EMSA - STEERING AND MANOEUVRABILITY STUDY

Final report

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Customer:	EMSA European Maritime Safety Agency, Cais do Sodré 1249-206 LISBOA - Portugal	Veritasveien 1 1363 Høvik Norway Tel: NO 945 748 931 MVA
Customer contact:	José Diaz Yraola	
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Objective:

The STEERSAFE project aims to provide a holistic analysis of the SOLAS regulations and associated circulars related to steering and manoeuvrability, provide a consistent update of these and to propose practical and meaningful performance parameters in normal service and in failure mode.

Prepared by:	Verified by:	Approved by:
Anna Kringlen Ervik Senior Engineer	Odd Olufsen Senior Principal Engineer	Olav Rognebakke Head of Section
Svein-Olav Hannevik Principal Approval Engineer		
Rainer Hamann Senior Principal Engineer		

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1 ABSTRACT

This report presents the findings from the STEERSAFE project, conducted by DNV for the European Maritime Safety Agency (EMSA).

The STEERSAFE project aims to provide a holistic analysis of the SOLAS regulations and associated circulars related to steering and manoeuvrability, provide a consistent update of these and to propose practical and meaningful performance parameters in normal service and in failure mode.

This report consolidates the previously performed STEERSAFE tasks and presents the findings from the final phase of the STEERSAFE project.

2 EXECUTIVE SUMMARY

This report presents the results from the EMSA STEERSAFE project. It consolidates the results of the tasks carried out during the first two phases of the project and presents the results from the final phase.

In the following, the objectives of the three different phases of the project are presented.

This first phase of the project aims to:

1) provide an overview of the current situation, in terms of a description of relevant steering and propulsion systems (Task 1) and the gaps and inconsistencies in the current SOLAS regulations for steering and manoeuvrability (Task 2), and

2) establish goals and functional requirements for steering and manoeuvrability (Task 3).

Goals and functional requirements are developed based on a comprehensive hazard identification considering a review of casualty and incident reports of databases, recursive investigation of IMO provisions and an expert workshop.

The second phase of the project aims to:

1) define performance requirements and parameters for safe steering and manoeuvrability in both normal and failure mode, as well as the operating conditions under which the parameters should be tested (Task 5b and 5c).

2) carry out the Verification of Conformity between the Functional Requirements previously proposed and the current IMO Provisions (Task 4), and

The final phase of the project aims to:

1) based on the previous work, carry out the revision of update and development of amendments to the present prescriptive regulations and associated IMO Resolutions and Circulars (Task 6), and

2) map the current practice in terms of propulsion and steering/manoeuvrability standards for Safe Return to Port (SRtP), analyse the results and, if relevant, propose a harmonised approach consistent with the revision/update of the performance requirements for steering (Task 7).

The results and findings from the above presented topics are summarized below.

2.1 Conclusions

2.1.1 Gaps in SOLAS regulations

The investigation of the current SOLAS regulations reveals that the regulations are in many cases technology-specific and prescriptive. Also, they do not address hazards related to erroneous operation. Furthermore, the redundancy requirements and testing for multi-unit configurations are not properly addressed, nor is the dependency of/interaction with other systems and functions. Currently, no specific requirements for testing and verification of manoeuvrability are included for reduced service condition for any of the technical solutions. For Safe Return to Port, required available capacity and performance parameters after failure need to be specified.

2.1.2 Hazards and failure modes

Hazards relevant to different parts of the steering system have been identified and later ranked according to likelihood and severity, providing the basis for the hazards that need to be addressed by the functional requirements. New identified hazards arise from increased system integration and complexity, and these are not considered in existing regulations.

2.1.3 Developing a Goal-Based Standard

A top goal for steering, which addresses the main concerns, is defined (*Prevent casualties arising from malfunctioning, insufficient performance or incorrect use of steering)*. To support the top goal, four individual goals, specifying *how* the top goal is achieved, are developed. Additionally, a top goal and two individual goals for propulsion are also defined.

Furthermore, functional requirements, mitigating the hazards previously selected and providing the criteria for meeting the goals, are defined.

The Verification of Conformity has proved that the functional requirements for steering and propulsion are in general conformed with by the current regulations, meaning that they provide adequate performance for safe operation and sufficient resilience for typical failures. In some cases, the terminology in the regulations is vague, for instance with respect to "sound" design; details of the overall assessment of the actuating system and the steering force unit are not provided.

Moreover, functional requirement VI (*Minimize impact of erroneous operation*) is regarded as *not* satisfied by the regulations. Today's modern systems, e.g. podded systems, have the potential to endanger the ship if not adequately operated. This risk is not considered by current regulations.

The final Goal-Based Standard for steering, encompassing goals and functional requirements, is presented in ***Appendix G***.

2.1.4 Detailed requirements for steering and maneuverability

During the second phase of the project, the Functional requirements I "The steering system provides adequate steering performance for ship operation" and VIII "The propulsion system provides adequate astern propulsion performance for ship operation" have been further developed to include clear and quantitative performance requirements and parameters in normal and failure mode.

The functional requirements for steering provide performance requirements, also referred to as expected performance, for the following:

- performance in normal and failure mode
- the resilience of the system
- the design considering uncertainty and degradation
- protection against impacts
- erroneous functionality
- operation and the basis for adequate operation

Stopping, turning, course keeping and changing of steering force direction abilities are considered to be the most important steering performance parameters. Associated sea trial tests, as well as performance requirements in normal and failure mode, are proposed. The suggested performance requirements for reduced service have been developed based on "best estimates" using the available expertise; however, they might need further finetuning to reflect the experience gained once these requirements are extensively applied.

Furthermore, based on the developed functional requirements, as well as a detailed investigation of system reliability of different system architectures, the redundancy on system level is considered equivalent to redundancy on component level, i.e. it is suggested to apply the same criteria for vessels with single and multiple propulsion lines and/or steering systems.

Preferably the ship performance shall be tested at a full-scale sea trial in the following condition; summer load line draft, even keel. However, if this is not possible, tests as close as possible to full load draught and zero trim shall be performed and a recognized method (CFD calculations or model tests) may be accepted for predicting the compliance at the specified condition. Full scale CFD calculations thoroughly verified by third party, are recommended.

2.1.5 Safe Return to Port

Safe Return to Port (SRtP) has been addressed with the aim to analyse the industry practice and, if appropriate, to propose a harmonized approach. It is concluded that the current lack of a harmonized approach in the SRtP scheme for the implementation of remaining propulsion performance after a casualty, has unfortunate consequences. It therefore seems appropriate to suggest a harmonization, in particular with regards to means of verification, calculation method and environmental conditions.

2.1.6 Revision of SOLAS regulations

The revision of the SOLAS regulations, associated Circulars and Unified Interpretations is carried out using the previously developed goals and functional requirements as a basis. The main changes are listed in the report, while the updated documents are included in ***Appendix H: Proposal to IMO***.

3 DEFINITIONS

Term	Explanation
Cold redundancy	Cold redundancy is for non-critical processes where time is not a high priority and human intervention is acceptable
Conventional steering system	One hydraulically operated rudder
Declared steering angle limits	Declared steering angle limits are the operational limits in terms of maximum steering angle, or equivalent, according to manufacturer's guidelines for safe operation, also taking into account the ship's speed or propeller torque/speed or other limitations.
Environmental load	Any kind of load due to weather, wind, wave etc.
Expected performance	Part of functional requirement (MSC.1Circ.1394/Rev.2) providing the criterion for verification of compliance
Fail-safe	A concept which is incorporated into the design of a product such that, in the event of a failure, it enters or remains in a safe state (EN 50129)
Failure	An occurrence in which a part, or parts of a system ceases to perform the required function, i.e. a state of inability to perform a normal function
Failure mode	Inability to perform intended function and manifestation
Functional requirement	Functional requirements provide the criteria to be complied with in order to meet the goals. (MSC.1Circ.1394/Rev.2)
Goal	High-level objectives to be met that addresses the issue(s) of concern and reflect the required level of safety
Hazard	A potential to threaten human life, health, property or the environment
Hot redundancy	Warm & hot redundancy are similar in arrangement, but hot redundancy offers instant process correction when a failure is detected
Insufficient performance	Performance does not meet the expectations for safe steering and manoeuvring
Load	Any kind of load acting in or on a system or component of system such as mechanical, hydraulic or electrical
Malfunctioning/malfunction	System or component blocked, broken down, output deviates from design intent
Mode	Manifestation, form or arrangement of being
Normal service	A system fully functional and provides intended performance

Operational profile	Conditions a vessel operates in, e.g. wind, waves, temperature, loading etc.
Overload	Load outside loads considered for design
Reduced service	Service of system in the event of a failure not causing complete loss, i.e. system delivers limited performance compared to normal service
Redundancy	Ability of a system to maintain its function when one failure has occurred
Steering actuating system	Steering actuating system is the equipment provided for supplying power to turn the steering force unit, i.e. comprising steering gear power unit, actuator and the system connecting them (e.g.: transmission or piping system).
Steering actuator	Steering actuator is a component which converts energy into mechanical motion to turn the steering force unit (e.g. hydraulic cylinder, piston, etc.).
Steering control system	Steering control system is the equipment by which orders are transmitted to the steering actuating system(s). Steering control systems comprise all components from the user input device to the receivers, including transmitters, controllers, piping, cables and data networks, hydraulic control pumps and their associated motors, motor controllers and solenoid valves, as appropriate.
Steering force unit	Steering force unit is the element generating the forces required to control the vessel (i.e. rudder and stock, rudder propeller, thruster, pod), including all parts up to the interface to the steering gear.
Steering gear	Steering gear is the machinery, actuating system(s) and ancillary equipment to direct the steering force unit for the purpose of steering the ship. The steering gear may include various combinations of steering actuating systems and tiller or equivalent component.

Steering gear power unit	Steering gear power unit is: .1 in the case of electric steering gear, an electric motor and its associated electrical equipment; .2 in the case of electrohydraulic steering gear, an electric motor and its associated electrical equipment and connected pump; or .3 in the case of other hydraulic steering gear, a driving engine and connected pump.
Steering system	Steering system(s) is the ship's mean(s) of directional control, including steering gear, steering control and monitoring system and steering force unit, as well as all means connecting to power supply
Warm redundancy	When time and response to a failure is more important but not critical, a warm redundancy strategy may suffice if a temporary outage is acceptable. The cycle can tolerate certain minutes of interruption, but the process must be restored quickly and automatically to avoid any integrity issues.

4 INTRODUCTION

DNV has been assigned the contract to carry out the Steering and Manoeuvrability Update Study (STEERSAFE) for EMSA.

This report presents and describes the work and findings from the entire project.

The work comprises seven tasks, which will be further outlined in Section 4.2.

4.1 Background

The recent decades have seen significant developments within steering and propulsion systems, facilitated by new technologies and motivated by increased efficiency and reduced emissions.

The SOLAS regulations for steering and manoeuvring are still referring to conventional systems with single propeller and rudder, and they have in general not been updated to account for new technologies. In view of overcoming some issues identified when introducing new steering technologies, various unified interpretations have been agreed by IMO. Although IMO Alternative Design is permitted for SOLAS Chapter II-1 Part C, the regulatory approach is regarded as a limiting factor in the development of new technologies.

The STEERSAFE project aims to propose a consistent update of the SOLAS regulations related to steering and manoeuvring, as well as an update of the performance standards in both normal service and in failure mode (reduced service). The study comprises conventional and non-conventional steering/propulsion arrangements.

4.2 Description of tasks

In the following, the seven tasks of the STEERSAFE projects are presented and described. The tasks have been defined by EMSA. Figure 4-1 provides an overview of the different STEERSAFE tasks and how they are linked together.

4.2.1 Task 1: Description and analysis of steering/propulsion systems

The various steering/propulsion systems, both conventional and non-conventional, and their application per ship type have been identified and described, using information from DNV's Nauticus Production System (NPS) that provides information on all relevant ship types and state-of-the-art steering/manoeuvring systems.

The following systems are included;

a) Traditional (e.g. shaft driven ships with conventional rudders).

b) Integrated propeller-rudder systems.

c) Azimuth thrusters.

d) Podded propulsors.

e) Waterjets.

f) Cycloidal propellers

The description includes technical solution, implications for manoeuvring, application and single/multi-unit arrangements. For identifying the safety relevant failure modes information in accident databases has been analysed considering EMCIP, IHS (Markit) and IMO GISIS as well as the expert knowledge by experienced approval engineers at DNV.

4.2.2 Task 2: Current regulations - gaps and inconsistencies

Experienced DNV approval engineers have been interviewed to identify common problems, gaps and inconsistencies found in practice when applying the current legislations to both existing conventional single or multiple rudder configurations, and non-conventional propulsion/steering systems, identified in Task 1. Furthermore, current measures and solutions to deal with the identified issues/challenges have been reported.

Furthermore, DNV has interviewed some of its major clients dealing with steering and manoeuvring (ship owners, manufacturers, shipyards and system integrators) for the purpose of highlighting problems and variations in the understanding of the current regulations.

4.2.3 Task 3: Development of goals and functional requirements

In this task the goals, functional requirements, hazards addressed and performance requirements regarding the steering and manoeuvrability capabilities – including the means of going astern – have been formulated, using the Goal-Based Standards (GBS) framework as defined in MSC.1/Circ.1394/Rev.2.

As specified by the IMO Guidelines, the functional requirements should address all relevant hazards and provide the criteria for verifying compliance. Therefore, the functional requirements have been developed on basis of the hazards identified in Task 5a as well as the outcome of Task 2 providing issues, gaps and inconsistencies of current regulatory framework. A certain hierarchical structure of goals and functional requirements is necessary to establish a GBS framework considering high-level elements for all ships and more detailed elements, for instance, for specific ship types.

The purpose of this project is not to invent new manoeuvring standards, but rather to consolidate and align current standards for all types of propulsion/steering. This task therefore aims to formulate the GBS enclosing the current legislative framework, i.e. regulations and associated documents.

The task consists of three steps:

- Draft goals and functional requirements based on the hazards identified in Task 5a and considering DNV experiences and results of developing function-based rules;
- Review and update the draft by interview of experienced DNV approval engineers and experts engaged in legislative work on propulsion/manoeuvring, and;
- To ensure high quality in the outcome and avoid obvious pitfalls, a group of experts has been established and consulted. A workshop has been organised, where the group of experts participated. EMSA has also been invited to participate in the workshop.

4.2.4 Task 4: Verification of current prescriptive regulations

This task covers the verification of current IMO regulations against Tier II functional requirements that specify the functions and related performance to be met in order to comply with the goals developed. The focus has been on identification of gaps between current regulations and the functional requirements developed in Task 3. If for instance a functional requirement is not covered by the current regulations, this is a gap. Similarly, if a rule comprised by the current regulations does not relate to any of the defined functional requirements, this is also a gap, revealing that the relevant rule may be redundant.

The following regulations have been part of the analysis:

- SOLAS Reg.II-1/28: Means of going astern
- SOLAS Reg.II-1/29: Steering gear
- SOLAS Reg.II-1/30: Additional requirements for electric and electrohydraulic steering gear
- SOLAS Reg.V/25: Operation of steering gear
- SOLAS Reg.V/26: Steering gear: testing and drills
- Resolution MSC.137(76) - Standards for ship manoeuvrability
- MSC/Circ.1053 - Explanatory notes to the standards for ship manoeuvrability
- Resolution A.601(15) - Recommendation on the provision and the display of manoeuvring information on board ships
- MSC.1/Circ.1398 - Unified Interpretation of SOLAS regulation II-1/29.
- MSC.1/Circ.1416/Rev.1 - Unified Interpretation of SOLAS regulations II-1/28 and 29.
- MSC.1/Circ.1536 - Unified Interpretation of SOLAS regulations II-1/29.3 and 29.4.

4.2.5 Task 5: Performance parameters in normal and failure mode

This task covers the following aspects:

a) A Hazard Identification (HazId) workshop involving DNV experts has been organized for the various propulsion systems in Task 1 a-f in single configuration in order to identify hazards and failure modes. In addition, an analysis has been performed for a multi-configuration. The concept of main/auxiliary steering gear has been evaluated for all systems in Task 1 a-f and multi-configurations with particular focus on which parts need to be duplicated to ensure redundancy.

b) Performance parameters and "preliminary" values for safe steering/manoeuvrability for both normal and failure modes have been suggested.

c) Typical conditions in which the vessels are operating under and what is practically feasible during sea trial have been evaluated to give recommendations on which conditions to perform propulsion/ steering tests.

d) A level of redundancy dependent on arrangement and technology has been proposed. The proposals are based on hazards and failure modes identified in 5a). Redundancy requirements have been applied to power, control and strength of components.

f) SOLAS Reg.V/25 states that "In areas where navigation demands special caution, ships shall have more than one steering gear power unit in operation when such units are capable of simultaneous operation". A specific revision of this regulation has been suggested.

g) SOLAS Reg.V/26 includes the requirements to testing and drills of the steering gear and specifies check items to be carried out within 12 hours before departure in addition to emergency steering drills that shall take place once every three months. A specific revision of this regulation has been suggested.

The output from the activities in paragraphs a) to d) were essential for the definition of the Functional Requirements in Task 3.

4.2.6 Task 6: Revision, update and development of present regulations

Based on the findings in the previous tasks, DNV has performed a general review, analysis and development of recommendations for updates of SOLAS Reg.II-1/28, 29 & 30 and SOLAS Reg. V/25 & 26, in addition to the associated IMO Resolutions and Circulars, such as:

- Resolution MSC.137(76) - Standards for ship manoeuvrability
- MSC/Circ.1053 - Explanatory notes to the standards for ship manoeuvrability
- Resolution A.601(15) - Recommendation on the provision and the display of manoeuvring information on board ships
- MSC.1/Circ.1398 - Unified Interpretation of SOLAS regulation II-1/29.
- MSC.1/Circ.1416/Rev.1 - Unified Interpretation of SOLAS regulations II-1/28 and 29.
- MSC.1/Circ.1536 - Unified Interpretation of SOLAS regulations II-1/29.3 and 29.4.
- Any other linked regulation or interpretation which DNV considers to be of importance to the study

4.2.7 Task 7: Minimum standard of propulsion and steering capabilities for SRtP

DNV has investigated the interpretation of the Safe Return to Port (SRtP) standard with respect to propulsion/steering performance among different players (administrations, class societies). Based on this an investigation has been performed, aiming to propose a common practice.

The investigation has been carried out by contacting the major flag states involved in the certification of passenger ships, e.g. Bahamas and Malta. In addition, a request for the same information has been addressed to IACS. The responses have been summarised and analysed.

The next step is to contrast the existing practice with the proposals developed in the previous Tasks 5b) and 6, and eventually suggest new recommendations.

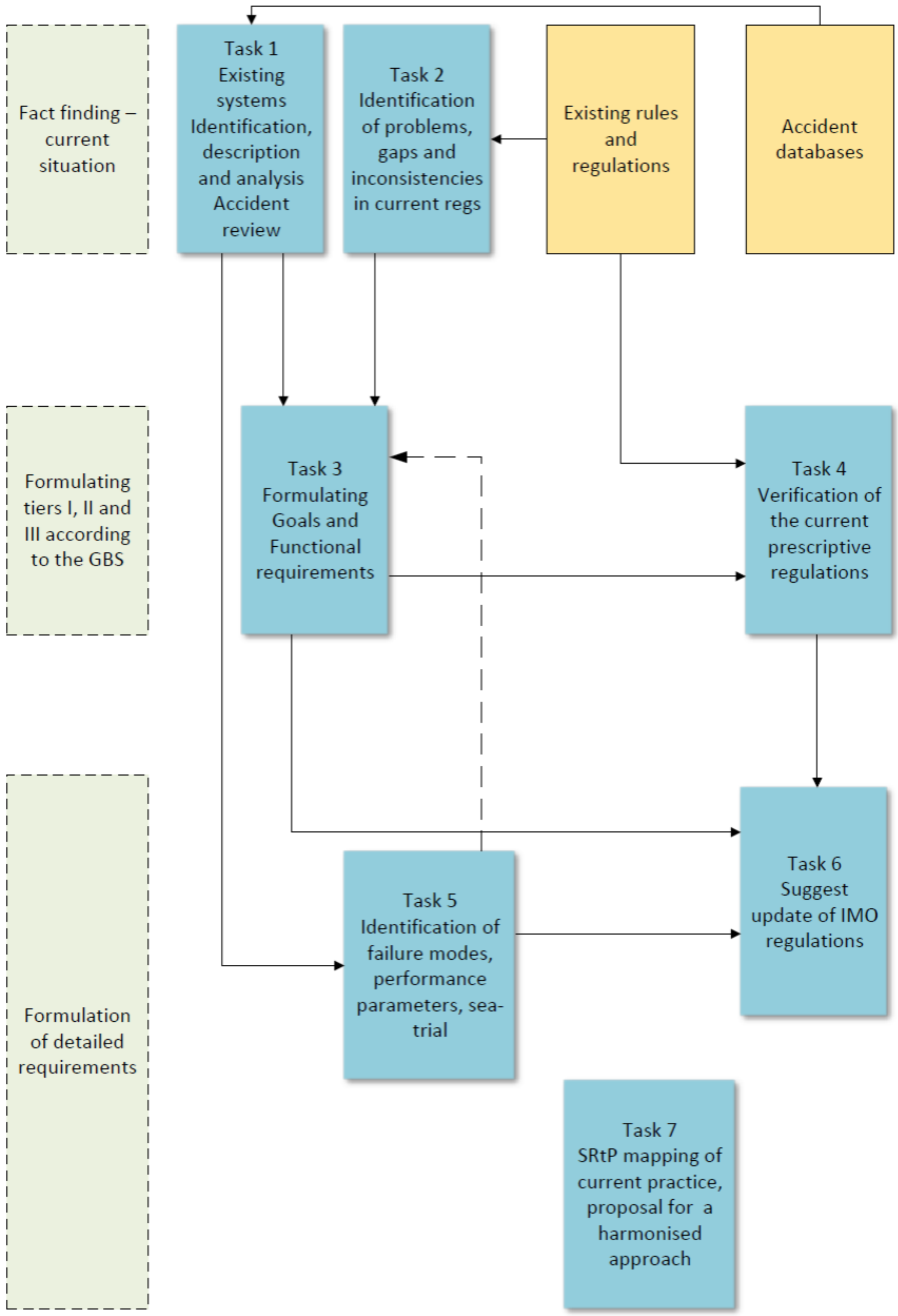

Figure 4-1 Overview of the STEERSAFE tasks

4.3 Objective and scope

The objectives of the STEERSAFE project are the following:

1. Provide a holistic analysis of the SOLAS regulations related to steering and manoeuvrability and associated circulars, resolutions and interpretations considering also non-conventional steering/propulsion arrangements;
2. Propose a consistent update of the elements described in the previous point;
3. Propose practical and meaningful performance steering and manoeuvrability standards in failure mode.

The first phase of the project provides a description of the various and relevant steering and propulsion systems, a gap analysis considering the current SOLAS regulations for steering, as well as an identification and analysis of hazards to the steering system. Finally, Tiers I & II of a Goal-Based Standard (GBS) framework for steering and manoeuvrability are developed: goals, functions and expected performance.

In the second phase, current SOLAS regulations are verified against the previously developed GBS Tiers I & II. Furthermore, performance requirements and parameters in normal and failure mode, as well as redundancy requirements for steering, are addressed. Procedures for the associated manoeuvring tests, aiming to map the steering performance and verify compliance with the requirements are thereafter established. Also, the operating conditions under which the performance is tested, are defined. The functional requirements are updated based on the findings in this phase (iterative process).

The final phase of the project concentrates on the revision of SOLAS regulations and associated Resolutions and Circulars, as well as Safe Return to Port (SRtP) practices and requirements.

4.4 Report structure

Section 5 – Current situation - aims to give an overview of the currently most used steering and propulsion systems, as well as the gaps and inconsistencies found from an investigation of the current IMO provisions for steering and manoeuvring. The details of the gap analysis is provided in ***Appendix A***.

Section 6 - Hazards and failure modes - covers the investigation of hazards to the steering system, relevant failure modes based on these hazards and finally the failures to be considered for reduced service. It also includes the motivation for the suggested discontinuation of the terms main and auxiliary steering gear. Detailed lists of hazards and failure modes are included in ***Appendix B***, ***Appendix C*** and ***Appendix D***.

Section 7 – Development of goals and functional requirements - describes the development of goals and functional requirements for steering and manoeuvrability. The overview of the initial[1] functions, expected performance and the addressed hazards is presented in ***Appendix E***. The final goals and functional requirements (functions and expected performance), first updated with the inputs from Section 8 and then after the Verification of Conformity (Section 9), are presented in ***Appendix G***.

Section 8 - Steering Performance, Documentation of Performance and Redundancy- deals with the most innovative aspects of the project: performance, documentation and

[1] Initial meaning that the functional requirements presented in Appendix E are not the final ones – these have been updated both prior to and during Verification of Conformity (described in Section 9)

redundancy requirements for steering in normal and failure mode. As the output from this part is essential for the development of the Functional Requirements, this section could have been considered as included in Section 7. Nevertheless, for the sake of clarity, it has been structured as a separate section.

Section 9 – Verification of conformity - describes the process of comparing the functional requirements with current IMO provisions in order to verify if current regulations together with Circulars and Unified Interpretations meet the functional requirements**. *Appendix F*** includes the details of the comparison between the functional requirements and the SOLAS regulations.

Section 10 – Trials and testing - presents test conditions and tests to be performed at sea trial, in order to map the performance and verify the previously developed performance requirements in normal and failure mode.

Section 11 – Safe Return to Port – discusses the need for a harmonized approach when it comes to Safe Return to Port and outlines a recommendation for this harmonization.

Section 12 – Revision of SOLAS regulations and associated documents summarizes the main changes and updates in the SOLAS regulations and associated documents. ***Appendix H: Proposal to IMO*** includes the proposals for updates to the current SOLAS regulations and associated documents.

5 CURRENT SITUATION

The background for the STEERSAFE study is the current incongruity between the last decades' technologic development in steering and propulsion systems, and the SOLAS regulations for steering and manoeuvrability, which are still referring to conventional rudder-propeller systems.

Consequently, the SOLAS regulations of today may not satisfactorily address the application of the variation in technical solutions and arrangements in use today (implying that there is a *gap*). Also, different IMO provisions may allow for deviating interpretations, e.g. with respect to compliance or achieved safety level (implying that there is an *inconsistency*).

This section aims to give an overview of the currently most used steering and propulsion systems, as well as the gaps and inconsistencies found from an investigation of the current IMO provisions for steering and manoeuvring.

5.1 Current steering and propulsion systems

In this section, the different relevant steering and propulsion systems categories are described. This includes an overview of the main components, characteristics and implications for manoeuvring as well as application per ship type.

The following system categories are considered;

- Conventional (shaft-driven propeller and rudder)
- Integrated propeller-rudder systems
- Azimuth thrusters
- Podded propulsors
- Waterjets
- Cycloidal propellers

5.1.1 Description of steering and propulsion systems

For each of the systems, an overview of the main components is included, as well as a schematic drawing of the system. The characteristics and application per ship type are also presented.

All systems have the following parts in common:

- Steering:
    - Bridge console
    - Communication to steering compartment[2]
    - Local control
    - Control system
    - Power supply to the steering system
    - Power unit
    - Actuator

[2] In cases steering and propulsion are combined (e.g. azimuth thruster, podded), the communication is to "machinery space"

- Propulsion:
  - Bridge console
  - Control system
  - Engine room console
  - Main engine(s) Auxiliary systems

For diesel electric systems, the following additional propulsion components are considered:

- Generator
- Cables
- Switchboard
- El. Motor

Conventional systems

This is the most commonly applied system with a shaft-driven propeller and a rudder behind. A schematic overview is shown in Figure 5-1.

For further analyses in this project we consider such a system to consist of the following parts:

- Steering:
  - Rudder stock bearings
  - Rudder blade
  - Rudder stock
  - Rudder stock connection to hull
  - Actuator

- Propulsion:
  - (Reduction gear)
  - Shaft and bearings
  - Propeller

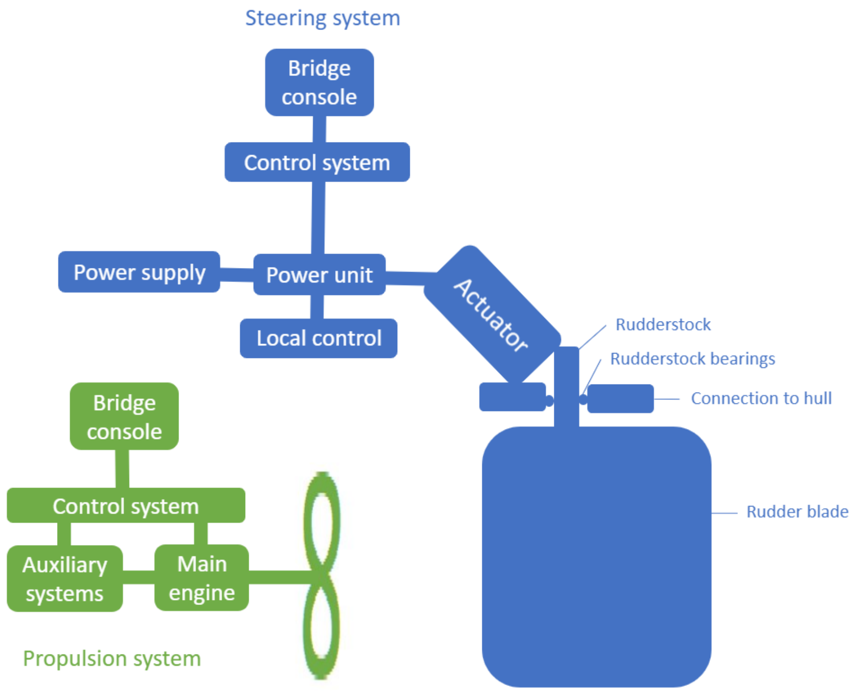

Figure 5-1 Conventional and integrated system

Integrated propeller-rudder systems

This is the same as the conventional system, except that the propeller boss is extended towards a rudder with a rudder bulb such that it looks like the shaft line ends in the rudder.

This system comprises the same parts as the conventional system. In addition, attention should be paid to the low clearance between propeller boss and rudder bulb.

The schematic overview (same as for the conventional system) is shown in Figure 5-1.

Azimuth thrusters

A schematic overview of the system is shown in Figure 5-2. The indicated arrangement is based on the most common diesel electric arrangement, whereas solutions with directly driven propellers also exist.

The propeller is in this case mounted on a thruster housing. The whole thruster housing and propeller can azimuth (rotate about the vertical axis) in order to provide steering.

For further analyses in this project we consider such a system to consist of the following parts:

- Steering:
  - Thruster housing
  - Azimuth bearings
  - Azimuth connection to hull
  - Actuator
- Propulsion:
  - Reduction gear
  - Shaft and bearings
  - Propeller

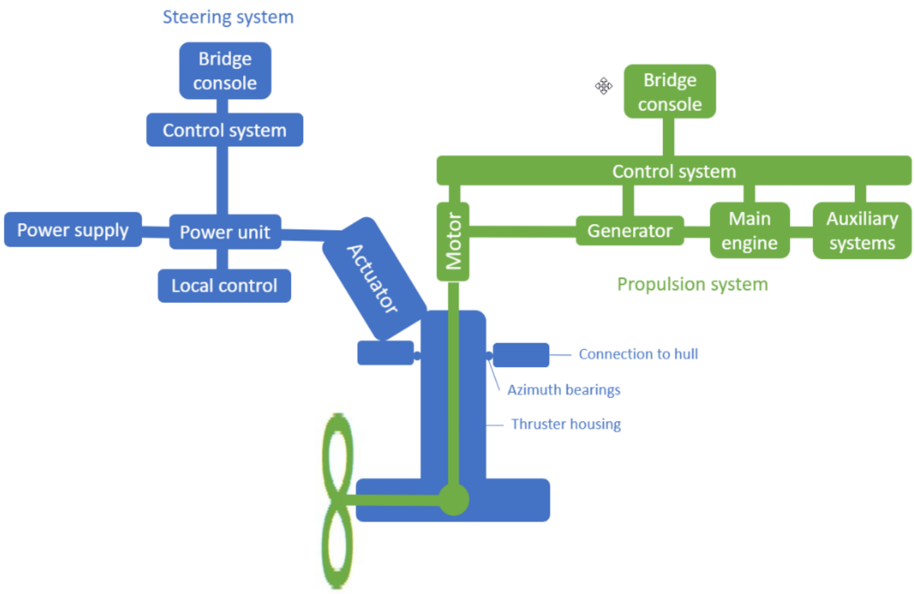

Figure 5-2 Azimuth system

Podded propulsors

A schematic overview of the system is shown in Figure 5-3.

This system is similar to the azimuth thrusters, except that the motor driving the propeller is located inside the thruster housing.

This system comprises the same parts as the azimuth system except that the gear is not present. Further, the electric motor driving the propeller may not be available for maintenance or repair at sea.

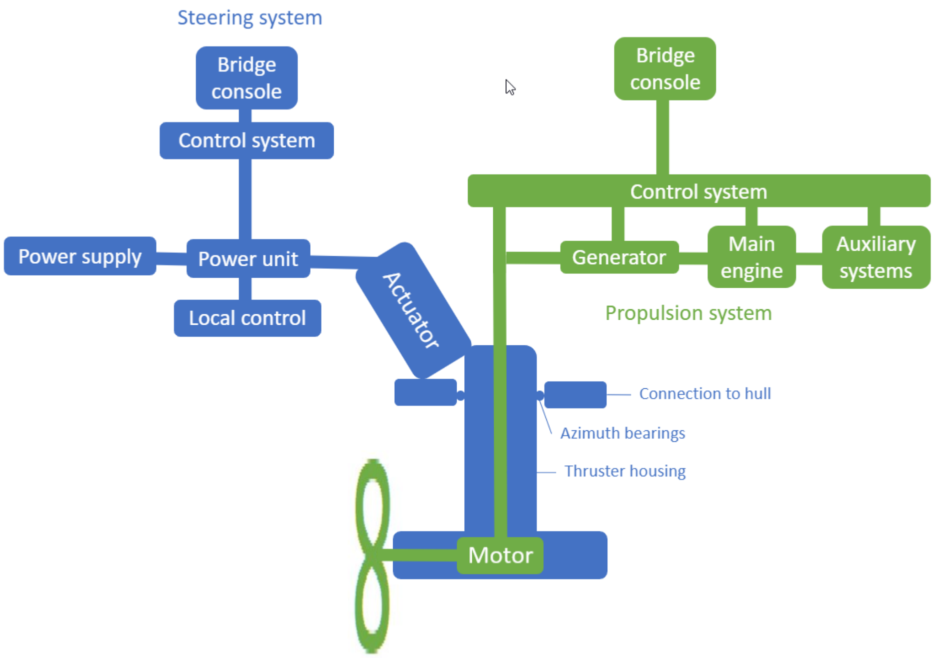

Figure 5-3 Podded propulsion system

Waterjets

A schematic overview of the system is shown in Figure 5-4.

In this case the propeller is located inside the vessel in a duct. This system can best be compared to a pump. Steering is provided by nozzle/rudder and a reversing bucket/deflector. The split reverse bucket is able of providing transverse force without longitudinal force, whereas the box-shaped deflector can produce transverse force proportional to the longitudinal force. This is illustrated in Figure 5-8.

For further analyses in this project we consider such a system to consist of the following parts:

- Steering:
    - Nozzle/flap for direction control
    - Reverse bucket
    - Steering actuator
    - Reverse actuator
- Propulsion:
    - Reduction gear
    - Shaft and bearings
    - Impeller (Propeller)

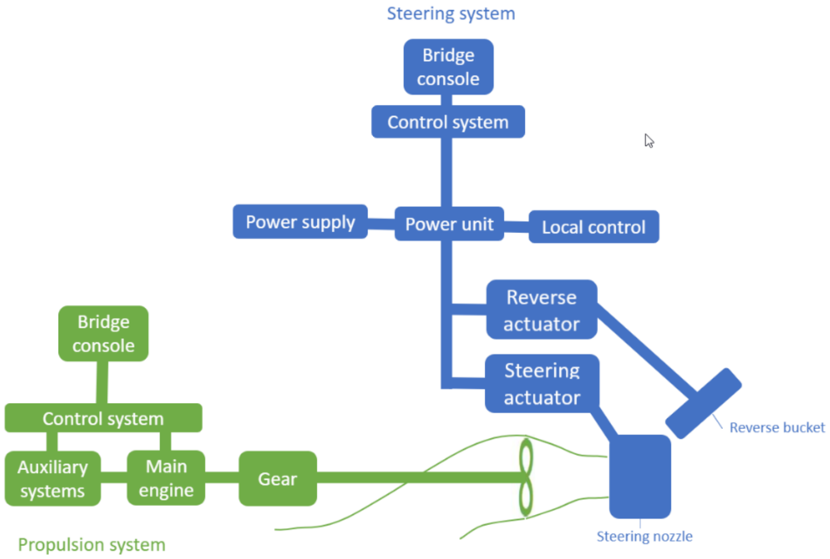

Figure 5-4 Waterjet system

Cycloidal propellers

A schematic overview of the system is shown in Figure 5-5.

This system is completely different from the others. In this case vertical fins are rotated around a vertical axis to provide thrust.

For further analyses in this project we consider such a system to consist of the following parts:

- Steering:
    - Actuator
    - Fin orientation mechanism

- Propulsion:
    - Reduction gear
    - Main bearings
    - Blades
    - Blade bearings
    - Connection to hull

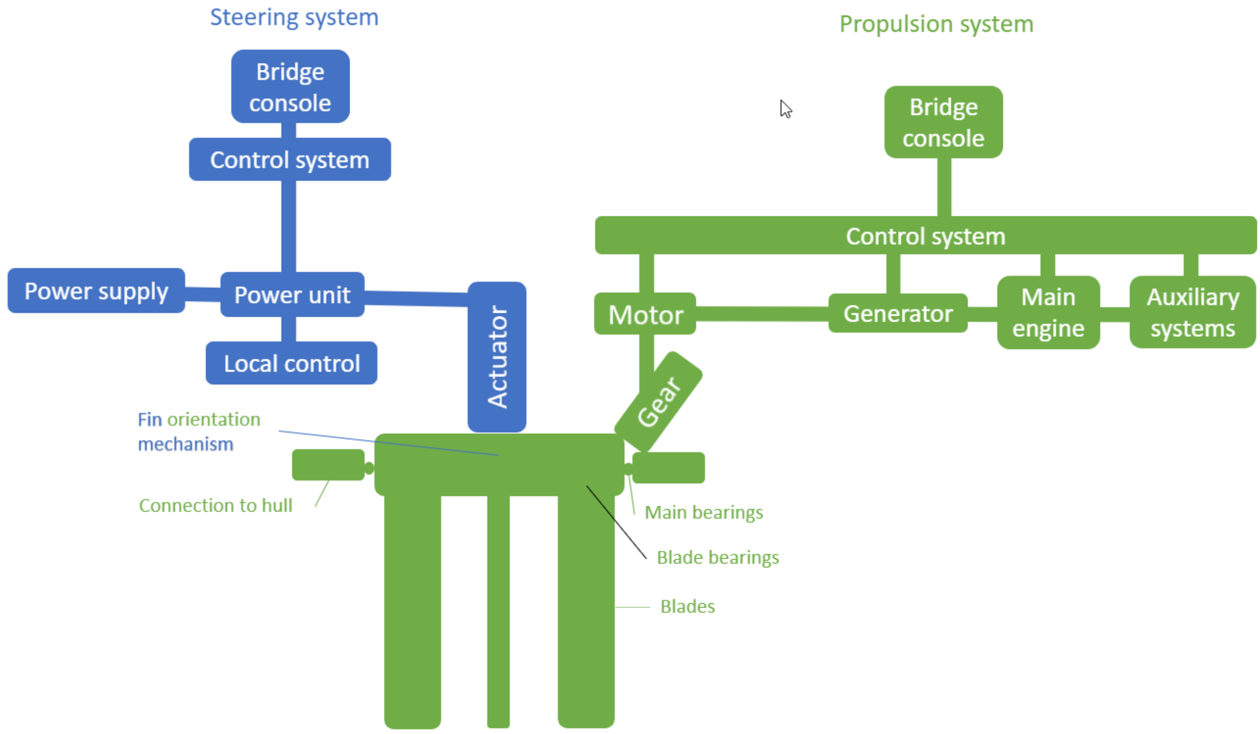

Figure 5-5 Cycloidal system

Generalised schematic description of steering system

To ease the further discussions, a generalised description of steering system is presented.

Steering of a vessel is achieved by a moment about z-axis (centre of gravity), typically generated by forces transversal to ship's longitudinal axis in order to keep or change the direction of the vessel. Schematic arrangement of force, momentum and ship is shown in Figure 5-6.

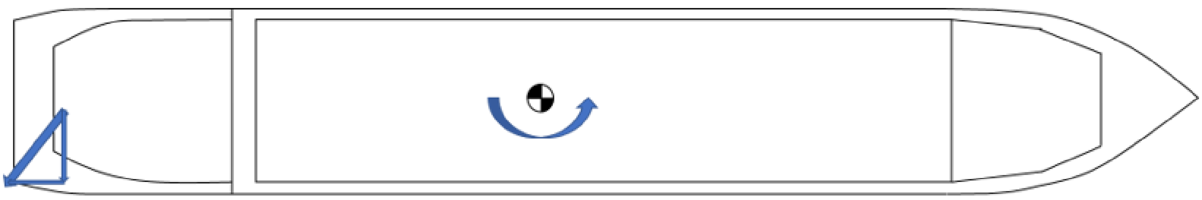

Figure 5-6 Principle sketch of steering

Typically, the steering system (Figure 5-7) consists of:

- Steering force unit - the unit generating the forces required to control the vessel (i.e. rudder and stock, rudder propeller, thruster, pod), including all parts up to the interface to steering gear.

- Steering gear - components for orienting the steering force unit. The steering gear may consist of various combinations of multiple power units or multiple actuating systems.

    - Steering actuating system

        - Power unit – providing power to actuator (e.g.: electric motor, hydraulic pump or equivalent).

        - Actuator – components converting power into mechanical action to turn steering force unit (e.g.: hydraulic cylinder, piston, hydraulic motor, piping or equivalent)

- Steering gear control system - components to control the steering process: connecting navigating bridge and steering actuator system, display of current settings and control settings.

These terms are in line with SOLAS definitions, however for simplification the listing of parts included has been shortened.

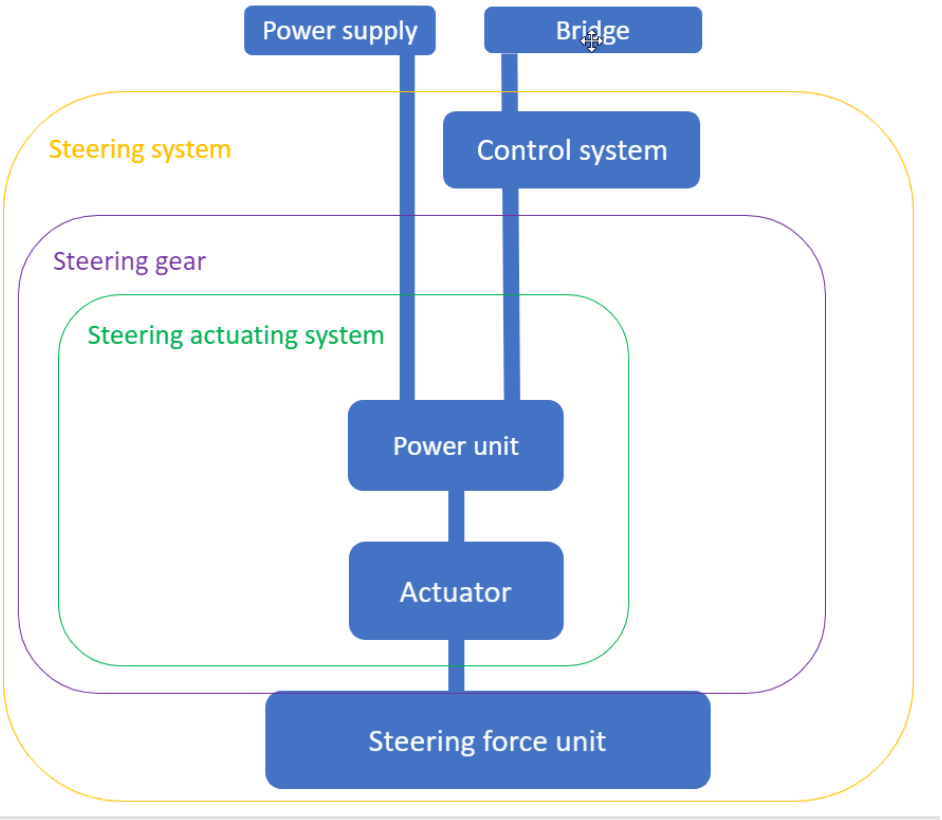

Figure 5-7 Generic sketch of steering system and sub-systems

5.1.2 Characteristics, implication for maneuvering and application

At sea, there is no significant difference in the performance in terms of manoeuvring for the different systems. However, in areas where navigation demands special caution there are significant differences:

- Conventional and integrated propeller-rudder systems produce very limited steering force in reverse.
- Azimuth thrusters, podded propulsors and cycloidal systems can produce full thrust in all directions. The response time with respect to thrust direction of the cycloidal is shorter than for the azimuth or pod.
- Waterjets have the shortest response time with respect to thrust magnitude and direction. This is because the pump can operate at full power and steering is provided by the nozzle and reversing bucket.

