming	When the ship's bottom re-enters the sea following emergence in rough water an impact occurs and high pressures may be generated. The resulting impulse is called bottom slamming. Similar effects can occur under a heavily flared form (called flare slamming), or on a twin hull vessel, e.g. a SWATH, cross structure (called box slamming).
Spectrum	A function defining the relationship between the amplitude and frequency of a process, such as the energy in an irregular wave system, or the ship response thereto.
Split (non)	Forward and/or aft foil systems configuration which presents the total forward and/or aft lifting surface divided (or not) in two parts.
Strut	Supporting structure connecting the hull to a lifting surface.
Superposition	The mathematical process of calculating the response of a linear system in irregular waves.
Superstructure	The part of the ship above the main hull.
Surface piercing	Configuration of foil and strut system: in calm water, foilborne condition the sea surface is pierced by the lifting areas.

Surge	Oscillatory horizontal longitudinal motion of the ship's centre of gravity.
Sway	Oscillatory horizontal lateral motion of the ship's centre of gravity.
Take-off	The transition time from the hullborne condition to the foilborne one.
Tandem	Configuration of foil surfaces: approximately 1/2 lift generated forward and 1/2 aft.
Worst heading	The heading on which the worst motion occurs. This will depend on the motion considered.
Yaw	Oscillatory angular motion about a vertical axis.

ANNEX VI

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