Figure 5-8 shows possible thrust and thrust directions for typical variants of the steering and propulsion systems. The different water jet variants are previously explained in Section 5.1.1.

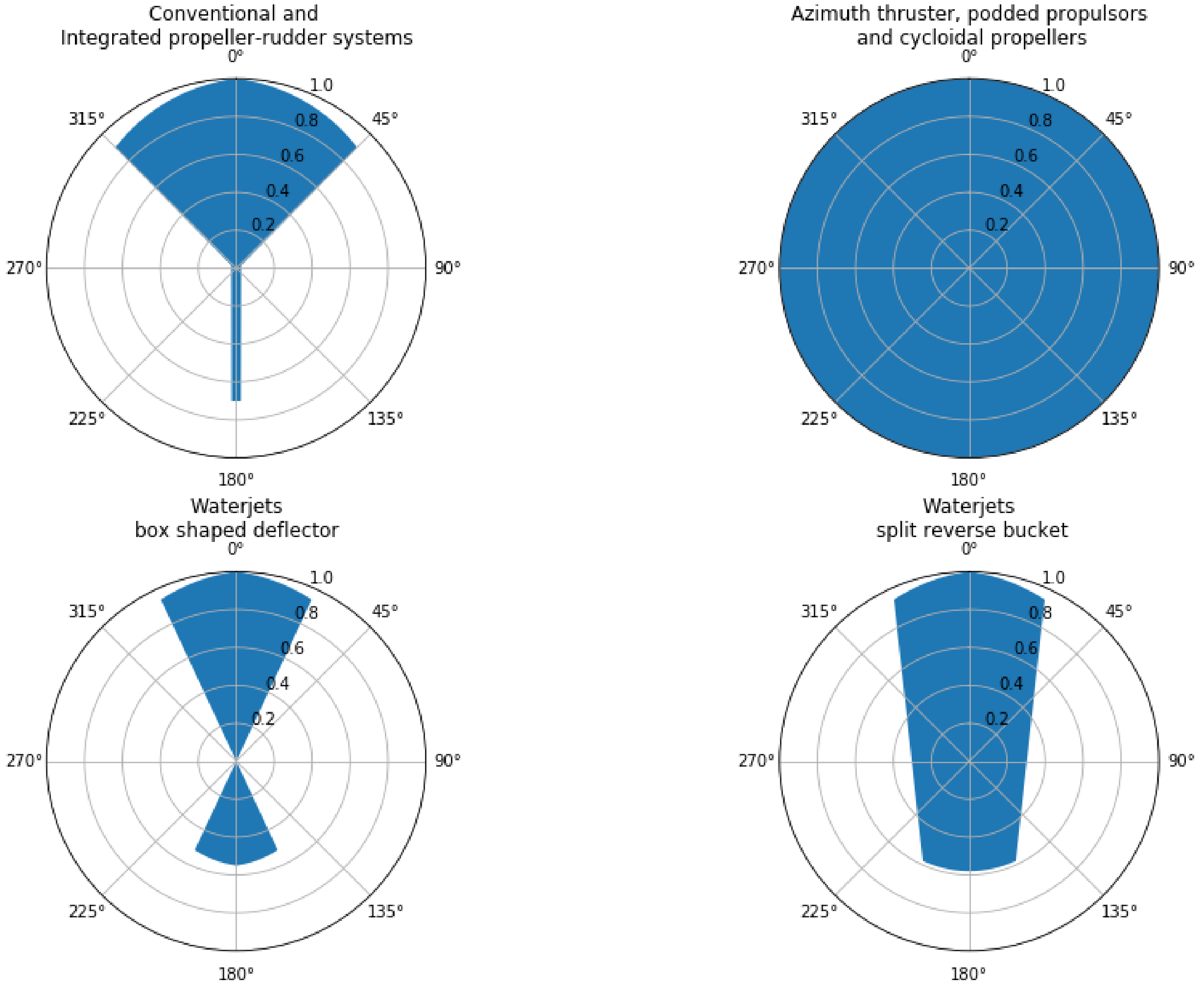

Figure 5-8 Plot of possible thrust and thrust directions for typical variants of the different propulsion systems.

As for application, conventional systems are still the most common for all categories of ships, see Table 5-1. Integrated propeller-rudder systems, azimuths and pods are however also widely used. Azimuth thrusters are becoming increasingly common for offshore vessels, while podded propulsion is frequently used for cruise vessels and ferries. Waterjets and cycloidal systems have a narrower application, typically limited to passenger vessels (waterjets), offshore (cycloidal) and special purpose vessels (both).

Fishing vessels, inland vessels, non-merchant vessel, non-propelled and non-ship structures are not considered in this study as they are exempted from SOLAS.

Table 5-1 Combinations of vessel types and propulsion solutions. Black = very common, dark grey = common, light grey = exists, white = rare/non-existing

	Tankers/ bulk carriers	Container	General cargo	Passenger	Ro-Ro	Offshore	Special purpose vessels
Percent of world fleet	23	4	19	5	2	5	16
Conventional							
Integrated							
Azimuth							
Pod							
Waterjets							
Cycloidals							

5.1.3 Single- versus multi-unit arrangement

All the propulsion and steering systems considered in this study exist on both single and multi-unit arrangement. Generally, the choice of single/ multi-unit arrangement is not depending on propulsion type, but rather on vessel type and application.

Single-unit configurations

For an arrangement with a single propulsion line a reduction in propulsion force (due to power reduction or mechanical damage) will reduce the steering ability about linearly with the propulsion loss. Complete loss of propulsion force will leave the vessel unable to steer for all systems. A minor exemption here is that the conventional and integrated propeller-rudder systems will provide some steering while the vessel is slowing down. The other systems will not.

The effect of a reduction in steering power will depend on the course-keeping stability of the vessel. For directionally stable vessels at open sea, significant reduction in steering power can be accepted and the vessel will still be able to continue the journey to port. For directionally unstable vessels, the steering power needs to be sufficient to be able to satisfy the autopilot or the helmsman. Complete loss of steering power will leave the vessel unable to steer.

Failure of steering force unit or other non-duplicated parts of steering system will typically lead to loss of steering or at least the need to limit the propulsion power.

Failure of components or systems which are duplicated (redundant) may, or may not, lead to reduced steering capability depending on the degree of redundancy (e.g. hydraulic actuating system with two pumps, each delivering 50% - versus 100% of required capacity).

Multi-unit configurations

For an arrangement with multiple propulsion units, the performance reduction due to failures in propulsion will in many cases be less than for single-unit configurations. This is because in the case of one failure, the other units will in most cases remain operative.

In general, multi-unit configurations will be resilient to any single failure of any duplicated component.

Most vessels with dual-unit configuration will have the units located at same distance from the stern and symmetrically about the centreline. The sideway distance between the units are typically in order of half the vessel breath. In case of failure, the state of the failed unit may be equally important as the type of unit with respect to performance after failure.

For the systems with rudder (conventional and integrated propeller-rudder systems) the position of the rudder after failure is important. Ideally, the rudder is steered somewhat inward. In worst case it is steered outwards, i.e. providing a steering force which will have to be counteracted by the remaining functional unit. In the latter case, the vessel might be unable to steer with the rudder even with one unit remaining functional. Steering outwards is worse than steering inwards due to the offset of the propulsor about the centreline.

For all systems except waterjets, the propeller will produce drag in case of complete failure. The amount of drag may vary somewhat between different propulsion systems and their state at failure. It is also an issue whether the propeller is locked or free milling.

Waterjet systems are not expected to have any noticeable negative effects from the faulty line.

All propulsion systems are expected to be able to provide steering after failure of one unit in a multi-unit configuration, with the exception of the failing unit having the rudder steered significantly outwards, as explained above.

Comparing the reliability of single unit towards multiple unit arrangements it is estimated that the single unit arrangement may be less likely to have to operate at reduced steering capacity. However, the multiple unit arrangement is less likely to suffer a complete loss of steering.

5.1.4 Other means of steering

Bow thrusters and propulsion units installed for use in special situations (e.g. Dynamic Positioning) are exempted from this study as this is not part of SOLAS today and these systems do not provide reliable steering when traveling long distances.

5.2 Gaps and inconsistencies in current regulatory framework

A review of relevant SOLAS regulations has been conducted to map *gaps* and *inconsistencies* between current regulations and the existing solutions for providing steering.

The following definitions apply:

- *Gap:* when current regulations do not satisfactorily address the application of the variation in technical solution and arrangements in use today.
- *Inconsistency:* when different IMO provisions allow for deviating interpretations, e.g. with respect to compliance or achieved safety level.

The regulations are also evaluated considering expected future developments and innovative solutions.

The results may be found below in general terms and thereafter for the different existing solutions. A paragraph by paragraph evaluation may be found in ***Appendix A*** in this report, including a linking to relevant hazards and failure modes which will be further handled in Section 6.

According to the review, the following gaps are identified as relevant hazards:

- Regulations are not addressing that erroneous operation or system fail may represent a hazard due to unexpected motions
- Regulations are not addressing that steering systems may be integrated with other systems and functions

These will be included in the evaluation of hazards in Section 6.

In Sections 5.2.3 and 5.2.4, the gaps and inconsistencies are treated for conventional systems and combined steering and propulsion systems (thrusters/pods and waterjets), respectively.

5.2.1 Relevant regulations and associated documents

This Section presents the SOLAS regulations and associated documents dealing with steering and manoeuvrability and which therefore have been reviewed in this project.

- SOLAS Ch.II-1 Regulation 28 – *Means of going astern* and the following documents which this regulation refers to:
    - MSC.1/Circ.1416/Rev.1 – *Unified interpretation of SOLAS Regulation II-1/28 and II-1/29 concerning the arrangements for steering capability and function on ships fitted with propulsion and steering systems other than conventional arrangements for a ship's directional control*
    - Resolution MSC.137(76) – *Standards for Ship Manoeuvrability*
    - MSC/Circ.1053 – *Explanatory Notes to the Standards for Ship Manoeuvrability*
    - Resolution A.601(15) – *Provision and Display of Manoeuvring Information on board Ships*
- SOLAS Ch.II-1 Regulation 29 – *Steering* gear and the following documents which this regulation refers to (in addition to those listed under Regulation 28):
    - Resolution A.415(XI) – *Improved steering gear standards for passenger and cargo ships*
    - Resolution A.416(XI) – *Examination of steering gear on existing tankers*
    - MSC.1/Circ.1398 – *Unified interpretation of SOLAS Regulation II-1/29 Mechanical, Hydraulic and Electrical Independency and Failure Detection and Response of Steering and Control Systems*
    - MSC.1/Circ.1536 – *Unified Interpretation of SOLAS Regulations II-1/29.3 and 29.4*
- SOLAS Ch.II-1 Regulation 30 – *Additional requirements for electric and electrohydraulic steering gear*
- SOLAS Ch.V Regulation 25 – *Operation of main source of electrical power and steering gear* and 26 – *Steering gear: Testing and drills*
- SOLAS Ch.II-1 Regulation 8-1 and Ch.II-2/21.4 – *Safe Return to Port (SRtP)*

5.2.2 General observations

In the following some general observations made when reviewing the regulations and associated documents in Section 5.2.1 are summarized, including comments for some adopted measures.

- Regulations are missing a top-level goal
    - Mandatory criteria for manoeuvring capability are only to a limited degree available in IMO instruments. The Manoeuvring standard (MSC.137(76)) is referred to in SOLAS merely by a footnote.

      To what extent the various administrations have implemented the MSC.137(76) is not known in detail, however, there are some indications that there are varying practices with regards to mapping of manoeuvring characteristics and extent of trials, particularly for ships with more than one steering system.
    - A prediction and verification of manoeuvring characteristics for the ship in a reduced condition (after failure of steering component/system) should be included.

      To our knowledge this is not done currently, beyond verification of turning speed of rudder/steering force unit.
- For the Safe Return to Port scenario the regulation is missing a guidance or preferably a quantification of required available capacity and performance parameters after failure.
- Regulations are considering the steering system as separated from other systems and functions
- It is necessary to clarify to what extent it is acceptable to integrate control systems for steering with other systems. Integration with autopilot and dynamic positioning system is common and integration with propulsion function is applicable in many cases. Practice has been to request that these "add-on" systems can be disconnected, and/or that an additional independent back-up system is provided.
- Regulations are technology-specific and normally prescriptive.
- Regulations are not addressing that erroneous operation or a system fail may represent hazards due to unexpected motions;
    - Steering systems may have several operation modes and functionalities. There is a need for increased focus on user interface and familiarisation for correct use.

      Operating modes may differentiate on permissible steering angles at different ship speeds. Erroneous operation or erroneous response from system may represent a hazard. System design should be "fail to safe". To our knowledge this is currently handled by operator familiarisation and possible signboards on bridge.
- All steering solutions are to some degree dependent on having available propulsion, however propulsion is not addressed.
    - There is a need to align the reliability level for steering and propulsion, however this is outside of scope for this project.

As SOLAS chapter II-1 is open for Alternative Design, functional requirements should be provided for this process enabling new technologies and regulations formulated as far as possible to be technology neutral.

5.2.3 Conventional steering system

Single rudder installation

- The Regulation is assuming hydraulic actuators. Electric actuators may be an option also for conventional rudder arrangements. There is a need to develop regulation to be technology neutral.
- Regulation 29.14: when the auxiliary steering gear is required operated by power, an alternative power supply (emergency power) is requested for larger ships (rudderstock >230 mm)
    - Regulation text should allow for an evaluation of availability of power – as some ships may be arranged with higher redundancy and separation of power supply which may provide equal or higher availability of power for steering than the connection to emergency power, and as such provide an equivalent safety level.
    - Regulation text should allow for an evaluation of the effect in steering capability. In case of electric propulsion, the loss of power will also result in loss of propulsion, and likely a very low steering capability.

Twin rudder installation

- Regulation is not addressing twin rudder installations;
    - There is a need to clarify if two independent rudder and steering gear arrangements are sufficient to comply with the redundancy requirements (main / auxiliary)– considering all types of ships – or clarify redundancy requirements for each of them.

      To our knowledge the practice has been for multiple steering not to request redundancy applied for each system. The continued work will be based on a consideration that the applied redundancy on a system level gives equivalent level of safety as redundancy on a component level.
    - Need to clarify to what extent testing of each rudder/steering system is required and to what extent symmetric behaviour or simulated behaviour is sufficient.

5.2.4 Combined steering propulsion systems

Thruster / POD

- Topics listed under “General observations” in Section 5.2.2 are applicable.
- Topics listed under “Single rudder installation” in Section 5.2.3 are applicable.
    - Note that Interpretation of Regulation 29.14 requests an additional alternative steering power supply (emergency power) for thrusters with propulsion power above 2500 kW with “a certain steering capability”
        - The regulation text should allow for an evaluation of availability of power – as some ships may be arranged with higher redundancy and separation

of power supply which may provide equal or higher availability of power for steering than the connection to emergency power, and as such provide an equivalent safety level.

  - The regulation is applicable for steering systems with "a certain steering capability". In case of electric propulsion, the loss of power will also result in loss of propulsion, and likely a very low steering capability. The term "certain steering capabilities" is not a specific definition and may open for different interpretations. The knowledge about the application of this term by the industry and administration is limited.

- Topics listed under "Twin rudder installation" in Section 5.2.3 are applicable.
- Single or multiple thruster/POD installation: same topics as for single/twin rudder installation

  To our knowledge the practice for multiple steering systems has been to not request redundancy for each system. The interpretation applicable to propulsion and steering systems other than conventional (MSC.1/Circ.1416/Rev.1. (1)) is challenging this practice, particularly in later revisions. However, the continued work will be based on a consideration that the applied redundancy on system level gives equivalent level of safety as redundancy on component level.

Waterjet

Waterjets are more frequently used for High-speed crafts (HSC), for which the HSC Code (made mandatory by SOLAS CH.X) is valid. The HSC Code requires the craft to be provided with means of directional control and designed such that a single fail in one system will not render any other systems inoperable or unable to bring the craft to a safe situation.

- Topics listed as general observations, for thruster/pod as well as for single rudder/twin rudder application are also valid for waterjets.

Cycloidal systems

Cycloidal systems are fully dependent on propulsion to provide steering.

Topics listed under "General observations" as well as those listed for thrusters and pods are applicable.

5.2.5 Input from external group of experts

During the workshop with the external group of experts to address the goals and functional requirements (summarized in Section 7.3.1 of this report), the participants were asked to give their feedback with respect to problems with the current regulations.

The observations summarized in Section 5.2.2 were presented. In addition, the following items were brought up and discussed;

- Should there be performance requirement on maneuvering (vessel as a whole) rather than steering gear? There are different views on this (quotes from the workshop):
  - *It is a good way of making requirements independent of steering/ propulsion system*

- *Not all ship designs commonly used today will pass the criteria as set out in MSC.137(76). This means that these types of ships will have to be designed differently.*
- *Many ships today supersede the performance parameters. It is a risk that these ships will be designed to only meet the minimum requirement to save cost.*
- *Experience shows no trace of maneuverability being a significant cause for accidents*
- *Some of the performance parameters are dependent on ship length. It is however not evident from a risk perspective why it should be allowed with a larger stopping distance for bigger ships as the ship size implies larger consequences of an accident.*

- The feedback from operators is that it is more important to know the performance of the ship, rather than having minimum requirements as different types of ships are operated differently.
- Redundancy requirements:
  - *Would reliability be a better approach? Reliability is probably more costly in practice, particularly for new technology. Reliability probably possible on component level, but difficult on system level. Further, the reliability approach requires more data (e.g. failure probability, mean-time-to-failure) than currently available[3].*
  - *Steering gear is perceived as very reliable. It is more common with errors on the control side.*
  - *Systems should be fault tolerant. Redundancy is one way of solving this. Independency is another approach with different pros and cons.*
  - *Redundancy makes systems more complex. This could be a source for failures. Further, redundancy may be restricted by common cause failures.*
  - *Propulsion is needed for steering. Requirements should be similar.*
  - *How to handle multiple propulsion lines?*
  - *Autonomous ships should be kept in mind, but we may still allow for human in the loop for fault handling. Requirements should possibly be technology (human) independent.*
  - *The US Coast Guard has steering test requirements for ships entering US waters.*
  - *Regulations and requirements should have a unique interpretation to avoid unfair competition.*

[3] Typically, such data is available for mass production parts, e.g. electronic components, but not for individual designed components.

6 HAZARDS AND FAILURE MODES

This section covers the investigation of hazards related to the steering system, relevant failure modes based on these hazards and finally the failures to be considered for reduced service. It also includes the motivation for the suggested discontinuation of the terms main and auxiliary steering gear.

Hazards relevant to different parts of the steering system have been identified and later ranked according to likelihood and severity, providing the basis for the hazards that need to be addressed when developing the functional requirements (Section 7).

The following definition of a hazard has been applied:

A hazard (or a hazardous event) is an event (external or related to the operation of the vessel) which leads to the loss of, or reduced performance of, the steering/propulsion system

Hazards have been identified in three ways; a) by a review of incident reports, b) by a typical Hazard Identification (HazId) workshop and c) by an analysis of SOLAS regulations.

In the following, the results from the different approaches listed above are summarized.

6.1 Incident Review

Three databases (EMCIP, DNV internal, IHS Markit) have been applied to extract incidents related to steering systems. In addition, information from the GISIS database (IMO Global Integrated Shipping Information System) is considered.

The European Marine Casualty Information Platform (EMCIP), (2), is a database and a data distribution system operated by EMSA, the European Commission and the EU/EEA Member States.

Upon a request from DNV, EMSA has provided data from the EMCIP database from 2011 and onwards, amounting to 13,500 occurrences excluding non-relevant ships, and including the following event types;

- Collision
- Contact
- Damage/loss of equipment
- Loss of control (loss of containment, loss of directional control, loss of electrical power, loss of propulsion power)

In addition to the EMCIP database, steering and rudder damages registered by DNV's internal database have been reviewed.

Unfortunately, none of these databases are indexed in a way that makes it easy to extract quantitative data regarding failures. In both databases, the best source of information regarding what kind of failure occurred is the description column containing a free text field, thus hampering any statistical investigation. Failures have therefore been identified by manual reading and interpretation of these fields in both databases.

Additionally, the IHS Markit Casualty database has been considered. An investigation of the description column shows that "steering/steering gear failure" and "loss of steering due to electric problems" have the potential to cause collision or grounding accidents. However, in most cases it is reported that consequences are limited to disturbance of ship operation, e.g. leading to unplanned repair. The brief review showed that in about 1 to 3% of the accidents the cause is assigned to steering. However, it is noted that human error is mentioned in many GISIS reports on collision accidents, mostly violation of COLREG regulations (International Regulations for Preventing Collisions at Sea) and other safety procedures. No information has been found mentioning that the underlying cause of accident is insufficient performance of the steering system in normal service, or insufficient consideration of ship (steering) performance.

Both EMCIP and DNV's internal database have been reviewed with main focus on incidents (either external or internal) resulting in reduced steering performance or loss of steering. The variation in damages is huge. However, some causes and failures are more commonly reported than others. Among the commonly observed failures are:

- Contact with bottom
- Missing parts (rudder flap, inspection plates)
- Object tangled in propeller
    - Mooring rope
    - Chain
    - Object in water jet
- Bad fuel
- Oil leak:
    - Seals
    - Valves
- Hydraulic pump failure
- Bearing failures
- Wear of pindles or hinges
- Water ingress
- Corrosion and erosion
- Fatigue
- Structural failure
    - Rods
    - Clutch
    - Gears
    - Reverse bucket
- Electrical faults (diesel electric systems)
    - Motor
    - Circuit breaker
    - Converter
- Control system
    - Lack of response
    - Uncontrolled commands
    - Reset
    - Erroneous indicators
    - Alarm errors
- Human error

Increasing number of components and increasing complexity of the systems is likely to lead to increased probability for failure, and this is also applicable for control systems (e.g. if the vessel has Dynamic Positioning).

Whereas the waterjet is well protected against impact with bottom, they appear to be more prone to complete stop, due to objects sucked into the waterjet. Several incidents are also observed related to fatigue of steering rods and the reverse bucket.

With regards to cycloidal systems, the bearings in the blade holding mechanism could be a challenge.

For all steering systems it is observed that complex control system seems to be more prone to errors (e.g. if the vessel has Dynamic Positioning).

The information provided by the incident review was used for verifying completeness of the hazard workshop as well as supporting the ranking of hazards (selecting hazards for developing functional requirements).

6.2 Hazard Identification Workshop

In order to identify and evaluate hazards and failure modes, a Hazard Identification (HazId) workshop was organized in January 2020, involving DNV experts within machinery, control systems, manoeuvring and operation. Both hazards and failure modes were addressed in the workshop.

For the hazards, the focus was put on the *commonalities* between the different steering and propulsion systems, i.e. hazards which are relevant to all systems (conventional, integrated, azimuths, pods, water jets and cycloidal systems) and thus the HazId was based on the generalised system as shown in Figure 5-6.

It has been found that new identified hazards arise from increased system integration and complexity and are not considered in existing regulations.

Details of the HazId workshop are provided in Section 6.2.2 and ***Appendix B*** in this report.

In the following, some clarifications are made with respect to terminology and method of work for identification of hazards and failure modes.

6.2.1 HazId technique and terminology

Hazard Identification (HazId) is a facilitated brainstorming process, involving people with relevant competence within an area. The aim is to identify hazards and their causes, consequences, as well as affected systems and safeguards. A criticality rating, defining the likelihood, consequence and thereby the risk, can be performed, resulting in a recommendation based on the findings. The criticality rating has been performed based on frequency index (FI) and severity index (SI) as specified in the IMO FSA Guidelines, (3).

Reference is made to ***Appendix B*** for further explanation on the criticality rating. For the purpose of this project, the severity relates to the availability of steering performance.

Hazards, causes and consequences were identified and discussed during the workshop, while safeguards and the associated risks were not considered, since this is not part of the objective for this part of the study. In a follow-up to the workshop the hazard list has been amended by safeguards of existing IMO provisions. It is noted that for many of the hazards, the IMO mandatory instruments provide safeguards but in a generic/general way, e.g. requiring redundancy for complete sub-systems.

The previously presented definition of *a hazard* has been applied:

A hazard (or a hazardous event) is an event (external or related to the operation of the vessel) which leads to the loss of, or reduced performance of, the steering/propulsion system

This is a further specification of the definition of a hazard in Section 3.

The hazards have been grouped into different parts of the steering/propulsion system; the control system, the electrical system, the hydraulic system and eventually mechanical-related hazards.

It should be noted that, in this hazard identification and in accordance with the applied definition, a hazard can also be the cause for another hazard, e.g. a cyber-attack is a hazard in itself (according to the definition above), but it can also be the cause for a software error, which also is a hazard.

6.2.2 Main hazards identified in the workshop

Hazards are addressed for different elements of the system; control, electrical, hydraulic/actuator and mechanical-related hazards.

The identified hazards are listed in ***Appendix B***, together with causes, consequences and safeguards, so-called risk-control options (RCO), distinguishing likelihood and consequence mitigation. If a safeguard is provided by SOLAS the reference is considered. It should however be noted that redundancy will in many cases mitigate the identified hazards.

Hazards are ranked according to Appendix 4 of IMO FSA Guidelines, (3), with a modified severity index (ref. ***Appendix B*** in this report).

All hazards with an RI of at least seven are regarded relevant.

In the following all hazards with a RI ⩾ 7, i.e. high-ranked hazards, are summarised.

Control system

For the control system the hazards include obvious harmful events such as water ingress, vibrations, wave impact, fire inside and outside of the system (internal/external fire), but also – since the ship systems have become more sophisticated and the functionality increases – more complex issues such as cyber-attack, software error, system complexity and network error which can lead to loss of steering, reduced performance and information overload to the operator. Without consideration of existing safeguards, the hazards with the highest Risk Index (RI) are:

- Vibrations (RI = 10) caused by working environment resulting in loose connections or breakage due to fatigue and subsequent loss of control system output (loss of performance)
- Accelerations (RI = 9) caused by rough weather resulting in loose or breakage of connections and subsequent loss of performance
- Cyber-attack (RI = 9) resulting in loss of performance
- Water ingress (RI = 8) caused by pipe failure, fire-fighting, loss of water tightness etc. and resulting in malfunction/loss of steering performance
- Integrating the steering control system with other systems or operating the steering control system by other systems (RI = 8) resulting in mutual dependency on performance/functionality
- Fire (external RI = 8, internal RI = 7) and subsequent loss of performance
- Human error (RI = 7) resulting in decreased performance
- Network error (RI = 7) e.g. caused by overload and resulting in reduced performance.

Several of the more complex hazards are not addressed in existing mandatory regulations for steering and propulsion (SOLAS Ch.II-1) but in other mandatory and non-mandatory IMO provisions. For instance, the hazard cyber-attack is addressed by non-mandatory IMO Guidelines (MSC-FAL.1/Circ.3, 2017). The hazard "energy surge" has been ranked low (RI = 4) and thus would not be further considered. However, after further discussion with DNV experts this hazard was replaced by Electric Magnetic Interference (EMI) which in their view has a higher Risk Index.

As shown in the table (***Appendix B***) the hazards vibration, accelerations, water ingress and fire are considered by IMO provisions, e.g. requiring redundancy and separation of the control system and specifying a damage case for passenger ships that shall not lead to loss of steering.

Electrical system

For the electrical system, the hazards with the highest risk index are:

- Blackout (RI = 9) e.g. caused by short-circuit or failure of power management system resulting in complete loss of steering performance
- Insufficient power available (RI = 9) e.g. caused by failure of power management system which again may be caused by software error resulting in loss of performance
- Main switchboard failure (RI = 8) e.g. caused by short-circuit and resulting in loss of steering performance

Additionally, the following hazards are regarded relevant also for the electrical system, but most are underlying causes for blackout or switchboard failure (vibrations, accelerations, water ingress, fire, integrating the steering control system with other systems or operating the steering control system by other systems):

- Vibrations (RI = 10) caused by working environment resulting in loose connections or breakage due to fatigue and subsequent loss of performance
- Accelerations (RI = 9) caused by rough weather resulting in loose or breakage of connections and subsequent loss of performance
- Cyber-attack (RI = 9) resulting in loss of performance
- Water ingress (RI = 8) caused by pipe failure, fire-fighting, loss of water tightness etc. and resulting in malfunction/loss of steering performance
- Integrating the power supply with other systems (RI = 8) resulting in mutual dependency on performance/functionality
- Fire (external RI = 8, internal RI = 7) and subsequent loss of performance

All these hazards relate to failures of the main switchboard and the resilience of the electric grid (short-circuit in any other system and the effect on the grid (blackout) and the reliability of electric power supply by onboard electric grid, and these are already addressed by IMO provisions, mainly in SOLAS Ch.II-1, Part D, e.g. Reg.40.1.2 Essential services, Reg.41 Resilience, Reg.42 (Pax) and Reg.43 (Cargo) Emergency source.

Thus, with respect to the electric power of the steering system it is essential that the integration of the steering system in the ship's electric grid is not the weak link that can reduce reliability.

Hydraulic/actuating system

The highest ranked hazards applicable to the hydraulic/actuating system are:

- Contamination of hydraulic fluid (RI = 10) e.g. caused by dust, dirt, wear and tear and resulting in a temporary loss of steering performance
- Overload (RI = 9) e.g. caused by erroneous estimation of service loads (wave, current), accidental loads (contact, grounding) and bearing failure resulting in loss of steering performance
- Fire (RI = 8) e.g. causing significant damage (destroyed connection between control system and actuator) resulting in loss of steering performance
- Mechanical damage (RI = 7) e.g. caused by dropped objects or ageing effects (corrosion, fatigue) resulting in loss of performance (for instance in hydraulic system: leakage/rupture)
- Loss of pressure (hydraulic only) (RI = 7) e.g. caused by ageing or failing of component (seal, flange, valve) resulting in loss of performance
- Lack of lubrication (RI = 7) resulting in blockage and subsequently loss of steering performance

Additionally, the following hazard is also regarded as relevant:

- Fire (external RI = 8, internal RI = 7) and subsequent loss of performance

For all of these hazards, safeguards are provided by the IMO provisions in SOLAS chapter II-1 Reg. 29 and SOLAS chapter V Reg. 26 reducing the risk index to significantly lower values. The hazard "mechanical impact" is covered by other provisions with respect to good seamanship.

Mechanical system

Mechanical hazards relate to failures in the steering force unit, e.g. rudder, rudder stock, thruster housing etc. The highest ranked hazards are:

- Overload (RI = 8) e.g. caused by erroneous estimation of service loads (wave, current), accidental loads (contact, grounding) and bearing failure resulting in loss of steering performance
- Fire (RI = 8) e.g. causing significant damage to/ deformation of mechanical components resulting in loss of steering performance
- Mechanical blockage (RI = 8) e.g. caused by object in the water and resulting in loss of performance
- Lack of lubrication (RI = 7) resulting in blockage and subsequently loss of steering performance

Additionally, the hazard "propulsor out of water" has an RI = 7. This hazard is partly relating to "overload" but also to the ship design/dimensions as well as human element. Ship design/dimension and human element (weather routing) are affecting the probability that a ship meets required weather conditions.

6.3 Hazards identified as covered by current SOLAS

SOLAS regulations 28, 29, 30 of chapter II-1 Part C, and 25 and 26 of chapter V have been reviewed with respect to underlying hazards.

Details of this review are summarised in ***Appendix C*** in this report.

The previous section summarises the outcome of the HazId workshop. In order to provide some justification for current SOLAS regulations, safeguards in SOLAS have been disregarded as far as possible for the ranking of the hazards.

For instance, Reg.II-1/29.1 requires two steering gears (main and auxiliary) arranged so that the failure of one will not affect the other, or, in other terms, arranged as two independent systems. This redundancy requirement is a safeguard making the system resilient against any failure leading to loss of one steering gear. Causes for such failure could be mechanical damage, internal and external overloads, blockage in machinery and power actuating system but also complete loss of one sub-system. Additionally, this safeguard addresses loss of performance due to fire in one of the subsystems or in adjacent compartment.

Without any further specification given in the regulation the more generic hazard categories are used, e.g. "component/system failure". For our example, the related hazard is "component failure" caused by a failure of any component of the steering gear leading to loss of control. In contrast, Reg.II-1/29.2.1 requires sound and reliable construction of any essential, not redundant component of steering gear and rudder stock. Similar to Reg.II-1/29.1, this relates to "component failure" caused by mechanical failure of structural element, e.g. by under-sizing due to incorrect load estimation or overestimation of material resistance.

Hazards identified by the review of relevant SOLAS regulations and referenced circulars address the following:

- **Component/system failure**: component failure can be caused by various incidents like degradation (corrosion, wear and tear, pollution of fluid), defect in electronic component, mechanical failure (due to operational loads (under dimensioned) or accidental loads (overloads)), leakage or rupture in a hydraulic system. A component failure will lead to loss of steering capability if not addressed by the system design. System failure refers to software or electrical sub-system. This category considers also erroneous or unnecessary shutdown by safety devices, e.g. fuse may trip in cases not harmful for the system/component.

- **Erroneous performance (erroneous functionality)**: the system is operating (no component failure) but the output deviates from the design specification, e.g. too low, too high, wrong time or reverse direction. Sources of erroneous performance are, for instance, earth faults, loop failure and software failure.

- **External impact:** All incidents outside the steering system itself belong to external incidents, like fire or flooding of other compartments, failure in ship's electric power supply (blackout) but also environmental impacts like energy surge, waves or cyber-attacks.

- **Delayed regain** of performance after failure (failure condition): component failures may be rectified or compensated by redundancy. However, in order to be effective this needs to be ready for use in due time requiring an easy detection, localisation and isolation of the failure, and activation of redundancy. This includes also delayed detection of malfunction under under-performance.

- **Insufficient performance** (steering system and safety devices): ship manoeuvring is a closed-loop system considering the main subsystems propulsion, steering and the human element. Any under-performance in one of the systems may render the whole system performance insufficient for safe ship operation. For instance, too low steering forces may lead to a situation where the ship cannot be safely operated in the given area. Further, insufficient propulsion performance may lead to increased stopping distance. However, both are mainly relevant when the vessel operates outside of her operational profile.

  SOLAS regulation 28 addresses information on propulsion performance in view of providing emergency manoeuvrability performance, i.e. by stopping or use other means of delivering forces for manoeuvring. Considering the crew as part of the manoeuvring system (part of the control loop), all these requirements are grouped into the category insufficient performance.

6.4 Hazards applied as input for functional requirements

6.4.1 General

Functional requirements should provide the function to mitigate the effect of hazards and related expected performance specifying the effectiveness that needs to be achieved.

The HazId workshop provided a list of hazards relating to the following failure modes: loss of or reduced steering performance caused by operational conditions (e.g. vibration, acceleration), loads encountered during normal operation and extreme weather conditions, external impact (either by sharing subsystems, accidental impacts like fire, object or blackout) and degradation. As already mentioned, most of these hazards and failure modes are already addressed by IMO provisions, however not in the provisions for steering and propulsion.

The SOLAS regulations focus more in general on loss of steering performance/force caused by component failure, external impact, and insufficient performance and delayed regain of performance. The hazards identified in the workshop (see also ***Appendix B***) provide details on the causes for component failure and external impact and are, to a large extent, already covered by SOLAS regulations or by other provisions, e.g. cyber-attack by MSC-FAL.1/Circ.3.

SOLAS implicitly provides availability expectations by specifying the hazards component/system failure and external impact that should not lead to complete loss of performance and in that case, which reduced performance is regarded as sufficient when these hazards occur, i.e. incident scenarios.

Thereafter, complete loss of steering performance should not occur due to;

- Failure in steering control system (component/system failure)
- Failure in actuator system (component/system failure)
- Failure in power actuating system (component/system failure)
- No control system is available
- Normal operational loads

- Overloads (external impact or produced by the system) should not damage the power system
- Degradation in power actuating system
- Operational loads
- Single failure in power supply
- Incidents in other onboard systems
- and for passenger ships; fire in or flooding of one of the compartments used for the steering system should not render the steering system inoperable

The propulsion (means of going astern) should provide an additional safety barrier in case of loss of steering capability or situation were the steering performance is not sufficient to avoid an accident.

To avoid complete loss of steering performance a mixture of reliability and redundancy requirements are provided by SOLAS. For redundancy the hazard of delayed regain is addressed by SOLAS.

Non-mandatory instruments (e.g. MSC.137(76), (4)) characterise minimum performance for the vessel, thereafter that the performance of the system vessel-steering (manoeuvrability) is not adequate, if;

- Inherent dynamic stability is insufficient
- Excessive oscillation of rudder required to keep predetermined course
- Steering force is not effective in transient manoeuvres
- Turning diameter is too large
- Stopping length is too large

6.4.2 Summary of identified hazards

A list of hazards that need to be addressed has been established based on the hazards identified in the incident review, the gap analysis summarized in Section 5.2 in this report, the HazId workshop as well as the SOLAS review. The list of hazards has been updated and expanded during the project to consider comments and additional findings, for instance hazards identified during the verification of conformity (described in Section 9).

The hazards that need to be addressed by the functional requirements are:

1. Insufficient performance of going astern
2. Insufficient performance of steering system for normal ship service
    a. Steering effort too high (dynamic unstable, difficult to keep course)
    b. Ship cannot be effectively controlled by steering system
    c. Ship cannot be operated efficiently (by helmsman)
3. Insufficient performance of steering system after failure in steering control and steering actuating system for reduced ship service

4. Component failure in control system leading to failure of control system, e.g. malfunctioning of any electrical or electronic component, software failure
5. Component failure in actuator system leading to failure of actuating system, e.g. malfunctioning of any electrical or electronic component, software failure, failure of mechanical/hydraulic component
6. Component failure in power system leading to failure of power system, e.g. malfunctioning of any electrical or electronic component, software failure, failure of mechanical/hydraulic component
7. Component failure caused by operational loads, e.g. mechanical component in steering force unit
8. Component failure caused by ageing/degradation
9. Erroneous performance of control system
10. Erroneous performance of actuator system
11. External impact on steering system by fire, water ingress, other onboard system (network, EMI), overloads, loss of power supply and mechanical impact
12. Delayed regain of steering performance after failure
    a. in control system or actuating system
    b. of power supply
13. Erroneous operation - Human element (human error)

6.4.3 Failure modes defined by hazards

Based on the previously identified hazards, the failure modes assigned to the systems under consideration are as follows:

- Propulsion:
    - Thrust inadequate to stop
        - Weather condition
        - Propulsion and vessel not harmonised
    - Thrust available too late to stop
        - Reversing process too slow
        - Human error
    - Malfunction of propulsion
        - Loss of propulsion
        - Not operating according to intended functionality
- Steering
    - Malfunction of steering
        - Loss of steering capability

            - Loss of steering control output due to failure in control system
            - Loss of output of actuating system (no input at steering force unit)
            - Steering force unit does not deliver output when other subsystems operate correctly
            - Steering actuating system and steering force unit damaged by operational loads
        - Not operating according to intended functionality
            - Erroneous steering control system output
            - Erroneous actuating system output
            - Steering force not controlled
    - Steering system functionality/performance inadequate for vessel operation
        - Ship's turning speed too low
        - Ship's turning diameter too large
        - Insufficient inherent dynamic stability
        - Excessive oscillation of rudder required to keep predetermined course
        - Steering force is not effective in transient manoeuvres
    - Steering system not used corresponding to performance
        - Helmsman has problems to operate steering system (human interface, inadequate consideration of human element in "control loop")
    - Steering system not available/low performance due to failure or external impacts
        - Failure of electric power/loss of electrical power supply
        - Reduced electrical power supply
        - Fire

Furthermore, current SOLAS regulations require redundancy for selected sub-systems as a safeguard for which the following failure modes are considered;

- Steering
    - Redundancy is not operating
    - Redundancy cannot be used because being blocked by initial failure
    - Redundancy not timely available
    - Redundant steering functionality/performance inadequate for vessel
        - Ship's turning speed too low
        - Ship's turning diameter too large
        - Steering force is not effective in transient manoeuvres

Appendix D in this report lists failure modes and related hazards for steering, propulsion and redundancy.

6.5 Reduced service

In this report, it is differentiated between performance in normal service and performance in reduced service. Normal service applies for an intact steering system, while reduced service applies for a steering system after an incident where the system delivers limited performance compared to normal service (reference is also made to definitions in Section 3).

6.5.1 Failures to be considered as leading to reduced service

Reviewing hazards, safeguards and failure modes as described in ***Appendices B***, ***C*** and ***D*** in this report, it is concluded that the following failures shall be considered as resulting in reduced service (section 6.5.2 provides justification on those failures not considered):

Control system:

- Failure of power supply
- Component/sensor failure
- Loop failure (short circuit, broken connection and earth faults)
- Data communication error
- Programmable system failures (hardware and software failure)

Actuation system

- Failure of power unit
- Failure in power supply (cabling)
- Failure of hydraulic system: leakage and malfunction of valves
- Failure of actuator – (Applicable for tankers, chemical tankers and gas carriers above 10 000 GT)

For trial testing and mapping of ship characteristics, the worst-case single failure should be considered. What is considered worst-case may depend on the steering system arrangement and which trial is performed. As a pragmatic approach, it is proposed to apply the following assumptions for steering in reduced service:

- For ships provided with a single steering system, the trials for reduced service may be performed with one power unit out of operation.
- For ships provided with multiple propulsion lines and/or steering systems, the trials for reduced service shall be performed with one steering system out of operation. It is suggested that the turning test to port side shall be performed with starboard system inoperative, and vice versa.

Similarly, it is proposed to apply the following assumptions for the stopping test in reduced service:

- The stopping test in reduced service is only applicable to ships provided with multiple propulsion lines and/or multiple steering systems and it shall be performed with one propulsion system and its corresponding steering system out of operation.

6.5.2 Failures not to be considered as leading to reduced service

Mechanical damage to the actuation system or to steering force unit is likely to result in loss of function.

Arranging for redundancy and speedily regaining of function may be difficult, and such failures are therefore considered to be beyond a reduced service. Such components need to be designed for high reliability.

The following failures are hence not considered for reduced service:

- Blockage/damage on tiller/mechanical transmission
- Blockage/seizure of hydraulic actuator
- Blockage/seizure of electric actuator (in case of mechanical system where el. motor is actuator)
- Blocking of steering force unit

In case of multiple actuators, it should be possible to mechanically disconnect a malfunctioning actuator. However, such action is to be considered as a repair and no time limit should be specified.

6.5.3 Discontinued use of terms main and auxiliary steering gear

The current regulations are using the terms main- and auxiliary steering gear and requirements for each of them are stated; in particular, for every tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and for every other ship of less than 70,000 gross tonnage. In the goal-based approach, the focus is on the ship performance and the steering system’s ability to maintain or regain steering capability. The terms main- and auxiliary steering are therefore recommended discontinued. The continuation is addressing requirements for system redundancy, ability to handle failure and the performance in normal and reduced service.

Nevertheless, in order to maintain an equivalent safety level as in current regulations, every tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and every other ship of less than 70,000 gross tonnage may comply with reduced acceptance criteria.

7 DEVELOPMENT OF GOALS AND FUNCTIONAL REQUIREMENTS

This Section describes the development of goals and functional requirements for steering and manoeuvrability, including the means of going astern.

The goals and functional requirements have been established using the *Generic Guidelines for Developing Goal-Based Standards* as defined in MSC.1/Circ.1394/Rev.2, (5). According to these guidelines, goal-based standards (GBS) are *high-level standards and procedures that are to be met through regulations, rules and standards for ships*.

A GBS is comprised of at least one goal, functional requirements associated with that goal, and verification of conformity, checking that rules/regulations meet the functional requirements including goals. The verification of conformity is described in Section 9.

7.1 General on Goal-Based Standards

The intention of the IMO goal-based standards is to provide broad and clear, as well as technology-independent goals and functional requirements that do not open to differing interpretations.

The *Generic Guidelines for Developing Goal-Based Standards*, (5), contain some examples for goals and functional requirements and their relation, see Figure 7-1.

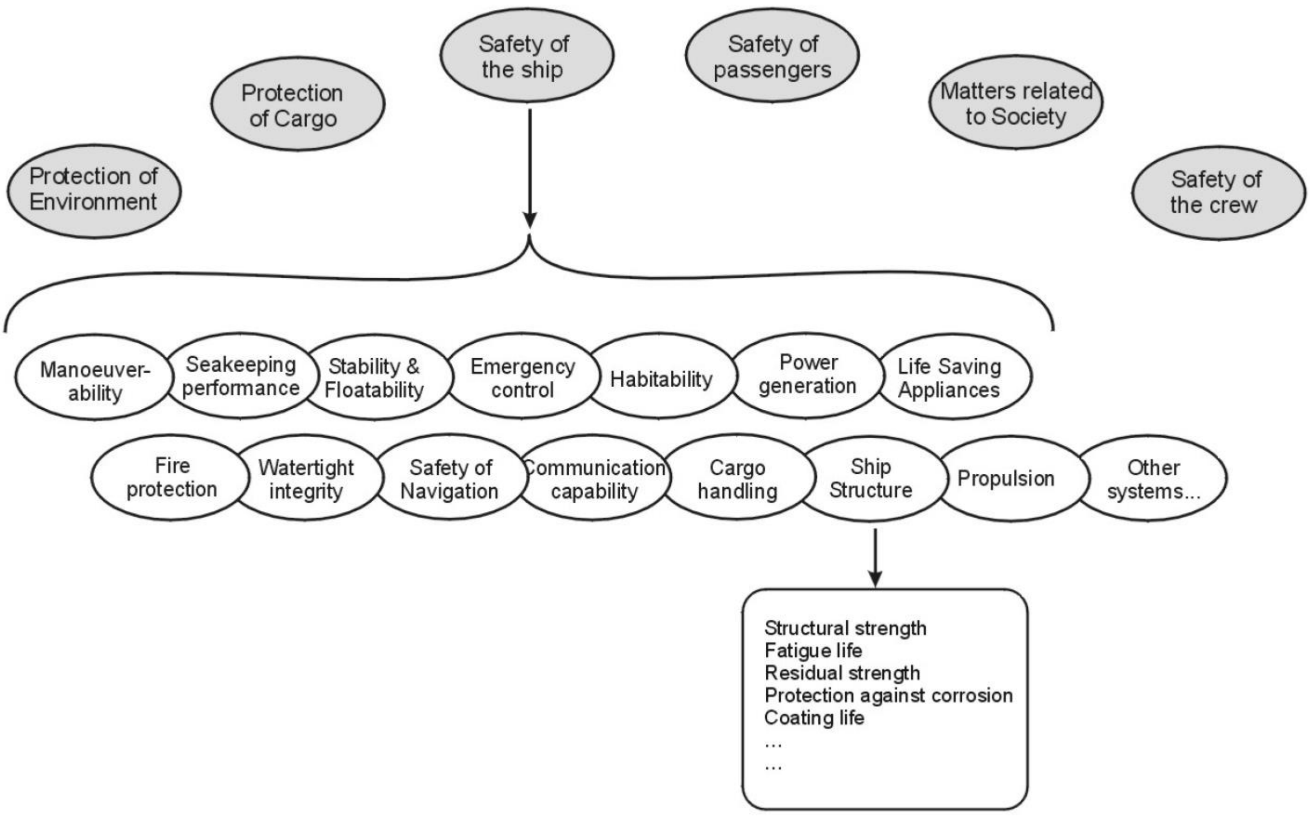

Figure 7-1 Simplified example of goal-based functional requirements for ship structure (from the Guidelines)

According to the guidelines in (5), goals are high level objectives to be met. A goal should address the issue(s) of concern and reflect the required level of safety.

Issues of concern are the potential marine casualty events for a ship. Marine casualties (MSC.255(84), 2008) are events, or a sequence of events, that result in death of or serious injury to a person (including all incidents leading to this), material damage to a ship, collision, grounding or disabling of ship, material damage to marine infrastructure and severe damage to environment. Today, marine casualties are distinguished by the following categories; collision, contact, fire and explosion, flooding/foundering, grounding and hull damage and machinery failure (see for instance FSAs on cruise ships, (6), and RoPax, (7)).

Goals may be developed based on a hazard identification to identify the relevant safety concerns. Generally, the top goal specifies the "why", i.e. why these requirements are developed. This may be further refined to sub-goals/individual goals by asking "how", i.e. which sub-goals are relevant for achieving the top goal. Goals are not expressed in terms of technological solutions, but in terms of functional objectives.

According to the Guidelines, (5), functional requirements should provide the function to mitigate the effect of hazards (functional behaviour in accordance with its safety goals) and related expected performance specifying the effectiveness that needs to be achieved, i.e. the condition or capability (performance like fault avoidance, tolerance, detection and control) necessary for reaching the goal. In order to focus the development of functional requirements, the hazards should be identified and ranked, and the hazards triggering the risk should be selected. Likewise, goals and functional requirements are not expressed in terms of technological solutions, but in terms of the general functionality to be achieved.

In addition, it should be noted that, in contrast to function-based design, functional requirements should provide the basis for IMO provisions as expressed by the phrase "Rules for Rules". This implies that the functional requirements provide the basis for regulations.

7.2 Steering system

A general description of the steering system is given to improve the readability of the following sections.

The ship's steering system is intended to provide dynamic control of slowly varying angular accelerations of a vessel, i.e. travelling from A to B on a given course and allowing course alteration. The performance and reliability/availability of propulsion and steering are essential and provide the basis for economic and safe ship operation.

For a description of the various steering system reference is made to Section 5.1.

Any failure in the steering system leading to complete loss of steering performance or rendering the performance insufficient under given conditions has the potential to cause collision, contact or grounding accidents and in the worst case capsizing or foundering. Thus, the ship's safety requires adequate and reliable manoeuvrability, i.e. propulsion for longitudinal acceleration and steering for angular acceleration.

It is worth to note that two different ways of generating the steering force (value) can be distinguished; a) passive systems using the fluid flow (force relates to fluid velocity and angle of rudder), and b) active systems producing a steering thrust (the propulsion force is applied in a varying direction).

Steering requires propulsion to generate the forces required to dynamically control the vessel. Steering ability and performance concern both the steering and propulsion systems because ships with powerful propulsion may have a smaller rudder, whereas ships with weaker propulsion may compensate for this with larger or more effective steering devices.

Additionally, the propulsion can also provide a barrier to mitigate the consequences of steering malfunctions, e.g. by stopping the vessel before further escalation, or widen the options for safe navigation, e.g. stopping instead of altering the course.

7.3 Developing a Goal-Based Standard for steering and manouvrability

The goals and functional requirements formulated in this project are addressing the steering and manoeuvrability capabilities for ships – including the means of going astern. They were developed on basis of the following:

- hazards identified in the HazId workshop (described in Section 6)
- gaps and inconsistencies in current regulatory framework (summarized in Section 5.2)
- hazards identified by investigating current IMO instruments (also in Section 6).

The process to obtain the first version of the goals and functional requirements was structured in three steps:

- Draft goals and functional requirements on the above referred basis and considering DNV experiences and results of developing function-based rules;
- Review and update the draft by interviewing experienced DNV approval engineers and experts engaged in legislative work on propulsion/manoeuvring.
- Discussion of hazards and draft goals and functional requirements with manufacturers and operators (inc. workshop with external experts).

The initial output of the development of functional requirements is presented in ***Appendix E***, containing both the functional requirements and the related hazards.

This first output was further updated with the results from Section 8, dealing with those aspects requiring further investigation: the performance, documentation and redundancy requirements for steering in normal and failure mode. Furthermore, the resulting functional requirements were compared with current IMO provisions in order to verify if current regulations together with Circulars and Unified Interpretations meet the functional requirements. This process is called the Verification of conformity, shown in the Goal-based standard framework in Figure 7-2. The development of functional requirements is an iterative process, as the output from the verification of conformity may result in updated functional requirements.

The functional requirements developed were thereafter refined and, according to the above, updated based on the verification of conformity. The verification of conformity is described in Section 9, and ***Appendix F*** provides the details of the verification.

The final functional requirements, resulting from the verification of conformity, are presented in ***Appendix G***.

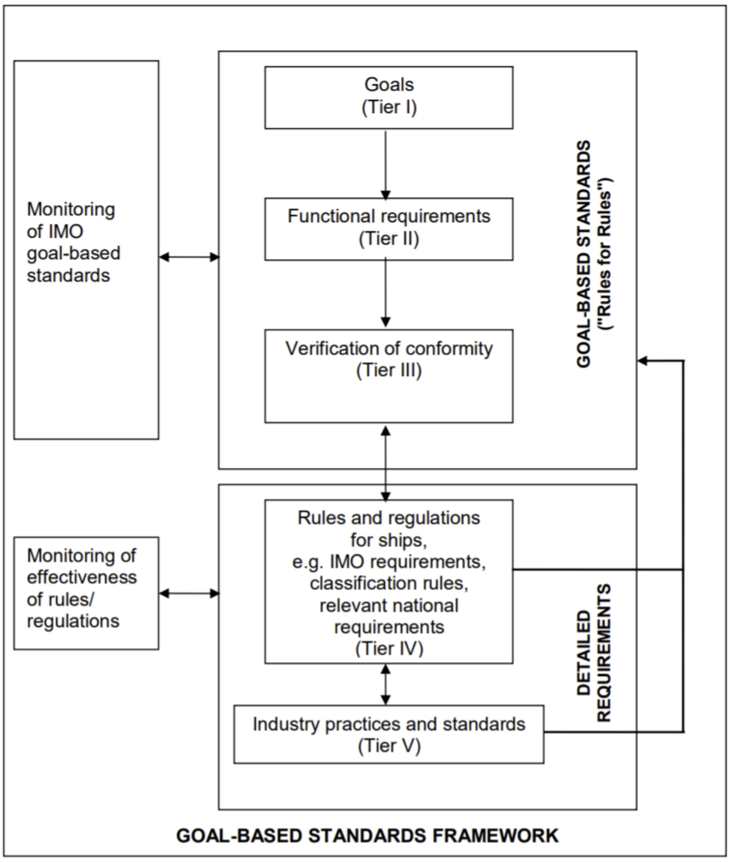

Figure 7-2 Goal-based standard framework, from the IMO Guidelines for GBS, (5)

7.3.1 Workshop with external experts

A workshop with external experts has been organized to receive feedback from the industry on the goals and functional requirements.

The workshop was organized in March 2020.

The external group of experts consisted of:

- Color Line
- Kongsberg Maritime
- Norwegian Maritime Authority (NMA) – *not able to attend the workshop*
- Norwegian University of Science and Technology – Department of Marine Technology – *not able to attend the workshop*

EMSA also participated at the workshop.

A draft document with the addressed hazards, goals and functional requirements was circulated before the workshop.

7.3.2 Goals

As previously mentioned, goals are high level objectives to be met, and should address the issue(s) of concern and reflect the required level of safety, (5).

Manoeuvrability of a ship, and thus steering and propulsion, is crucial for the safety of human, environmental safety and safety of property. The root cause for collision, contact and grounding is not necessarily a failure in the steering system. Most of these ship accidents have other root causes like human error (wrong consideration of performance and weather condition) or failures in other ship systems (blackout, loss of propulsion). Loss of steering may not lead directly to an accident, but it may for instance lead to excessive ship motions due to loss of capability to keep a weathervane heading.

Consequences of steering system failure or under-performance depend on the operational area as well as the ship type. A failure in areas where navigation demands special caution has a much higher potential for causing an accident than an incident in open sea with lower traffic density and larger distance to the coast. Similarly, the consequences, in terms of possible loss of lives, are higher for a large cruise ship than for a small general cargo ship.

It should be noted that propulsion can help to mitigate consequences of steering failure, e.g. by stopping the vessel and remain in a position until the issue is rectified. The main concerns regarding loss or insufficient performance of the steering system, and for propulsion in context of stopping the ship are:

- Injuries or fatality due to high motion or acceleration,
- Accidents of the vessel such as collision, contact or grounding which may result in breach of watertight integrity or hull failure or total loss of vessel; and,
- Loss of stability due to ship motion (e.g. cargo shift).

A top goal for steering is defined, and to support the top goal, four individual goals, specifying *how* the top goal is achieved, are developed. Additionally, a top goal and two individual goals for propulsion are defined.

In the following, the top goals and individual goals for steering and propulsion are presented.

Top Goals for steering and propulsion

Malfunctioning, insufficient performance, as well as incorrect use of steering lead to loss or reduced control of the ship and have the potential for a casualty event. Accordingly, the top safety related goal for steering is to:

Prevent casualties arising from malfunctioning, insufficient performance or incorrect use of steering.

And the propulsion related goal is to:

Prevent casualties arising from malfunctioning or insufficient performance of propulsion to control the vessel.

In this context the term *malfunctioning* means:

- The steering system is not providing any output (any steering force; is not operating).
- The steering system provides an output but at a level which deviates from the design intention, e.g. output too low/high, at the wrong time or reversed.

And *insufficient performance* of the system means that the system is in normal service but:

- Steering forces are not sufficient to operate the vessel under given conditions (e.g. operational area, wind, waves, current);
- The steering control loop is not adequate to safely operate the vessel which means that the interaction between vessel, steering system and setting (human element) has insufficient performance (addresses the complete control loop consisting of settings to steering system – ship dynamics - "target comparison"), and
- The propulsion is not sufficient to compensate for navigational incidents.

In other words, safe ship operation requires a high availability of sufficient steering performance.

Individual goals for steering and propulsion

The individual goals specify "how" the top goals should be achieved. For steering, the following individual goals are defined;

- *The steering performance is sufficient to secure proper control of the vessel*
- *Maintain steering performance*
- *Limit effect of erroneous functionality*
- *Limit incorrect use*

Likewise, to support the top goal for propulsion, the following individual propulsion goals are defined;

- *The propulsion performance is sufficient to stop the vessel*
- *Limit incorrect use*

The individual goal "maintain steering performance" considers the aspects of

- Reliability of components to minimise probability of component failure
- Fault tolerance, i.e. the steering system is arranged to prevent loss of steering capability due to component or sub-system failure
- Protection of the system to minimise probability of losing steering capability due to incidents externally of steering system
- Monitoring functionality to allow for timely counter measures

Figure 7-3 shows the top goal for steering and propulsion, as well as the individual goals.

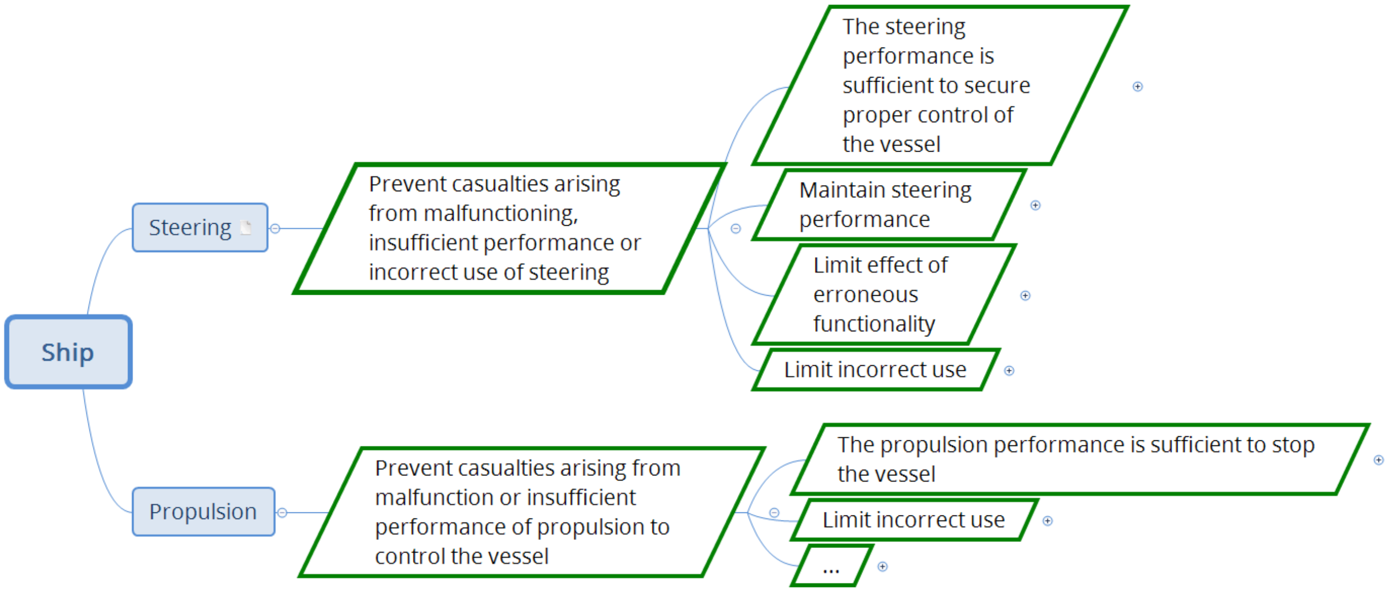

Figure 7-3 Structure of the top goals and individual goals for steering and propulsion

7.3.3 Functional requirements

Functional requirements should mitigate the effect of hazards and provide the criteria that need to be satisfied to meet the goal. A functional requirement consists of a function and expected performance, (5).

The functional requirements are presented in two steps a) the functions and b) related expected performances. The functional requirements have been developed based on the hazards and failure modes summarised in Section 6.4.

The initially developed functional requirements, and their related hazards, can be found in table format in ***Appendix E***.

The goal of the requirements for steering is to prevent casualties caused by malfunction, insufficient performance and incorrect use. The objectives of the functional requirements are hence;

- that the steering system on board of a ship is resilient with respect to component failure (component failure will not cause complete loss of functionality)
- that the components have a marginal likelihood of malfunction, and
- that the operating characteristics enable safe ship operation.

Thereafter, the functions for steering need to focus on malfunction (loss or erroneous functionality), insufficient functionality and erroneous operation.

Functions

Addressing the hazards presented in Section 6.4.2, the following functions have been established;

- Function I: The steering system provides adequate steering performance for ship operation

- Function II: The steering capability is maintained or can be regained in case of malfunction in either the steering control or steering actuating sub-systems or both together
- Function III: The steering system is designed adequately for operational loads
- Function IV: The steering system is protected from external impacts
- Function V: The steering system is arranged to minimize impact of erroneous functionality
- Function VI: The steering system is arranged to minimize impact of erroneous operation
- Function VII: Proper ship operation is enabled by providing information about ship's manoeuvring characteristics
- Function VIII: The propulsion system provides adequate astern propulsion performance for ship operation
- Function IX: Proper ship operation is enabled by providing information about ship's stopping characteristics

These functions address the following:

- Function I: system performance and operating characteristics are adequate for safe operation of the ship by minimising the hazards of increased steering effort and complex/sophisticated control of the vessel;
- Function II: high availability of steering performance by minimising the hazard of component failure (consequences);
- Function III: high reliability by minimising the hazard of component failure due to erroneous determination of operational loads;
- Function IV: high reliability by minimising the hazard of system failure due to external impacts, i.e. impacts resulting from normal operation of other systems or incidents and aims on the protection by spatial and systemic separation;
- Function V: minimising the effect (consequences) of the hazard erroneous functionality;
- Function VI: minimising the effect of human error;
- Function VII: minimising the likelihood of human error;
- Function VIII: relates to hazards relating to low performance of changing the direction of thrust in order to prevent casualties when the steering performance is not sufficient (due to the situation) or there is no steering capability.
- Function IX: minimising the likelihood of human error

A schematic overview of top goals, individual goals and functions is shown in Figure 7-4.

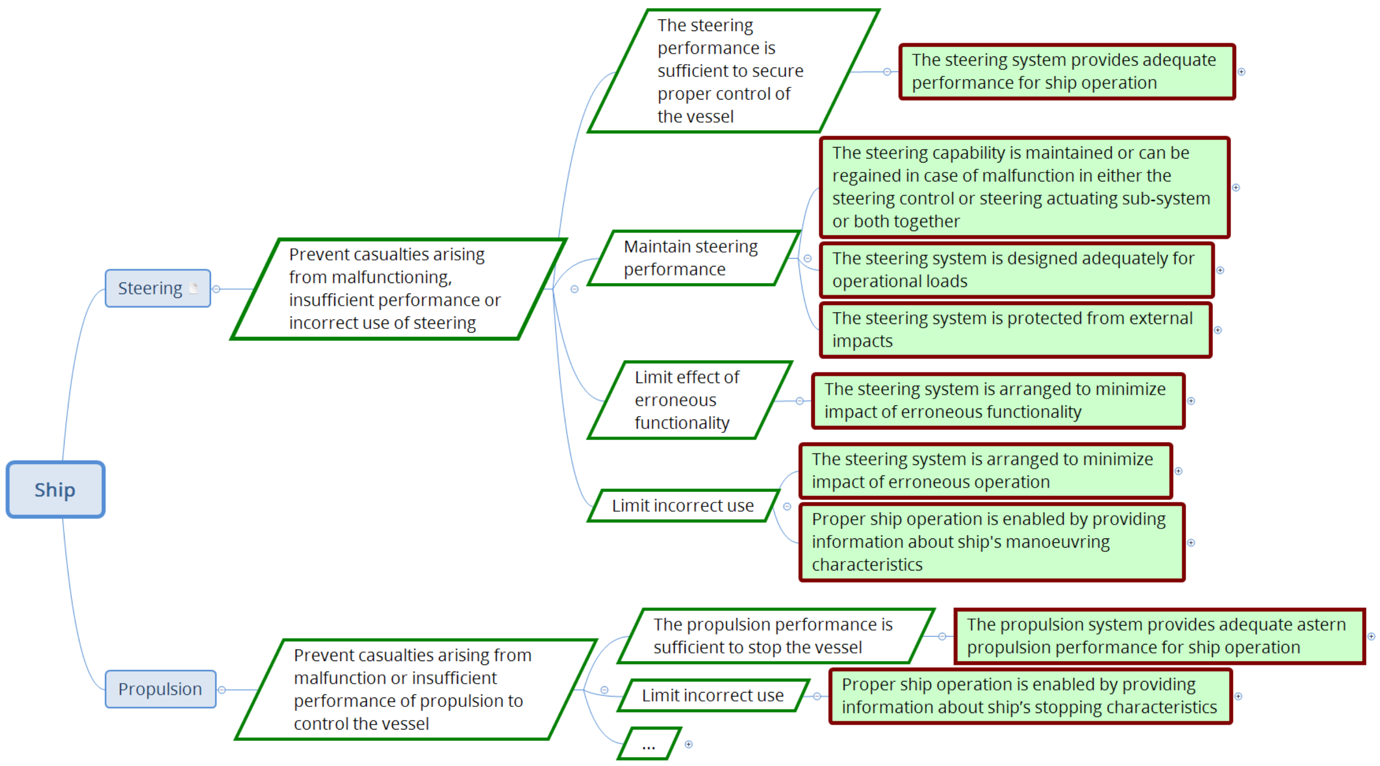

Figure 7-4 Relation between goals, sub-goals (green bounded parallelogram) and functions (red bounded box).

Expected performance

The functions presented above are amended by expected performance to provide the criterion for verification of compliance.

The expected performances need to be achieved by a steering system integrated in the ship and considering the operating and environmental conditions throughout the period that the ship is assumed to operate.

The expected performance does not necessarily make the vessel fit for purpose but ensures a certain minimum performance and hence also safety level for the steering function.

The expected performances formulated for steering and propulsion address the following:

- performance in normal and failure mode
- the resilience of the system
- the design considering uncertainty and degradation
- protection against impacts
- erroneous functionality
- operation and the basis for adequate operation

Section 8 presents and outlines the expected performance related to steering performance in normal and failure mode, documentation requirements and redundancy requirements.

As previously referred, the initial set of functional requirements is presented in ***Appendix E***. They were further updated with the results from Section 8 and, finally, the resulting functional requirements were thereafter refined based on the verification of conformity (Section 9). The final functional requirements are presented in ***Appendix G***.

8 STEERING PERFORMANCE, DOCUMENTATION OF PERFORMANCE AND REDUNDANCY

As briefly introduced in Section 7.3.3, this section gives a more detailed description and overview of the most innovative aspects of the project: the expected performance related to steering and propulsion performance (in terms of stopping) in normal and failure mode, documentation of performance and redundancy. This section could have been considered as included in Section 7 but, for the sake of clarity, it was structured as a separate section.

After an introduction in 8.1, the ship's steering performance is discussed by bringing in different perspectives, as well as performance parameters in current regulations, in Sections 8.2, 8.3, 8.4 and 8.5.

The important performance parameters for steering and propulsion are then selected. These are further outlined and discussed in Sections 8.6 and 8.7, and summarized here to give an overview;

- Course-keeping ability
- Turning ability
- Stopping ability
- Steering gear strength and steering angle speed

Thereafter, the requirements to documentation are described in Section 8.8.

Eventually, redundancy requirements are treated in Section 8.9.

The expected performance related to steering and propulsion performance can be found in ***Appendix G*** under Function I and Function VIII.

The expected performance related to documentation of performance can be found in ***Appendix G*** under Function VII and IX*.*

The expected performance related to redundancy can be found in ***Appendix G*** under Function II*.*

8.1 General on ship steering performance

Ships are designed to resolve a large variety of transportation needs. In the following, vessels and operation covered by SOLAS (loosely speaking; passenger and cargo ships in international operation) are considered.

In the current SOLAS regulations, the main factors affecting the required safety level for a particular ship with respect to steering are the ship size and cargo carried.

Another important aspect when designing the steering system is the area of operation. In general, ships on international voyage are designed for unrestricted operation with respect to environment. When determining the required ship strength, requirements are set to what kind of environment the ship shall be able to withstand. It seems reasonable to require the vessel to be manoeuvrable in the same environmental conditions.

In practical vessel design, berthing frequency can also significantly affect the design of the steering system. However, this is mostly relevant to the performance in port/harbour areas and is not considered to be part of the scope herein.

In the following, the ship steering performance is discussed from the operator's, designer's and legislative perspective.

8.2 Performance from the operator's perspective

A vessel operator will typically expect the vessel to be manoeuvrable in any permissible weather (except cyclones and tornados). This includes both the ability to follow a straight course and execute course changes in a reasonable time.

For vessels with a traditional steering system the operators often refer to steering speed, meaning the minimum forward speed they need to steer the vessel in the prevailing conditions. The steering speed is important because it affects the speed of flow over the rudder and hence the steering force that can be generated by the rudder. For typical traditional steering systems, it is therefore equally important to have sufficient forward speed as well as high performance of the steering system. This is reflected in e.g. MARPOL annex VI, Chapter 4, Regulation 21 where it is required that "For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization". Current guidelines for such are found in MEPC.1/Circ.850/Rev.2 and cover bulk carriers and tankers.

The incident databases investigated in connection with this project do not indicate insufficient performance of a fully functional steering system to be a common cause for incidents. More common causes are malfunction and external impacts. Hence, improved manoeuvring performance is not found to be necessary to ensure safe operation.

Furthermore, it is accepted by operators that different vessels behave differently. In operation, the variation in steering performance is handled by the operator when planning the manoeuvres to be performed. In this regard, it is considered to be of outmost importance that the operator knows the capabilities of the vessel's steering system. It is therefore suggested to focus on making the vessel's manoeuvring data available to the operator rather than tightening the performance requirements.

8.3 Performance from the designer's perspective

When designing a vessel, safety is not the only concern. The performance with respect to the transport task to be solved and the cost of the vessel are also important.

The performance of a vessel is a key parameter for a designer. However, the performance of a vessel other than from a safety perspective is not the scope of SOLAS and hence not further discussed.

Cost is an important competitive measure when designing a steering system and an important factor when regulations set the appropriate safety level. The cost of parts, operation, possible reduction of payload and documentation requirements all contribute to the cost of a steering system.

The most obvious cost associated with the steering system is the physical parts. This includes power supply, bridge console, control system, power unit, actuator and the steering force unit. It is obvious that increased requirements to redundancy and hence duplication of functions increase the cost. It is therefore important that the rules are formulated in an unambiguous way in this respect to ensure fair competition.

A cost to be considered when designing the steering system that is not so obvious, is the trade-off between payload capacity and steering performance. E.g. in some trades the vessel is limited by length restrictions. The length of the cargo area will then be dependent of the length of the rudder. Hence, installing a larger rudder to improve steering will reduce the length (and displacement) available for payload.

Documentation of manoeuvring characteristics can be a significant cost depending on the requirements set to steering. If manoeuvring requirements are defined at vessel level in all foreseeable weather and loading conditions, the cost of documenting this with good certainty will be huge. On the other hand, if simpler methods are used, the cost will be lower, but the uncertainty larger, making it difficult to verify and compare such calculations. The simple methods may be particularly problematic in a competitive situation. As the uncertainty is large it is very difficult to conclude that a calculation is not correct. This could lead the way for creative solutions to produce the most favourable calculation. Due to the uncertainty, it will be very difficult for a verifier to disapprove such a calculation. One possible solution to this could be to develop a prescriptive simplified method which everyone has to use. However, it will then be difficult to adapt new technologies and agree on general performance differences between different technologies (e.g. regular vs. high lift rudder).

It should be noted that the cost of providing documentation is approximately the same for rule compliance and operator guidance. However, for the purpose of operator guidance, uncertainties in simplified predictions will not have large cost consequences in terms of steering solution selected. In real life the vessel will be affected by environmental conditions. Predictions are therefore merely an indication, and the operator should always consider it as such. This means that the operator anyway will need to account for some uncertainty in the predictions and the simplified methods should provide sufficient accuracy for operator guidance.

8.4 Performance from the legislative perspective

For flag states and class societies verifying compliance with SOLAS, the requirements and the enforcement should be unambiguous to ensure minimum performance and fair competition. Applying simplified methods with large uncertainties will both make it difficult to assess if the criteria in the rules are satisfied and to ensure fair competitions among designers, yards, vendors and regulators.

8.5 Performance parameters in current regulations

The current regulations, with respect to steering, focus on two main parameters:

1. Availability, in terms of redundancy/ strength requirements
2. Speed of steering force change, in terms of minimum rudder rate

Redundancy requirements ensure that the steering system has a high availability. Examples of such requirements are main and auxiliary steering gear and two independent control systems.

The requirements on speed of steering force change originates from the desire from the operator to be able to change the steering force quickly. Experience indicate that the values in today’s rules are reasonable.

There are currently no requirements on the steering force to be achieved. The requirement of being able to turn the rudder to ±35 degrees is believed to originate from the need to test the strength of the steering system. Generally, it is perceived that the load on the rudder is maximum at 35 degrees and hence this requirement. It could be argued; why test 35 degrees if the rudder only can turn 20 degrees? Should not the maximum load then be at 20 degrees? This is indeed correct assuming the vessel is doing a turning circle (as required at sea trial). However, in real operation, the inflow to the rudder will be different and inflow angles to the rudder corresponding to 35 degrees rudder angle will certainly be achieved. One example of a manoeuvre causing this is to give counter rudder during a turn. Due to the yaw rate and drift of the vessel a rudder angle of attack corresponding to 35 degrees steering in a turning circle can easily be achieved.

8.6 Discussion on manoeuvring performance

Proving vessel manoeuvring performance per Function I - Provide steering performance adequate for ship operation – with high accuracy, is a challenging and costly task. Currently only full-scale tests or CFD simulations are able to predict the performance with high accuracy. However, the cost of such tests and simulations is currently exceeding what is regarded as acceptable by designers, yards and owners. The cost is first of all driven by the large number of combinations of environmental and vessel conditions that would have to be tested to ensure the performance in any weather or operating condition. Some examples of parameters to be considered are wind speed, wind direction, wind spectrum, wave height, wave period wave direction, wave spectrum, wave spreading, water depth, draft, trim, vertical centre of gravity and speed of the vessel.

A common legislative approach to such a problem is to define one or more combinations to be investigated and assume that decent performance in these selected combinations yields a reasonable performance in other combinations not tested. The current practice for steering and manoeuvring is per MSC.137(76) to evaluate/ test performance in calm water (although not mandatory) and assume that a certain performance in this condition will give sufficient performance also in harsh/ extreme weather.

Further, requirements to the steering performance can be formulated either on vessel level or steering system level. At vessel level, the requirement could e.g. be to be able to perform a turning circle within the recommendation by MSC.137(76). On a steering system level, the requirement could be to change the steering force angle with a certain speed.

The easiest update of the current regulations to account for non-conventional steering systems would be to refer to steering force instead of rudder angle and update the requirements accordingly.

Another option could be to include requirements also to steering and manoeuvring on ship level. This could e.g. be done by making MSC.137(76) mandatory and enforce the recommended performance parameters as requirements. The big advantage of this will be that the steering/ manoeuvring requirements are put on ship level which then will be fully technology neutral and reflect the behaviour experienced by the operator. There are however some arguments for not doing this, at least in full:

- The consequences of enforcing MSC.137(76) criteria are uncertain both with respect to them being appropriate limits for various vessel types as well as possible negative consequences due to possible design changes; e.g. increased fuel consumption due to e.g. hull form, increased rudder size or reduced deadweight.
- Certain vessel types are not meeting MSC.137(76) today. Typically, full block vessels ($C_b>0.7$) with a low length to breadth ratio ($L/B<6$) tend to have poor directional stability

and hence difficulties with satisfying the zig-zag test criteria (8). A search in the IHS Fairplay database (9) reveals that about 40% of the relevant vessels listed with length, breadth, draught and displacement data fall into this group.

- From a risk perspective, it is counter intuitive that MSC.137(76) allows for worse steering performance for larger vessels representing a larger risk.
- Enforcing MSC.137(76) as a minimum limit might result in all vessels being designed to this minimum rather than more reasonable traditional performance determined by intended operation.
- The manoeuvring behaviour of different vessels differs quite significantly. Seafarers are aware of this and adjust operation accordingly.
- From the incident databases consulted in the STEERSAFE project, it is not observed any evidence indicating that poor performance per MSC.137(76) is a cause of accidents.
- Enforcing MSC.137(76) without modifications will result in an uneven playing field. Tests are to be performed at scantling draft. For some vessels this is not achievable at sea trial and tests are performed at ballast draft. Extrapolating from ballast to scantling draft represents a significant uncertainty (assuming a cost-efficient method). Uncertainty is large as the manoeuvring performance can be significantly different.

It is considered most important that the bridge officers know the behaviour of the vessel. This has repeatedly been highlighted in conversations with vessel operators. It is therefore recommended to require documentation per MSC.137(76) as operator guidance, possibly with a clear statement to inform the captain if any criteria are not met.

Based on this it is considered more important to increase the requirement for documentation of predicted performance rather than increasing the performance requirements. This being said, it is still, from a safety perspective, suggested to require that the vessel can prove a certain minimum manoeuvring performance with respect to course keeping, turning and stopping. The zig-zag test is also a relevant manoeuvring test, but it is found to be less related to safety and more related to practical navigation of the vessel.

8.7 Suggested updates for steering performance parameters and requirements

In the following, the recommended steering performance parameters and requirements, as well as the performance after failure, are presented and described.

As introduced in section 6.5, the steering performance distinguishes two operational conditions, a) *normal service* for intended undisturbed ship operation, and b) *reduced service* for ship operation after malfunctioning of steering system. There are many failures that can lead to a reduced condition. In order to simplify testing and enforcement, it is suggested to consider the following as the reduced service to be documented:

- For ships with a single steering system: failure of one power unit
- For ships with multiple propulsion lines and/or steering systems: one steering system out of operation

Similarly, it is proposed to apply the following assumptions for the stopping performance when the propulsion system is in reduced service: It is only applicable to ships provided with multiple propulsion lines and/or multiple steering systems and it shall be performed with one propulsion system and its corresponding steering system out of operation

With the introduction of goal-based regulations, where the performance requirements are on ship level, it is no longer reasonable to use the term auxiliary steering gear. This is because it is not up to the regulations to decide how the performance is achieved. Nevertheless, in order to keep the reduced performance requirement on auxiliary steering systems on smaller vessels compared to larger vessels, a similar reduction in reduced service performance is proposed.

The current performance requirements only consider the steering system and not the combined interaction of the ship and the steering system. To better align with the goal-based approach, it is found reasonable to introduce performance requirements also at ship level. The suggestion elaborated in the following is to a large extent based on making relevant parts of MSC.137(76) mandatory.

In a goal-based framework the expected performance should be strongly related to the function. However, the cost and uncertainty of predicting the ship manoeuvring performance in any environmental condition are too large to be of practical use. Therefore, a common legislative approach, where the performance in calm conditions implies a certain minimum performance also in harsh conditions, is adopted. It is therefore suggested to evaluate and test the performance in calm water, and to assume that a certain performance will give sufficient performance also in harsh and extreme weather.

8.7.1 Course-keeping

Course keeping is key to ensure a predictable behaviour of the ship both from the operator's perspective and also from the perspective of other seafarers. It is also important to ensure that manoeuvres are executed without large overshoot.

Traditionally, course-keeping has been evaluated by the zig-zag test. However many ships today, particularly those with high block coefficient (Cb>0.7) and low length to breadth ratio (L/B<6), may not satisfy the MSC.137(76) zig-zag test criteria. It is therefore not recommended to enforce these requirements. The zig-zag test is nevertheless considered a relevant test giving key information about the manoeuvring performance of the vessel. It is recommended to perform the test at sea trials and suggested to require documentation of the performance per MSC.137(76).

A straight course is important for the behaviour of the vessel to be predictable to other vessels. It is therefore suggested to test the ship ability to keep a straight course at a preset heading (heading keeping test). With respect to keeping a straight course, it is suggested to allow the use of autopilot. The vessel shall be closed loop straight-course stable with yaw oscillations less than ±2 degrees for 30 minutes. The limitation on yaw angle is taken from Res.A.822(19), (10), which is developed for high speed crafts. However, due to the lack of a similar criterion in Res. 342(IX), which is applicable to all vessels, the 2 degrees yaw angle limit is selected. The duration of 30 minutes is introduced to ensure that the autopilot is tested over sufficiently long time. In Res. 342(IX) it is required to "keep a pre-set course with minimum operation of the vessel's steering gear". The requirement on minimum operation of the vessel's steering gear is believed to originate from the need to reduce wear and tear. This is highly relevant for most steering gears but is not seen as future proof or particularly relevant for cycloidals due to the strong link between propulsion and steering. It is therefore not recommended to include a criterion on maximum oscillations in steering force. It is expected that the suggested requirements are satisfied by most current designs.

8.7.2 Turning ability

Turning ability is important to avoid possible dangerous situations. Experience is that most ships are able to meet the current criteria associated with the turning test. It is therefore suggested to test the ship turning ability by the classical turning circle test performed as per MSC.137(76) and that all vessels shall satisfy the recommended performance in MSC.137(76). A challenge for all tests in this respect will be the requirement of the tests to be conducted at scantling draft. This will be discussed later in Section 10.1.

8.7.3 Stopping ability

Propulsion at large is not considered in this project, only in connection with stopping.

Likewise turning ability, stopping ability is important to avoid possible dangerous situations.

Experience is that most ships are able to meet the current criteria associated with the stopping test. Stopping ability is hence suggested tested by the full astern stopping test in MSC.137(76), and the recommended performance (stopping length) shall be satisfied. The test shall be carried out with a predetermined stopping procedure available to the operator at the bridge.

In case the ship is provided with multiple propulsion lines, the stopping ability shall also be tested in a reduced service. It is proposed to use the same test in reduced service with somewhat reduced performance requirements, which may need further finetuning to reflect the experience gained once these requirements are extensively applied. It is proposed to adopt the max limit of 20 ship lengths stated in current MSC.137(76) as the performance criteria in reduced condition. The reduced condition shall be considered as the least favourable fault in any of the propulsion systems and its corresponding steering system. The approach speed shall consequently be adjusted based on remaining available propulsion.

However, for ships where stopping in normal service is done by turning the propulsion force unit, a failing steering system is assumed to have the most severe consequences on stopping. This is because the ship is potentially sailing at full speed, since the propulsion is working, but the faulty steering line can not be used during the stopping procedure. The test shall hence be performed with approach as in normal service and with the least favourable steering system out of operation. The inoperative steering system will be placed in a neutral position. After the stop order is given, the propulsion line corresponding to the failing steering system should be inoperative.

It is believed that the test for the above-mentioned ships reflects the real operation. It is assumed that on a ship with two thrusters and one faulty steering system, the propulsion system corresponding to the faulty steering system will still be used and steering of the ship done by the other thruster.

A ship with single propeller, driven by two engines, is considered as a single propulsion line.

8.7.4 Steering gear strength and steering angle speed

Two important aspects of the steering system are the steering gear strength and the ability to change steering force direction rapidly. This is necessary to allow for efficient control by operators and autopilots.

Steering speed and steering force have traditionally been tested by requiring the ship to be able to steer the rudder +/-35 degrees (steering force), and from +35 degrees to -30 degrees in 28 seconds (steering speed) (Reg. 29.3.2). The purpose of this criterion is to enforce a certain minimum requirement on the time from full rudder in one direction to hard rudder in the other direction.

Per MSC.137(76) the turning circle test can be performed with “comparative steering angles” for non-conventional steering systems. The reason for this is that the non-conventional steering systems may achieve, at a lower steering angle, a similar steering force as traditional systems. In order to make the requirement for steering speed technology neutral, it is more reasonable to use the turning circle steering angles as reference when comparing the steering speed.

In order to allow for a slow approach of the extreme steering angle (to reduce the possibility of overload) it is suggested to put the requirement not on the full range of steering angles used in the turning test, but adopting a similar approach as of today.

Moreover, in order to make the phrasing technology neutral, it is suggested to replace 30 degrees out of 35 degrees available steering angle with 85% of declared steering angle. The time requirement to cover the range from declared steering angle on one side to 85% of the declared steering angle on the other side is suggested to be 28 seconds, in line with today’s requirement for traditional systems.

The steering system shall also be able to turn the steering force unit both to port and starboard, from declared steering angle on one side to declared steering angle on the other side, with ship running ahead at maximum ahead service speed.

Note that this can be a significant reduction of the requirement to non-conventional steering systems compared to MSC.1/Circ.1416/Rev.1, 29.3.2, but it seems to be more equivalent to the requirements to traditional systems. For systems with declared steering angles of 35 degrees, the criterion in MSC.1/Circ.1416/Rev.1, 29.3.2 is equivalent. However, non-conventional steering systems may have declared steering angles significantly lower than 35 degrees. This means that they achieve a similar steering performance as a traditional system at a much smaller steering angle. For the operator it is the time from full rudder on one side to full rudder on the opposite side that matters and not the steering speed. It is therefore considered to be more technology neutral to require same time between declared steering angles, than the same steering speed. The time required to get from maximum port steering force to 85% of maximum starboard steering force will then be the same, regardless of the type of steering system.

In accordance with the above paragraph, it is hence not recommended to enforce the current interpretation (MSC.1/Circ.1416/Rev.1) for non-conventional steering systems with a required steering speed of 2.3 degrees per second.

If the +/-35 degrees requirement is removed from current regulation 29.3.2 when making it technology neutral, this will with the above proposal implicitly affect the required steering speed also for traditional steering systems as the maximum steering angles used in the steering gear test may be reduced. The purpose of the 35 degrees steering angle is also to test the strength of the steering system. It is therefore suggested to require the declared steering angles to be +/-35 degrees for traditional steering systems.

8.7.5 Performance after failure

As already mentioned at the beginning of this section, it is desirable to maintain some steering capacity also in reduced condition (see assumptions in Section 6.5.1).

For vessels with twin steering-propulsion lines and traditional steering system, the turning and course-keeping performance after losing one steering-propulsion line will significantly depend on the state of the faulty line. If e.g. the rudder is locked in an unfavourable position, the remaining manoeuvring capacity for the vessel can almost vanish. However, it seems unreasonable to require redundancy to such rare events, particularly when there is no redundancy on the steering force unit in a traditional single line system.

In the following paragraphs the performance in reduced condition is outlined for course-keeping, turning ability, steering gear strength and speed. Performance after failure in connection with stopping is treated in Section 8.7.3. Reduced performance requirements may need further finetuning to reflect the experience gained once they are extensively applied.

Course-keeping

In reduced service, it is expected that the vessel is still able to travel on a straight course with normal propulsion service. It is therefore proposed to include this in the testing. The heading-keeping test for reduced service is to be conducted at same draft, trim and forward speed as the normal service condition.

Turning

As for the turning ability after failure, it is suggested to allow for an increase in advance and tactical diameter of approximately 25% compared to requirement in intact condition.

Steering gear strength and steering angle speed

For ships with single steering systems, with redundancy in actuating system (two equal hydraulic pumps, each with 50% capacity), the permissible time to achieve available steering angle is suggested doubled. This is similar to the current practice for larger vessels. The test is to be conducted at the same draft, trim and forward speed as the normal service condition. For smaller ships[4] in reduced service, which in current regulation may be provided with an auxiliary steering gear, it is proposed to keep the current requirements for auxiliary steering systems: to be able to steer from 50% of declared steering angle on one side to 50% of declared steering angle on the other in less than 60 seconds, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater. As indicated above, for all other vessels in reduced service, the same test as in normal service applies with a doubling of the allowed steering time. Reference is also made to Section 6.5.3.

8.7.6 Summary of steering parameters, tests and criteria

The performance parameters discussed in the previous sections, as well as the tests and criteria, are summarized in Table 8-1.

[4] tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage, and every other ship of less than 70,000 gross tonnage

Table 8-1 Steering parameters, tests and criteria.

					Requirement / Criteria	
Performance parameter	**Purpose**	**Test**	**Ship type**	**Test speed[5]**	**Normal service**	**Reduced service**
Course keeping	To ensure predictable behaviour	Heading keeping test	All	At least 90% of the ship's speed corresponding to 85% of the maximum engine output	Yaw deviations less than 2 degrees in 30 minutes	
Turning ability	To avoid dangerous situations	Turning circle test	All, except passenger ship of 70.000 gross tonnage and upwards		Advance ≤4.5L Tactical diameter ≤5L	Advance ≤5.6L Tactical diameter ≤6.25L
			Passenger ship of 70.000 gross tonnage and upwards			Advance ≤4.5L Tactical diameter ≤5L
Stopping ability	To avoid dangerous situations	Full astern stopping test	All		Track reached ≤15L	Track reached ≤20L (Only for ships with multiple propulsion lines/systems)
Changing of force direction	To ensure efficient control	Steering gear test	Passenger ship of 70,000 gross tonnage and upward	Maximum ahead service speed	1. Maximum declared steering angle on one side->maximum declared steering angle on other side 2. Maximum declared steering angle on one side ->85% of maximum declared steering angle on other side in not more than 28s	Max->85%Max in not more than 28s
			Tanker of 10,000 gross tonnage and upwards and every other cargo ship of 70,000 gross tonnage and upwards	Maximum ahead service speed		Max->85%Max in not more than 56s
			Tankers of less than 10.000 gross tonnage and every other ship of less than 70,000 gross tonnage.	50% of maximum ahead service speed or, at least, 7 knots		50%Max->50%Max in not more than 60s

The expected performance related to steering and propulsion performance can be found in ***Appendix G*** under Function I and Function VIII. The regulatory embedment of the proposed performance requirements discussed in the previous sections can be found in ***Appendix H***: ***Proposal to IMO***, under the proposals for amending SOLAS II-1/Reg. 28 & 29, Res. MSC.137(76) and MSC/Circ.1053.

8.8 Suggested updates for Documentation of performance

It is of outmost importance that the operator knows the vessel's manoeuvring and stopping capacity. It is therefore suggested to enhance the requirement to documentation made available to the operator (officer in charge of navigation watch).

It is suggested to, as a minimum, require the display of a wheelhouse poster as per Resolution A.601(15), (11). This will give the operator information about key parameters of the vessel

[5] A discussion of the speed during the tests is included in Section 10.1.1

including turning and stopping ability. Further, it is proposed to, as a minimum, include test results as per MSC.137(76)(proposal) in a manoeuvring booklet. The full scope of the manoeuvring booklet as per Resolution A.601(15) should not be mandatory as it is too extensive and costly.

To ensure a reasonable cost level, it is suggested to allow simplified calculations for the manoeuvring characteristics, except for data which shall be verified by tests as listed in Section 10.2.

The expected performance related to documentation of performance can be found in ***Appendix G*** under Function VII and IX.

8.9 Suggested updates for Redundancy requirements

When designing a system for reliability it is important to identify what kind of reliability is wanted. The design of the system will be different if it is desired to maximize the availability of 100% performance compared to at least 50% performance. This is exemplified by considering three very simplified systems:

A. One component with 100% performance
B. Two redundant components with 50% performance each
C. Two redundant components with 100% performance each

Assuming all components have the same failure rate, the availability of 100% performance will be highest for C with A on second. A will be better than B since there are more components that can fail in B.

The availability of at least 50% performance will be equal in B and C, and lowest in A.

Comparing this to the current regulations, it is evident that it is deemed more important to retain some performance, than having 100% performance.

In the current regulations it is considered sufficient that vessels with one propulsion line is redundant (although with reduced performance) to any single failure except for failures in the steering force unit. Assumedly, accepting loss of steering due to a failure in steering force unit is based on cost-benefit evaluation and to avoid the need for multiple propulsion lines on all vessels. It is suggested to continue with this safety level.

For vessels with multiple propulsion lines and/or steering systems, it is more difficult to determine the relevant redundancy requirement. In the interpretation applicable for unconventional steering-propulsion systems (MSC.1/Circ.1416/Rev.1), it is required that each line provides the redundancy required for a single propulsion line. This requirement significantly increases the redundancy of multiple steering-propulsion line configurations compared to single propulsion line configurations. However, it is also increasing cost and complexity and thus, this fairly new interpretation has met significant resistant in the industry. In the continued work our proposal is to not follow the interpretation in MSC.1/Circ.1416/Rev.1.

Acknowledging redundancy on system level as equivalent to redundancy on component level (two steering gears are equally reliable as one steering gear with two actuating units) will eliminate the need for redundancy on each propulsion line. However, in this case the reliability after the first failure is significantly reduced compared to a single propulsion line vessel. This is because for the steering to fail in a single propulsion line vessel, the same component will have to fail twice. In a twin propulsion line vessel, any failure in the remaining propulsion line will lead to loss of steering. As there is more that can go wrong, there is a higher probability of failure and hence a lower reliability. Traditionally, redundancy towards two single failures have not been considered in the regulatory framework. Hence, the argument of reduced reliability after first fault could be discarded.

Further to this discussion it should be noted that on a vessel with twin propulsion lines and redundancy on both lines (as if they were single lines), the probability of the first single failure will be larger, compared to a vessel with twin propulsion lines and no redundancy on each line, as there are more components that can fail.

The conclusion is to suggest the application of the same criteria for vessels with single and multiple propulsion lines and/or steering systems. Redundancy on system level is considered equivalent to redundancy on component level and it is considered more important to have some performance rather than to maximise the availability of full performance. The solution with the highest availability of some performance is favoured, minimising the probability of complete loss.

In case of failures, it is in today's regulations allowed for some time to regain function. From a practical point of view, it seems reasonable, as it often will require action to isolate the fault. The required time for isolating faults and regain steering currently depend on type of failure and failing system. Failure in control system or power supply shall be automatically detected and system restored in 45 seconds. Detection of hydraulic failures shall for larger tankers be automatic (45 seconds), but for all other ships it may be manual.

Both tankers and passenger ships are in current regulations requested to have higher capabilities, however automatic identification and isolation of failures in hydraulic system are only requested for tankers. Passenger ships represent high risk, and it may be argued that such ships should have a minimised delay in regaining steering capability – in line with the requirements for tankers. For practical purposes, ships subject to SRtP will always have more than one steering system, and ships with multiple steering systems will maintain steering capability without delay. An evaluation would be necessary prior to proposing that ships not subject to SRtP, and provided with a single steering system, should be arranged with automatic detection and isolation of hydraulic failures. As this is considered a major change in requirements compared with current regulations, such a change has not been proposed based on the current work.

Reviewing the expected performance for control system and comparing with the current regulation, interpretations and current practices, it was decided to change the wording in the expected performance (see ***Appendix G***, Function II) from "not lead to loss of steering capability " and " Normal service steering capability is maintained" to: "not lead to complete loss of steering capability" and "Reduced service steering capability is maintained". It is required that the ship is provided with two independent control systems. However, in case of multiple steering systems, each would be provided with a control system, and a failure in the control system may give loss of one steering system. The ship will in this case be left with a reduced service steering capability.

The expected performance related to redundancy can be found in ***Appendix G*** under Function II.

9 VERIFICATION OF CONFORMITY

In line with the IMO Generic Guidelines for Developing Goal-Based Standards, (5), the developed functional requirements have been compared with current IMO provisions in order to verify if current regulations together with Circulars and Unified Interpretations meet the functional requirements.

According to the Guidelines (5), the Verification should consider the following elements;

1. Identification of the functional requirement(s) that are being addressed by the rules/regulations;
2. Extent to which the rules/regulations cover the functional requirements and contribute towards meeting the goal(s);
3. Rule/regulation commentary;
4. Technical documentation;
5. Quality assurance;
6. Methods for obtaining feedback on the effectiveness of the rules/regulations and for promoting continuous improvement

It is noted that items 3 to 6 were specified in context of the development of GBS ship construction standards for bulk carriers and oil tankers and are not considered here.

Hence, in this project the verification of conformity will concentrate on identifying the objectives of the rules/regulations, identifying related functional requirement and if/how the rules regulations meet the functional requirements. An evaluation of the clarity and coverage of the functional requirements is also carried out.

The functional requirements which were the basis for the verification of conformity are listed in the numbering matrix in the beginning of ***Appendix F*** of this report.

The verification has been performed in two steps:

1. In the first step a "line-by-line" check is carried out starting from the requirements in the regulation and identifying the related functional requirement(s) (function and expected performance), i.e. the functional requirement that should be fulfilled by the regulation. Functional requirements shall provide the background for regulations (IMO speech: rules for rules), and the regulations provide one possibility to meet the functional requirements and thus the goal.

   Thereafter, the comparison concentrates on the following question; *what is the objective of the regulation, and which functional requirement addresses this objective?*

   Some regulations cover several objectives, which have been broken down for this task.

2. In the second step it is evaluated whether the regulation meets the expected performance, i.e. fulfil the criteria specified by the functional requirement.

For this comparison the following provisions were considered:

- SOLAS Reg.II-1/28: Means of going astern;
- SOLAS Reg.II-1/29: Steering gear;

- SOLAS Reg.II-1/30: Additional requirements for electric and electrohydraulic steering gear;
- SOLAS Reg.V/25: Operation of steering gear;
- SOLAS Reg.V/26: Steering gear: testing and drills;
- Resolution MSC.137(76) - Standards for ship manoeuvrability, (4);
- MSC/Circ.1053 - Explanatory notes to the standards for ship manoeuvrability, (12);
- MSC.1/Circ.1398 - Unified Interpretation of SOLAS Reg.II-1/29, (13);
- MSC.1/Circ.1416/Rev.1 - Unified Interpretation of SOLAS Reg.II-1/28 and Reg.II-1/29. (1);
- MSC.1/Circ.1536 - Unified Interpretation of SOLAS Reg.II-1/29.3 and Reg.II-1/29.4, (14); and,
- Resolution A.601(15) - Recommendation on the provision and the display of manoeuvring information on board ships, (11).

Additionally, IACS UI SC242 is considered regarding the interpretation of regulations.

The updated functional requirements, resulting from the verification of conformity, can be found in ***Appendix G*** in this report.

9.1 Main findings from the Verification of Conformity

It has been concluded that, in general, the functional requirements for steering and propulsion are conformed with by the current regulations, i.e. they provide adequate performance for safe operation and sufficient resilience for typical failures. This conclusion is supported by the investigation on incident reports as well as DNV experiences.

The main findings of the verification of conformity are the following:

- In some cases, the terminology in the regulations is vague, e.g. with respect to "sound" design, i.e. details of the overall assessment of the actuating system and the steering force unit are not provided. Likewise:
    - with respect to the protection of the system against incidents in other systems.
    - "speedily" is only specified for tankers of certain size and not for other ship types/categories
- Performance requirements in MSC.137(76) do not consider the performance after failure.
- Functional requirement VI (*Minimize impact of erroneous operation*) is regarded not to be satisfied by the regulations. Today's modern systems, e.g. podded systems, have the potential to endanger the ship if not adequately operated.

9.2 Details of the Verification of Conformity

In the following, the details from the verification process are included.

9.2.1 General findings

Before discussing the details of the verification of conformity, some general findings are summarised:

- Overlap with other IMO provisions: SOLAS Reg.II-1/29.8.1, 29.14 and SOLAS Reg.II-1/30.2 seem to overlap with regulations in other parts of SOLAS, i.e. chapter II-1, part D which is specifying which essential services need to be provided in case of failure in electrical power supply (~emergency electrical power supply). In order to avoid inconsistency within SOLAS it is recommended to have a clear specification of the systems and the interfaces with other systems.
- Equivalency of other designs: These regulations describe system configurations which are regarded safety equivalent to corresponding regulations:
    - SOLAS Reg.II-1/29.6.3 enables non-hydraulic steering gears requiring equivalency to 29.6.1.1 to .3;
    - SOLAS Reg.II-1/29.16.2.2 is another design solution for 29.16.2.1
    - SOLAS Reg.II-1/29.16.3 requiring equivalency to 29.16.2.1 to .2 for systems not of hydraulic type
    - SOLAS Reg.II-1/29.17 et seq.: equivalency to 29.16 for tankers, chemical tankers and gas carriers of 10,000 ⩽ DWT < 100,000
    - SOLAS Reg.II-1/30.4: equivalency to 29.5.1 & 2 and 29.7.3 for small ships < 1,600 GT

  SOLAS Chapter II-1, part C, D and E have been opened for Alternative Design (MSC.1/Circ.1212/Rev.1) since January 1st 2009 and the process of approval is specified by MSC.1/Circ.1455. Thus, these guidelines just explicitly offer acceptable alternatives and, therefore, guidance to the Administration, but they might be considered as not really necessary. All regulations focusing on "equivalency" are not assigned to the functional requirements.
- Grandfathering: typically, new regulations are only applicable for ships after an enter into force date[6] and retroactive measures are the exception:
    - SOLAS Reg.II-1/29.19 et seq. and 29.20 et seq. set retroactive requirements for tankers, chemical tankers and gas carriers ⩾ 10,000 GT built before 1 September 1984.
    - SOLAS Reg. II-1/29.6.2 and 29.18 exclude certain ships built before 1 September 1986 from the redundancy requirements for hydraulic steering gear system. The upgrading focuses on achieving a certain degree of redundancy (control system, limit impact, communication etc.) and the hydraulic system is excluded as long as reliability had been demonstrated. These means are not achieving the resilience level of a new building.

  The functional requirements focus on the state-of-the-art ship design and thus grandfathering is not considered in verification of compliance.
- SOLAS Reg.V/26.6 is understood to provide for the enforcement of regulations 26.1 & 2 and 26.4. Enforcement is understood as a general issue of IMO provisions and not only of steering-propulsion system that should be addressed once in SOLAS for all chapters

[6] Typically, one of the following three dates is relevant: building contract, keel laid and delivery.

but not in the regulations on systems. Accordingly, this regulation is not considered in the verification.

- Several regulations and related unified interpretations (MSC.1/Circ.1416 and MSC.1/Circ.1536) address the demonstration by sea trials[7] of certain characteristics (SOLAS Reg.II-1/28.2, 28.3, 28.4, 29.3 et seq., 29.4.1, 29.4.2 et seq.), and specify test conditions (e.g. draught, trim, speed, unrestricted water, calm weather). According to our understanding, steering-propulsion systems in general need to be verified with respect to complying with the Tier IV requirements. Such demonstration or testing is regarded to be part of the approval process and "demonstration" needs not to be mentioned in several regulations. Instead, all tests and test conditions should be brought together in one circular (e.g. like MSC.81(70), (15)). The expected performance of steering-propulsion system is specified by FR I and FR VIII. All regulations and recommendations focusing on test specifications are not considered and are not assigned to functional requirements.
- MSC.1/Circ.1416/Rev.1 specifies how the redundancy requirements for steering control system and steering actuating system shall be applied for multiple steering-propulsion system and that the requirements need to be satisfied by each of the multiple steering-propulsion systems (see also discussion in Section 8.9)

All the regulations and recommendations not considered (the parts of it) in the verification of conformity are summarised in ***Appendix F*** ("Regulations not assigned to functional requirements"). IMO instruments provide also so-called "chapeau text" which has not been assigned to functional requirements and is not considered in the summary in ***Appendix F***.

Additionally, this table considers the regulations that could not be assigned to one of the draft functional requirements as provided and the corrective action is mentioned (highlighted in bold in column "discussion").

9.2.2 Verification of IMO provisions/ Comparing functions towards regulations

The relation between functional requirements and the SOLAS regulations is summarised in ***Appendix F*** and, in the following, the findings are discussed individually for each functional requirement.

Appendix F provides:

- a table numbering the functional requirements and related expected performance, assigned numbering of FRs and EPs, and indicating which of the EPs are not considered by current regulations (column "C");
- for each functional requirement, a table with the regulations assigned to the functional requirement;
- a table summarising all regulations not assigned to a functional requirement (see also general findings in Section 9.2.1).

[7] Including alternative sea trial conditions or ways of demonstrating compliance

FR I: Provide steering performance adequate for ship operation

The performance requirements for the steering system are specified in various regulations and additionally in MSC.137(76), MSC/Circ.1053, MSC.1/Circ.1416/Rev.1 and MSC.1/Circ.1536. MSC.137(76) specifies minimum characteristics for ship manoeuvrability which are an aspect not adequately addressed by the SOLAS regulations. MSC/Circ.1053 provide explanatory notes to MSC.137(76) only. MSC.1/Circ.1416/Rev.1 and MSC.1/Circ.1536 provide interpretations on how to apply the performance regulations which are referring to "traditional" design to novel designs.

The performance of the vessel (manoeuvrability) is relevant with respect to FR I. Related specifications are made in MSC.137(76). SOLAS Reg.II-1/29.3 and 29.4 specify the dynamic performance for systems with rudder considering two operational conditions: normal operation and reduced service. Regarding the dynamic behaviour, the regulations consider only traditional arrangements. This complies with the expected performance, e.g. turning the steering force angle from neutral to 90% of declared angle in less than 14 s.

It is assumed MSC.137(76) is considered to be mandatory by the flag states. Therefore, the functional requirements and expected performance in normal service are fulfilled. Reduced service is not addressed. This comparison is based on the updated functional requirements as summarised in ***Appendix F***.

FR II: Steering capability is maintained or can be regained in case of malfunction of one of the sub-systems for steering control or steering actuating or both together

This functional requirement focuses on the resilience of steering gear and control system, i.e. being one-failure tolerant. To comply with this functional requirement redundancy is required.

SOLAS Reg.II-1/29.1 is requiring this redundancy in general and 29.4.1 that it shall be speedily available. However, only for tankers, chemical tankers and gas carriers "speedily" is specified to 45 seconds (29.16, 29.17). Regulations exclude some components from duplication, e.g. steering wheel/lever (MSC.1/Circ.1398). Regulation 29.7.2 excludes systems with telemotor from the redundancy requirement for the control system, i.e. such system will not be in compliance with the EP. Regulation 29.7.3 requires redundant control system only when auxiliary steering gear is power operated, i.e. no redundancy if not power operated. In general, this can fulfil FR II if the performance requirements are met with respect to time to regain and the performance of the steering system as specified in FR I.

SOLAS Reg.II-1/29.17 et seq. allow systems without redundancy of power actuator (single failure tolerant) and require instead a more thorough structural assessment, provided that steering capability after single failure in piping or one of the power units can be regained within 45 s. As stated in Regulation 29.17 this deviation from 29.16 is only permitted if safety equivalence is achieved.

SOLAS Reg.II-1/29.15 requires for some ship size categories that the steering gear shall comprise of identical power units. Redundancy is required by FR II but not how to be realised, i.e. the FR II focus on availability and not on the design. Additionally, it is noted that this requirement is not considering common cause failure.

The functional requirement requires no hot redundancy but regaining steering capability within set time limits depending on the ship type. This is achieved by the regulations, e.g. 29.16.1 for tanker but not for cargo and passenger ships (regulation provides no interpretation of speedily). Only SOLAS Reg.V/25 requires that redundancy in steering gear power unit shall be in operation in areas demanding special caution. For ships < 1600 GT SOLAS Reg.II-1/30.4 allows operation by electric motor "primarily intended for other services". This can only be regarded compliant if the time threshold is met by the design.

MSC.1/Circ.1416/Rev.1 requires that redundancy requirements are applicable to each system in multiple steering-propulsion systems. In general, this provides a higher availability of steering capability compared to single steering-propulsion system and thus exceeds the expected performance (further considerations regarding the redundancy requirements for multi steering propulsion systems are summarised in Section 8.9).

The speedily regain of performance relates also to the timely identification of malfunction. The regulations require means for monitoring availability/performance and alarms in case of malfunction. These indicators cover electrical power supply (Reg.II-1/29.8.4), control system (29.11.1), low-level alarm (29.12.2), motors in electric and electrohydraulic systems (30.1), overload (30.3) and low electrical power (30.3). These indicators cover all relevant parameters.

Further, the regulations specify means to enable speedily regain of steering capability, i.e. information for starting redundancy (Reg.V/26.3) and short ways to activate (Reg. II-1/29.5.2, 29.8.3). These requirements are regarded as a contribution to meet the functional requirement. However, the effectiveness can hardly be evaluated.

The availability of redundancy is adequately addressed in the regulations by requiring an independence of redundant systems to avoid e.g. blocking. This is addressed in Reg.II-1/29.1 and 29.2.3 (relief valves), 29.6.1.3 (isolation), 29.8.2, 29.9 (limit impact on each other), and further by MSC.1/Circ.1398-3.1 to separate redundant sub-systems from each other.

In summary the regulations meet the requirements of FR II.

FR III: Steering system is designed adequately for operational loads

The regulations address this functional requirement in a relatively general way (SOLAS Reg.II-1/29.2.1) and in general specify only two operational loads relating to maximum speed ahead 29.3.1 (implicitly) and maximum astern speed (29.3.4), i.e. the focus is on the actuating system and the steering force unit. Also in MSC.1/Circ.1416/Rev.1, this is only considered in a general format. The term "sound" used in the regulations could be interpreted as a requirement for Tier IV/Tier V rules for structural assessment. The requirements for the hydraulic system (29.2.3) are more detailed, e.g. by mentioning fatigue, pressure boundary conditions and pulsating loads. Additionally, negative impact by safety devices is considered in 29.8.5 and 30.3. Degradation (explicitly) is only considered for hydraulic systems (29.12.1), i.e. contamination of hydraulic fluid. Inspection, which is regarded as part of reliability concept, is touched only by functionality test to be performed on regular basis before departure (Reg. V/26.1 and 26.2).

In summary, the regulations touch the relevant topics in a generic way, leaving space for interpretation. Tier IV, classification rules, consider the detailed specifications with respect to design loads and assessment and provide a closed concept for assessment. It is noted that in the HazId workshop and the investigation on casualty reports there were raised no concerns that the current regime is not meeting the safety expectations.

FR IV: Steering system is protected from external impacts

The impact on the steering system caused by malfunction or incidents needs to be minimised. Examples of impacts and incidents are fire, loss of electrical power, water ingress and EMI (Electro-Magnetic Interference). Protection against external impacts requires safety barriers to potential threats. The regulations try to achieve this by:

- requiring a separation of the steering gear compartment from machinery spaces (29.13.1);
- by separation of electrical power supply (29.8.1) (emergency power supply is specified in Part D);
- being able to disconnect additional control systems (MSC.1/Circ.1398), separation of feed-back units, limit switches and connections for control system (joint steering mode selector) (MSC.1/Circ.1398);
- requiring separation of electrical power supply (30.2) which reduces the impact by failures in other electrical machinery or their power supply (by MSC.1/Circ.1416 this is required for each of a multiple steering-propulsion system);
- Regulation 29.2.3 requires the existence of pressure relief valves which act as a passive load limiter (performance of means is further specified by 29.2.2);
- Further, Regulation 29.1 (asking for an arrangement of the two systems so that the failure of one will not render the other one inoperative) could also be interpreted in this way (regarding the failure of one sub-system as external impact on the redundant).

These regulations adequately specify the separation from other systems. However, the protection level is unclear. The automatic restart is regarded as an adequate means to minimise the impact of electrical power failure.

FR V: Minimize impact of erroneous functionality

This functional requirement focuses on means of limiting the consequences of erroneous functionality, e.g. by limiting the operational capabilities and early detection or fail-safe behaviour. Regulations relating to this functional requirement are 29.11.1 (independent indication of rudder angle) and MSC.1/Circ.1398 (detection of most probable failures such as loop failure in programmable systems, detection, data communication, computer (hardware/software)). Further, it is required that rudder characteristics are monitored. Fail-safe behaviour is required for most probable failures by MSC.1/Circ.1398 paragraph 4.2.

These regulations meet the expected performance, except for monitoring deviations to design characteristics, as it is not mentioned that this monitoring needs to be separated from control system which is only required for rudder angle (29.11.1). Furthermore, it is noted that EP No. 3 and 4 are not considered.

FR VI: Minimize impact of erroneous operation

The only regulation having a certain relation to this functional requirement is Reg.II-1/29.11.1 requiring rudder angle indication in navigation location as well as MSC.1/Circ.1398, paragraphs 4.1.4.1 and 4.1.4.3. The independent indication of rudder position may help to identify erroneous inputs, e.g. rudder position starts to deviate from the envisaged position, but this is not really limiting the possibility of erroneous input. Thus, this is not considered to be sufficient because today’s modern system performance, e.g. podded system, has the potential to endanger the ship if not adequately operated. This risk is not considered by current regulations.

FR VII: Enabling proper operation by considering steering control loop

Ship manoeuvring can be regarded as a control loop – decide on the course – set the steering force – compare set-point and actual point – update set of steering force. A reliable and safe operation requires an adjustment of all components of the control loop. In case of human element closing the loop, it is necessary to provide adequate information on the capabilities/performance of the ship including steering-propulsion system and familiarisation by training and drill. Further, the overstrain of an element needs to be prevented (this is already partly considered by FR I).

The regulations require information on operational procedures (Reg. V/26.3.1), manoeuvring (Resolution A.601, (11): pilot card, wheelhouse poster, manoeuvrability booklet), familiarisation of officer (Reg. V/26.3.2) and drills on the operation of the auxiliary system (Reg. V/26.4). This is what is typically expected to be provided and thus complies with the functional requirement.

FR VIII: Provide propulsion performance adequate for ship operation

SOLAS Reg.II-1/28 in combination with MSC.137(76) satisfy the functional requirement with respect to stopping length for normal operation. Achieving a certain stopping length in reduced service is not addressed.

9.2.3 Evaluation of functional requirements based on regulation

In the third step of the verification of conformity, the functional requirements are reviewed with respect to clarity and coverage of regulations, i.e. whether the objective and performance under consideration can be concluded from the functional requirement. This part of the comparison shows that the functional requirements in general cover the technical requirements of current regulations. However, some potential inaccuracies and aspects are identified to be additionally considered in the further development of the functional requirements. These are summarised in this section.

- SOLAS Reg.II-1/28.2: this requirement has two objectives;

    a) adequate stopping distance (further specified by MSC.1/Circ.137) which is appropriately addressed by FR VIII; and,

    b) information to crew or operator. This needs to be adequately covered by the functional requirement for propulsion. Thus, it is suggested to add the following functional requirement;

    Enabling proper operation by providing information about vessel's stopping characteristics

    Expected Performance:

    - Provide adequate and accessible information for all persons involved in navigation at all navigation positions

- SOLAS Reg.II-1/29.5.1: FR II requires means for speedily regain of the steering performance after malfunction and provides two time thresholds. The requirement for tankers can only be satisfied by a high degree of automation, however this is not the case for other ships (15 minutes). 29.5.1 requires automatic restart after power failure that relates to speedily restart in general and not only for tankers.

    Thus, it is suggested to amend the EP of FRII as follows:

    "*Automatic restart of steering system when electrical power is regained after failure in electrical power supply*"

- SOLAS Reg.II-1/29.7.2: FR II covers the redundancy aspect but is not specifying from which position the steering system is operated. Thus, it is suggested to amend the EP of FR II as follows:

"Malfunction of steering control system will not lead to loss of steering capability.

Steering system can be operated from navigation position".

- SOLAS Reg.II-1/29.8.1: this regulation aims at protecting the steering system from the impact of failures in other system, e.g. short circuit. This is addressed by FR IV. However, in order to improve clarity with respect to inclusion of electric circuit providing electrical power, it is suggested to amend the EP of FR IV as follows;

  "Steering control system and actuator system are separated from other ship systems, *and their electrical power supply arranged as separate circuit"*

- SOLAS Reg.II-1/29.8.1: this regulation aims on protecting the steering system from the impact of failures in other system, in this case focusing on requiring a redundant electrical power supply. If the electrical connection to the switchboard (main & emergency) is assigned to the steering system, then this is not adequately addressed by draft FRs. For the time being in this respect the following expected performance is suggested (FR IV):

  Electrical power supply is maintained after malfunction in electric circuit

- SOLAS Reg.II-1/29.11.1 and .2 aim at being able to identify malfunction of control system which is adequately covered by FR IV. Secondly, this will enable to manoeuvre the vessel from control station in steering gear compartment without remote control system (communication between navigation position and control position). In order to cover this aspect, it is suggested to amend the EPs of FRII as follows:

  "*Steering force unit angle indicated independent of control system*" and

  "*Indication of steering force unit angle in all locations from which the steering gear can be operated*".

- SOLAS Reg.II-1/29.13.2: in the hazard identification this regulation was understood to aim at speedily regain of the steering capability after failure. This has been changed in this second analysis to cover also the objective of protecting people when working in the steering gear compartment. It is noted that occupational safety is not addressed by the goal and subsequently no functional requirement exists. However, occupational safety is regarded as a relevant goal (for all systems on board) which addresses a general issue and not only the steering system. The following goal and FR may address this hazard but have not been considered in the updated functional requirements:

  Goal: Prevent occupational accidents

  and the related functional requirement:

  Protect people of threats originate from steering system or when accessing the steering system

  Expected Performance:

  - Provide safe working access to steering [gear] system

- SOLAS Reg. 30.3: FR II covers "loss of availability" but not "overload". It is suggested to amend EP of FR II as follows:

  "Loss of availability *and overload* are indicated by an alarm".

- SOLAS Reg. 30.3: FR II covers "Availability of steering system continuously monitored and indicated on navigation position" This is not adequately considering the possibility of low performance due to reduced power supply. Thus, it is suggested to amend the EP of FR II as follows:

  Availability *and performanc*e of steering system continuously monitored and indicated at navigation position

- It is noted that SOLAS Reg.II-2/21 and SOLAS II-1/8-1.3 for Safe Return to Port (SRtP) require redundancy of complete steering system i.e. compensation of complete loss of one system. Additionally, internal redundancy is required by the unified interpretation MSC.1/Circ.1416/Rev.1. The impact on reliability is also discussed in Section 8.9. As long as these two requirements remain (redundancy on system level and on ship level) both EPs are regarded to provide sufficient clarity, i.e. in FR II the malfunction is addressed (-> malfunction in the system will not lead to loss) and in FR IV on ship level complete loss of one system (-> reduced steering capability).

For a detailed overview of the verification of conformity, reference is made to ***Appendix F***. The updated functional requirements, resulting from the verification of conformity, can be found in ***Appendix G***.

10 TRIALS AND TESTING

This section presents the tests to be performed and related test conditions to verify the performance requirements established in Section 8.7.

10.1 Test conditions

The test conditions are here discussed in a separate section rather than in connection with the individual tests as most of the discussion is general and applicable to all tests.

As per MSC.137(76), the recommendation is that tests are performed in:

- Deep unrestricted water
- Calm environment
- Even keel at summer load line draft
- Steady approach at the test speed

No correction for water depth or environment should be allowed. The manoeuvres with performance requirements should always be initiated with the weather from directly astern.

A more detailed discussion on test conditions is included below.

10.1.1 Discussion on test conditions

it is necessary to be aware of the implication of variations in conditions on the manoeuvring performance.

The manoeuvring characteristics of a vessel is affected by the water depth and proximity to the shore. At open sea proximity to shore can be neglected. Along some of the common trading routes there are areas with reduced water depth. As a rule of thumb, the manoeuvring performance can start to be affected when water depth is less than four times the vessel draft (ITTC – Recommended Procedures and guidelines 7.5-04-02-01). Generally, a vessel in shallow water is perceived by the operator as less manoeuvrable with increased turning radius and stopping distance. For the suggested tests with performance requirements it will, in most cases, be conservative to execute the tests in shallow water as long as no corrections for such is allowed.

The environment during the test can significantly affect the results. What is regarded as calm environment will be dependent on the vessel size. In order to motivate for tests in calm water and get conservative results it is suggested to require that tests with performance requirements are conducted with the weather from astern. In case of the turning circle test, the vessel should initiate the manoeuvre with the weather from astern. Following this recommendation and not allowing corrections is expected to give conservative results.

In general, a vessel will operate at many different loading conditions. The variation in loading conditions depend on the ship type. E.g. cruise vessels typically have small variations in draft and trim whereas bulk carriers usually operate in either ballast or laden condition with significant differences in draft and trim. With respect to manoeuvring, particularly trim is expected to affect both the course keeping ability and turning ability. A trim by the stern, which is common in ballast condition to submerge the propeller, will usually result in a more course stable vessel. A trim by the stern will hence probably improve the course keeping ability but could possibly reduce the turning ability. The loading condition can also have a significant effect on the stopping ability. The breaking force provided by the propeller will be similar in both ballast and laden condition, but the mass of the vessel can be significantly different leading to different stopping distances.

The current contractual setup and sales process for vessels require all tests to be carried out by the yard prior to vessel delivery to the owner. This means that all manoeuvring tests will have to be carried out by the yard prior to vessel delivery. This can provide challenges in getting deep unrestricted water, calm environment and summer load line draft at a reasonable cost. In most parts of the world it is possible to find locations with sufficient water depth to avoid significant effects on manoeuvring performance. In some parts of the world it could be challenging to find both deep water and calm environment in a reasonable time frame. However, this is managed today for speed trials which are conducted on most new ships and should hence also be manageable for manoeuvring trials. For some vessel types it is economically and practically infeasible to take onboard sufficient weight to achieve summer load line draft. In these cases, speed trials are usually conducted at ballast draft and results extrapolated by use of model tests to contractual (design) draft.

Preferably the ship performance shall be tested at a full-scale sea trial in the condition specified by MSC.137(proposal), i.e. summer load line draft, even keel. However, if this is not possible, tests as close as possible to full load draught and zero trim shall be performed and a recognized method (CFD calculations or model tests) may be accepted for predicting the compliance at the condition specified in MSC.137(proposal). Full scale CFD calculations (as elaborated in MSC.1053(proposal)), thoroughly verified by third party, are recommended.

In case CFD calculations are applied to predict the performance, the calculations should include the free surface, 6-dof vessel motion, appropriate modelling of friction and wake, and resolve the time varying flow around propeller blades/ fins and rudders or similar. (For water jets the impeller may not be resolved but replaced by a force accelerating the water.)

There are uncertainties in scaling model test results, particularly due to the increased resistance model scale, however, at this stage it has not been considered appropriate to exclude model tests as a means for predicting performance.

With regards to the speed during the tests, a differentiation has been made between the steering gear test and the other tests in Table 8-1. For the heading-keeping test, the turning test and the stopping test, the test speed is, as previously, specified as at least 90% of the ship's speed corresponding to 85% of the maximum engine output. However, the steering gear test should be performed for maximum ahead service speed, as its intention is to test the strength of the steering gear. For the other tests, it would be a significant change to test at maximum ahead service speed, and it is hence suggested that there is a difference in speed for these tests and the steering gear test.

10.2 Tests to be performed

In order to verify the previously established performance requirements in Section 8.7, the following tests shall be performed at the conditions specified above:

- Heading keeping test
- Turning test
- Steering gear test
- Stopping test

For an overview of the tests, test speed and requirements, reference is made to Table 8-1. In the following, the tests are further outlined.

10.2.1 Heading keeping test

- **Test:** Running at constant heading and observe yaw fluctuations (now included in MSC 137(76)(proposal)). Autopilot may be engaged.

  Acceptance criterion: Yaw oscillations less than ±2 degrees for 30 minutes.

  Same criterion applies for normal and reduced service

- **Assumptions and alternatives:**

  For ships provided with single steering system, the reduced service may be considered as operating with one power unit inoperative.

  For ships provided with multiple steering systems and/or multiple propulsion lines, the reduced service may be considered operating with the least favourable steering system out operation.

  - Reduction of propulsion on the propulsor associated with the faulty steering may only be done if operational restrictions apply.
  - The inoperative steering system shall be placed in neutral position.

10.2.2 Turning test

- **Test:** Turning circle procedure as described in MSC 137(76)(proposal) and MSC Circ. 1053(proposal)
- **Acceptance criterion:** The vessel can perform a turning circle both to port and starboard with the following performance:
  - Normal service: advance <4.5 ship lengths, diameter<5 ship lengths.
  - Reduced service: advance <5.6 ship lengths, diameter<6.25 ship lengths.
- **Assumptions and alternatives:**

  For ships provided with single steering system the reduced service may be considered as operating with one power unit inoperative.

  For ships provided with multiple steering systems and/or multiple propulsion lines the reduced service may be considered operating with the least favourable steering system out of operation.

  - The inoperative steering system shall be placed in neutral position.
  - Reduction of propulsion on the propulsor associated with the faulty steering may only be done if operational restrictions apply.
  - It is suggested to have the port system out of operation in a starboard turn and vice versa.

10.2.3 Steering gear test

- **Test:** Turning of steering force unit both to port and starboard
- **Acceptance criterion:** Each steering gear can turn the steering force unit both to port and starboard with the following performance at scantling draft:
    - Normal service, running ahead at maximum ahead service speed:
        - from declared steering angle limit on one side to declared steering angle limit on the other side
        - from declared steering angle limit on one side to 85% of declared steering angle limit on the other side in not more than 28 seconds
    - Reduced service (only applicable for ships with single steering system), running ahead at maximum ahead service speed:
        - from declared steering angle limit on one side to 85% of declared steering angle limit on the other side in not more than 56 seconds.
- **Assumptions and alternatives:**

For rudder-based steering systems, the declared steering angle limit should not be less than 35 degrees.

For tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and every other ship of less than 70,000 gross tonnage, the following alternative requirement applies in reduced service:

- from 50% declared steering angle limit on one side to 50% of declared steering angle limit on the other side in not more than 60 seconds, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.

10.2.4 Stopping test - bring the ship to rest

- **Test:** Full astern stopping test according to MSC 137(76)(proposal) and MSC Circ. 1053(proposal).
- **Acceptance criteria:**
    - Normal service: Vessel can be brought to rest with stopping distance within 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.
    - Reduced service (only applicable for ships with multiple propulsion lines/systems): Vessel can be brought to rest with stopping distance within 20 ship lengths
- **Assumptions and alternatives:**

  For rudder-based steering systems, the rudder shall be maintained at neutral position throughout the test.

When testing a ship with multiple propulsion lines, the procedure shall be repeated with the following modifications:

- The test is performed with one propulsion system and its corresponding steering system out of operation.
- The inoperative propeller may be allowed to windmill (depending on manufacturers specification and recommendation).
- The steering system corresponding to the inoperative propulsion line shall be placed at neutral position.
- The approach speed shall consequently be adjusted based on remaining available propulsion.

- For non-rudder-steered ships where the stopping in normal operation condition is done by turning the steering force units, the test described in the previous points shall be performed with all the propulsion systems active until the stop order is given. Consequently, the approach speed shall be same as in normal operational condition.

11 SAFE RETURN TO PORT

The SOLAS regulations for SRtP (SOLAS Reg. II-1/8-1 & II-2/21.4) are given on a functional, overall level and focus largely on *design aspects* of the systems covered by the regulations; i.e. propulsion and steering. However, the interim explanatory notes given in MSC.1/Circ.1369 link the design requirements to *operational aspects*, and the circular gives interpretations and recommendations on how to meet the goals of SOLAS for the systems to 'remain operational'.

For the propulsion system, a numerical acceptance criterion is given, namely that the vessel, after the casualty thresholds as indicated, shall be capable of providing 6 knots in BF8 conditions. This implies that a SRtP vessel, which must have two (or more) propulsion lines, shall be capable of providing 6 knots at BF 8 conditions after a casualty that lead to the most severe damage, normally loss of one machinery space/propulsion line. This is an interpretation given in MSC.1/Circ.1369, and no specific interpretations are given for the steering system to remain operational after a casualty in the context of SRtP.

The 6kn/BF8 criterion is not only decisive for the dimensioning of propulsion machinery, but also for the duration of dimensioning SRtP voyage and hence the fuel capacity that must be available for either machinery room after associated casualties.

11.1 Industry practice

11.1.1 Propulsion capability

For all practical purposes, any SRtP ship is designed with two (or in some cases, three) propulsion lines, normally of equal capacity. It is unlikely that a single propulsion line and a swing-up thruster or another alternative means to provide propulsion will be able to meet the performance requirement of 6 knots in BF 8 conditions, (at least not without strict operational limitations), even though it is theoretically possible to meet the SOLAS goals with such installations.

Furthermore, the two propulsion lines are normally equipped with equivalent steering capabilities, either a rudder for shafted propulsion systems or azimuth steering for thruster/POD arrangements. This implies that the steering capabilities of each steering system are normally equal and designed according to the SOLAS regulations for multiple-engine installations (covered in other tasks under this study).

Nevertheless, the 6kn/BF8 acceptance criterion has largely become an industry standard, presumably also partly because the same, or similar, criterion in many class societies is applied for the voluntary notations covering redundant propulsion systems. However, the practices among the class societies and flag administrations on how the propulsion capabilities are calculated and verified vary significantly; the method of calculation, model tests in test basin and/or sea trials – and the scope of verification/approval.

Any calculation method includes assumptions and simplifications, and different methods may further include different assumptions and simplifications. Furthermore, “BF8 conditions” is not an accurate criterion, especially as the different BF levels represent a range of wave- and wind conditions; the selection of environmental parameters may have a significantly different impact even within the defined BF8 range.

When one propulsion line is out of service and the vessel operates at 6 knots/BF8 – or higher speed at calmer weather - the passive propeller constitutes a significant drag force whether or not it is locked – or freewheeling. If freewheeling, the machinery- and transmission arrangement is decisive for the drag resistance and it is very hard to estimate these forces; if the propeller is locked, the drag force is presumably even higher. The class societies have different approaches to how the passive propeller is incorporated in the calculations; it may be neglected, or it may be estimated and included – with assumptions.

In any event, the assumptions, simplifications, calculations methods – and the representation of BF8 conditions – may largely influence the result, and hence the acceptance criterion for the installed propulsion power. This again may lead to a situation where a proposed machinery arrangement may be accepted by one class/flag administration but not by another. This may be highly relevant for certain vessel types, e.g. expedition vessels or RoPax ferries that may have limited propulsion capacity and normal operating speed around 12-15 kn. For such vessels, it may be hard to achieve the goal of 6kn at BF8 with only one propulsion line operative – depending on the calculation method.

A harmonized approach for the calculations, demonstration and verification of the propulsion systems ability to remain operational is therefore recommended as different practices may have wide implications for the projects. Similar vessels operating in the same area may have different capabilities, and further, this may have an unfortunate impact on the market competition and selection of e.g. yards/designs, class societies and flag administrations.

11.1.2 Dimensioning SRtP voyage

SOLAS V/Reg.30 and the MSC.1/Circ.1369 require that the SRtP capabilities for passenger ships are included in the 'List of exemptions and operational limitations.' This normally includes the SRtP range – or the dimensioning voyage and i.e. the distance in nautical miles and the duration of the voyage shall be stated in the document.

When it comes to the dimensioning SRtP voyage, i.e. the maximum designed range of the ship after a casualty, the duration of the voyage depends on different factors; particularly the achievable speed with one propulsor together with the weather- and sea state applied for the assumed return to port voyage. The installed propulsion power shall in this degraded state provide sufficient propulsion to achieve 6kn/BF8 while the power plant(s) simultaneously provides the electrical power needed for the SRtP power balance.

The MSC circular does not contain specific interpretations on the weather- and sea conditions for the duration of the voyage back to port, e.g. the duration of the BF8 conditions and the expected conditions for the remaining part of the voyage. The class societies apply different practices which in turn lead to differences in the calculated duration of the voyage, and consequently, calculation of fuel consumption and provisions for the safe areas.

This difference in practice may therefore have significant implications for the design and arrangement of e.g. fuel systems, and a harmonized approach for the environmental conditions during the dimensioning SRtP voyage should be established. A vessel should be assigned with the same operational limitations regardless of the class society or flag administration involved in the new-building project.

11.1.3 Steering capability

As mentioned above, the normal system arrangement for an SRtP vessel includes two separate propulsion lines, each driven by a separate machinery room – and each propulsion line equipped with a steering system of equal capabilities.

No specific SRtP acceptance criterion is given for the expected steering capabilities after a casualty, i.e. the steering performance after the dimensioning damage scenario (normally loss of one machinery space/propulsor). No links are given in the IMO documentation between steering capabilities and the propulsion capabilities (6kn/BF8). The common understanding is that the SRtP regulations do not entail additional capacity requirements for the two steering systems beyond the general SOLAS regulations for passenger ships with redundant propulsion lines; e.g. that each steering system shall be capable of turning the rudder according to the main SOLAS requirements (+/- 35 deg in 28 sec).

This implies that the general interpretation of 'remain operational' for steering systems in the context of SRtP is that after loss of one steering system, the remaining steering system fulfil the existing SOLAS regulations.

The industry practice on this seems to be quite consistent s, and it is generally not common to require any specific verification of the steering systems' ability to actually provide steering in 6kn/BF8 conditions, neither by calculations nor trials.

In task 5 of this study, it is proposed that ships with multiple propulsion-steering systems (e.g. passenger ships complying with SRtP) operating in reduced service (with the least favourable steering system out of operation) shall maintain certain manoeuvring characteristics, e.g. ability to turn within a specified number of ship lengths. This seems to be well within the intentions of the SRtP regulations, and it is therefore recommended not to sharpen the general acceptance criterion for the steering system capability in the SRtP regulations.

11.2 Recommendation

Based on the above discussion, it appears that the lack of a harmonized approach in the SRtP scheme for the implementation of remaining propulsion performance after a casualty has unfortunate consequences. Therefore it seems appropriate to suggest a harmonization. This applies in particular to the following key aspects:

1. Means of verification: calculation and/or model tests, sea trials
2. Calculation method, assumptions, simplifications and key parameters for the hydrodynamical performance
3. Environmental conditions for the duration of the dimensioning SRtP voyage

and consequently

4. The formal operational limitations (SOLAS V/Reg.30) for a vessel should be equivalent regardless of society/flag.

The practice within DNV on these subjects is the result of the experience gained in the approximately 90 SRtP projects in our class since the enforcement of the SRtP regulations in 2010, and the outcome of the investigations done in this study have not changed our view on our approach. Consequently, the recommended harmonization from this study will be quite aligned with the DNV present approach. The details of this approach are given in the SRtP class notation DNVGL-RU-SHIP Pt.6 Ch.2, (16), Sec.11, sub-section [3.1.2.4] and [4.2], and the class guideline on Safe Return to Port, DNVGL-CG-0004, (17), Appendix E.

The details of the method with its requirements, assumptions and parameters are not elaborated in detail in this report, but the key principles applied are outlined in the following.

11.2.1 Means of verification: calculation and/or model tests, sea trials

- The hydrodynamical performance of the vessel in the dimensioning state of degradation shall be calculated and documented in a report that shall be submitted for approval. (covering the casualty scenario that has the most severe impact for the propulsion)
- The calculation and report may be supplemented – or substituted – by appropriate test basin trials and report
- No practical verification of the achievable speed in the dimensioning damage scenario is required at sea. There are several reasons for this, e.g.:
    - the test would normally be conducted in far less severe conditions than BF 8 – and the hydrodynamical performance of the vessel in calm seas would substantially differ from the calculated conditions
    - the assumptions and simplifications represent calculated uncertainties

11.2.2 Calculation method, assumptions, simplifications and key parameters for the hydrodynamical performance

- The calculation method shall be according to the method that is provided in the DNV GL class guideline on SRtP, (17).
- The following key assumptions and parameters shall be applied:
    - the BF8 conditions as given in the DNV GL class notation for SRtP
    - The dragging force from the passive propeller is neglected

11.2.3 Environmental conditions for the duration of the dimensioning SRtP voyage

- The dimensioning return to port voyage shall be based on
    - The first 3 hours of operation against the wind in BF8 conditions with environmental parameters as specified in the DNV GL rules; at the designed vessel speed (minimum 6 kn)
    - The remaining part of the voyage at BF4 conditions with environmental parameters as specified in the DNV GL rules; at the designed vessel speed (normally the achievable speed with the propulsion power required to provide 6 knots at BF8)
- The calculation shall be based on the SRtP power balance, i.e. that all consumers in all the SRtP systems required by SOLAS to remain operational are incorporated

- The above calculations determine the duration of the dimensioning voyage – and consequently the need for fuel reserves to be available for each engine room (and also the necessary provisions for the safe areas to cover the duration of the voyage)

11.2.4 The formal operational limitations (SOLAS V/Reg.30) for a vessel should be equivalent regardless of society/flag

- The operational limitations required to be identified should be consistent, and at least contain the following characteristics:
  - SRtP range
  - Duration of the voyage
  - Eventual pre-requisites or assumptions for the above, e.g. if the characteristics differ for the dimensioning casualties affecting the propulsion capabilities, e.g. if the propulsion lines are not equal, if there are three propulsion lines, if the SRtP voyage are based on different fuels or batteries.
  - Other possible limitations, for instance related to environmental properties

With regards to eventual recommendation on the steering capabilities for SRtP, there is, as stated above, not proposed any strengthening the SRtP requirements, since the established practice is considered acceptable.

11.2.5 Suggested update of IMO instruments

The operational implications of the SRtP scheme are not covered in SOLAS, and the main guideline from IMO on the subject is the MSC.1/Circ.1369 'Interim explanatory notes' from 2010. However, the industry has not yet reached a harmonized practice on the key operational aspects of the SRtP scheme.

After 10 years of industry practice on building and operating SRtP ships, it may be appropriate to develop the temporary interpretations of the MSC Circular into a more permanent version, with particular focus on the key issues addressed above.

This proposal is also substantiated by different initiatives among several stakeholders in the industry that also encourage an update of the IMO instruments to promote a more consistent uptake and application of the SRtP regulations for both the new-building- and operational phase; e.g. the

- Cruise Ship Safety Forum recommendations on SRtP (303/2020)
- BMA/Malta/IACS submission MSC/102/21/12 on a proposed work programme on SRtP
- BMA Marine Notice 03 on SRtP

Furthermore, the SRtP regulations apply to any passenger ship above 120m or having 3 or more main vertical zones (MVZ). Since an MVZ may be up to 48 m long, any ship above 96 m has '3 or more' MVZ's, and hence subject to the SRtP regulations (unless a special consideration and justification suggests otherwise). This implies that the regulations apply to both the large cruise ships and the relatively smaller expedition ships and RoPax ferries; to vessels operating in any geographical area; the most remote areas where assistance may be days away – to fixed crossing of fjords or narrow seas – in areas where BF8 may be highly unlikely.

For the vessels in the lower end of the scale, i.e. with lengths of 100-120 m, compliance with all aspects of the regulations may be a challenge, i.e. since the regulations require all affected systems to be arranged with redundancy and segregation. As the implications of the regulations are extensive, not only for propulsion and steering – but also for all the other SRtP systems, safe areas etc., it may be questioned if some form of regulatory differentiation between the ship types and operational areas would be appropriate. This may also be included in the proposed revision of the MSC Circular, providing applicable interpretations for ships where the full scope of SRtP may be considered as excessive.

Neither the industry nor the public benefit from a situation where the different flag administrations and class societies develop their own interpretations and acceptance criteria on the essential topics of the SRtP regulations to meet the intentions– which is to increase the safety level of passenger ships.

12 REVISION OF SOLAS REGULATIONS AND ASSOCIATED DOCUMENTS

This Section presents the main changes and updates of the SOLAS Regulations and associated documents.

The Regulations and Circulars with proposed changes are provided in ***Appendix H***: Proposal to IMO.

12.1 General

In previous tasks, goals and functional requirements have been developed in accordance with the IMO Generic Guidelines for developing Goal-Based Standards (5). Based on this draft, the revision of SOLAS regulations and associated documents is carried out.

The IMO guidelines for GBS also provide an example of a structure of GBS regulations merging goals, functional requirements and Tier IV regulations in one document. Other practical examples exist in IMO's regulatory framework, for instance:

- SOLAS Ch.II-1 Regulation 3-10: GBS ship construction standards for bulk carriers and oil tankers in conjunction with MSC.287(87) specifying a set of functional requirements that need to be satisfied by tier IV classification rules and thus referring to requirements outside of IMO framework;
- SOLAS Ch.II-2, Part A 2 summarising functional objectives (can be regarded as goals) and functional requirements at the top of Chapter II-2 and structuring regulation according to the functional objectives (goals);
- SOLAS Ch. XIV Safety measures for ships operating in Polar Waters in conjunction with the Polar Code, the latter contains the goals and functional requirements in each chapter of the Code;
- IGF Code providing a goal for the Code as well as goals for each chapter, and a set of functional requirements at the beginning of the Code, with references to these in each chapter.

All these formats were developed by different IMO working groups and finally agreed by the Committee. However, it can be concluded that the discussion on the format of IMO GBS has not been finished yet (see also MSC 91/5/1).

In DNV's view, placing of goals and functional requirements should follow an IMO agreement considering the complete framework including an agreement on the structure of the framework.

Goals and functional requirements have been integrated into the reviewed SOLAS regulations II-1/28 & 29, however, it turned out that due to the comprehensive functional requirements in the present case, the structure of expected performance requirements got lost. Thus, DNV suggests to integrate the complete structure of goals, functional requirements and expected performance in a separate document, e.g. an MSC Circular. At the end of ***Appendix H***, a proposal for a Circular on "Goals, functional requirements and expected performance criteria for SOLAS regulations II-1/28 & 29" is offered.

12.2 Suggested changes and updates

The following sections present an outline listing of main changes proposed for the regulations and associated documents which are revised. The Regulations and Circulars with proposed changes are provided as separate documents.

It should be noted that the suggested performance requirements for reduced service have been developed based on "best estimates" and might need further finetuning to reflect the experience gained once these requirements are extensively applied.

SOLAS Ch.II-1 Regulation 3 – *Definitions*

- Improved some definitions to better reflect the proposed regulation text
- Added definitions found necessary for proposed regulation text

SOLAS Ch.II-1 Regulation 28 - Means of going astern

- Heading changed to "Means of stopping and going astern"
- Added goal and function requirements.
- Added criteria for stopping distance as mandatory
- Added criteria for stopping distance in a failure condition, for multiple propulsion line ships

SOLAS Ch.II-1 Regulation 29 – *Steering* gear

- Heading changed to "Steering"
- The regulation has been re-formulated and re-structured entirely.
- The wording is technology neutral, however, differentiates on particular solutions where found necessary.
- Added reference to separate document listing goal and function requirements.
- Added mandatory requirements for course stability and turning circle
- Added criteria for course stability and turning circle in a failure condition as mandatory
- Incorporated the content of MSC.1/Circ.1416, MSC.1/Circ.1398 in order to make them mandatory
- Added regulations addressing solutions with multiple steering systems
    - The proposal is accepting redundancy on ship level/system level to be equivalent to redundancy on component level. This may deviate from the interpretation in MCS.1/Circ.1416 (please refer also to discussion in section 8.9)
    - Accepting ship level redundancy, the requirements have been differentiated on single/multiple steering installation for the following 1) steering actuation system 2) control system 3) electric power supply 3) connection to hydraulic storage tank
- Incorporated content of Ch.II-1 Regulation 30

- Added alarms for converters

SOLAS Ch.II-1 Regulation 30 – Additional requirements for electric and electrohydraulic steering gear

Regulation has been deleted, and content incorporated in the new regulation 29.

SOLAS Ch.II-1 Regulation 8-1 and Ch.II-2/21.4 – *Safe Return to Port (SRtP)*

No proposed changes as it is regarded as a goal-based regulation.

SOLAS Ch.V Regulation 25 – Operation of steering gear

- Added requirement for ships with multiple steering systems to have more than one system in operation when operating in an area of special caution.

SOLAS Ch.V Regulation 26 – Steering gear: Testing and drills

- Improved terminology to be technology neutral for steering type
- Added manoeuvring characteristic as part of familiarisation scope

Resolution MSC.137(76) – Standards for Ship Manoeuvrability

- Improved terminology to be technology neutral for steering type
- Replaced ±35 degrees with declared steering angle
- Added heading keeping test
- Added max yaw deviation
- Added criteria for reduced service/failure condition for course stability, turning circle and stopping ability

MSC/Circ.1053 – Explanatory Notes to the Standards for Ship Manoeuvrability

- Improved terminology to be technology neutral for steering type
- Modified procedure (heading towards wind changed to head from wind) as this is considered to be more conservative and less possible to exploit during tests
- Added procedure for tests in failure condition
- Added alternative procedure for stopping
- Added CFD simulation as prediction method

MSC.1/Circ.1416/Rev.1 – Unified interpretation of SOLAS Regulation II-1/28 and II-1/29 concerning the arrangements for steering capability and function on ships fitted

with propulsion and steering systems other than conventional arrangements for a ship's directional control

- Content of document has been incorporated in proposed text for regulation 29
- Document may be considered obsolete.
- Please note that the proposal is accepting redundancy on ship level/system level to be equivalent to redundancy on component level. This may deviate from the interpretation in MCS.1/Circ.1416

MSC.1/Circ.1398 – Unified interpretation of SOLAS Regulation II-1/29 Mechanical, Hydraulic and Electrical Independency and Failure Detection and Response of Steering and Control Systems

- Content of document has been incorporated in proposed text for regulation 29
- Document may be obsolete however it may be considered to keep the examples in the Appendix.

MSC.1/Circ.1536 – Unified Interpretation of SOLAS Regulations II-1/29.3 and 29.4

- Improved terminology to be technology neutral for steering force unit

Resolution A.415(XI) – Improved steering gear standards for passenger and cargo ships

No change proposed. Document obsolete.

Resolution A.416(XI) – Examination of steering gear on existing tankers

No change proposed. Document obsolete.

Resolution A.601(15) – Provision and Display of Manoeuvring Information on board Ships

- Removed obsolete text
- Enforced wheelhouse poster
- Changed terminology to be technology neutral for steering type

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LIST OF APPENDICES

Appendix A. Current regulations - gaps and inconsistencies

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
SOLAS	Chapter II-1 Regulation 28	Means of going astern	Inconsistency: Paragraph is addressing several issues (stopping, means of going astern and trial/mapping of manoeuvring characteristics) which should be addressed in separate paragraphs, with more informative headings Comment: testing for "multiple propeller" needs further clarification Gap: Mapping of manoeuvring characteristics of vessel is merely addressed by footnote referring to MSC.137 Gap: Regarding mapping of manoeuvring characteristics; testing at reduced steering capacity (after fail/disturbed system) should be added	- Insufficient propulsion performance astern - insufficient steering (normal and reduced service) - Human element	-Thrust inadequate to stop/too late available to stop - Control loop inadequate

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Unified Interpretation of SOLAS Regulation II-1/28 and II-1/29 concerning the arrangements for steering capability and function on ships fitted with propulsion and steering systems other than traditional arrangements for a ship's directional control	Comment: is not addressing enhanced requirements for tankers GAP: is not considering challenges related to combining propulsion and steering in the same component	-Incident in other onboard system	- Loss of steering control output, Erroneous actuating system output
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 28			
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.1			
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.2			
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.3	GAP: Large steering angles at high ship speed may represent a hazard, therefore the interpretation has limited operation to be within "declared steering angles". Regulation should also address the need to ensure that these	Human element failure in steering control system	-Control loop inadequate, Erroneous actuating system output

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
			limits are not exceeded due to erroneous performance or operation		
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.4	Comment: not sure where aux. Steering gear come into consideration for thruster/waterjet		
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.6	Inconsistency: If applied to each of thrusters the interpretation is raising the requirement for redundancy compared with basic SOLAS requirements, not acknowledging the redundancy on system level (in case two or more thrusters installed) as equivalent to basic requirement requesting redundancy on component level for a single unit installation. This also apply to requirement for power supply. Not stated if it also applies to the control system	Insufficient performance (astern, normal and reduced service)	
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 29.14	Inconsistency: - interpretation of 29.14 is vague (applicable in case of certain proven steering capability) and the requested provision is likely to have little or no benefit on ships steering, particularly for electric driven propulsion.		
MSC.1	Circ. 1416/Rev.1 issued 26/06/2019	Interpretation of Reg. 30	Inconsistency: In case of two thrusters installed, this interpretation doubles the redundancy level required by basic SOLAS		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
Resolution	MSC.137(76)	Standard for ship manoeuvring	Comment: - Standard is defining turning circle as 35 deg. rudder angle. Consider if a neutral terminology can be established. Applicable also for def. of zig zag manoeuvring GAP: - should extend the standard to also address testing with reduced capacity (pump failure or equal) Further; include in standard requirements for testing for multiple propulsion line/ rudder arrangements, and what tests are required with one steering arrangement out of operation. - specify failure modes to handle and capacity after fail - include testing at reduced vessel speed	-Human element - Delay in regaining of steering performance - all hazards related to single fail	-Control loop inadequate - Loss of steering control output, Loss of output of actuating system,
	Annex to MSC.137	Standard for ship manoeuvring			
MSC	Circ.1053 Ch.1	explanatory notes to Standard for ship manoeuvring Guidelines for the application of the standard	Comment: - should merge the standard and the explanatory notes - consider if the terms used can be made technology neutral (i.e.: turning circle defined as 35 deg. Rudder). Note: 35 deg. turning angle may exceed safe angle for thruster/waterjet operation at full speed - consider if zig zag at 10 deg rudder is suitable for all types (rephrase "rudder angle" if suitable alternative is found)		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
	Circ.1053 CH.2	explanatory notes to Standard for ship manoeuvring Guidelines for the application of the standard	GAP: - should be updated to be technology neutral, hence open for any procedure to bring ship to rest	-	-
	Circ.1053 CH.3	explanatory notes to Standard for ship manoeuvring Prediction guidance	Comment: - may be considered if mathematical simulation should be more promoted as suitable way to document manoeuvring capabilities - technology neutral terms to be implemented as far as possible		
	Circ.1053 Appendix 1-5	explanatory notes to Standard for ship manoeuvring Appendix - nomenclature and ref. System	Comment: -Appendix 2: stating that mathematical model is not yet accurate. Still valid? - Appendix 3: item 3.2 and 3.3 not representative for steering propulsion unit - Appendix 3: item 7, tabulated factor not representative neither for alternative steering propulsion unit nor for el.motor driven propulsion - Form for reporting: format need to be changed to adopt other solution than "rudder angle"		
Resolution	A.601(15)	Provision and display of Manoeuvring information onboard ships	Comment: Presentation (sketches) may be modified to be technology neutral		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
SOLAS	Chapter II-1 Regulation 29 29.1	Steering gear	Inconsistency: requesting "one big and one small steering gear". Should request redundancy/independency or ability to regain steering after failure.	-	
SOLAS	Chapter II-1 Regulation 29 29.2	Steering gear	GAP: Paragraph 2.2 and 2.3 are assuming a specific technical solution. However, intention of regulation should be applied regardless of solution; to protect towards overload and dimension for occurring loads (specification of load condition required).	- Normal operational loads, Overloads	- Loss of steering capability, Loss of output of actuating system
SOLAS	Chapter II-1 Regulation 29 29.3	Main steering gear	Inconsistency: Regulation is a mix of design load cases, test regime and specifying power source for the steering gear - Design criteria should be addressed separately - Performance criteria addressed separately - Required tests to be addressed separately. Ref to relevant standard (e.g.: MSC.137 and MSC.1516) as found relevant. Comment: A practical approach would be to apply deepest ballast condition at trial condition – as this is easier achievable for shipyard, and request prediction of fully loaded condition by interpolation (as may current regulation open for in SOLAS II-1/29.3.2 & 29.4.2,		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
			MSC.1/Circ.1536. and MSC.1/Circ.1053, paragraph 3.4.) . A selection of predictions could be verified at first laden voyage.		
SOLAS	Chapter II-1 Regulation 29 29.4	Auxiliary steering gear	Same Inconsistency and comment as given for Reg.29.3 (main steering gear) above		
SOLAS	Chapter II-1 Regulation 29 29.5	Steering gear			
SOLAS	Chapter II-1 Regulation 29 29.6	Steering gear -When Main steering gear consist of two power units	Inconsistency: presented as an exception, while this is in reality standard solution for conventional rudder application. GAP: Not clear how this shall be applied to multiple rudder/thruster installation. Regulation may be read such that full steering gear capacity shall be available for passenger ships after failure (failure of pump), i.e.: 2 pumps required for each rudder). It may also be considered that two independent rudders and steering gear provide redundancy on system level and hence should represent an equivalent level of safety.	Insufficient performance (astern, normal and reduced service)	- Loss of steering capability, Loss of output of actuating system, Loss of steering control output

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
SOLAS	Chapter II-1 Regulation 29 29.7	Steering gear control	Comment: (I) 29.7.2 : hydraulic telemotor is usually not relevant and should also be duplicated if it is the only means for remote control (manual operation from steering gear compartment still acceptable solution). May consider to include a size limit for when manual control from steering gear compartment is acceptable.		
SOLAS	Chapter II-1 Regulation 29 29.8	Steering gear control system	Comment: 29.8.4 - Preferably include a list of most likely fail scenarios which shall result in alarms/ indications (both for control fail and other fail in SG system)		
SOLAS	Chapter II-1 Regulation 29 29.9	Steering gear-electric power			
SOLAS	Chapter II-1 Regulation 29 29.10	Steering gear - means of communication			
SOLAS	Chapter II-1 Regulation 29 29.11	Steering gear	Comment: consider finding neutral alternative to "rudder position"		
SOLAS	Chapter II-1 Regulation 29 29.12	Steering gear - hydraulics	GAP: Regulation 12.3, Not clear how this shall be applied to multiple rudder/thruster installation. Requested fixed storage tank for re-filling is a mean for regaining steering. It should be considered that two independent rudders and steering gears (with separate system tanks) provide	-component fail in actuating system -component failure caused by aging/degradation	- Loss of steering capability, Loss of output of actuating system

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
			redundancy on system level and hence should represent an equivalent level of safety.		
SOLAS	Chapter II-1 Regulation 29 29.13	Steering gear - compartment	GAP: some steering solutions combine propulsion and steering in the same unit. This may challenge the requirement for steering being "separated from machinery spaces" Comment: consider what shall be required for steering compartment in case it is also propulsion machinery space wrt. fire detection/extinguishing or other means of minimising risk of loss of steering/propulsion	- External impact on steering system, fire, water ingress - Incident in other onboard system	-Loss of steering capability, Loss of propulsion
SOLAS	Chapter II-1 Regulation 29 29.14	Steering gear- additional alternative power supply	GAP: Requirement is not considering if ship is designed with higher level of redundancy on power supply with reduced risk of loss of power to steering gear. GAP: requirement is not considering if the movement of rudder will have effect on ships course in the event of loss of power/propulsion	-Insufficient performance (astern, normal and reduced service), Loss of electric power	-Loss of steering capability, (Loss of propulsion),
SOLAS	Chapter II-1 Regulation 29 29.15	Steering gear	Comment: Suggest change wording such that Paragraph 29.6 arrangement is basic solution, and open for "aux steering gear" as alternative for ships of		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
			smaller size (tanker <10.000 gt and others < 70.000 gt)		
SOLAS	Chapter II-1 Regulation 29 29.16	Steering gear - tanker	GAP: Not clear how this shall be applied to multiple rudder/thruster installation. Regulation may be read such that full steering gear capacity shall be available for tankers after failure (failure of pump), i.e..: 2 pumps required for each rudder). It may also be considered that two independent rudders and steering gear provide redundancy on system level and hence should represent an equivalent level of safety.	Insufficient performance (astern, normal and reduced service)	- Loss of steering capability, Loss of output of actuating system, Loss of steering control output
SOLAS	Chapter II-1 Regulation 29 29.17	Steering gear - tanker	Comment: this is a particular solution. Keep as accepted solution/deviation		
Resolution	A.415(XI)	on improved steering gear standard for passenger and cargo ship			
Resolution	A.416(XI)	on examination of steering gears on existing tankers			
MSC.1	Circ.1398	Unified interpretation of SOLAS Reg.-1/29 mechanical, hydraulic and electric independence and failure detection and response	Comment: regarding hydraulic locking (4.1.1.4): To be technology neutral the wording of the alternative as described in 4.1.3 should be used as primary: Critical deviation between order and response.		

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
MSC.1	Circ.1536	Unified Interpretation of SOLAS Regulations II-1/29.3 and 29.4, trial at not deepest draft			
SOLAS	Chapter II-1 Regulation 30	Additional requirements for electric and electrohydraulic steering gear	Inconsistency: modern overcurrent protection does not require the 200% margin		
SOLAS	Chapter V Regulation 25	Operation of steering gear - running two pumps in area of special caution -& 26 Steering gear: Testing and drills	Inconsistency: regulation represent a concrete operational action to be taken in areas which require special caution, if the steering gear has multiple power units which can be operated simultaneous. May request that regulation is developed such that multiple power unit is mandatory OR that special caution is taken independent of units.		
SOLAS	Chapter V Regulation 26	Steering gear: Testing and drills	GAP: modern control systems often offer several operation modes and other functionalities which also shall be familiarised to operator. Operation instruction should focus on user interface at navigation position and available backup systems in addition to the local steering as means to regain steering Comment: -modify terms to be technology neutral Comment: May expand on operation instruction	Human element	-Control loop inadequate

Doc.ref	Doc. Ref. Paragraph	Name or topic	Gap/Inconsistency/Comment	Addressed in hazard:	Addressed in Failure mode
SOLAS	Chapter II-1,B1-Regulation 8-1 and Chapter II-2, G Regulation 21.4	Safe return to port	GAP: missing a guidance or preferably a quantification of required available capacity and performance parameters after fail Comment: Steering and steering control is included - however not clarified the required available capacity after fail	Insufficient performance (astern, normal and reduced service)	-Loss of steering capability, (Loss of propulsion),

Appendix B. Hazard Identification Workshop

Participants in HazId workshop

- Eivind Ruth (Resistance and propulsion – DNV Maritime Advisory)
- Svein Olav Hannevik (Machinery – DNV Approval)
- Lisbeth Iversland (Control systems – DNV Approval)
- Odd Magne Nesvåg (Ship systems and components – DNV Approval)
- Odd Charles Hestnes (Marine Cybernetics + operational experience – DNV Maritime Advisory)
- Magnus Jordahl (HazId facilitator – DNV Maritime Advisory)
- Anna K. Ervik (PM and scribe – DNV Maritime Advisory)
- Jose Diaz Yraola (EMSA)

In addition, in as a follow-up of the workshop, the identified hazards were ranked in a separate meeting, including the following participants;

- Magnus Jordahl (see above)
- Svein-Olav Hannevik (see above)
- Anna Kringlen Ervik (see above)
- Rainer Hamann (Risk Assessment/IMO Goal-Based Standards - DNV Regulatory Affairs)

The following criteria have been used for the rating of the hazards. Likelihood and frequency are taken from FSA Guidelines (3) and Severity is amended focusing on the loss of manoeuvrability. RI (Risk Index) = FI (Frequency Index) + SI (Severity Index)

Consequence (Severity)		Likelihood/Frequency						
		1	2	3	4	5	6	7
Index	**Asset damage Downtime**	Likely to occur once in the lifetime (20) of a world fleet of 5000 ships	Likely to occur once in the lifetime (20) of a fleet of 500 ships	Likely to occurs once per year in a fleet of 1000 ships	Likely to occurs once per year in a fleet of 100 ships	Likely to occurs once per year in a fleet of ten ship	Likely to occurs once per year on one ship	Likely to occurs once per month on one ship
		10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10
1	Very limited/negligible effect on steering performance (at this moment, may lead long-term loss of functionality)	2	3	4	5	6	7	8
2	Reduced steering performance (slower reaction but steering forces not reduced)	3	4	5	6	7	8	9
3	Significantly reduced steering performance (i.e. performance of what is specified as auxilliary steering = reduced steering forces -> vessel needs to operate slower)	4	5	6	7	8	9	10
4	Total loss of steering, can be regained at sea (system can be repaired and at least reduced performance regained)	5	6	7	8	9	10	11
5	Total loss of steering, cannot be regained at sea	6	7	8	9	10	11	12

HazId tables

FI = Frequency Index, SI = Severiy Index, RI = Risk Index

Hazards for control system

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
A1	Water ingress	Spill Broken windows Broken seal Hull penetration Pipe failure Fire-fighting system failure Human error	Malfunction of equipment Potential loss of or reduced performance of steering	assuming that the ship is well designed: unlikely Malfunction of control system -> loss of control system.	3	5	8	protect control system against water ingress (SOLAS ch.II Part B-2)	Provide redundancy separated (29.1, 29.7.2) SRtP (II-1 21) Steering without remote control system (29.7.1, 29.8.2)
A2	Vibrations	Equipment too close to machinery with rotating parts Malfunction of external equipment Cavitation Vortex shedding Broken damper Mechanical failure	Loose connections or cables Malfunction of control equipment Fatigue	For components not designed for this environment: likely Malfunction of control system -> loss of control system.	5	5	10	design control system for ship's vibration protect system against vibration	Provide redundancy separated (29.1) Steering without remote control system (29.7.1)

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
		Heavy sea Wind							
A3	Accelerations due to environmental loads	Rough weather	Loose connections or cables Malfunction of control equipment Fatigue Broken damper	Malfunction of control system -> loss of control system.	4	5	9	design control system for ship's accelerations protect system against	Provide redundancy separated (29.1, 29.7.2) Steering without remote control system (29.7.1, 29.8.2)
A4	Fire in the system	short circuit overheating flammable liquids (spill or leak) mechanical impact foreign objects	Malfunction of equipment Potential loss of or reduced performance of steering	Low probability but loss of control system	2	5	7	Minimise likelihood of fire Today system work on 24 V which makes it very unlikely that fire occurs	Provide redundancy separated (29.1, 29.7.2) SRtP (II-1 21) Steering without remote control system (29.7.1, 29.8.2)

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD	
								~FI	~SI
A5	External fire		Malfunction of equipment Potential loss of or reduced performance of steering	Fire on ship ~10^-3; in vicinity of control even less if hits control system -> loss	3	5	8	Minimise likelihood of fire (SOLAS Ch.II-2) Separated from machinery space (29.13.1)	Provide redundancy separated (29.1, 29.7.2) SRtP (II-1 21) Steering without remote control system (29.7.1, 29.8.2)
A6	Cyber attack		Loss of steering	Complete loss of control system without any other possibility of intervention complete loss	4	5	9	IMO Guidelines (MSC-FAL.1/Circ.3)	
A7	Software error	software update system complexity	loss of steering malfunction of system	reduced control of steering -> reduced performance	3	3	6		
A8	Energy surge	power system failure lightning	Malfunction of equipment Potential loss of or	Not considered today. According to H.	1	3	4		

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
			reduced performance of steering	Bluhm not possible					
A9	Human error	system complexity HMI inadequate training	incorrect operation reduced availability temporary loss of steering potential loss of steering 'Information overload for operators	not clear how to estimate likelihood effect: reduced performance	4	3	7	STCW Part A VIII-17	
A10	System complexity	increased functionality increased integration demand	false behaviour of the system	not clear how to estimate likelihood effect: reduced performance Only that failures not relating to human interventions	2	4	6		

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD	
								~FI	~SI
A11	Network error	overload component failure restart security breach	Reduced performance potential loss of steering	NEEDS sharing with other onboard systems if so FI=3 More likely than cyber-attack Common machinery bus, navigation bus	3	4	7	Steering system completely independent (No sharing with other systems)	
A12	Overbuildings of the steering system (autopilot, DP system, safety systems)			Steering "used/operated" by other systems …	4	4	8		Disconnect additional System(s)

Hazards for electrical power system

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
B1	Blackout	short-circuit operation mode power demand changes	Loss of steering	No electric supply, no steering Blackout occurs often however mostly in areas not leading to dangerous situations Only relevant if in coastal/restricted water or harbour Electrician: likelihood for blackout seems a bit high (FI = 4)	4	5	9	SOLAS Ch. II-1 Part D	Provide emergency energy (29.14)
B2	Insufficient power available	software error power management system failure system complexity integration problems	reduced performance	When power is unbalanced -> blackout! Thus, standard is that If power not in balance single, less important consumers are disconnected. Steering is essential and will remain operable.	4	5	9	Reliability of power management system (already considered SOLAS Ch. II-1 Part D	Provide emergency energy (29.14)
B3	Main switchboard failure	short circuit overheating mechanical impact foreign objects	Partly loss of steering	Less likely than blackout no power - no steering Impacts & objects lead to light arc -> complete loss of SB	3	5	8	SOLAS Ch. II-1 Part D	provide emergency power supply (29.14), e.g. via emergency

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
									switchboard or stored energy
B4	System integration	Separate system suppliers	reduced performance	Not directly linked to ship service time but per system. Assuming one failure per 100 ships and per ship life = 1/2000 i.e. FI=2…3	2	3	5	Quality assurance for complete system integrated in ship	

Hazards for actuating system

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	 ~SI
C1	Overload	External force (waves, current, etc) blockage bearing failure	damage to the system potential reduced capacity loss of function	Single overload leads to damage of the system (deformation or fracture) Likelihood depends on the adequateness of anticipated loads Likelihood of severe weather conditions and blockage leading to non repairable loss FI=3…4 (considering current design) means one to two cases in our container fleet Internal produced overloads depend on design, e.g. what max. pressure could be provided. Blockage: hydraulic system works against "obstacle" and produces overpressure.	4	5	9	safety factor (29.2.1) (adjusted to knowledge level) Inherent limitation of loads (pressure relief) (29.2.2.)	Redundancy (29.5, 29.6.1)

C2	Contamination of oil	wear and tear human error failing seals corrosion	damage to the system potential reduced capacity loss of function	Hydraulic system not completely sealed (dust) plus wear causes contamination of oil dirt during refill. reduced or lost performance (valves very sensitive on dirt); cannot be speedily rectified	6	4	10	Cleaning devices (29.12.1) Inspection&maintenance No hydraulic system	Redundancy (29.1, ff)
C3	Loss of pressure	low oil level leaks failing seals pipe/hose rupture failing valves human error power failure	loss of function	Human error: "opening of valve -> loss of oil" (only during maintenance) Regarding other causes: due to operation and environmental influence, leakage is regarded to occur about, leakage can be detected before "rupture" focus on "loss of performance" FI=3	3	4	7	Inspection & maintenance (V 26.2) Adequate design	Redundancy (29.6.1.3, 29.6.1, 29.1) Speedily regain system (refill) (29.12.3)

C4	Mechanical damage	Dropped objects External force corrosion	damage to the system potential reduced capacity loss of function	If system is not separated from other machinery space it is FI=3; Corrosion/fatigue is long-term process and easier to detect in inspection FI=3. Corrosion and fatigue can lead to leakage/rupture in hydraulic system External: grounding -> deformations	3	4	7	separate steering system installation from other areas (e.g. machinery space) (29.13.1, 29.13.2) Inspection regime	Redundancy (29.5, 29.6.1)
C5	Fire	fatigue	mechanical deformation degraded material properties loss of function	As long as it is not broken down to compartment level same as for control system (ex. Fire) Fire impact directly on system	3	5	8		For high risk (Pax): SRtP (many people affected) Separate from machinery space (29.13.1)
C6	Lack of lubrication		failing bearings	long-term process. First leads to higher steering forces (SI = 3) Frequently reported but	5	2	7	Inspection	

				often identified before consequences						
C7	Uncertain design loads	uncertainties in environmental loads uncertain load model? Limited knowledge about operational loads	overloads	Cause for e.g. external overloads -> same as overloading	8	5	0	safety factor (29.2.1) (adjusted to knowledge level) Inherent limitation of loads (29.2.2.)	

[8] Experts were not able to make a sound estimation of the probability

Hazards for steering force unit (rudder, rudder stock, Thruster housing etc.,)

	Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FI	~SI
D1	External overload	Waves and current Collision and grounding Ice Foreign object in water	structural damage to components and steering mechanism reduced performance or loss of function failing bearings	single overload leads to damage of the system (deformation or fracture) likelihood depends on the adequateness of anticipated loads Likelihood of severe weather conditions leading to non-repairable loss FI=3…4 (considering current design) means one to two cases in our container fleet	4	4	8		Limits tiller to limit maximum rudder angle (external forces) -> afterwards yielding of shaft **expecting** that damage is limited and reduced performance still available IACS M42 requires that all components transmitting mechanical forces and not protected against overloads by structural "means" have at least a strength equivalent to the rudder stock in way of tiller.
D2	Internal overload	overload in hydraulic pressure overcurrent in electric system failing bearings	damage to components and steering mechanism reduced	Hydraulic means higher forces on the mechanical parts or on the hydraulic system	1	3	4		

			performance or loss of function						
D3	Operating outside design limits	human error system error	damage to steering mechanism, rudder, thruster housing insufficient stability (excessive forces)		3	3	6	Training systems	
D4	Propulsor out of water	heavy seas design of the vessel	Overspeed mechanical and electrical damage	When propulsor is out of water we are losing also steering force -> reduced manoeuvrability for all propulsion systems Consequences for vessel more important than for the steering system!	2	5	7	Weather routing (good seamanship)	
D5	Mechanical blockage	foreign object in the water initial low clearance (integrated	loss of function	In severe cases steering capability is not regained at sea.	3	5	8	design for low probability (arrangement of steering)	

		prop.-rudder system and nozzles)							
D6	Mechanical damage	Cavitation Vibrations/fatigue Impact	Rudder damage Reduced performance loss of rudder/parts of rudder		4	2	6		
D7	Fire		mechanical deformation degraded material properties loss of function	see row C6			0		
D8	Lack of lubrication		failing bearings	in a longer run it can cause blockage of rudder	2	5	7	inspection	
D9	Uncertain design loads	uncertainties in environmental loads uncertain load model? Limited knowledge about operational loads	overloads		3	4	7		

Hazards for propulsion

Hazard	Cause	Consequence	Explanation	FI	SI	RI	SAFEGUARD ~FR	 ~SI
loss of propulsion		loss of steering function		3	4	7		
stopping length too long	dynamics of machinery (time to go astern too long)	CN, GR	accidents cannot be avoided in emergency situations (e.g. other ship not following COLREG) GR accidents ~10^-3 CN~10^-2 -> this can only provide a fraction to these categories and requires that crew does not react according to ship's performance, i.e. too late. Further, stopping is not only means to avoid accident. Alternative: change course. Thus 10^-5. Consequences on ship level	1	5	6		

Appendix C. Hazards recursively identified in SOLAS regulations

SOLAS Chapter II-1, Part C

Reg 28	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
1	Propulsion & ME	Insufficient performance	1	Propulsion power not sufficient to stop the vessel (design error)	Accident (CN, CT, GR) cannot be avoided	Performance	--
2	Propulsion, Machinery	Insufficient performance	1	Propulsion power not speedily available to stop the vessel (design error)	Accident (CN, CT, GR) cannot be avoided	Performance	--
3	Documentation of performance	Insufficient performance (crew not aware of performance) Human error	1 13	Inadequate consideration of performance when navigating the vessel	Accident (CN, CT, GR) cannot be avoided	Performance	Information
4	Documentation of performance	Human error	13	No consideration of supplementary means	Accident (CN, CT, GR) cannot be avoided	Performance	Information

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
1	Steering gear	Component/system failure	4 5 6 7 8	Any failure of component in steering gear Component damaged Degradation	Loss of steering capability	Availability	Redundancy
2.1	Steering gear Rudder stock	Component/system failure	7	Mechanical failure of component in steering gear and rudder stock due to incorrect consideration of operational/accidental loads	Loss of steering capability	Reliability	Quality of design
	Bearings	Component/system failure	7	Mechanical failure of bearings	Reduced performance Loss of steering capability	Reliability	Type of component
2.2	Actuator (hydraulic)	Component/system failure	7	Failure of hydraulic system (rupture due to overpressure; wrong determination of pressure loads)	Loss of steering capability	Reliability	Min. loads
	Actuator (hydraulic)	Component/system failure	5	Fatigue loads in hydraulic system (pulsation)	Loss of steering capability	Reliability	Determination of loads

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
2.3	Actuator (hydraulic)	Component/system failure	5 (focus on availability of redundancy, see Section 6.4.3)	Blockage by hydraulic element, e.g. pressure cannot be influenced/controlled	Loss of steering capability	Availability	Independency of redundancy
	Actuator (hydraulic)	External impact	11 (7)	Failure of hydraulic system due to overloads (rupture due to overpressure)	Loss of steering capability	Reliability	Safety device (limitation of max. loads)
3.1	Steering gear Rudder stock	Insufficient performance	2	Steering power not sufficient to provide full performance at max service speed ahead (assume fully loaded vessel)	Ship cannot safely manoeuvre	Performance	Min. performance for steering
3.2	Steering gear Rudder stock	Insufficient performance	2a	Steering system does not provide adequate dynamics	Ship cannot safely manoeuvre Too low turning speed	Performance	Min. performance for rudder turning
3.2.1 - 3	Demonstration of compliance						
3.3	Steering gear Rudder stock	Insufficient performance	2c	Positioning forces too high due to dimensions of steering force system	Ship cannot safely manoeuvre Design performance cannot be achieved	Performance	Power support for certain dimensions

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
3.4	Steering gear Rudder stock	Component/system failure	7	Insufficient consideration of operational loads	Reduced performance / Loss of steering capability	Reliability	Determination of loads
4.1	Steering gear Rudder stock	Insufficient performance	3	Steering power not sufficient to provide full performance at max service speed ahead (assume fully loaded vessel)	Ship cannot safely manoeuvre	Performance	Min. performance for steering
	Steering gear Rudder stock	Delayed regain	12	Delayed regain of steering capability after failure of main Delay in starting the system	Loss of steering capability	Availability	
4.2	Steering gear Rudder stock	Insufficient performance	2a	Steering system does not provide adequate dynamic	Ship cannot safely manoeuvre	Performance	Min. performance for rudder turning
4.2.1 - 3	Demonstration of compliance						
4.3.	Power unit	Insufficient performance	2b	Steering system does not provide adequate dynamic	Ship cannot safely manoeuvre	Performance	Min. performance for rudder turning
5.1	Power unit	Delayed regain	12	Restart process after power failure (main switchboard)	Loss of steering capability	Availability	Automatic restart

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
5.2	Power unit	Delayed regain	11 12	Distance to control panel	Loss of steering capability	Availability	Positions to restart
	Power unit	Delayed regain	11 12	Failure in any power unit not detected	Loss of steering capability	Availability	Alarm
	29.6.1 & 2 specify reduced performance available after failure of main						
6.1.1	Power unit	Insufficient performance	3	Failure of any one of power units	Performance not sufficient for safely navigate passenger ship	Performance	Min. performance for rudder turning
6.1.2	Power unit	Insufficient performance	3	Failure of any one of power units	Performance not sufficient for safely navigate cargo ship	Performance	Min. performance for rudder turning
6.1.3	Power unit (Piping system)	Component/system failure (6) Delayed regain	5 12	Failure in piping (only hydraulic)	Loss of steering capability	Availability	Independency of redundancy
6.2	Grandfathering						
6.3	Equivalence to be achieved by other						

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
7.1	Steering gear control	Component/system failure	4	Malfunctioning of control system to navigation position	Loss of steering	Availability	Redundancy
		Insufficient performance	(4) (System can be operated without restriction of performance)	System cannot be adequately operated	Performance not sufficient for safely navigate ship	Performance	
7.2	Steering gear control	Component/system failure	(4)	Malfunctioning of control system to navigation position	Loss of steering	Availability	Redundancy
7.3	Steering gear control	Component/system failure	(4)	Malfunctioning of control system to navigation position	Loss of steering	Availability	Redundancy
8.1	Steering gear control	External impact	11	Failure in circuit (e.g. overload, short circuit) or by other consumer	Loss steering control Loss of steering	Availability	Power supply independent of other consumers
8.2	Steering gear control	Component/system failure	4 11	Steering control blocked/malfunctioning and cannot be disconnected	Loss of steering	Availability	Independency of redundancy

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
8.3	Steering gear control	Delayed regain	12	System cannot be speedily restarted due to distance to control panel	Loss of steering	Availability	Direct access to restart position
8.4	Steering gear control	Hidden defect	12	Failure in any power unit not noticed	Loss of steering	Availability	Alarm
8.5	Steering gear control	Component/system failure	4 7 (consider amendment)	Safety means cause stop because too sensitive	Loss of steering	Availability	Limit safety devices (fuse)
9	Electric power Steering gear control	External impact	11	Impact on power circuits and control systems of incidents in other ship systems	Loss of steering	Availability	Protect against impact
10	Steering gear compartment	Delayed regain (12) Component failure	12 4, 5	Countermeasures after failure cannot be coordinated Steering system cannot be operated directly	Loss of steering	Availability	Performance of redundancy Communication

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
11.1	Steering gear control Rudder	Component/system failure	4 9 10	Malfunction of steering gear control Erroneous functionality	Loss of rudder angle indication at navigation position -> Vessel cannot be steered from navigation position	Performance	Independent indication Navigate at navigation position without steering gear control
11.2	Steering gear control	Component/system failure	4 9	Failure of control system no rudder angle indication in navigation position	Vessel cannot be steered from steering gear compartment	Performance	Navigate in steering gear control
12.1	Actuator (hydraulic)	Component/system failure	8 (5)	Contamination of hydraulic system leads to blockage or reduced power	Loss of steering/reduced performance	Reliability	Mitigate potential failure source
12.2	Actuator (hydraulic)	Component/system failure	5	Leackage in hydraulic system	Loss of steering	Availability	Alarm
12.3	Actuator (hydraulic)	Delayed regain	12	Hydraulic oil cannot be speedily refilled after leakage in hydraulic system	Loss of steering	Availability	Material for repair
13.1	Steering gear Actuator	Delayed regain	12	Countermeasures delayed due to problems to reach defect component/system	Loss of steering	Availability	Fast access

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
	Steering gear Actuator	External impac	11	Fire or other impact cause failure of steering system	Loss of steering	Availability	Protect against impact Separate compartment
13.2	Steering gear Actuator	Delayed regain	12	Countermeasures delayed due to insufficient space	Loss of steering/no steering	Availability	Working environment
	Steering gear Actuator	Falling of crew	(see Progress Report 2, (18))	Insufficient/unsafe workspace	Injury - fatality Loss of steering/no steering		
14	Electric power	External impact	11	Due to loss of power supply	Loss of steering	Availability	Redundancy (emergency power)
	Electric power	Delayed regain	12	Due to loss of power supply	Loss of steering	Availability	Available in 45 s
15	Power unit	Insufficient performance	2	Failure in power unit		Performance	Tanker Min. performance for rudder turning
16.1	Actuator	Delayed regain	12	Failure in one power actuating system	Loss of steering	Availability	Performance of redundancy

Reg 29	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
16.2	Steering gear (main)	Component failure	5 6	Failure in one power actuating system	Loss of steering	Performance	Performance of redundancy
16.3	Equivalency						
17	Same as 16 but allowing different solutions						
18	Same as 16 but allowing different solutions						
19	Same as 16 but allowing different solutions						
20	Same as 16 but allowing different solutions						

Reg 30	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
1	Steering gear (electric/electric hydraulic)	Component/system failure	5	Failure in electric hydraulic system	Loss of steering system/capability/low performance	Availability	Alarm Inform on performance at navigation position/steering position
2	Steering gear (electric/electric hydraulic)	Component/system failure	5 11	Failure in electric circuit	Loss of steering	Availability	Redundancy Back-up for power supply directly from main switchboard, one may be emergency. For aux system may be connected to one serving main
	Steering gear (electric/electric hydraulic)	Component/system failure	6 (7)	Failure due to overload	Loss of steering	Availability	Rating adequate
3	Steering gear (electric/electric hydraulic)	Component/system failure	6 (7)	Failure due to overload	Loss of steering	Availability	Alarm

Reg 30	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	Ref. to Section 6.4.2				
	Steering gear (electric/electric hydraulic)	Component/system failure	7 6	Failure due to overload protection devices	Loss of steering	Availability	Adequate settings Avoid unnecessary stopping due to electric overload (system “failure” due to safety means/ only short circuit protection
	Steering gear (electric/electric hydraulic)	Delayed regain	12	No/low availability e.g. due to electric overload, not detected	Loss of steering	Availability	Alarm
4	Steering gear (electric/electric hydraulic)	Component/system failure	5	Failure of main system	Loss of steering		For small vessel aux system

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Reg 25	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
	Operation Steering	Delayed regain	12	Redundancy not directly available	Loss of steering system/capability/low performance	Availability	Stand-by operation if possible

Reg 26	Focus	Hazard		Cause	Consequence	Reg aims on	Means
		Focus	**Ref. to Section 6.4.2**				
1&2	Steering	Insufficient performance Component failure	8	System not in good condition /	Loss of steering system/capability/low performance	Availability	testing
3.1	Steering	Delayed regain	12 (13)	Unable to handle malfunction (Human element)	Loss of steering	Availability	Manual for using redundancy
3.2	Steering	Delayed regain	12 (13)	Unable to handle malfunction (Human element)	Loss of steering	Availability	Familiarization with change over
4	Steering	Delayed regain	12 (13)	Unable to handle malfunction (Human element)	Loss of steering	Availability	Training and drills for emergency

5	Steering	Alternative to 1&2	12 (13)				
6	Steering	Reporting on ...	12 (13)				

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Reg 21	**Focus**	**Hazard**		**Cause**	**Consequence**	**Reg aims on**	**Means**
		Focus	**Ref. to Section 6.4.2**				
	Steering gear	External impact	11	Fire in any compartment (includes fire in compartments used for steering system)	Loss of steering	Availability	Steering performance available after **fire** in any space surrounded by A class boundary
Reg.8-1	Steering gear	External impact	11	Flooding of any compartment	Loss of steering	Availability	A passenger ship shall be designed so that the systems specified in regulation II-2/21.4 remain operational when the ship is subject to flooding of any single watertight compartment

Appendix D. Failure modes and hazards

Steering system

Failure mode L1[9]	Failure mode L2	Failure mode L1	Hazard L1	Hazard L2	Hazard L3
Malfunction of steering	Loss of steering capability	Loss of steering control output	Component failure	Failure of electrical component	Vibration
					Acceleration
				Failure of electronic component	Vibration
					Acceleration
			Fire		
			Water ingress		
			Loss of (electric) power	Blackout	Cyber-attack
					Water ingress
				Main switchboard failure	Fire
					Water ingress
				Failure in power transmission	Vibration
					Acceleration
					Fire
					Water ingress
				Network error	
			Software error		Cyber-attack
			Damaged by other ship systems	Network error	
		Loss of output of actuating system	Component failure	Valve blocked	
				Loss of hydraulic oil/pressure	
				Electric motor blocked	

9 Level indicator

Failure mode L1[9]	Failure mode L2	Failure mode L1	Hazard L1	Hazard L2	Hazard L3
		(no input at steering force unit)	Mechanical damage/failure	Overload	
				Fatigue	
				Impact by objects	
			Fire		
			Water ingress		
			Loss of (electric) power		
		Steering force unit does not deliver output when other subsystems operate correctly	Mechanical damage/failure	Overload	
				Fatigue	
			Force unit lost	Overload	
				Fatigue	
			Blocked	Floating object	
				No lubrication moving parts	
		Steering actuating system and steering force unit damaged by operational loads	Mechanical damage/failure	Overload	
				Fatigue	
			Force unit lost	Overload	
				Fatigue	
	Not operating according to intended functionality	Erroneous steering control system output	Faulty component		
			Impact by other system		
			Software		
			Cyber-attack		
		Erroneous actuating system output	Faulty component	Loss of hydraulic oil	
				Valve	
				Electronic	

Failure mode L1[9]	Failure mode L2	Failure mode L1	Hazard L1	Hazard L2	Hazard L3
				Software	
			Impact by other system		
			Cyber-attack		
		Steering force not controlled	Force unit misaligned		
			Force unit blocked		
Steering system not used corresponding to performance	Helmsman har problems to operate steering system (human interface, control loop inadequate)		Human error	Lack of training & drill	
				Lack of information	
			Software		
Steering system not available/low performance due to failure external impacts	Failure of electric power/loss of electrical power supply		Loss of (electric) power	Overload in electrical system / blackout	
				Short circuit in other ship system	
	Reduced electrical power supply		Insufficient electrical power supply		
	Fire		Fire		
Steering system functionality/performance inadequate for vessel operation	Ship's turning speed too low		Steering & hull not harmonised		
	Ship's turning radius too large		Steering & hull not harmonised		
	Inherent dynamic stability insufficient		Steering & hull not harmonised		

Failure mode L1[9]	Failure mode L2	Failure mode L1	Hazard L1	Hazard L2	Hazard L3
	Excessive oscillation of rudder required to keep predetermined course		Steering & hull not harmonised		
	Steering force not effective in transient manoeuvre		Steering & hull not harmonised		

Propulsion

Failure mode L1	Failure mode L2	Hazard L1	Hazard L2	Hazard L3
Thrust inadequate to stop	Weather condition			
	Propulsion & vessel not harmonised			
Thrust too late available to stop	Reversing process too slow			
	Human error	Lack of training & drill		
		Lack of information		
Malfunction of propulsion	Loss of propulsion	Mechanical damage/failure	Overload	Propeller out of water
			Fatigue	
			Impact by objects	
	Not operating according to intended functionality	…		

Redundancy

Failure mode L1	Failure mode L2	Hazard L1
Redundancy is not operating	Loss of steering control output	Blocked
		Common cause failure (same failure affects both main and redundancy)
		Component failure (in redundant system)
	Loss of output of actuating system (no input at steering force unit)	Blocked
		Common cause failure (same failure affects both main and redundancy)
		Component failure (in redundant system)
Redundancy cannot be used because being blocked by initial failure	Loss of steering control output	Blocked
	Loss of output of actuating system (no input at steering force unit)	Blocked
Redundancy not timely available	Failure not noticed	
	Distance to starts system	
	Loss of output of actuating system (no input at steering force unit)	
Redundant steering functionality/performance inadequate for vessel	Ship's turning speed too low	Steering & hull not harmonised
	Ship's turning radius too large	Steering & hull not harmonised
	Steering force not effective in transient manoeuvre	Steering & hull not harmonised

Appendix E. Functions – expected performance – hazards

Steering system

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
I. Provide steering performance adequate for ship operation	• Ship-steering system inherent dynamic stable in case of undisturbed as well as disturbed steering system operation	Insufficient performance for normal operation: Steering effort too high (dynamic instable, difficult to keep course)	2 (a)
	• The ship can maintain a straight course without excessive oscillations of steering force unit or heading in case of undisturbed as well as disturbed steering system operation	Insufficient performance for normal operation: Excessive oscillation of rudder required to keep predetermined course Steering effort too high (dynamic instable, difficult to keep course) Cannot be operated efficiently (by helmsman)	 2 (b) 2 (a) 2 (c)
	• Ability to turn/change course a. In case of undisturbed steering system operation: Meeting requirements for normal service condition b. In case of disturbed steering system	Ship cannot be effectively controlled by steering system (in normal ship operation) Cannot be operated efficiently (by helmsman) Ship cannot be effectively controlled by steering system (after failure in steering control or actuating system)	2 (b) 2 (c) 3

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
	operation: Meeting requirements for reduced service condition		
	Steering system operation and ship manoeuvring concur with intended use and predicted characteristics	Cannot be operated efficiently (by helmsman) Steering forces too high	2 (c)
II. Steering capability is maintained or can be regained in case of malfunction of one of the sub-systems steering control or steering actuating or both together	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	Component failure in actuator system leading to failure of actuating system, i.e. malfunctioning of any electrical or electronic component, software failure, failure of mechanical/hydraulic component. Example: Steering system is blocked or rendered inoperable by failure in hydraulic system	5
	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	Component failure in control system leading to failure of control system, i.e. malfunctioning of any electrical or electronic component, software failure Example: Control system is blocking redundancy rendering the whole steering system inoperable	4

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
	Normal service steering capability is available without steering remote control system - Steering gear can be locally operated without remote control system	Loss of steering control output including any redundancy in control system Component failure in control system leading to failure of control system, i.e. malfunctioning of any electrical or electronic component, software failure	4
	Steering performance will be speedily regained: For tankers > 10.000 GT: within 45 s (e.g. by warm redundancy) Not tanker or tanker ⩽ 10.000 GT: within 15 min. (e.g. by cold redundancy)	Delayed regain of steering performance after failure in control system or actuating system (redundancy not timely available or normal service cannot be timely regained) Cause: Component failure in control system or actuating power system	12 (a, b) (4,5,6)
	Availability of steering system continuously monitored and indicated on navigation position	Delayed regain of steering performance after failure in control system or actuating system Erroneous operation - Human element (not noticed that only reduced performance available) - System/component failure not noticed	12 (a), 13
	Loss of availability is indicated by an alarm	Delayed regain of steering performance after failure in control system or actuating system - System/component failure not noticed	12 (a)

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
III. Steering system is designed adequately for operational loads	Components have adequate strength for ship operation and specified design life, considering:	System/components damaged by operational loads	7
	-All mechanical, hydraulic and electrical loads	Not all operational loads considered	
	-Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice)	System/components damaged by operational loads (static, fatigue) Design loads do not cover operational loads of the intended ship operation	7
	-Material properties and component properties	System/components damaged by operational loads (static, fatigue) Material properties and manufacturing quality not adequately considered	7
	-Safety factor adequate to address uncertainty in load determination and material/component properties	System/components damaged by operational loads (static, fatigue) Uncertainty in operational loads and material/component properties > safety factor	7
	-Actuating system is protected from overloads resulting from malfunctioning of the system	System/components damaged by overloads (static, fatigue) Internally caused overloads	7, 9, 10, 11

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
	Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality	Corrosion, wear and tear reduce component properties, i.e. reduce structural resistance	8
	System operable under ship motion and environmental conditions	Failure of steering system (control, actuating, force unit) under normal operational condition of vessel (motion: acceleration, heel)	7 (3 to 6)
	Inspection concept adequate for steering system design	Failure of steering system (control, actuating, force unit) Example: Erroneous activation of safety device due to too high sensitivity	3, 4, 5, 6
	Inspection concept adequate for steering system design.	Failure of steering system (control, actuating, force unit) System pre-damaged by corrosion, wear and tear Redundancy not available (not functioning)	3 to 8
IV. Steering system is protected from external impacts	Steering control system and actuator system are separated from other ship systems	Failure and incident in other onboard systems should not render steering system inoperable.	11 (see also Section 6.2.2: "Integrating steering control system …")

Function	**Expected Performance**	**Rationale (i.e. hazards addressed)**	**Reference to Hazard no. (from list in Section 6.4.2)**
	Steering system is protected from external impacts by fire	Fire in other onboard systems (e.g. short circuit) and/or compartments	11
	Steering system performance is not affected by Electric magnetic interference	Malfunction of control system or actuating system due to EMI	11 (see also Section 6.2.2: hazards for control system)
	Actuating system is protected from overloads, respectively; • Overloads due to external forces • Overloads resulting from erroneous operation	Steering actuating system and steering force unit damaged by overloads, e.g. due to adverse weather conditions or erroneous operation	11
For Pax of 120 m in length or more or having three or more main vertical zones: Steering capability available after loss of any A-bounded space	Fire: reduced service capability available after loss of any space of origin • up to the nearest A class boundaries protected by fixed fire extinguishing system; or,	Passenger ship loses steering capability by a fire or water ingress (e.g. collision, grounding)	11

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
	• and adjacent spaces up to nearest A class boundaries outside the space of origin		
	Flooding: reduced service steering capability available after flooding of any single watertight compartment		
V. Minimize impact of erroneous functionality	Steering system shall be arranged with a fail-safe behaviour in case of failures	Erroneous performance of control system Erroneous performance of actuator system	9, 10
	Malfunction in data communication and programmable systems are easily detectable		
	Consequences of malfunction in data communication and programmable systems are limited and do not render the system inoperable or with insufficient performance and at least reduced service performance is maintained		

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
	Earth fault does not render the system inoperable or with insufficient performance and at least reduced service performance is maintained		
VI. Minimize impact of erroneous operation	Minimize possibilities of steering system operation threatening ship safety: • Limit possibility of erroneous input • Limit effect of erroneous input	Erroneous operation of steering system (Human element), e.g. operate steering system in a way endangering ship safety	13
VII. Enabling proper operation by considering steering control loop	Provide information about vessel's manoeuvrability characteristics	Erroneous operation - Human element: helmsman does not adequately consider manoeuvrability capabilities	13
	Provide familiarisation of vessel's manoeuvrability characteristics	Erroneous operation - Human element: helmsman does not operate the system according to its characteristics	13

Propulsion system

Function	Expected Performance	Rationale (i.e. hazards addressed)	Reference to Hazard no. (from list in Section 6.4.2)
VIII. Provide propulsion performance adequate for ship operation	Direction of propulsion thrust can speedily be changed between ahead and astern to bring the ship to rest	Thrust too late available to stop	1
	Propulsion thrust astern is adequate for evasive manoeuvres Propulsion, including stopping length concurs with intended use and anticipated characteristics	Thrust too late available to stop (human element: ship not operated according to capabilities) Thrust insufficient to stop vessel timely (performance so poor that it cannot be safely operated)	1

Appendix F. Verification of conformity

Numbering Matrix

FR No	FR Text	EP No		C[10]	EP Text
I	Provide steering performance adequate for ship operation	1	.0	Y	The ship can maintain a straight course *with yaw oscillations less than ±2 degrees for 60 minutes. Applicable both for normal and reduced service condition.*
		2	.0	Y	Ability to turn/change course
		2	.1	Y	a. In case of undisturbed steering system operation: Meeting requirements for normal service: *advance: <4.5 ship length, diameter<5 ship length.* The steering system shall be able to cover neutral to 90% of max declared steering angle in not more than 14 sec. [11]
		2	.2	Y	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle in not more than 28 sec [12]
		3	.0	Y	Steering system operation and ship manoeuvring concur with intended use and predicted characteristics
II	Steering capability is maintained or can be regained in case of malfunction of one of the sub-systems steering control or steering actuating or both together	1	.0	Y	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained
		1	.1	Y	For passenger ships, and tankers, chemical tankers and gas carriers ≥ 10,000 GT normal performance is maintained
		1	.2	Y	and for all other ships at least reduced service performance is maintained
		2	.0	Y	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.
		3	.0	Y	Normal service steering capability is available without steering remote control system

[10] Considered by current IMO regulations and recommendations (Y/N)

[11] This Expected Performance has not been updated to consider the updated requirements to steering gear strength and steering angle speed, outlined in Section 8.7.4.

[12] This Expected Performance has not been updated to consider the updated requirements to steering gear strength and steering angle speed, outlined in Section 8.7.4.

FR No	FR Text	EP No		C[10]	EP Text
		4	.0	Y	Steering performance will be speedily regained
		4	.1	Y	For tankers >10.000 GT within 45 s (e.g. by warm redundancy)
		4	.2	N	For all other ships within 15 min. (e.g. by cold redundancy)
		5	.0	Y	Availability of steering system continuously monitored and indicated on navigation position
		6	.0	Y	Loss of availability is indicated by an alarm
III	Steering system is designed adequately for operational loads	1	.0	Y	Components have adequate strength for ship operation and specified design life, considering:
		1	.1	Y	All mechanical, hydraulic and electrical loads
		1	.2	Y	Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice)
		1	.3	Y	Material properties and component properties
		1	.4	Y	Safety factor adequate to address uncertainty in load determination and material/component properties
		1	.5	Y	Actuating system is protected from overloads resulting from malfunctioning of the system
		2	.0	Y	Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality
		3	.0	N	System operable under ship motion and environmental conditions
		4	.0	Y	Steering system availability is not hampered by safety devices
		5	.0	Y	Inspection concept adequate for steering system design
IV	Steering system is protected from external impacts	1	.0	Y	Steering control system and actuator system are separated from other ship systems
		2	.0	Y	Steering system is protected from external impacts by fire
		3	.0	N	Steering system performance is not affected by Electric magnetic interference

FR No	FR Text	EP No		C[10]	EP Text
		4	.0	Y	Actuating system is protected from overloads, respectively;
		4	.1	Y	Overloads due to external forces
		4	.2	Y	Overloads resulting from erroneous operation
		5	.0	Y	Additionally, passenger ships of 120 m in length or more or having three or more main vertical zones:
		5	.1	Y	Fire: reduced service capability available after loss of any space of origin up to the nearest A class boundaries protected by fixed fire extinguishing system; or adjacent spaces up to nearest A class boundaries outside the space of origin
		5	.2	Y	Flooding: reduced service steering capability available after flooding of any single watertight compartment
V	Minimize impact of erroneous functionality	1	.0	Y	Steering system shall be arranged with a fail-safe behaviour in case of failures
		2	.0	Y	Malfunction in data communication and programmable systems are easily detectable
		3	.0	N	Consequences of malfunction in data communication and programmable systems are limited and do not render the system inoperable or with insufficient performance and at least reduced service performance is maintained
		4	.0	N	Earth fault does not render the system inoperable or with insufficient performance and at least reduced service performance is maintained
VI	Minimize impact of erroneous operation	1	.0		Minimize possibilities of steering system operation threatening ship safety:
		1	.1	N	Limit possibility of erroneous input
		1	.2	Y	Limit effect of erroneous input
VII	Enabling proper operation by providing information about	1	.0	Y	Provide information about vessel’s manoeuvrability characteristics
		2	.0	Y	Provide familiarisation of vessel’s manoeuvrability characteristics

FR No	FR Text	EP No		C[10]	EP Text
	ship's manoeuvring characteristics				
VIII	Provide propulsion performance adequate for ship operation	1	.0	Y	Propulsion, including stopping length, concurs with intended use and anticipated characteristics
		1	.1	Y	*Vessel can be brought to rest with stopping distance within 15 ship lengths*
		1	.2	N	*For ships provided with multiple propulsion lines and/or steering systems: In reduced service the vessel can be brought to rest with stopping distance within 20 ship lengths*

FR I: Provide steering performance adequate for ship operation

EP			**Regulation**			
No			**Chapter**	**No**	**Text**	**Objective**
3	.0	Steering system operation and ship manoeuvring concur with intended use and predicted characteristics	II-1	29.3.1	of adequate strength and capable of steering the ship at maximum ahead service speed which shall be demonstrated;	adequate capabilities of steering gear
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	II-1	29.3.2	capable of putting the rudder over from 35° on one side to 35° on the other side with the ship at its deepest seagoing draught and running ahead at maximum ahead service speed and, under the same conditions, from 35° on either side to 30° on the other side	Performance requirement (steering system) only traditional - max. angle - dynamic performance of the rudder

EP			Regulation			
No			**Chapter**	**No**	**Text**	**Objective**
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	II-1	29.3.3	operated by power where necessary to meet the requirements of paragraph 3.2 and in any case when the Administration requires a rudder stock of over 120 mm diameter in way of the tiller, excluding strengthening for navigation in ice; and	Requirement for power operation, but the background is not very clear
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	II-1	29.4.1	The auxiliary steering gear shall be of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;	Reduced steering performance sufficient to steer/operate the system at navigable speed
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	II-1	29.4.2	The auxiliary steering gear shall be capable of putting the rudder over from 15° on one side to 15° on the other side in not more than 60 s with the ship at its deepest seagoing draught and running ahead at one half of the maximum ahead service speed or 7	Performance requirement reduced service (steering system) only traditional - min. angle - dynamic performance of the rudder

EP			Regulation			
No			Chapter	No	Text	Objective
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	II-1	29.4.3	operated by power where necessary to meet the requirements of paragraph 4.2 and in any case when the Administration requires a rudder stock of over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice.	Requirement for power operation
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	II-1	29.15	In every tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards and in every other ship of 70,000 gross tonnage and upwards, the main steering gear shall comprise two or more identical power units complying with the provisions of paragraph	For tanker, chemical tanker or gas carrier > 10000 GT Two or more identical power units Performance
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	II-1	29.16.2.1	two independent and separate power actuating systems, each capable of meeting the requirements of paragraph 3.2; or	performance requirement for tankers and after failure in power actuating system

EP			Regulation			
No			Chapter	No	Text	Objective
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	137	5.3.1	Turning ability The advance should not exceed 4.5 ship lengths (L) and the tactical diameter should not exceed 5 ship lengths in the turning circle manoeuvre.	Thresholds for adequate turning performance
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	137	5.3.2	Initial turning ability With the application of 10° rudder angle to port/starboard, the ship should not have travelled more than 2.5 ship lengths by the time the heading has changed by 10° from the original heading.	Ship's dynamic (basic dynamic behaviour)
1	.0	The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 60 minutes. Applicable both for normal and reduced service.	137	5.3.3.1	Yaw-checking and course-keeping abilities .1 The value of the first overshoot angle in the 10°/10° zig-zag test should not exceed: .1 10° if L/V is less than 10 s; .2 20° if L/V is 30 s or more; and .3 (5 + 1/2(L/V)) degrees if L/V is 10 s or more, but l	- overshoot -> reaction

EP			Regulation			
No			Chapter	No	Text	Objective
1	.0	The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 60 minutes. Applicable both for normal and reduced service.	137	5.3.3.2	Yaw-checking and course-keeping abilities .2 The value of the second overshoot angle in the 10°/10° zig-zag test should not exceed: .1 25°, if L/V is less than 10 s; .2 40°, if L/V is 30 s or more; and .3 (17.5 + 0.75(L/V))°, if L/V is 10 s or more, but	- overshoot -> reaction
1	.0	The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 60 minutes. Applicable both for normal and reduced service.	137	5.3.3.3	Yaw-checking and course-keeping abilities The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°	- overshoot -> reaction
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	1416	3.1	of adequate strength and capable of steering the ship at maximum ahead service speed which should be demonstrated	being able to use the system according to specifications

EP			Regulation			
No			Chapter	No	Text	Objective
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	1416	3.2	capable of changing direction of the steering-propulsion unit from one side to the other at declared steering angle limits at an average turning speed of not less than 2.3°/s with the ship running ahead at maximum ahead service speed	Performance changing steering force direction, normal service
3	.0	Steering system operation and ship manoeuvring concur with intended use and predicted characteristics	1416	3.3	for all ships, operated by power; and	adequate capabilities of steering gear
2	.0	Ability to turn/change course	1416	4.1	of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency	being able to turn/change course
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	1416	4.2	capable of changing direction of the ship's directional control system from one side to the other at declared steering angle limits at an average turning speed, of not less than 0.5°/s; with the ship running ahead at one half of the maximum ahead service	Performance changing steering force direction, reduced service

EP			Regulation			
No			Chapter	No	Text	Objective
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	1416	4.3	for all ships, operated by power where necessary to meet the requirements of SOLAS regulation II-1/29.4.2 and in any ship having power of more than 2,500 kW propulsion power per steering-propulsion unit	Design requirement, reduced service
2	.1	a. In case of undisturbed steering system operation: Meeting requirements for normal service: advance: <4.5 ship length, diameter<5 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 14 sec.	1536	1	In order for ships to comply with the performance requirements stated in regulations II-1/29.3.2 and 29.4.2, they are to have steering gear capable of meeting these performance requirements when at their deepest seagoing draught	steering gear strong enough to bring rudder into this position, normal performance
2	.2	b. In case of disturbed steering system operation: Meeting requirements for reduced service: advance: <5.6 ship length, diameter:<6.25 ship length. The steering system shall be able to cover neutral to 90% of max declared steering angle (either side) in not more than 28 sec	1536	1	In order for ships to comply with the performance requirements stated in regulations II-1/29.3.2 and 29.4.2, they are to have steering gear capable of meeting these performance requirements when at their deepest seagoing draught	steering gear strong enough to bring rudder into this position, reduced performance

FR II: Steering capability is maintained or can be regained in case of malfunction of one of the sub-systems steering control or steering actuating or both together

EP			**Regulation**			
No			**Chapter**	**No**	**Text**[13]	**Objective**
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	II-1	29.1	Unless expressly provided otherwise, every ship shall be provided with a main steering gear and an auxiliary steering gear to the satisfaction of the Administration. The main steering gear and the auxiliary steering gear shall be so arranged that the fail	- redundancy - back-up not blocked
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.1	Unless expressly provided otherwise, every ship shall be provided with a main steering gear and an auxiliary steering gear to the satisfaction of the Administration. The main steering gear and the auxiliary steering gear shall be so arranged that the fail	- redundancy - back-up not blocked
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	II-1	29.2.3	Relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. The setting of the relief valves shall not exceed the design pressure. The valves	(Automatic) Pressure relief to avoid blockage

[13] Please consider that not the complete text of the regulation is considered

EP			Regulation			
No			Chapter	No	Text[13]	Objective
4	.0	Steering performance will be speedily regained	II-1	29.4.1	The auxiliary steering gear shall be of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;	Speedily availability of reduced at least performance
4	.0	Steering performance will be speedily regained	II-1	29.5.1	arranged to restart automatically when power is restored after a power failure; and	Speedily regain steering capability after power failure
4	.0	Steering performance will be speedily regained	II-1	29.5.2	capable of being brought into operation from a position on the navigation bridge.	Speedily regain steering capability after failure (normal or back-up)
6	.0	Loss of availability is indicated by an alarm	II-1	29.5.2	In the event of a power failure to any one of the steering gear power units, an audible and visual alarm shall be given on the navigation bridge.	Inform crew about failure
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	II-1	29.6.1	Where the main steering gear comprises two or more identical power units, an auxiliary steering gear need not be fitted, provided that:	Specification of redundancy
1	.1	For passenger ships, and tanker, chemical tanker and gas carrier ≥ 10,000 GT normal performance is maintained	II-1	29.6.1.1	in a passenger ship, the main steering gear is capable of operating the rudder as required by paragraph 3.2 while any one of the power units is out of operation;	Redundancy performance for pax

EP			Regulation			
No			Chapter	No	Text[13]	Objective
1	.2	and for all other ships at least reduced service performance is maintained	II-1	29.6.1.2	in a cargo ship, the main steering gear is capable of operating the rudder as required by paragraph 3.2 while operating with all power units;	Redundancy performance for cargo
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	II-1	29.6.1.3	the main steering gear is so arranged that after a single failure in its piping system or in one of the power units the defect can be isolated so that steering capability can be maintained or speedily regained.	Maintain speedily regain (not blocked by failure)
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.7.1	for the main steering gear, both on the navigation bridge and in the steering gear compartment;	redundancy for steering control system
3	.0	Normal service steering capability is available without steering remote control system	II-1	29.7.1	for the main steering gear, both on the navigation bridge and in the steering gear compartment;	locations from where control is possible
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.7.2	where the main steering gear is arranged in accordance with paragraph 6, by two independent control systems, both operable from the navigation bridge. This does not require duplication of the steering wheel or steering lever. Where the control system consists of a hydraulic telemotor, a second independent system need not be fitted,	Limitation of redundancy Telemotor will not meet EP

EP			Regulation			
No			**Chapter**	**No**	**Text[13]**	**Objective**
					except in a tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards;	
3	.0	Normal service steering capability is available without steering remote control system	II-1	29.7.3	for the auxiliary steering gear, in the steering gear compartment	Design features for redundancy in steering control system
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.7.3	and, if power operated, it shall also be operable from the navigation bridge and shall be independent of the control system for the main steering gear	Design features for redundancy in steering control system
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.8.2	means shall be provided in the steering gear compartment for disconnecting any control system operable from the navigation bridge from the steering gear it serves;	Avoid blocking of redundancy
4	.0	Steering performance will be speedily regained	II-1	29.8.3	the system shall be capable of being brought into operation from a position on the navigation bridge;	Brought into operation from bridge
6	.0	Loss of availability is indicated by an alarm	II-1	29.8.4	in the event of a failure of electrical power supply to the control system, an audible and visual alarm shall be given on the navigation bridge; and	alarm to start counteractions

EP			Regulation			
No			Chapter	No	Text[13]	Objective
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	II-1	29.9	The electrical power circuits and the steering gear control systems with their associated components, cables and pipes required by this regulation and by regulation 30 shall be separated as far as is practicable throughout their length.	separate from other system, limit impact of failure in one sub-system of steering system
3	.0	Normal service steering capability is available without steering remote control system	II-1	29.10	A means of communication shall be provided between the navigation bridge and the steering gear compartment.	means of communication shall be provided between the navigation bridge and the steering gear compartment
3	.0	Normal service steering capability is available without steering remote control system	II-1	29.11.1	if the main steering gear is power-operated, be indicated on the navigation bridge. The rudder angle indication shall be independent of the steering gear control system;	limit impact of malfunction in control system (operate without control system)
3	.0	Normal service steering capability is available without steering remote control system	II-1	29.11.2	be recognizable in the steering gear compartment.	Steering gear can be operated independent of remote control system
6	.0	Loss of availability is indicated by an alarm	II-1	29.12.2	a low-level alarm for each hydraulic fluid reservoir to give the earliest practicable indication of hydraulic fluid leakage. Audible and visual alarms shall be given on the navigation bridge and in the machinery space where they can be readily observed; a	low-level alarm for each hydraulic fluid reservoir alarm on bridge and in machinery

EP			Regulation			
No			Chapter	No	Text[13]	Objective
4	.0	Steering performance will be speedily regained	II-1	29.12.3	a fixed storage tank having sufficient capacity to recharge at least one power actuating system including the reservoir, where the main steering gear is required to be power-operated. The storage tank shall be permanently connected by piping in such a man	fixed storage tank having sufficient capacity to recharge at least one power actuating system including the reservoir
4	.0	Steering performance will be speedily regained	II-1	29.13.1	readily accessible and, as far as practicable, separated from machinery spaces; and	speedily regain capability by human interaction
4	.1	For tankers >10.000 GT within 45 s (e.g. by warm redundancy)	II-1	29.14	Where the rudder stock is required to be over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice, an alternative power supply, sufficient at least to supply the steering gear power unit which complies with the requirements	REMARK: this regulation overlaps with II-1 Part D, e.g. 42.2 (Pax) and 43.2 (cargo) asking for emergency power supply for essential services alternative power supply (gear + control) automatic start in 45 s for at least 30 min
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	II-1	29.15	In every tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards and in every other ship of 70,000 gross tonnage and upwards, the main steering gear shall comprise two	Redundancy

EP			Regulation			
No			Chapter	No	Text[13]	Objective
					or more identical power units complying with the provisions of parag	
4	.1	For tankers >10.000 GT within 45 s (e.g. by warm redundancy)	II-1	29.16.1	the main steering gear shall be so arranged that in the event of loss of steering capability due to a single failure in any part of one of the power actuating systems of the main steering gear, excluding the tiller, quadrant or components serving the same	speedily regain
1	.1	For passenger ships, and tanker, chemical tanker and gas carrier ≥ 10,000 GT normal performance is maintained	II-1	29.16.2.1	two independent and separate power actuating systems, each capable of meeting the requirements of paragraph 3.2; or	performance requirement for tankers and after failure in power actuating system
5	.0	Availability of steering system continuously monitored and indicated on navigation position	II-1	30.1	Means for indicating that the motors of electric and electrohydraulic steering gear are running shall be installed on the navigation bridge and at a suitable main machinery control position.	information on availability
5	.0	Availability of steering system continuously monitored and indicated on navigation position	II-1	30.3	Short circuit protection and an overload alarm shall be provided for such circuits and motors.	overload alarm

EP			Regulation			
No			Chapter	No	Text[13]	Objective
5	.0	Availability of steering system continuously monitored and indicated on navigation position	II-1	30.3	Where a three-phase supply is used an alarm shall be provided that will indicate failure of any one of the supply phases. The alarms required in this paragraph shall be both audible and visual and shall be situated in a conspicuous position in the main ma	reduced performance due to reduced electrical power supply
4	.0	Steering performance will be speedily regained	V	25	Operation of main source of electrical power and steering gear In areas where navigation demands special caution, ships shall have more than one steering gear power unit in operation when such units are capable of simultaneous operation.	minimise time to regain steering performance after failure
4	.0	Steering performance will be speedily regained	V	26.3.1	Simple operating instructions with a block diagram showing the change-over procedures for remote steering gear control systems and steering gear power units shall be permanently displayed on the navigation bridge and in the steering compartment.	Info on bridge enable speedily regain of steering capability

EP			Regulation			
No			**Chapter**	**No**	**Text**[13]	**Objective**
4	.0	Steering performance will be speedily regained	V	26.3.2	All ships' officers concerned with the operation and/or maintenance of steering gear shall be familiar with the operation of the steering systems fitted on the ship and with the procedures for changing from one system to another.	Info for officer enable speedily regain of steering capability
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	2.1	Two independent steering gear control systems	Redundancy
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.1	Separation of duplicated components	Separation of components to limit effect of malfunction
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.2	All electronic components of steering gear control system should be duplicated. This does not require duplication of the steering wheel or steering lever.	Specification or redundancy requirements
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.3	If a joint steering mode selector switch (uniaxial switch) is employed for both steering gear control systems, the connections for the circuits of the control systems should be divided accordingly and separated from each other by an isolating plate or by	Specification or redundancy requirements

EP			Regulation			
No			Chapter	**No**	**Text[13]**	**Objective**
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.4	In the case of double follow-up control (see appendix, example 2), the amplifiers should be designed and fed so as to be electrically and mechanically separated. In the case of non-follow-up control and follow-up control, it should be ensured that the fol	Specification or redundancy requirements
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.6	The feed-back units and limit switches, if any, for the steering gear control systems should be separated electrically and mechanically connected to the rudder stock or actuator separately.	Separation of components to limit effect of malfunction
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.7.1	Hydraulic system components in the power actuating or hydraulic servo systems controlling the power systems of the steering gear (e.g., solenoid valves, magnetic valves) should be considered as part of the steering gear control system and should be duplic	Specification or redundancy requirements
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1398	3.7.2	Hydraulic system components in the steering gear control system that are part of a power unit may be regarded as being duplicated and separated when there are two or more separate power units provided and the piping to each power unit can be isolated.	Specification or redundancy requirements

EP			Regulation			
No			Chapter	No	Text[13]	Objective
5	.0	Availability of steering system continuously monitored and indicated on navigation position	1398	4.1	Failure detection	specify failures to be considered
6	.0	Loss of availability is indicated by an alarm	1398	4.1	Failure detection	
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.1	power supply failure;	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.2	loop failures in closed loop systems, both command and feedback loops (normally short circuit, broken connections and earth faults)	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.3	if programmable electronic systems are used	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.3.1	data communication errors	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.3.2	computer hardware and software failures	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.1.4	hydraulic locking considering order given by steering wheel or lever	alarm to start counteractions
6	.0	Loss of availability is indicated by an alarm	1398	4.1.2	All failures detected should initiate an audible and visual alarm on the navigation bridge. Hydraulic locking should always be warned individually unless system design makes manual action unnecessary.	alarm to start counteractions

EP			Regulation			
No			Chapter	No	Text[13]	Objective
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	1	For a ship fitted with multiple steering-propulsion units, such as, but not limited to, azimuthing propulsors or water jet propulsion systems, each of the steering-propulsion units should be provided with a main steering gear and an auxiliary steering gear	multiple steering-propulsion; require complete redundancy for each of the systems
2	.0	Malfunction of steering control system will not lead to loss of steering capability. Normal service steering capability is maintained.	1416	1	For a ship fitted with multiple steering-propulsion units, such as, but not limited to, azimuthing propulsors or water jet propulsion systems, each of the steering-propulsion units should be provided with a main steering gear and an auxiliary steering gear	multiple steering-propulsion; require complete redundancy for each of the systems
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	1	For a ship fitted with a single steering-propulsion unit, the requirement in SOLAS regulation II-1/29.1 is considered satisfied if the steering gear is provided with two or more steering actuating systems and is in compliance with interpretation of SOLAS	Redundancy in steering gear.
4	.0	Steering performance will be speedily regained	1416	4.1	of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency	speedily

EP			Regulation			
No			Chapter	No	Text[13]	Objective
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	6.1	For a ship fitted with a single steering-propulsion unit where the main steering gear comprises two or more identical power units and two or more identical steering actuators, an auxiliary steering gear need not be fitted provided that the steering gear	
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	6.1.1	in a passenger ship, is capable of satisfying the requirements in interpretation to SOLAS regulation II-1/29.3 while any one of the power units is out of operation	refers to Reg 29.3 and Reg 29.1
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	6.1.2	in a cargo ship, is capable of satisfying the requirements in interpretation to SOLAS regulation II-1/29.3 while operating with all power units	refers to Reg 29.3 and Reg 29.1
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	6.1.3	is arranged so that after a single failure in its piping system or in one of the power units, steering capability can be maintained or speedily regained	refers to Reg 29.3 and Reg 29.1
1	.0	Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained	1416	6.1n	For a ship fitted with multiple steering-propulsion units, where each main steering system comprises two or more identical steering actuating systems, an auxiliary steering gear need not be fitted provided that each steering gear	refers to Reg 29.1; two independent steering gears

EP			Regulation			
No			Chapter	No	Text[13]	Objective
1	.1	For passenger ships, and tanker, chemical tanker and gas carrier ≥ 10,000 GT normal performance is maintained	1416	6.1.1n	in a passenger ship, is capable of satisfying the requirements in interpretation to SOLAS regulation II-1/29.3 while any one of the steering gear steering actuating systems is out of operation	multiple steering-propulsion; require complete redundancy for each of the systems
1	.2	and for all other ships at least reduced service performance is maintained	1416	6.1.2n	in a cargo ship, is capable of satisfying the requirements in interpretation to SOLAS regulation II-1/29.3 while operating with all steering gear steering actuating systems	
4	.0	Steering performance will be speedily regained	1416	6.1.3n	is arranged so that after a single failure in its piping or in one of the steering actuating systems, steering capability can be maintained or speedily regained	
4	.1	For tankers >10.000 GT within 45 s (e.g. by warm redundancy)	1416	14	This interpretation is valid to steering-propulsion units having a certain proven steering capability due to ship speed also in case propulsion power has failed. Where the propulsion power exceeds 2,500 kW per thruster unit, an alternative power supply, s	Focus: emergency power supply (failure of electrical power supply)

FR III: Steering system is designed adequately for operational loads

EP			Regulation			
No			**Chapter**	**No**	**Text**	**Objective**
1	.0	Components have adequate strength for ship operation and specified design life, considering:	II-1	29.2.1	All the steering gear components and the rudder stock shall be of sound and reliable construction to the satisfaction of the Administration. Special consideration shall be given to the suitability of any essential component which is not duplicated. Any su	design of gear and rudder is reliable
2	.0	Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality	II-1	29.2.1	All the steering gear components and the rudder stock shall be of sound and reliable construction to the satisfaction of the Administration. Special consideration shall be given to the suitability of any essential component which is not duplicated. Any su	requirements for bearings
1	.4	Safety factor adequate to address uncertainty in load determination and material/component properties	II-1	29.2.2	The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the maximum working pressure to be expected under the operational condition	Hydraulic system only Safety factor on max. hydraulic working pressure ≥ 1.25, scantlings, min. pressure

EP			Regulation			
No			Chapter	No	Text	Objective
1	.5	Actuating system is protected from overloads resulting from malfunctioning of the system	II-1	29.2.2	The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the maximum working pressure to be expected under the operational condition	Hydraulic system only Safety factor on max. hydraulic working pressure ≥ 1.25, scantlings, min. pressure
1	.5	Actuating system is protected from overloads resulting from malfunctioning of the system	II-1	29.2.3	Relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. The setting of the relief valves shall not exceed the design pressure. The valves	(Automatic) Pressure relief - settings of valves ≤ design pressure - avoid overloads in hydraulic system
1	.0	Components have adequate strength for ship operation and specified design life, considering:	II-1	29.3.1	of adequate strength and capable of steering the ship at maximum ahead service speed which shall be demonstrated;	Adequate strength to operate the rudder

EP			Regulation			
No			Chapter	No	Text	Objective
1	.1	All mechanical, hydraulic and electrical loads	II-1	29.3.4	so designed that they will not be damaged at maximum astern speed; however, this design requirement need not be proved by trials at maximum astern speed and maximum rudder angle.	Focus: consideration of operational loads
1	.2	Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice)	II-1	29.3.4	so designed that they will not be damaged at maximum astern speed; however, this design requirement need not be proved by trials at maximum astern speed and maximum rudder angle.	Focus: consideration of operational loads
1	.3	Material properties and component properties	II-1	29.3.4	so designed that they will not be damaged at maximum astern speed; however, this design requirement need not be proved by trials at maximum astern speed and maximum rudder angle.	Focus: consideration of operational loads
1	.0	Components have adequate strength for ship operation and specified design life, considering:	II-1	29.4.1	The auxiliary steering gear shall be of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;	Adequate strength to operate the rudder in reduced services
4	.0	Steering system availability is not hampered by safety devices	II-1	29.8.5	short circuit protection only shall be provided for steering gear control supply circuits.	avoid loss of steering due to malfunction of safety devices
2	.0	Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality	II-1	29.12.1	arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system;	avoid failure due to contamination

EP			Regulation			
No			**Chapter**	**No**	**Text**	**Objective**
1	.1	All mechanical, hydraulic and electrical loads	II-1	30.2	Each electric or electrohydraulic steering gear comprising one or more power units shall be served by at least two exclusive circuits fed directly from the main switchboard; however, one of the circuits may be supplied through the emergency switchboard. A	sufficient electrical power supply
1	.1	All mechanical, hydraulic and electrical loads	II-1	30.3	Short circuit protection and an overload alarm shall be provided for such circuits and motors.	Short circuit protection
1	.1	All mechanical, hydraulic and electrical loads	II-1	30.3	Protection against excess current, including starting current, if provided, shall be for not less than twice the full load current of the motor or circuit so protected, and shall be arranged to permit the passage of the appropriate starting currents.	settings of safety devices not too sensitive
5	.0	Inspection concept adequate for steering system design	V	26.1	Within 12 hours before departure, the ship's steering gear shall be checked and tested by the ship's crew. The test procedure shall include, where applicable, the operation of the following: .1 the main steering gear; .2 the auxiliary steering gear; .3 th	verify correct functionality
5	.0	Inspection concept adequate for steering system design	V	26.2	2 The checks and tests shall include: .1 the full movement of the rudder according to the required capabilities of the steering gear; .2 a visual inspection for the steering gear and its connecting linkage; and .3 the operation of the means of communicati	Focus: verify correct functionality

EP			Regulation			
No			Chapter	No	Text	Objective
1	.0	Components have adequate strength for ship operation and specified design life, considering:	1416	2.1	All components used in steering arrangements for ship directional control should be of sound reliable construction to the satisfaction of the Administration or recognized organizations acting on its behalf. Special consideration should be given to the sui	Generalising the requirements of 29.2.1 for being applicable to all types of systems
1	.0	Components have adequate strength for ship operation and specified design life, considering:	1416	3.1	of adequate strength and capable of steering the ship at maximum ahead service speed which should be demonstrated	adequate strength
1	.0	Components have adequate strength for ship operation and specified design life, considering:	1416	3.4	so designed that they will not be damaged at maximum astern speed; this design requirement need not be proved by trials at maximum astern speed and declared steering angle limits	adequate strength
1	.0	Components have adequate strength for ship operation and specified design life, considering:	1416	4.1	of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency	adequate strength
1	.1	All mechanical, hydraulic and electrical loads	1416	30.2	For a ship fitted with multiple steering systems, the requirements in SOLAS regulation II-1/30.2 are to be applied to each of the steering systems	sufficient electrical power supply

FR IV: Steering system is protected from external impacts

EP			Regulation			
No			**Chapter**	**No**	**Text**	**Objective**
4	.1	Overloads due to external forces	II-1	29.2.2	The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the maximum working pressure to be expected under the operational condition	Protect system against internal overloads caused e.g. by malfunction of pump
4	.1	Overloads due to external forces	II-1	29.2.2	The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the maximum working pressure to be expected under the operational condition	Protect system against external overloads (weakest link)
4	1	Overloads due to external forces	II-1	29.2.3	Relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces.	Protect system against external overloads (weakest link)

EP			Regulation			
No			Chapter	No	Text	Objective
4	2	Overloads resulting from erroneous operation	II-1	29.2.3	Relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces.	Protect system against overloads resulting from erroneous operation (weakest link)
1	.0	Steering control system and actuator system are separated from other ship systems	II-1	29.8.1	if electric, it shall be served by its own separate circuit supplied from a steering gear power circuit from a point within the steering gear compartment, or directly from switchboard busbars supplying that steering gear power circuit at a point on the sw	Electric: separate circuit from steering gear of switchboard
1	.0	Steering control system and actuator system are separated from other ship systems	II-1	29.9	The electrical power circuits and the steering gear control systems with their associated components, cables and pipes required by this regulation and by regulation 30 shall be separated as far as is practicable throughout their length.	
1	.0	Steering control system and actuator system are separated from other ship systems	II-1	29.13.1	readily accessible and, as far as practicable, separated from machinery spaces; and	protect against external impact

EP			Regulation			
No			Chapter	No	Text	Objective
2	.0	Steering system is protected from external impacts by fire	II-1	29.13.1	readily accessible and, as far as practicable, separated from machinery spaces; and	protect against external impact
1	.0	Steering control system and actuator system are separated from other ship systems	II-1	30.2	Each electric or electrohydraulic steering gear comprising one or more power units shall be served by at least two exclusive circuits fed directly from the main switchboard; however, one of the circuits may be supplied through the emergency switchboard. A	separated electrical power supply and emergency electrical power supply
5	.1	up to the nearest A class boundaries protected by fixed fire extinguishing system; or,and adjacent spaces up to nearest A class boundaries outside the space of origin	II-2	21	Safe return to port* When fire damage does not exceed the casualty threshold indicated in paragraph 3, the ship shall be capable of returning to port while providing a safe area as defined in regulation 3. To be deemed capable of returning to port, the fo	steering capability available after fire in one "compartment", i.e. complete loss of one system
5	.2	Flooding: reduced service steering capability available after flooding of any single watertight compartment	II-1	8-1.3	Safe return to port* A passenger ship shall be designed so that the systems specified in regulation II-2/21.4 remain operational when the ship is subject to flooding of any single watertight compartment.	steering capability available after flooding of one "compartment"", i.e. complete loss of one system
1	.0	Steering control system and actuator system are separated from other ship systems	1398	3.5	Control circuits for additional control systems, e.g., steering lever or autopilot should be	Disconnect other systems

EP			Regulation			
No			Chapter	No	Text	Objective
					designed for all-pole disconnection (see appendix, examples 1, 2 and 3).	
1	.0	Steering control system and actuator system are separated from other ship systems	1416	30.2	For a ship fitted with multiple steering systems, the requirements in SOLAS regulation II-1/30.2 are to be applied to each of the steering systems	separated electrical power supply and emergency electrical power supply

FR V: Minimize impact of erroneous functionality

EP			Regulation			
No			Chapter	No	Text	Objective
2	.0	Malfunction in data communication and programmable systems are easily detectable	II-1	29.11.1	if the main steering gear is power-operated, be indicated on the navigation bridge. The rudder angle indication shall be independent of the steering gear control system;	limit impact of malfunction in control system (detect malfunction)
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1	Failure detection	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.1	power supply failure;	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.2	loop failures in closed loop systems, both command and feedback loops (normally short circuit, broken connections and earth faults)	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.3	if programmable electronic systems are used	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.3.1	data communication errors	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.3.2	computer hardware and software failures	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.1.4	hydraulic locking considering order given by steering wheel or lever	specify failures to be considered

EP			Regulation			
No			Chapter	No	Text	Objective
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.2	All failures detected should initiate an audible and visual alarm on the navigation bridge. Hydraulic locking should always be warned individually unless system design makes manual action unnecessary.	specify failures to be considered
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.4.1	Direction: Actual rudder position follows the set value	identification of malfunction
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.4.2	Delay: Rudder's actual position reaches set position within acceptable time limits	identification of malfunction
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.1.4.3	Accuracy: The end actual position should correspond to the set value within the design offset tolerances	identification of malfunction
1	.0	Steering system shall be arranged with a fail-safe behaviour in case of failures	1398	4.2	System response upon failure: The most probable failures, e.g., loss of power or loop failure, should result in the least critical of any new possible conditions.	minimise consequences of malfunction
2	.0	Malfunction in data communication and programmable systems are easily detectable	1398	4.2	System response upon failure: The most probable failures, e.g., loss of power or loop failure, should result in the least critical of any new possible conditions.	minimise consequences of malfunction

FR VI: Minimize impact of erroneous operation

EP			Regulation			
No			Chapter	No	Text	Objective
1	.0	Minimize possibilities of steering system operation threatening ship safety:	II-1	29.11.1	if the main steering gear is power-operated, be indicated on the navigation bridge. The rudder angle indication shall be independent of the steering gear control system;	(identification of erroneous operation)
1	.2	Limit effect of erroneous input	1398	4.1.4.1	Direction: Actual rudder position follows the set value	identification of erroneous operation
1	2	Limit effect of erroneous input	1398	4.1.4.3	Accuracy: The end actual position should correspond to the set value within the design offset tolerances	identification of erroneous operation

FR VII: Enabling proper operation by providing information about ship’s manoeuvring characteristics

EP			Regulation			
No			Chapter	No	Text	Objective
1	.0	Provide information about vessel’s manoeuvrability characteristics adequate for all persons involved in navigation and in all locations used for navigation of vessel: * Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)	V	26.3.1	Simple operating instructions with a block diagram showing the change-over procedures for remote steering gear control systems and steering gear power units shall be permanently displayed on the navigation bridge and in the steering compartment.	Info on bridge enable speedily regain of steering capability
2	.0	Provide familiarisation of vessel’s manoeuvrability characteristics	V	26.3.2	All ships' officers concerned with the operation and/or maintenance of steering gear shall be familiar with the operation of the steering systems fitted on the ship and with the procedures for changing from one system to another.	Familiarisation of officer enable speedily regain of steering capability
2	.0	Provide familiarisation of vessel’s manoeuvrability characteristics	V	26.4	In addition to the routine checks and tests prescribed in paragraphs 1 and 2, emergency steering drills shall take place at least once every three months in order to practise emergency steering procedures. These drills shall include direct control within	familiarisation of performance considering all operational modes

EP			Regulation			
No			Chapter	No	Text	Objective
1	.0	Provide information about vessel's manoeuvrability characteristics adequate for all persons involved in navigation and in all locations used for navigation of vessel: * Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)	A.601	1.2.1	Pilot card	for pilot
1	.0	Provide information about vessel's manoeuvrability characteristics adequate for all persons involved in navigation and in all locations used for navigation of vessel: * Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)	A.601	1.2.2	Wheelhouse poster	for crew
1	.0	Provide information about vessel's manoeuvrability characteristics: *Manoeuvring data predictions per MSC.137(76) shall be readily available to the operator. When tests are performed, these results shall be used.	A.601	1.2.3	Manoeuvring booklet	for crew

FR VIII: Provide propulsion performance adequate for ship operation

EP			Regulation			
No			Chapter	No	Text	Objective
1	.1	Vessel can be brought to rest with stopping distance within 15 ship lengths (conditions as specified in MSC.137(76))	II-1	28.1	Sufficient power for going astern shall be provided to secure proper control of the ship in all normal circumstances.	Control vessel by stopping (threshold in MSC.137) Normal circumstances is understood not to include emergency manoeuvre.
1	.1	Vessel can be brought to rest with stopping distance within 15 ship lengths (conditions as specified in MSC.137(76))	II-1	28.2	The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, shall be demonstrated and recorded.	time to reverse thrust
1	.1	Vessel can be brought to rest with stopping distance within 15 ship lengths (conditions as specified in MSC.137(76))	II-1	28.2	The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, shall be demonstrated and recorded.	the stopping distance
1	.1	Vessel can be brought to rest with stopping distance within 15 ship lengths (conditions as specified in MSC.137(76))	137	5.3.4	Stopping ability The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exce	Distance to stop the same in one size category

Regulations not assigned to functional requirements

Chapter	Reg. No	Regulation Text	Discussion
II-1	28.2	The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, **shall be demonstrated** and recorded.	The part highlighted in bold is not considered by FR. In general demonstrations is regarded as integrated in the approval process.
II-1	28.2	The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, shall be demonstrated and **recorded.**	**Recorded regarded as "providing information". This aspect has been considered for steering but not for propulsion.** **→ new FR VIII*bis* suggested**
II-1	28.3	The stopping times, ship headings and distances recorded on trials, together with the results of trials to determine the ability of ships having multiple propellers to navigate and manoeuvre with one or more propellers inoperative, shall be available on board for the use of the master or designated personnel.	**This regulation requires trials to be performed and information be provided. No performance requirements are specified. Thus, this regulation focus solely on "providing information".** **→ new FR VIII*bis* suggested**
II-1	28.4	Where the ship is provided with supplementary means for manoeuvring or stopping, the effectiveness of such means shall be demonstrated and recorded as referred to in paragraphs 2 and 3.	**This regulation requires trials to be performed and information be provided. No performance requirements are specified. Thus,**

Chapter	Reg. No	Regulation Text	Discussion
			this regulation focus solely on "providing information". → **new FR VIII*bis* suggested**
II-1	29.3.1	of adequate strength and capable of steering the ship at maximum ahead service speed which shall **be demonstrated**;	The part highlighted in bold is not considered by FR. In general demonstrations is regarded as integrated in the approval process.
II-1	29.3.2.1	during sea trials the ship is at even keel and the rudder fully submerged whilst running ahead at the speed corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch; or	SPECIFICATION SEA TRIAL
II-1	29.3.2.2	where full rudder immersion during sea trials cannot be achieved, an appropriate ahead speed shall be calculated using the submerged rudder blade area in the proposed sea trial loading condition. The calculated ahead speed shall result in a force and torque applied to the main steering gear which is at least as great as if it was being tested with the ship at its deepest seagoing draught and running ahead at the speed corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch; or	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.3.2.1
II-1	29.3.2.3	the rudder force and torque at the sea trial loading condition have been reliably predicted and extrapolated to the full load condition. The speed of the ship shall correspond to the number of maximum continuous revolutions of the main engine and maximum design pitch of the propeller;	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.3.2.1

Chapter	Reg. No	Regulation Text	Discussion
II-1	29.4.2	where it is impractical to demonstrate compliance with this requirement during sea trials with the ship at its deepest seagoing draught and running ahead at one half of the speed corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch or 7 knots, whichever is greater, ships regardless of date of construction, including those constructed before 1 January 2009, may demonstrate compliance with this requirement by one of the following methods:	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.4.1
II-1	29.4.2.1	during sea trials the ship is at even keel and the rudder fully submerged whilst running ahead at one half of the speed corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch or 7 knots, whichever is greater; or	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.4.1
II-1	29.4.2.2	where full rudder immersion during sea trials cannot be achieved, an appropriate ahead speed shall be calculated using the submerged rudder blade area in the proposed sea trial loading condition. The calculated ahead speed shall result in a force and torque applied to the auxiliary steering gear which is at least as great as if it was being tested with the ship at its deepest seagoing draught and running ahead at one half of the speed corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch or 7 knots, whichever is greater; or	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.4.1
II-1	29.4.2.3	the rudder force and torque at the sea trial loading condition have been reliably predicted and extrapolated to the full load condition; and	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING to 29.4.1
II-1	29.6.2	The Administration may, until 1 September 1986, accept the fitting of a steering gear which has a proven record of reliability but does not comply with the requirements of paragraph 6.1.3 for a hydraulic system.	GRANDFATHERING

Chapter	Reg. No	Regulation Text	Discussion
II-1	29.6.3	Steering gears, other than of the hydraulic type, shall achieve standards equivalent to the requirements of this paragraph to the satisfaction of the Administration.	EQUIVALENCY Other types of steering gear shall meet the same standards ("reliability")
II-1	29.8.1	if electric, it shall be served by its own separate circuit supplied from a steering gear power circuit from a point within the steering gear compartment, or directly from switchboard busbars supplying that steering gear power circuit at a point on the switchboard adjacent to the supply to the steering gear power circuit;	**Redundancy for electrical power supply (switchboard to steering system)** **→ New EP suggested**
II-1	29.13.2	provided with suitable arrangements to ensure working access to steering gear machinery and controls. These arrangements shall include handrails and gratings or other nonslip surfaces to ensure suitable working conditions in the event of hydraulic fluid leakage.	**Occupational safety not considered by FRs** **→ New FR suggested but this requires also an additional goal.**
II-1	29.16.2.2	at least two identical power actuating systems which, acting simultaneously in normal operation, shall be capable of meeting the requirements of paragraph 3.2. Where necessary to comply with this requirement, interconnection of hydraulic power actuating systems shall be provided. Loss of hydraulic fluid from one system shall be capable of being detected and the defective system automatically isolated so that the other actuating system or systems shall remain fully operational;	EQUIVALENCY to Reg. 29.16.2.1
II-1	29.16.3	steering gears other than of the hydraulic type shall achieve equivalent standards	EQUIVALENCY to Reg. 29.16.2.1

Chapter	Reg. No	Regulation Text	Discussion
II-1	29.17	For tankers, chemical tankers or gas carriers of 10,000 gross tonnage and upwards, but of less than 100,000 tonnes deadweight, solutions other than those set out in paragraph 16, which need not apply the single failure criterion to the rudder actuator or actuators, may be permitted provided that an equivalent safety standard is achieved and that:	EQUIVALENCY to Reg. 29.16
II-1	29.17.1	following loss of steering capability due to a single failure of any part of the piping system or in one of the power units, steering capability shall be regained within 45 s; and	EQUIVALENCY to Reg. 29.16
II-1	29.17.2	where the steering gear includes only a single rudder actuator, special consideration is given to stress analysis for the design including fatigue analysis and fracture mechanics analysis, as appropriate, to the material used, to the installation of sealing arrangements and to testing and inspection and to the provision of effective maintenance. In consideration of the foregoing, the Administration shall adopt regulations which include the provisions of the Guidelines for acceptance of non-duplicated rudder actuators for tankers, chemical tankers and gas carriers of 10,000 gross tonnage and above but less than 100,000 tonnes deadweight, adopted by the Organization*.	EQUIVALENCY to Reg. 29.16
II-1	29.18	For a tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards, but less than 70,000 tonnes deadweight, the Administration may, until 1 September 1986, accept a steering gear system with a proven record of reliability which does not comply with the single failure criterion required for a hydraulic system in paragraph 16.	GRANDFATHERING Exemption for ships until X need not to comply with regulations 29.16

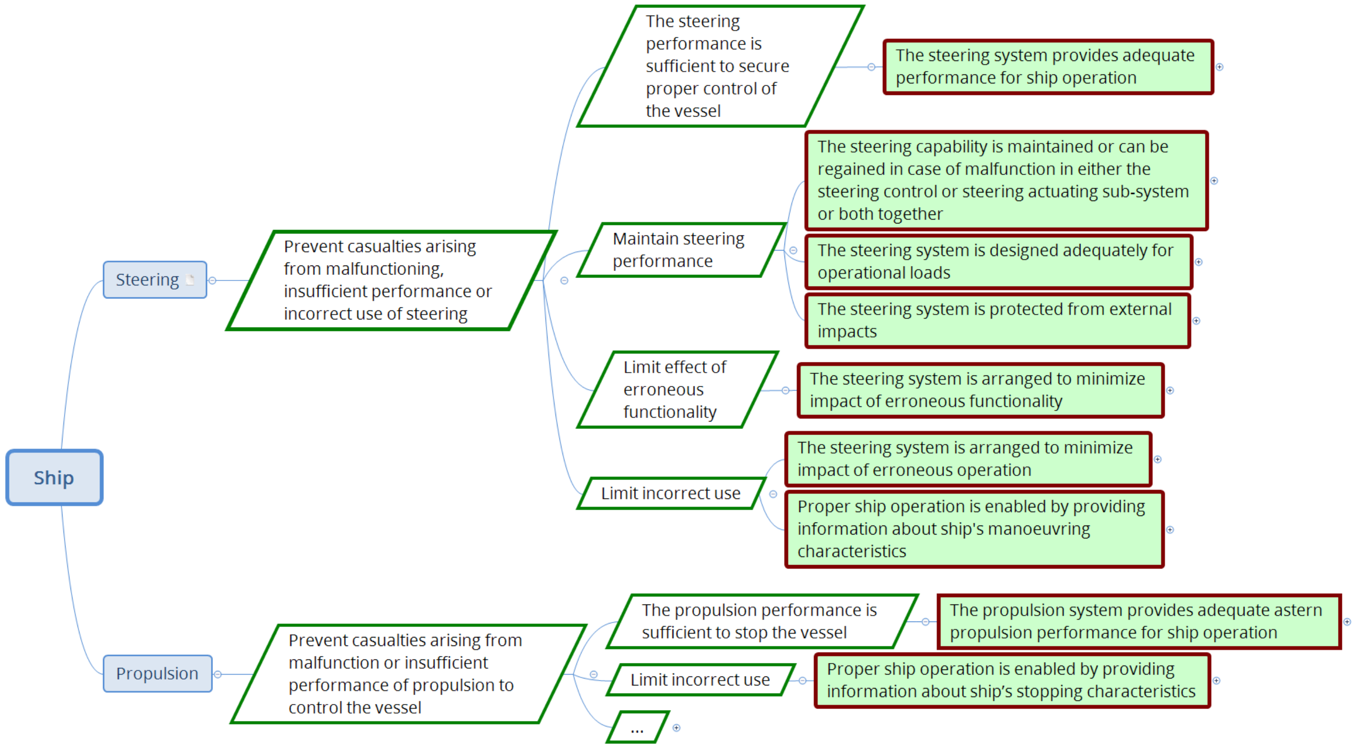
Chapter	Reg. No	Regulation Text	Discussion
II-1	29.19	Every tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards, constructed before 1 September 1984, shall comply, not later than 1 September 1986, with the following:	Upgrading ships built before need to comply with some regulations not later than
II-1	29.19.1	the requirements of paragraphs 7.1, 8.2, 8.4, 10, 11, 12.2, 12.3 and 13.2;	Upgrading ships built before need to comply with some regulations not later than
II-1	29.19.2	two independent steering gear control systems shall be provided each of which can be operated from the navigation bridge. This does not require duplication of the steering wheel or steering lever;	Upgrading ships built before need to comply with some regulations not later than
II-1	29.19.3	if the steering gear control system in operation fails, the second system shall be capable of being brought into immediate operation from the navigation bridge; and	Upgrading ships built before need to comply with some regulations not later than
II-1	29.19.4	each steering gear control system, if electric, shall be served by its own separate circuit supplied from the steering gear power circuit or directly from switchboard busbars supplying that steering gear power circuit at a point on the switchboard adjacent to the supply to the steering gear power circuit.	Upgrading ships built before need to comply with some regulations not later than
II-1	29.20	In addition to the requirements of paragraph 19, in every tanker, chemical tanker or gas carrier of 40,000 gross tonnage and upwards, constructed before 1 September 1984, the steering gear shall, not later than 1 September 1988, be so arranged that, in the event of a single failure of the piping or of one of the power units, steering capability can be maintained or the rudder movement can be limited so that steering capability can be speedily regained. This shall be achieved by:	UPGRADING
II-1	29.20.1	an independent means of restraining the rudder; or	UPGRADING

Chapter	Reg. No	Regulation Text	Discussion
II-1	29.20.2	fast-acting valves which may be manually operated to isolate the actuator or actuators from the external hydraulic piping together with a means of directly refilling the actuators by a fixed independent power-operated pump and piping system; or	UPGRADING
II-1	29.20.3	an arrangement such that, where hydraulic power systems are interconnected, loss of hydraulic fluid from one system shall be detected and the defective system isolated either automatically or from the navigation bridge so that the other system remains fully operational.	UPGRADING
II-1	30.4	When in a ship of less than 1,600 gross tonnage an auxiliary steering gear which is required by regulation 29.4.3 to be operated by power is not electrically powered or is powered by an electric motor primarily intended for other services, the main steering gear may be fed by one circuit from the main switchboard. Where such an electric motor primarily intended for other services is arranged to power such an auxiliary steering gear, the requirement of paragraph 3 may be waived by the Administration if satisfied with the protection arrangement together with the requirements of regulation 29.5.1 and .2 and 29.7.3 applicable to auxiliary steering gear.	EQUIVALENCY to Reg 29.4.3, 29.5.1 and 29.7.3 for vessel < 1,600 GT
V	26.5	The Administration may waive the requirements to carry out the checks and tests prescribed in paragraphs 1 and 2 for ships which regularly engage on voyages of short duration. Such ships shall carry out these checks and tests at least once every week.	EXEMPTION to 26.1 and 26.2
V	26.6	The date upon which the checks and tests prescribed in paragraphs 1 and 2 are carried out and the date and details of emergency steering drills carried out under paragraph 4, shall be recorded.	ENFORCEMENT

Chapter	Reg. No	Regulation Text	Discussion
1398	4.1.3	Alternatively to 4.1.1.2 and 4.1.1.3, depending on the rudder characteristic, critical deviations between rudder order and response should be indicated visually and audibly as steering failure alarm on the navigating bridge	ALTERNATIVE solution to comply with 4.1.1.2 and 4.1.1.3
1416		Ship manoeuvrability tests, such as according to resolution MSC.137(76) on Standards for ship manoeuvrability, should be carried out with steering angles not exceeding the declared steering angle limits.	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING
1416		Definition: Declared steering angle limits are the operational limits in terms of maximum steering angle, or equivalent, according to manufacturers' guidelines for safe operation, also taking into account the ship's speed or propeller torque/speed or other limitation; the "declared steering angle limits" are to be declared by the directional control system manufacturer for each ship specific non-traditional steering mean; ship manoeuvrability tests, such as those in the Standards for ship manoeuvrability (resolution MSC.137(76)) should be carried out with steering angles not exceeding the declared steering angle limits.	DEFINITION
1536	2	In order to demonstrate this ability, the trials may be conducted in accordance with section 6.1.5.1 of the standard ISO 19019:2005 (Sea-going vessels and marine technology – Instructions for planning, carrying out and reporting sea trials)	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING
1536	3	On all occasions when trials are conducted with the vessel not at the deepest seagoing draught, the loading condition can be accepted on the conditions that either	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING
1536	3.1	The rudder is fully submerged (at zero speed waterline) and the vessel is in an acceptable trim condition	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING

Chapter	Reg. No	Regulation Text	Discussion
1536	3.2	The rudder torque at the trial loading condition has been reliably predicted (based on the system pressure measurement) and extrapolated to the maximum seagoing draught condition using the following method to predict the equivalent torque and actuator pressure at the deepest seagoing ...	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING
1536	3.3	Alternatively, the designer or builder may use computational fluid dynamic (CFD) studies or experimental investigations to predict the rudder stock moment at the full seagoing draught condition and service speed. These calculations or experimental investigations should be to the satisfaction of the Administration.	SPECIFICATION SEA TRIAL/EQUIVALENT TESTING
1536	4	In any case for the main steering gear trial, the speed of the ship corresponding to the number of maximum continuous revolution of main engine and maximum design pitch applies.	SPECIFICATION SEA TRIAL Conditions
A.601	1.1	In pursuance of the Recommendation on Data Concerning Manoeuvring Capabilities and Stopping Distances of Ships, adopted by resolution A.160(ES.IV), and paragraph 10 of regulation II/1 of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, Administrations are recommended to require that the manoeuvring information given herewith is on board and available to navigators.	Chapeau text

Appendix G. Final goals and functional requirements for steering and manoeuvring



Top goal and individual goals for steering

Top goal for steering: *Prevent casualties arising from malfunctioning, insufficient performance or incorrect use of steering*

- Individual goal 1: The steering performance is sufficient to secure proper control of the vessel
- Individual goal 2: Maintain steering performance
- Individual goal 3: Limit effect of erroneous functionality
- Individual goal 4: Limit incorrect use

Top goal and individual goals for propulsion

Top goal for propulsion: Prevent casualties arising from malfunctioning or insufficient performance of astern propulsion to control the vessel

- Individual goal 1: The propulsion performance is sufficient to stop the vessel
- Individual goal 2: Limit incorrect use

Function I: The steering system provides adequate steering performance for ship operation

Expected performance:

- The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 30 minutes. Applicable for both normal and reduced service.
- Ability to turn/change course. Performance during Turning circle manoeuvre:
    - In normal service: advance within 4.5 ship lengths, tactical diameter within 5 ship lengths.
    - In reduced service: advance within 5.6 ship lengths, tactical diameter within 6.25 ship lengths.
- Steering gear performance

  Each steering gear can turn the steering force unit both to port and starboard with the following performance at scantling draft:
    - In Normal service, running ahead at maximum ahead service speed:
        - from declared steering angle limit on one side to declared steering angle limit on the other side
        - from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 28 seconds
    - In Reduced service (only applicable to ships with single steering system):
        - from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 56 seconds, running ahead at maximum ahead service speed
        - For tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and every other ship of less than 70,000 gross tonnage, the requirement may be reduced to:

          from 50% of declared steering angle limit on one side to 50% of declared steering angle limit on the other in not more than 60 seconds, running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.

Function II: The steering capability is maintained or can be regained in case of malfunction in either the steering control or steering actuating sub-systems or both together

Expected Performance:

- Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained;
    - For passenger ships of 70,000 gross tonnage and upwards, normal service performance is maintained
    - and for all other ships, at least reduced service performance is maintained
    - For multiple steering-propulsion systems, redundancy can be realized on ship level

- Malfunction of steering control system will not lead to complete loss of steering capability;
    - Reduced service steering capability is maintained.
    - Steering system can be operated from navigation position.
    - Steering force unit angle indicated independent of control system
    - Indication of steering force unit angle in all locations the steering gear can be operated from
- Normal service capability is available without steering remote control system
- Steering capability (either normal or reduced) will be speedily regained;
    - For tanker, chemical tanker and gas carrier of 10,000 gross tonnage and upwards within 45 s (e.g. by warm redundancy)
    - For all other ships within 15 min. (e.g. by cold redundancy)
    - Automatic restart of steering system when electrical power is regained after failure in electrical power supply
- Availability and performance of steering system continuously monitored and indicated on navigation position
- Loss of availability and overload is indicated by an alarm

Function III: The steering system is designed adequately for operational loads

Expected Performance:

- Components have adequate strength for ship operation and specified design life, considering:
    - All mechanical, hydraulic and electrical loads
    - Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice, maximum speed ahead/astern)
    - Safety factor adequate to address uncertainty in load determination and material/component properties
    - Actuating system is protected from overloads resulting from malfunctioning of the system
- Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality
- System operable under ship motion and environmental conditions
- Steering system availability is not hampered by safety devices
- Inspection concept adequate for steering system design

Function IV: The steering system is protected from external impacts

Expected Performance:

- Steering control system and actuator system are separated from other ship systems, and their electrical power supply arranged as separate circuit
- Electrical power supply maintained after malfunction in electric circuit
- Steering system is protected from external impacts by fire;
  - Separate routing of cabling for power supply and control system
  - No routing through areas of high risk of fire
  - Separate steering gear compartment from other machinery spaces
- Actuating system is protected from overloads, respectively;
  - Overloads due to external forces
  - Overloads resulting from erroneous operation

Additionally, passenger ships of 120 m in length or more or having three or more main vertical zones:

- Fire: reduced service steering capability available after loss of any space of origin
  - up to the nearest A class boundaries protected by fixed fire extinguishing system; or,
  - adjacent spaces up to nearest A class boundaries outside the space of origin
- Flooding: reduced service steering capability available after flooding of any single watertight compartment

Function V: The steering system is arranged to minimize impact of erroneous functionality

Expected Performance:

- Steering system shall be arranged with a fail-safe behaviour in case of failures
- Malfunction in data communication and programmable systems are automatically detected
- Consequences of malfunction in data communication and programmable systems are limited and do not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained
- Earth fault does not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained

Function VI: The steering system is arranged to minimize impact of erroneous operation

Expected Performance:

- Minimize possibilities of steering system operation threatening ship safety:
    - Limit possibility of erroneous input
        - Declare safe operational limits for steering system considering at least speed and stability
    - Limit effect of erroneous input

Function VII: Proper ship operation is enabled by providing information about ship's manoeuvring characteristics

Expected Performance:

- Provide information about ship's manoeuvring characteristics adequate for all persons involved in navigation and available at all navigation positions;
    - Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)
    - Comprehensive details of manoeuvring characteristics per MSC.137 shall be readily available to the operator

- Provide familiarisation of ship's manoeuvrability characteristics (drills and training)

Function VIII: The propulsion system provides adequate astern propulsion performance for ship operation

Expected Performance:

- Ship can be brought to rest with stopping distance within 15 ship lengths
- In reduced service, ships provided with multiple propulsion-steering systems can be brought to rest with stopping distance within 20 ship lengths

Further, but not addressed in this project:

- Propulsion thrust ahead is adequate for ship ahead operation

Function IX: Proper ship operation is enabled by providing information about ship's stopping characteristics

Expected Performance:

- Provide information about ship´s stopping characteristics adequate for all persons involved in navigation and available at all navigation positions

Appendix H. Proposal to IMO

This appendix includes the regulatory proposals for SOLAS regulations related to steering and manouvrability and associated Circulars and Resolutions.

This comprises, in this order, proposals for updates of the the following regulations, circulars and resolutions (for the documents in italics, see note below):

- SOLAS Reg.II-1/28: Means of going astern
- SOLAS Reg.II-1/29: Steering gear
- SOLAS Reg.II-1/30: Additional requirements for electric and electrohydraulic steering gear
- SOLAS Reg.V/25: Operation of steering gear
- SOLAS Reg.V/26: Steering gear: testing and drills
- *MSC.1/Circ.1398 – Unified interpretation of SOLAS Regulation II-1/29 Mechanical, Hydraulic and Electrical Independency and Failure Detection and Response of Steering and Control Systems*
- *MSC.1/Circ.1416/Rev.1 – Unified interpretation of SOLAS Regulation II-1/28 and II-1/29 concerning the arrangements for steering capability and function on ships fitted with propulsion and steering systems other than conventional arrangements for a ship's directional control*
- *Resolution A.415(XI) – Improved steering gear standards for passenger and cargo ships*
- *Resolution A.416(XI) – Examination of steering gear on existing tankers*
- MSC.1/Circ.1536 - Unified Interpretation of SOLAS regulations II-1/29.3 and 29.4
- Resolution MSC.137(76) - Standards for ship manoeuvrability
- MSC/Circ.1053 - Explanatory notes to the standards for ship manoeuvrability
- Resolution A.601(15) - Recommendation on the provision and the display of manoeuvring information on board ships

It should be noted that circulars MSC./Circ.1416/Rev.1 and MSC.1/Circ.1398 may be revoked as their contents have been incorporated into the regulations. Furthermore, Resolution A.415(XI) and Resolution A.416(XI) are considered to be obsolete and are proposed deleted.

Finally, the proposed new "MSC.1/Circ. XXXX: Goals, functional requirements and expected performance criteria for SOLAS regulations II-1/28 & 29 and V/25 & 26" is included as the last document in this appendix.

SOLAS Ch. II-1, Part A, regulation 3

Regulation 3 is amended as follows:

Regulation 3 Definitions relating to Parts C, D and E

For the purpose of parts C, D and E, unless expressly provided otherwise:

1 Steering system(s) is the ship's mean(s) of directional control, including steering gear, steering control and monitoring system and steering force unit, as well as all means connecting to power supply.

~~1~~ 2 Steering ~~gear~~ control system is the equipment by which orders are transmitted ~~from the navigating bridge~~ to the steering ~~gear power units.~~ actuating system(s). Steering ~~gear~~ control systems comprise all components from the user input device to the receivers, including transmitters, ~~receivers~~, controllers, piping, cables and data networks, hydraulic control pumps and their associated motors, motor controllers~~, piping~~ and ~~cables~~ solenoid valves, as appropriate.

3 Steering control and monitoring system is the steering control system and all monitoring devices, alarms and indicators (remote and local) needed to provide the steering function

4 Steering gear is the machinery, actuating system(s) and ancillary equipment to direct the steering force unit for the purpose of steering the ship. The steering gear may include various combinations of steering actuating systems and tiller or equivalent component.

~~2 Main steering gear is the machinery, rudder actuators, steering gear, power units, if any, and ancillary equipment and the means of applying torque to the rudder stock (e.g. tiller or quadrant) necessary for effecting movement of the rudder for the purpose of steering the ship under normal service conditions.~~

~~3~~ 5 Steering gear power unit is:

.1 in the case of electric steering gear, an electric motor and its associated electrical equipment;

.2 in the case of electrohydraulic steering gear, an electric motor and its associated electrical equipment and connected pump; or

.3 in the case of other hydraulic steering gear, a driving engine and connected pump.

~~4 Auxiliary steering gear is the equipment other than any part of the main steering gear necessary to steer the ship in the event of failure of the main steering gear but not including the tiller, quadrant or components serving the same purpose.~~

6 Steering actuator is a component which converts energy into mechanical motion to turn the steering force unit (e.g. hydraulic cylinder, piston, etc.).

7 Steering actuating system is the equipment provided for supplying power to turn the steering force unit, i.e. comprising steering gear power unit, actuator and the system connecting them (e.g.: transmission or piping system).

8 Steering force unit is the element generating the forces required to control the vessel (e.g. rudder and stock, rudder propeller, thruster, pod), including all parts up to the interface to the steering gear.

9 Declared steering angle limits are the operational limits in terms of maximum steering angle, or equivalent, according to manufacturer's guidelines for safe operation, also taking into account the ship's speed or propeller torque/speed or other limitations.

10 Neutral position is a position of the steering force unit producing none or the lowest possible steering force in straight ahead course.

~~5~~ 11 Normal operational and habitable condition is a condition under which the ship as a whole, the machinery, services, means and aids ensuring propulsion, ability to steer, safe navigation, fire and flooding safety, internal and external communications and signals, means of escape, and emergency boat winches, as well as the designed comfortable conditions of habitability are in working order and functioning normally.

~~6~~ 12 Emergency condition is a condition under which any services needed for normal operational and habitable conditions are not in working order due to failure of the main source of electrical power.

~~7~~ 13 Main source of electrical power is a source intended to supply electrical power to the main switchboard for distribution to all services necessary for maintaining the ship in normal operational and habitable conditions.

~~8~~ 14 Dead ship condition is the condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power.

~~9~~ 15 Main generating station is the space in which the main source of electrical power is situated.

~~10~~ 16 Main switchboard is a switchboard which is directly supplied by the main source of electrical power and is intended to distribute electrical energy to the ship' s services.

~~11~~ 17 Emergency switchboard is a switchboard which in the event of failure of the main electrical power supply system is directly supplied by the emergency source of electrical power or the transitional source of emergency power and is intended to distribute electrical energy to the emergency services.

~~12~~ 18 Emergency source of electrical power is a source of electrical power, intended to supply the emergency switchboard in the event of a failure of the supply from the main source of electrical power.

~~13 Power actuating system is the hydraulic equipment provided for supplying power to turn the rudder stock, comprising a steering gear power unit or units, together with the associated pipes and fittings, and a rudder actuator. The power actuating systems may share common mechanical components (i.e. tiller, quadrant and rudder stock) or components serving the same purpose~~.

~~14~~ 19 Maximum ahead service speed is the greatest speed which the ship is designed to maintain in service at sea at the deepest sea-going draught.

~~15~~ 20 Maximum astern speed is the speed which it is estimated the ship can attain at the designed maximum astern power at the deepest sea-going draught.

~~16~~ 21 Machinery spaces are all machinery spaces of category A and all other spaces containing propelling machinery, boilers, oil fuel units, steam and internal combustion engines, generators and major electrical machinery, oil filling stations, refrigerating, stabilizing, ventilation and air conditioning machinery, and similar spaces, and trunks to such spaces.

~~17~~ 22 Machinery spaces of category A are those spaces and trunks to such spaces which contain:

.1 internal combustion machinery used for main propulsion;

.2 internal combustion machinery used for purposes other than main propulsion where such machinery has in the aggregate a total power output of not less than 375 kW; or

.3 any oil-fired boiler or oil fuel unit.

~~18~~ 23 Control stations are those spaces in which the ship' s radio or main navigating equipment or the emergency source of power is located or where the fire recording or fire control equipment is centralized.

~~19~~ 24 Chemical tanker is a cargo ship constructed or adapted and used for the carriage in bulk of any liquid product listed in either:

.1 chapter 17 of the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk adopted by the Maritime Safety Committee by resolution MSC.4(48), hereinafter referred to as "the International Bulk Chemical Code", as may be amended by the Organization; or

.2 chapter VI of the Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk adopted by the Assembly of the Organization by resolution A.212(VII), hereinafter referred to as "the Bulk Chemical Code", as has been or may be amended by the Organization,

whichever is applicable.

~~20~~ 25 Gas carrier is a cargo ship constructed or adapted and used for the carriage in bulk of any liquefied gas or other products listed in either:

.1 chapter 19 of the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk adopted by the Maritime Safety Committee by resolution MSC.5(48), hereinafter referred to as "the International Gas Carrier Code", as may be amended by the Organization; or

.2 chapter XIX of the Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk adopted by the Organization by resolution A.328(IX), hereinafter referred to as "the Gas Carrier Code", as has been or may be amended by the Organization,

whichever is applicable.

SOLAS Ch. II-1, Part C, regulation 28

Regulation 28 is amended as follows:

Regulation 28 Means of stopping and going astern~~*~~

1 SCOPE

This regulation is addressing ships astern propulsion and stopping ability.

2 GOAL[1]

The goal of this regulation is to prevent casualties arising from malfunction or insufficient performance of astern propulsion to control the vessel.

3 FUNCTIONAL REQUIREMENTS

In order to achieve the goal in paragraph 2 above, the following functional requirements shall be met:

1. The propulsion system provides adequate astern propulsion performance for ship operation.
2. Proper ship operation is enabled by providing information about ship's stopping characteristics.

4 MEANS OF GOING ASTERN

~~1~~ Sufficient power for going astern shall be provided to secure proper control of the ship in all normal circumstances.

5 STOPPING ABILITY

5.1 All ships under normal operational condition shall have stopping ability meeting the criteria in paragraph 5.3.4.1 of Resolution MSC.137(76).

5.2 All ships provided with multiple propulsion lines shall have stopping ability meeting the criteria in paragraph 5.3.4.2 of Resolution MSC.137(76) while any one of the propulsion systems and its corresponding steering system is out of operation.

5.3 Compliance with stopping ability requirements shall be demonstrated by trials and the results shall be recorded.

5.4 Trials shall be performed according to procedure and in condition as described in Resolution MSC.137(76) and Circular MSC/Circ.1053.

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[1] Refer to *Goals, functional requirements and expected performance criteria for SOLAS regulations II-1/28 & 29 and V/25 & 26* (MSC.1/Circ. XXXX).

~~* Refer to the Recommendation on the provision and the display of manoeuvring information on board ships (resolution A.601(15)), the Standards for ship manoeuvrability (resolution MSC.137(76)), and the Explanatory notes to the standards for ship manoeuvrability (MSC/Circ.1053).~~

5.5 The stopping times, -distances and ship headings recorded on trials, along with stopping procedure shall be presented in wheelhouse poster and manoeuvring booklet as defined in Resolution A.601(15); readily available on board for the use of the master and designated personnel.

~~2 The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, shall be demonstrated and recorded.*~~

~~3 The stopping times, ship headings and distances recorded on trials, together with the results of trials to determine the ability of ships having multiple propellers to navigate and manoeuvre with one or more propellers inoperative, shall be available on board for the use of the master or designated personnel.~~

~~4~~ 5.6 Where the ship is provided with supplementary means for manoeuvring or stopping, the effectiveness of such means shall be demonstrated by trials and the results recorded as referred to in paragraph~~s 2 and 3~~ 5.5.

SOLAS Ch. II-1, Part C, regulation 29

The whole Regulation 29 is replaced as follows:

Regulation 29 Steering

1 SCOPE

This regulation is addressing steering function and steering performance of the ship, as well as requirements for the steering system(s) and its power supply.

2 GOAL[2]

The goal of this regulation is to prevent casualties arising from malfunction, insufficient performance or incorrect use of steering system(s).

3 FUNCTIONAL REQUIREMENTS

In order to achieve the goal in paragraph 2 above, the following functional requirements shall be met:

1. The steering system provides adequate steering performance for ship operation.
2. The steering capability is maintained or can be regained in case of malfunction in either the steering control or steering actuating sub-systems or both together.
3. The steering system is designed adequately for operational loads.
4. The steering system is protected from external impacts.
5. The steering system is arranged to minimize impact of erroneous functionality.
6. The steering system is arranged to minimize impact of erroneous operation.
7. Proper ship operation is enabled by providing information about ship's manoeuvring characteristics.

[2] Refer to *Goals, functional requirements and expected performance criteria for SOLAS regulations II-1/28 & 29 and V/25 & 26* (MSC.1/Circ. XXXX).

4 SHIP STEERING PERFORMANCE

4.1 For the purpose of present paragraph 4, a ship with steering system in reduced service is assumed to be as follows:

4.1.1 For ships with single steering system, one power unit shall be out of operation.

4.1.2 For ships with multiple steering systems, the least favourable steering system shall be out of operation.

4.2 All ships shall, both under normal operational condition and when the steering system is in reduced service, meet the criteria for heading keeping ability in paragraph 5.3.5 of Resolution MSC.137(76).

4.3 All ships under normal operational condition shall meet the criteria for turning ability in paragraph 5.3.1.1 of Resolution MSC.137(76).

4.4 Passenger ships of 70,000 gross tonnage and upwards shall, when the steering system is in reduced service, meet the criteria for turning ability in paragraph 5.3.1.1 of Resolution MSC.137(76).

4.5 Passenger ships of less than 70,000 gross tonnage and any cargo ship shall, when the steering system is in reduced service, meet the criteria for turning ability in paragraph 5.3.1.2 of Resolution MSC.137(76).

4.6 Compliance with ship steering performance requirements shall be demonstrated by trials and the results shall be recorded.

4.7 Trials to be performed according to procedure and in condition as described in Resolution MSC.137 and in Circular MSC/Circ.1053.

5 INFORMATION TO OFFICER IN CHARGE OF NAVIGATIONAL WATCH

To enable proper operation, information about ship's manoeuvring characteristics shall be made readily available for the use of the master or designated personnel in the form of:

.1 Simple operation instruction showing available backup solutions, switchover procedure and responses to alarms to speedily regain steering. Instruction shall be displayed at navigation position(s) and in steering gear compartment(s)

.2 Pilot card, as defined in Resolution A.601(15).

.3 Wheelhouse poster, as defined in Resolution A.601(15).

.4 Manoeuvring booklet, as defined in Resolution A.601(15). Its content shall cover, as a minimum, the standard manoeuvres as listed in Resolution MSC.137(76), based on trial results and/or predictions, as appropriate.

6 DESIGN PRINCIPLES

6.1 All steering system components shall be of sound and reliable construction based on adequate strength assessment for ship operation and specified design life considering:

.1 mechanical, hydraulic and electrical loads;

.2 characteristic loads resulting from operation of the steering system at the ship:

  .1 environmental loads such as but not limited to waves, ice and ship motion;

.2 loads generated from operation of steering gear within the ships design speed range ahead and astern;

.3 static and fatigue design criteria;

.4 degradation due to operational environment;

.5 degradation by wear and tear and

.6 safety factor(s) for scantling calculations adequately addressing uncertainty in load determination, material properties and component tolerances.

6.2 Special consideration shall be given to the suitability of any essential component which is not duplicated.

6.3 System shall be operable under ship motion and environmental conditions.

6.4 Loads resulting from malfunction of the system itself or external generated loads, including dynamic effects, shall be limited to the design loads. Load limitation shall be provided by passive means.

6.5 To minimise the impact of erroneous operation or failure, the steering system shall prevent operation outside of declared steering angle limits considering combination of permissible steering angles and ship speed.

6.6 To minimise the impact of erroneous functionality, the failures likely to cause uncontrolled movement of steering force unit shall be identified. Steering gear shall be arranged so that, in the event of such failures, the steering force unit will stop in the current position or return to midship/neutral without manual intervention.

7 FAILURE TOLERANCE OF STEERING SYSTEM

7.1 General

7.1.1 Every ship shall be provided with steering system(s) arranged so that any of the following single failures does not render the ship without steering capability:

.1 Control system:

- .1 Failure of power supply
- .2 Component/sensor failure
- .3 Loop failure (short circuit, broken connection and earth faults)
- .4 Data communication error
- .5 Programmable system failures (hardware and software failure)

.2 Steering gear

- .1 Failure of power unit
- .2 Failure in connection to power supply
- .3 Failure of hydraulic system: leakage and malfunction of valves
- .4 In the case of tankers, chemical tankers and gas carriers of 10,000 gross tonnage and upwards: failure of actuator

7.1.2 The following failures do not need to be considered:

.1 Blockage/damage on tiller/mechanical transmission

.2 Blockage/seizure of hydraulic actuator

.3 Blockage/seizure of electric actuator

.4 Blocking/damage on steering force unit

7.2 Ships with multiple steering systems

A ship with multiple steering systems is considered to be sufficiently fault tolerant as per 7.1, provided the following is complied with:

7.2.1 Each steering system is provided with an independent steering gear capable of meeting the requirements in paragraph 8.1.1.

7.2.2 To minimise the impact of either power unit or actuator failure, means shall be provided for positioning and locking any failed steering system in neutral position.

7.3 Ships with single steering system

A ship with single steering system is considered to be sufficiently fault tolerant as per 7.1, provided the following is complied with:

7.3.1 The steering actuating system shall be so arranged that after a single failure in one of the power units or, in case of hydraulic power operated, its piping system, the defect can be isolated so that steering capability can be maintained or regained within 15 minutes.

7.3.2 Every tanker, chemical tanker or gas carrier of 10,000 gross tonnage and upwards provided with a single steering system shall comply with the following:

7.3.2.1 The steering actuating system shall be so arranged that after a single failure in one of the power units, actuators or, in case of hydraulic power operated, its piping system; the defect can be isolated so that steering capability as per 8.1.1 can be maintained or automatically regained within 45 seconds.

7.3.2.2 Two identical steering actuating systems shall be arranged. However, tankers, chemical tankers or gas carriers of less than 100,000 tonnes deadweight do not need to have redundant actuators provided that an equivalent safety standard is achieved and special consideration is given to the following:

- .1 stress analysis for the design including fatigue analysis and fracture mechanics analysis;
- .2 installation of sealing arrangements;
- .3 testing and inspection;
- .4 provision of effective maintenance.

8 STEERING GEAR PERFORMANCE

8.1 Each steering gear shall have the following performance:

8.1.1 Ability in normal operational condition, operating at maximum ahead service speed:

- .1 Turn each steering force unit between declared steering angles limits;
- .2 Turn each steering force unit from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 28 seconds. The steering gear shall be operated by power where necessary to meet this requirement and, in any case:

.1 for rudder based steering systems, when the Administration requires a rudder stock of over 120 mm diameter in way of tiller, excluding strengthening for navigation in ice;

.2 for thruster based steering systems.

8.1.2 For ships with single steering system, ability when one power unit is out of operation:

.1 Passenger ships of 70,000 gross tonnage and upwards shall meet the requirements in paragraph 8.1.1.
.2 Tankers, chemical tankers and gas carriers of 10,000 gross tonnage and upwards and every other cargo ship of 70,000 gross tonnage and upwards shall be able to turn the steering force unit from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 56 seconds, with the ship running ahead at maximum ahead service speed;
.3 Any other ship not considered in the previous two subparagraphs shall be able to turn the steering force unit from 50% of declared steering angle limit on one side to 50% of declared steering angle limit on the other in not more than 60 seconds, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.
.4 The steering gear shall be operated by power where necessary to meet this requirement and, in any case:

.1 for rudder based steering systems, when the Administration requires a rudder stock of over 230 mm diameter in way of tiller, excluding strengthening for navigation in ice;

.2 for thruster based steering systems, when the propulsion power per thruster unit exceeds 2,500 kW.

8.1.3 For rudder-based steering systems, the declared steering angle limit shall be 35 degrees unless otherwise is substantiated.

8.2 Compliance with steering gear performance requirements shall be demonstrated by trials and the results shall be recorded.

8.3 Trials shall be performed with the ship at its deepest seagoing draught and even keel. Where this cannot be achieved, the procedure in MSC.1/Circ.1536 may be followed to predict full load results based on test results.

9 CONTROL SYSTEM

9.1 Steering control and monitoring function

9.1.1 Steering control and monitoring systems shall be arranged to ensure safe, efficient and reliable operation of the steering system from the dedicated control positions.

9.1.2 No single failure in steering control system shall cause loss of steering capability.

9.1.3 Availability and performance of steering system shall be continuously monitored and indicated on navigation position.

9.2 Control systems

9.2.1 All ships shall be provided with at least two independent steering control systems.

9.2.2 The two independent steering control systems shall, as far as practicable, be arranged with physical segregation.

9.2.3 It shall be possible to operate each independent steering control system both remotely from the navigating bridge and locally from the steering gear compartment(s) as follows:

- .1 Remote control:
  - .1 The navigating bridge is the main command position for remote steering.
  - .2 Means to bring the steering system into operation shall be provided.
  - .3 If multiple steering modes are available, a mode selector function and indication shall be provided.
- .2 Local control:
  - .1 The local control shall not depend on any part of the control system located outside the steering gear compartment.
  - .2 Means shall be provided to disable remote control.

9.2.4 Independent steering control systems may be interfaced to common external systems/units (e.g. autopilot, dynamic positioning or mode selector) if no single failures in the external system/unit can propagate to the independent steering control systems.

9.2.5 A common lever/steering wheel may serve independent steering control systems provided that the electrical transmitters and circuits serving the control systems are independent.

9.3 Alarm and monitoring

9.3.1 Alarm functions for all steering systems may be arranged in a common alarm system.

9.3.2 The most probable failures with the potential of functional loss, reduced or erroneous system performance shall be detected and alarmed. At least, the following failures shall be included:

1. Steering Control and monitoring system failures:
   1. Equipment/component failures
   2. Power supply failure including earth fault
   3. Loop failure in closed loop systems (open loop, short circuit, earth fault)
   4. Sensor failure
   5. Data communication failure
   6. Hardware/Software failure in programmable systems
2. Steering function response failures:
   1. Deviation between steering command and feedback
3. Steering gear failures:

1. Conflicting operation of two steering actuators in a common steering system that may cause blocking and loss of steering
2. Power unit failure
3. If hydraulically powered: low level alarm in reservoir, hydraulic locking, leakage, malfunction of valves

4. Power units failures: electric power supply failures: phase failure, overload
5. Converters failures: power supply failure, converter failure, converter trip and earth failure.

9.3.3 Failure conditions shall initiate alarms at the navigating bridge and/or engine-/control room.

9.3.4 Alarms presented at the navigating bridge shall be limited to those requiring attention from bridge personnel, according the following categories:

1. All alarms requiring immediate attention and action from the bridge: Alarm status shall be continuously displayed, readily observable at the steering stand;
2. All other failures and conditions not immediately affecting steering capabilities shall be presented by warnings. Warnings are presented for precautionary reasons and can be displayed individually or in groups

9.3.5 All alarms and warnings shall be given in engine-/control room, including those presented at the navigating bridge.

9.3.6 Alarm acknowledgment shall, in general, be only possible from the location that is responsible to respond. Only alarms that specifically demand attention from the navigation bridge shall be acknowledged from the bridge.

9.3.7 For unattended machinery operations, the engine-/control room alarms shall be presented through the alarm systems.

9.4 Indicators

9.4.1 All necessary indicators for the safe operation of the ship shall be provided at each control position including:

.1 remotely at the navigating bridge: steering force angle indication for each steering force unit, independent of any remote control system;

.2 remotely at other control positions, if provided: steering angle indication for each steering force unit;

.3 locally in the steering gear compartment(s):

1. steering angle indication for each steering force unit. Indication system shall be independent of the remote control system;
2. vessel heading.

9.4.2 Steering gear power units

The steering gear power units shall be:

.1 provided with necessary means for control and indication from the required steering control positions,

.2 arranged to re-start automatically when power is restored after a power failure.

9.5 Power supply

Each steering control system shall be:

1. fed by a separate circuit from either the circuit of the power units of the associated steering gear from a point within the steering gear compartment, or directly from

switchboard busbars supplying the power units of the associated steering gear at a point on the switchboard adjacent to the supply to the power units of the associated steering gear, and

2. the switchboard connection shall be provided with short circuit protection.

9.6 Response to failures

A single failure in a steering control system shall:

1. Not affect the other, independent steering control system
2. Lead to the least critical state of the steering system
3. If leading to loss of control of the associated steering force unit, put the steering force unit to neutral position or freeze it in its present steering angle. In the latter case, it shall be arranged such that the steering force unit can be positioned and locked in neutral position by the means prescribed in paragraph 7.2.2.
4. Not impair the steering systems ability to automatically prevent steering angles beyond the declared limits in any mode of operation
5. Be detected and alarmed

10 HYDRAULIC POWER SUPPLY

10.1 Hydraulic power-operated steering gear shall be provided with the following:

1. arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system;

2. a low-level alarm for each hydraulic fluid reservoir to give the earliest practicable indication of hydraulic fluid leakage.

3. relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. The setting of the relief valves shall not exceed the design pressure. The valves shall be of adequate size and so arranged as to avoid an undue rise in pressure above the design pressure.

4. for ships with single steering system: a fixed storage tank having sufficient capacity to recharge at least one steering actuating system including the reservoir.
   The storage tank shall be:

   .1 permanently connected by piping in such a manner that the hydraulic systems can be readily recharged from a position within the steering gear compartment; and,

   .2 provided with a contents gauge.

10.2 The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the maximum working pressure to be expected under the operational conditions specified in paragraph 8.1.1, taking into account any pressure which may exist in the low pressure side of the system. At the discretion of the Administration, fatigue criteria shall be applied for the design of piping and components, taking into account pulsating pressures due to dynamic loads.

11 ELECTRIC POWER SUPPLY

11.1 Electric power supply for steering gear shall be arranged such that a single circuit failure will not render the ship without steering capability.

11.2 In case the ship is provided with multiple steering systems, each steering gear shall be served by at least one exclusive circuit fed directly from the main switchboard. In case of a split switchboard, the circuits shall be taken from separate sides.

11.3 In case the ship is provided with a single steering system, the steering gear shall be served by at least two exclusive circuits fed directly from the main switchboard. In case of a split switchboard, the circuits shall be taken from separate sides; however, one of the circuits may be supplied through the emergency switchboard.

11.3.1 For ships of less than 1,600 gross tonnage, the steering gear complying with paragraph 8.1.1 may be fed by only one electric circuit from the main switchboard when the steering gear complying with paragraph 8.1.2, if different, is required to be operated by power and either:

1. is not electrically powered or,

2. is electrically powered by an electric motor primarily intended for other services. The requirement in paragraphs 11.6 and 11.7 may be waived by the Administration for such a non-exclusive circuit if satisfied with the protection arrangement together with the requirements in paragraphs 9.4.2 and 9.2.3.

11.4 Alternative electric power supply

11.4.1 An alternative electric power supply shall be provided from the emergency source of electrical power or from an independent and dedicated power source located in the steering gear compartment:

1. For rudder based steering systems, when the Administration requires a rudder stock of over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice.
2. For thruster based steering systems proving certain steering capability due to ship speed also in case propulsion power has failed, when the propulsion power per thruster unit exceeds 2,500 kW.

11.4.2 This alternative electric power supply shall:

1. be provided automatically within 45 seconds;
2. be sufficient to turn the steering force unit from 50% of declared steering angle limit on one side to 50% of declared steering angle limit on the other in not more than 60 seconds, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater;
3. be sufficient to power the associated control system and the steering angle indicator;
4. for every ship of 10,000 gross tonnage and upwards, have a capacity for at least 30 minutes of continuous operation and in any other ship for at least 10 minutes. The Administration may waive this requirement provided that an equivalent availability of power supply is proven.

11.5 The circuits supplying an electric or electrohydraulic steering gear shall have adequate rating for supplying all motors which can be simultaneously connected to them and may be required to operate simultaneously.

11.6 Short circuit protection and an overload alarm shall be provided for circuits and motors.

11.7 If excess current protection is provided, the release current shall not be less than twice the full load current. Circuits obtaining their power supply via an electronic converter, which are limited to full load current, are exempted from the requirement to only trip upon short circuit.

11.8 Converters shall be provided with alarm for power supply failure, converter failure, converter trip and earth failure.

12 STEERING GEAR COMPARTMENT

12.1 To protect steering system from external impacts, the steering gear compartment(s) shall as far as practicable be separated from other machinery spaces.

12.2 To enable regaining steering by local control, as well as enabling inspection and maintenance, the steering gear compartment(s) shall be:

1. readily accessible;

2. provided with suitable arrangements to ensure working access to steering gear machinery and controls. These arrangements shall include handrails and gratings or other non-slip surfaces;

3. provided with means of two-way communication between the navigating bridge and the steering gear compartment.

SOLAS Ch. II-1, Part C, regulation 30

Regulation 30 is deleted.

Regulation 30 Additional requirements for electric and electrohydraulic steering gear

[content incorporated in Reg.29]

SOLAS Ch. V, regulation 25

Regulation 25 is amended as follows:

Regulation 25 Operation of steering gear

In areas where navigation demands special caution, ships shall have more than one steering gear power unit in operation when such units are capable of simultaneous operation. Ships with multiple steering systems shall have more than one steering system in operation.

SOLAS Ch. V, regulation 26

Regulation 26 is amended as follows:

Regulation 26 Steering gear: Testing and drills

1 Within 12 hours before departure, the ship's steering gear shall be checked and tested by the ship's crew. The test procedure shall include, where applicable, the operation of the following:

.1 the ~~main~~ steering gear(s);

.2 ~~the auxiliary steering gear;~~ manual isolation arrangements to regain steering

.3 the remote steering gear control systems;

.4 the steering positions located on the navigation bridge;

.5 the emergency power supply;

.6 the ~~rudder~~ steering angle indicators in relation to the actual position of the steering force unit ~~rudder~~;

.7 the remote steering gear control system power failure alarms;

.8 the steering gear power unit failure alarms; and

.9 automatic isolating arrangements and other automatic equipment.

2 The checks and tests shall include:

.1 the full movement of the ~~rudder~~ steering force unit according to the required capabilities of the steering gear;

.2 a visual inspection for the steering gear and its connecting linkage; and

.3 the operation of the means of communication between the navigation bridge and steering gear compartment.

3.1 Simple operating instructions with a block diagram showing the change-over procedures for remote steering gear control systems and steering gear power units shall be permanently displayed on the navigation bridge and in the steering compartment.

3.2 All ships' officers concerned with the operation and/or maintenance of steering gear shall be familiar with the operation of the steering systems fitted on the ship and with the procedures for changing from one system to another, as well as the ship's manoeuvring characteristics.

4 In addition to the routine checks and tests prescribed in paragraphs 1 and 2, emergency steering drills shall take place at least once every three months in order to practise emergency steering procedures. These drills shall include direct control within the steering gear compartment, the communications procedure with the navigation bridge and, where applicable the operation of alternative power supplies.

5 The Administration may waive the requirements to carry out the checks and tests prescribed in paragraphs 1 and 2 for ships which regularly engage on voyages of short duration. Such ships shall carry out these checks and tests at least once every week.

6 The date upon which the checks and tests prescribed in paragraphs 1 and 2 are carried out and the date and details of emergency steering drills carried out under paragraph 4, shall be recorded.

Circular MSC.1/Circ.1536

Annex to MSC.1/Circ.1536 is amended as follows:

ANNEX

UNIFIED INTERPRETATIONS OF SOLAS REGULATION~~S~~ II-1/29.8~~3~~ ~~AND II-1/29.4~~

Regulation II-1/29 – Steering~~ gear~~

1 In order for ships to comply with the performance requirements stated in regulation~~s~~ II-1/29.8.1~~3.2 and 29.4.2~~, they are to have steering gear capable of meeting these performance requirements when at their deepest seagoing draught.

2 In order to demonstrate this ability, the trials may be conducted in accordance with section 6.1.5.1 of the standard ISO 19019:2005 (Sea-going vessels and marine technology – Instructions for planning, carrying out and reporting sea trials).

3 On all occasions when trials are conducted with the vessel not at the deepest seagoing draught, the loading condition can be accepted on the conditions that either:

.1 The ~~rudder~~ steering force unit is fully submerged (at zero speed waterline) and the vessel is in an acceptable trim condition.

.2 For traditional steering systems with rudder: The rudder torque at the trial loading condition has been reliably predicted (based on the system pressure measurement) and extrapolated to the maximum seagoing draught condition using the following method to predict the equivalent torque and actuator pressure at the deepest seagoing draught:

$$Q_F = Q_T \alpha$$

$$\alpha = 1.25\left(\frac{A_F}{A_T}\right)\left(\frac{V_F}{V_T}\right)^2$$

where:

α is the Extrapolation factor.

Q_F is the rudder stock moment (torque in the rudder stock) for the deepest service draught and maximum service speed condition.

Q_T is the rudder stock moment (torque in the rudder stock) for the trial condition.

A_F is the total immersed projected area of the movable part of the rudder in the deepest seagoing condition.

A_T is the total immersed projected area of the movable part of the rudder in the trial condition.

V_F is the contractual design speed of the vessel corresponding to the maximum continuous revolutions of the main engine at the deepest seagoing draught.

V_T is the measured speed of the vessel (considering current) in the trial condition.

Where the rudder actuator system pressure is shown to have a linear relationship to the rudder stock torque the above equation can be taken as:

$$P_F = P_T \alpha$$

where:

P_F is the estimated steering actuator hydraulic pressure in the deepest seagoing draught condition.

P_T is the maximum measured actuator hydraulic pressure in the trial condition.

Where constant volume fixed displacement pumps are utilized then the regulations can be deemed satisfied if the estimated steering actuator hydraulic pressure at the deepest draught is less than the specified maximum working pressure of the rudder actuator. Where a variable delivery pump is utilized pump data should be supplied and interpreted to estimate the delivered flow rate corresponds to the deepest seagoing draught in order to calculate the steering time and allow it to be compared to the required time.

Where A_T is greater than $0.95A_F$ there is no need for extrapolation methods to be applied.

.3 Alternatively, the designer or builder may use computational fluid dynamic (CFD) studies or experimental investigations to predict the rudder stock moment at the full seagoing draught condition and service speed. These calculations or experimental investigations should be to the satisfaction of the Administration.

4 ~~In any case for the main steering gear trial, t~~The speed of the ship corresponding to the number of maximum continuous revolutions of the main engine and maximum design pitch applies in general for the trial condition, except for testing the performance stated in regulation II-1/29.8.1.2.3, where one half of that speed or 7 knots, whichever is greater, applies.

Resolution MSC.137(76)

Annex to Resolution MSC.137(76) is amended as follows:

ANNEX

STANDARDS FOR SHIP MANOEUVRABILITY

1 Principles

1.1 The Standards for ship manoeuvrability (the Standards) should be used to evaluate the manoeuvring performance of ships and to assist those responsible for the design, construction, repair and operation of ships.

1.2 It should be noted that the Standards were initially developed for ships with traditional propulsion and steering systems (e.g. shaft driven ships with conventional rudders~~).~~) and have been further updated to also consider other known propulsion/steering systems (azimuthing thrusters, water jets and cycloidals). Therefore, the Standards and methods for establishing compliance may continue to be periodically reviewed and updated by the Organization, as appropriate, taking into account new technologies, research and development, and the results of experience with the present Standards.

2 General

2.1 The Standards contained in this document are based on the understanding that the manoeuvrability of ships can be evaluated from the characteristics of conventional trial manoeuvres. The following two methods can be used to demonstrate compliance with these Standards:

> .1 scale model tests and/or computer predictions using mathematical models can be performed to predict compliance at the design stage. In this case full- scale trials should be conducted to validate these results. The ship should then be considered to meet these Standards regardless of full-scale trial results, except where the Administration determines that the prediction efforts were substandard and/or the ship performance is in substantial disagreement with these Standards; and
>
> .2 the compliance with the Standards can be demonstrated based on the results of the full-scale trials conducted in accordance with the Standards. If a ship is found in substantial disagreement with the Standards, then the Administration should take remedial action, as appropriate.

3 Application

3.1 Notwithstanding the points raised in paragraph 1.2 above, the Standards should be applied to ships of all ~~rudder~~steering and propulsion types, of 100 m in length and over, and tankers, chemical tankers and gas carriers regardless of the length. The criteria contained in paragraphs 5.3.1, 5.3.4 and 5.3.5 shall be also applicable to any ship subject to Chapter II-1 of the 1974 SOLAS Convention.

3.2 In the event that the ships referred to in paragraph 3.1 above undergo repairs, alterations or modifications, which, in the opinion of the Administration, may influence their manoeuvrability characteristics, the continued compliance with the Standards should be verified.

3.3 Whenever other ships, originally not subject to the Standards, undergo repairs, alterations or modifications, which, in the opinion of the Administration, are of such an extent that the ship may be considered to be a new ship, then that ship should comply with these Standards. Otherwise, if the repairs, alterations and modifications, in the opinion of the Administration, may influence the manoeuvrability characteristics, it should be demonstrated that these characteristics do not lead to any deterioration of the manoeuvrability of the ship.

3.4 The Standards should not be applied to high-speed craft as defined in the relevant Code.

4 Definitions

4.1 *Geometry of the ship*

4.1.1 *Length* (L) is the length ~~measured between the aft and forward perpendiculars~~as defined in the International Convention on Load Lines in force.

4.1.2 *Midship point* is the point on the centreline of a ship midway between the aft and forward perpendiculars.

4.1.3 *Draught* (T_a) is the draught at the aft perpendicular.

4.1.4 *Draught* (T_f) is the draught at the forward perpendicular.

4.1.5 *Mean draught* (T_m) is defined as $T_m = (T_a + T_f)/2$.

4.1.6 *Trim* (τ) is defined as $\tau = (T_a - T_f)$.

4.1.7 Δ is the full load displacement of the ship (tonnes).

4.2 *Standard manoeuvres and associated terminology*

Standard manoeuvres and associated terminology are as defined below:

.1 The test speed (V) used in the Standards is a speed of at least 90% of the ship's speed corresponding to 85% of the maximum engine output.

.2 Turning circle manoeuvre is the manoeuvre to be performed to both starboard and port with ~~35° rudder angle or the maximum rudder angle permissible~~declared steering angle limit (SOLAS, II-1, 3.9) at the test speed, following a steady approach with zero yaw rate.

.3 Advance is the distance travelled in the direction of the original course by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 90° from the original course.

.4 Tactical diameter is the distance travelled by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 180° from the original course. It is measured in a direction perpendicular to the original heading of the ship.

.5 Zig-zag test is the manoeuvre where a known amount of helm is applied alternately to either side when a known heading deviation from the original heading is reached.

.6 The 10°/10° zig-zag test is performed by ~~turning the rudder~~steering alternately by ~~10°~~1/3 of the declared steering angle limit to either side following a heading deviation of 10° from the original heading in accordance with the following procedure:

> .1 after a steady approach with zero yaw rate, the ~~rudder~~steering is put over to ~~10°~~1/3 of the declared steering angle limit to starboard or port (first execute);
>
> .2 when the heading has changed to 10° off the original heading, the ~~rudder~~steering is reversed to ~~10°~~1/3 of the declared steering angle limit to port or starboard (second execute); and
>
> .3 after the ~~rudder~~steering has been turned to port/starboard, the ship will continue turning in the original direction with decreasing turning rate. In response to the ~~rudder~~steering, the ship should then turn to port/starboard. When the ship has reached a heading of 10° to port/starboard of the original course the ~~rudder~~steering is again reversed to ~~10°~~1/3 of the declared steering angle limit to starboard/port (third execute).

.7 The first overshoot angle is the additional heading deviation experienced in the zig-zag test following the second execute.

.8 The second overshoot angle is the additional heading deviation experienced in the zig-zag test following the third execute.

.9 The 20°/20° zig-zag test is performed using the procedure given in paragraph 4.2.6 above using ~~20° rudder angles~~2/3 of the declared steering angle limit as steering angle and 20° change of heading, instead of ~~10° rudder angles~~1/3 of the declared steering angle limit and 10° change of heading, respectively.

.10 Full astern stopping test determines the track reach of a ship from the time an order for full astern is given until the ship stops in the water.

.11 Track reach is the distance along the path described by the midship point of a ship measured from the position at which an order for full astern is given to the position at which the ship stops in the water.

.12 The heading keeping test is performed by running straight ahead for 30 minutes. Autopilot may be engaged.

.13 The maximum yaw deviation is the maximum heading deviation from the preset heading.

.14 A ship with steering system in reduced service is assumed to be as follows (SOLAS, II-1, 29.4.1):

.1 For ships with single steering system, one power unit shall be out of operation.

.2 For ships with multiple steering systems, the least favourable steering system shall be out of operation.

4.3 Definitions contained in regulation 3 of SOLAS Chapter II-1 are also applicable.

5 Standards

5.1 The standard manoeuvres should be performed without the use of any manoeuvring aids which are not continuously and readily available in normal operation.

5.2 *Conditions at which the standards apply*

In order to evaluate the performance of a ship, manoeuvring trials should be conducted to both port and starboard and at conditions specified below:

.1 deep, unrestricted water;

.2 calm environment;

.3 full load (summer load line draught), even keel condition; and

.4 steady approach at the test speed.

5.3 *Criteria*~~*~~

~~* For ships with non-conventional steering and propulsion systems, the Administration may permit the use of comparative steering angles to the rudder angles specified by this Standard.~~

The manoeuvrability of the ship is considered satisfactory if the following criteria are complied with:

.1 Turning ability

.1 Standard criteria: t~~T~~he advance should not exceed 4.5 ship lengths (L) and the tactical diameter should not exceed 5 ship lengths in the turning circle manoeuvre.
.2 Reduced criteria: the advance should not exceed 5.6 ship lengths (L) and the tactical diameter should not exceed 6.25 ship lengths in the turning circle manoeuvre.
.3 The standard criteria are applicable to (SOLAS, II-1, 29.4.3-4):
a. All ships under normal operational condition.
b. Passenger ships of 70,000 gross tonnage and upwards also when the steering system is in reduced service.
.4 The reduced criteria are applicable to (SOLAS, II-1, 29.4.5):
a. Passenger ships of less than 70,000 gross tonnage and any cargo ship when the steering system is in reduced service.

.2 Initial turning ability
With the application of ~~10° rudder~~1/3 of the declared steering angle limit to

port/starboard, the ship should not have travelled more than 2.5 ship lengths by the time the heading has changed by 10° from the original heading.

.3 Yaw-checking and course-keeping abilities

.1 The value of the first overshoot angle in the 10°/10° zig-zag test should not exceed:

.1 10° if L/V is less than 10 s;

.2 20° if L/V is 30 s or more; and

.3 [5 + 1/2(L/V)] degrees if L/V is 10 s or more, but less than 30 s, where L and V are expressed in m and m/s, respectively.

.2 The value of the second overshoot angle in the 10°/10° zig-zag test should not exceed:

.1 25°, if L/V is less than 10 s;

.2 40°, if L/V is 30 s or more; and

.3 [17.5 + 0.75(L/V)]°, if L/V is 10 s or more, but less than 30 s.

.3 The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°.

.4 Stopping ability

.1 Standard criterion: ~~t~~The track reach in the full astern stopping test should not exceed 15 ship lengths. However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

.2 Reduced criterion: the track reach in the full astern stopping test should not exceed 20 ship lengths.

.3 The standard criterion is applicable to (SOLAS, II-1, 28.5.1):

a. All ships under normal operational condition.

.4 The reduced criterion is applicable to (SOLAS, II-1, 28.5.2):

a. All ships provided with multiple propulsion lines while any one of the propulsion systems and its corresponding steering system is out of operation.

.5 Heading keeping ability

The maximum yaw deviation should not exceed 2 degrees during the heading keeping test both under normal operational condition and when the steering system is in reduced service.

6 Additional considerations

6.1 In case the standard trials are conducted at a condition different from those specified in paragraph 5.2.3, necessary corrections should be made in accordance with the guidelines contained in the Explanatory notes to the Standards for ship manoeuvrability~~, developed by the Organization*.~~ (MSC/Circ.1053).

6.2 Where standard manoeuvres indicate dynamic instability, alternative tests may be conducted to define the degree of instability. Guidelines for alternative tests such as a spiral test or pull-out manoeuvre are included in the Explanatory notes to the Standards for ship manoeuvrability, referred to in paragraph 6.1 above.

Circular MSC.1/Circ.1053

Annex to MSC.1/Circ.1053 is amended as follows:

ANNEX

EXPLANATORY NOTES TO THE STANDARDS FOR SHIP MANOEUVRABILITY

CHAPTER 1 GENERAL PRINCIPLES

1.1 Philosophy and background

1.1.1 The purpose of this section is to provide guidance for the application of the Standards for Ship Manoeuvrability (resolution MSC.137(76)) along with the general philosophy and background for the Standards.

1.1.2 Manoeuvring performance has traditionally received little attention during the design stages of a commercial ship. A primary reason has been the lack of manoeuvring performance standards for the ship designer to design to, and/or regulatory authorities to enforce. Consequently some ships have been built with very poor manoeuvring qualities that have resulted in marine casualties and pollution. Designers have relied on the shiphandling abilities of human operators to compensate for any deficiencies in inherent manoeuvring qualities of the hull. The implementation of manoeuvring standards will ensure that ships are designed to a uniform standard, so that an undue burden is not imposed on shiphandlers in trying to compensate for deficiencies in inherent ship manoeuvrability.

1.1.3 IMO has been concerned with the safety implications of ships with poor manoeuvring characteristics since the meeting of the Sub-Committee on Ship Design and Equipment (DE) in 1968. MSC/Circ.389 titled "Interim Guidelines for Estimating Manoeuvring Performance in Ship Design", dated 10 January 1985, encourages the integration of manoeuvrability requirements into the ship design process through the collection and systematic evaluation of ship manoeuvring data. Subsequently, the Assembly, at its fifteenth session in November 1987, adopted resolution A.601(15), entitled "Provision and Display of Manoeuvring Information on board Ships". This process culminated at the eighteenth Assembly in November 1993, where "Interim Standards for Ship Manoeuvrability" were adopted by resolution A.751(18).

1.1.4 After the adoption of resolution A.751(18), the Maritime Safety Committee, at its sixty-third session, approved MSC/Circ.644 titled "Explanatory notes to the Interim Standards for ship manoeuvrability", dated 6 June 1994, to provide Administrations with specific guidance so that adequate data could be collected by the Organization on the manoeuvrability of ships with a view to amending the aforementioned Interim Standards. This process culminated at the seventy-sixth session of the Maritime Safety Committee in December 2002, where Standards for ship manoeuvrability were adopted by resolution MSC.137(76).

1.1.5 The Standards were selected so that they are simple, practical and do not require a significant increase in trials time or complexity over that in current trials practice. The Standards are based on the premise that the manoeuvrability of ships can be adequately judged from the results of typical ship trials manoeuvres. It is intended that the manoeuvring performance of a ship be designed to comply with the Standards during the design stage, and that the actual manoeuvring characteristics of the ship be verified for compliance by trials. Alternatively, the compliance with the Standards can be demonstrated based on the results of full-scale trials, although the Administration may require remedial action if the ship is found in substantial disagreement with the Standards. Upon completion of ship trials, the shipbuilder should examine the validity of the manoeuvrability prediction methods used during the design stage.

1.2 Manoeuvring characteristics

The "manoeuvring characteristics" addressed by the IMO Standards for ship manoeuvrability are typical measures of performance quality and handling ability that are of direct nautical interest. Each can be reasonably well predicted at the design stage and measured or evaluated from simple trial-type manoeuvres.

1.2.1 Manoeuvring characteristics: general

1.2.1.1 In the following discussion, the assumption is made that the ship has normal actuators for the control of forward speed and heading positioned close to the stern (i.e., ~~a stern~~ propeller(s) and ~~a stern~~ rudder~~).~~(s), azimuthing thruster(s), water jet(s) or cycloidal(s)). However, most of the definitions and conclusions may also apply to ships with other (novel) types of control actuators.

1.2.1.2 In accepted terminology, questions concerning the manoeuvrability of a ship include the stability of steady-state motion with "fixed controls" as well as the time-dependent responses that result from the control actions used to maintain or modify steady motion, make the ship follow a prescribed path or initiate an emergency manoeuvre, etc. Some of these actions are considered to be especially characteristic of ship manoeuvring performance and therefore should be required to meet a certain minimum standard. A ship operator may choose to ask for a higher standard in some respect, in which case it should be remembered that some requirements may be mutually incompatible within conventional designs. For similar reasons the formulation of the IMO Standards for ship manoeuvrability has involved certain compromises.

1.2.2 Manoeuvring characteristics: some fundamentals (Reference is made to Appendix 1)

1.2.2.1 At a given engine output and ~~rudder~~steering angle δ, the ship may take up a certain steady motion. In general, this will be a turning motion with constant yaw rate *y*~~ψ~~, speed V and drift angle β (bow-in). The radius of the turn is then defined by the following relationship, expressed in consistent units:

R = V/*y*~~ψ~~.

1.2.2.2 This particular ship-~~rudder~~steering angle configuration is said to be "dynamically stable in a turn of radius R". Thus, a straight course may be viewed as part of a very wide circle with an infinite radius, corresponding to zero yaw rate.

1.2.2.3 Most ships, perhaps, are "dynamically stable on a straight course" (usually referred to as simply "dynamically stable") with the rudder in a neutral position close to midship. In the case of a single screw ship with a right-handed propeller, this neutral helm is typically of the order δ_0 = -1° (i.e., 1° to starboard). Other ships which are dynamically unstable, however, can only maintain a straight course by repeated use of rudder control. While some instability is fully acceptable, large instabilities should be avoided by suitable design of ship proportions and stern shape.

1.2.2.4 The motion of the ship is governed mainly by the propeller thrust and the hydrodynamic and mass forces acting on the hull. During a manoeuvre, the side force due to ~~the rudder~~steering is often small compared to the other lateral forces. However, the introduced controlling moment is mostly sufficient to balance or overcome the resultant moment of these other forces. In a steady turn there is complete balance between all the forces and moments acting on the hull. Some of these forces seeming to "stabilize" and others to "destabilize" the motion. Thus the damping moment due to yaw, which always resists the turning, is stabilizing and the moment associated with the side force due to sway is destabilizing. Any small disturbance of the equilibrium attitude in the steady turn causes a change of the force and moment balance. If the ship is dynamically stable in the turn (or on a straight course) the net effect of this change will strive to restore the original turning (or straight) motion.

1.2.2.5 The general analytical criterion for dynamic stability may be formulated and evaluated with the appropriate coefficients of the mathematical model that describes the ship's motion. The criterion for dynamic stability on a straight course includes only four "linear stability derivatives" which together with the centre-of-gravity position, may be used to express the "dynamic stability lever". This lever denotes the longitudinal distance from the centre-of-pressure of the side force due to pure sway (or sideslip) to the position of the resultant side force due to pure turning, including the mass force, for small deviations from the straight-line motion. If this distance is positive (in the direction of positive x, i.e. towards the bow) the ship is stable. Obviously "captive tests" with a ship model in oblique towing and under the rotating arm will furnish results of immediate interest.

1.2.2.6 It is understood that a change of trim will have a marked effect mainly on the location of the centre-of-pressure of the side force resulting from sway. This is easily seen that a ship with a stern trim, a common situation in ballast trial condition, is likely to be much more stable than it would be on an even draught.

1.2.2.7 Figure 1 gives an example of the equilibrium yaw-rate/~~rudder~~steering angle relation for a ship which is inherently dynamically unstable on a straight course. The yaw rate is shown in the non-dimensional form for turn path curvature discussed above. This diagram is often referred to as "the spiral loop curve" because it may be obtained from spiral tests with a ship or model. The dotted part of the curve can only be obtained from some kind of reverse spiral test. Wherever the slope is positive, which is indicated by a tangent sloping down to the right in the diagram, the equilibrium balance is unstable. A ship which is unstable on a straight course will be stable in a turn despite the ~~rudder~~steering being fixed in the midship or neutral position. The curvature of this stable turn is called "the loop height" and may be obtained from the pullout manoeuvre. Loop height, width and slope at the origin may all be regarded as a measure of the instability.

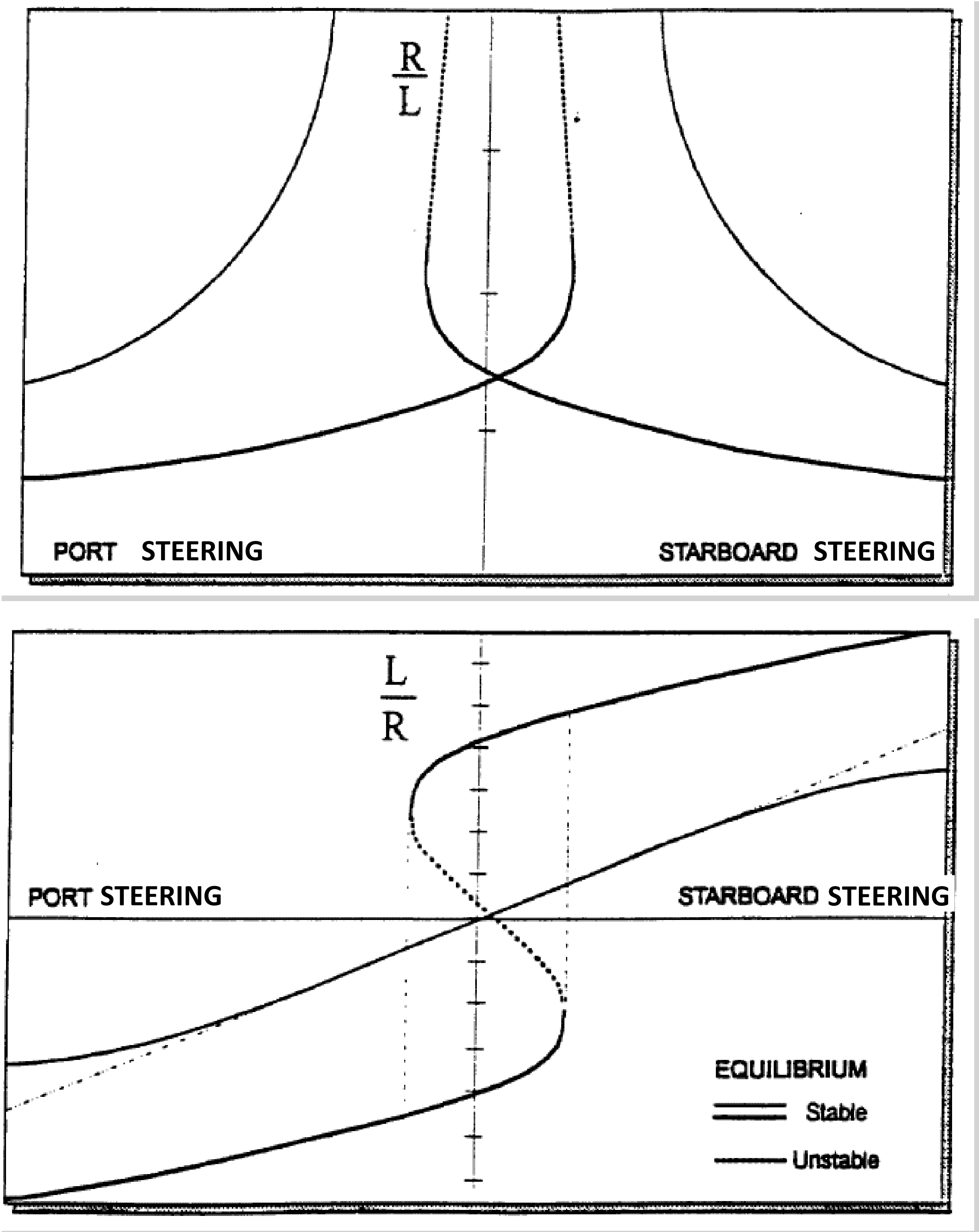


Figure 1 - The equilibrium yaw rate/~~rudder~~steering angle relation

1.2.2.8 If motion is not in an equilibrium turn, which is the general case of motion, there are not only unbalanced damping forces but also hydrodynamic forces associated with the added inertia in the flow of water around the hull. Therefore, if the ~~rudder~~steering is left in a position the ship will search for a new stable equilibrium. If the ~~rudder~~steering is shifted (put over "to the other side") the direction of the ship on the equilibrium turning curve is reversed and the original yaw tendency will be checked. By use of early counter-~~rudder~~steering it is fully possible to control the ship on a straight course with helm angles and yaw rates well within the loop.

1.2.2.9 The course-keeping ability or "directional stability" obviously depends on the performance of the closed loop system including not only the ship and ~~rudder~~steering but also the course error sensor and control system. Therefore, the acceptable amount of inherent dynamic instability decreases as ship speed increases, covering more ship lengths in a given period of time. This results because a human helmsman will face a certain limit of conceptual capacity and response time. This fact is reflected in the IMO Standards for ship manoeuvrability where the criterion for the acceptable first overshoot in a zig-zag test includes a dependence on the ratio L/V, a factor characterizing the ship "time constant" and the time history of the process.

1.2.2.10 In terms of control engineering, the acceptable inherent instability may be expressed by the "phase margin" available in the open loop. If the ~~rudder~~steering is oscillated with a given amplitude, ship heading also oscillates at the same frequency with a certain amplitude. Due to the inertia and damping in the ship dynamics and time delays in the steering engine, this amplitude will be smaller with increasing frequency, meaning the open loop response will lag further and further behind the ~~rudder~~steering input. At some certain frequency, the "unit gain" frequency, the response to the counter-~~rudder~~steering is still large enough to check the heading swing before the oscillation diverges (i.e., the phase lag of the response must then be less than 180°). If a manual helmsman takes over the heading control, closing the steering process loop, a further steering lag could result but, in fact, he will be able to anticipate the swing of the ship and thus introduce a certain "phase advance". Various studies suggest that this phase advance may be of the order of 10° to 20°. At present there is no straightforward method available for evaluating the phase margin from routine trial manoeuvres.

1.2.2.11 Obviously the course-keeping ability will depend not only upon the counter-~~rudder~~steering timing but also on how effectively the ~~rudder~~steering can produce a yaw checking moment large enough to prevent excessive heading error amplitudes. The magnitude of the overshoot angle alone is a poor measure for separating the opposing effects of instability and ~~rudder~~steering effectiveness, additional characteristics should therefore be observed. So, for instance, "time to reach second execute", which is a measure of "initial turning ability", is shortened by both large instability and high ~~rudder~~steering effectiveness.

1.2.2.12 It follows from the above that a large dynamic instability will favour a high "turning ability" whereas the large yaw damping, which contributes to a stable ship, will normally be accompanied by a larger turning radius. This is noted by the thin full-drawn curve for a stable ship included in figure 1.

1.2.2.13 Hard-over turning ability is mainly an asset when manoeuvring at slow speed in confined waters. However, a small advance and tactical diameter will be of value in case emergency collision avoidance manoeuvres at normal service speeds are required.

1.2.2.14 The "crash-stop" or "crash-astern" manoeuvre is mainly a test of engine functioning and ~~propeller~~propulsion reversal. The stopping distance is essentially a function of the ratio of astern power to ship displacement. A test for the stopping distance from full speed has been included in the Standards in order to allow a comparison with hard-over turning results in terms of initial speed drop and lateral deviations.

1.2.3 Manoeuvring characteristics: selected quality measures

The IMO Standards for ship manoeuvrability identify significant qualities for the evaluation of ship manoeuvring characteristics. Each has been discussed above and is briefly defined below:

.1 *Inherent dynamic stability:*

A ship is dynamically stable on a straight course if it, after a small disturbance, soon will settle on a new straight course without any corrective ~~rudder~~steering. The resultant deviation from the original heading will depend on the degree of inherent stability and on the magnitude and duration of the disturbance.

.2 *Course-keeping ability:*

The course-keeping quality is a measure of the ability of the steered ship to maintain a straight path in a predetermined course direction without excessive oscillations of ~~rudder~~steering or heading. In most cases, reasonable course control is still possible where there exists an inherent dynamic instability of limited magnitude.

.3 *Initial turning/course-changing ability:*

The initial turning ability is defined by the change-of-heading response to a moderate helm, in terms of heading deviation per unit distance sailed (the P number) or in terms of the distance covered before realizing a certain heading deviation (such as the "time to second execute" demonstrated when entering the zig-zag manoeuvre).

.4 *Yaw checking ability:*

The yaw checking ability of the ship is a measure of the response to counter-~~rudder~~steering applied in a certain state of turning, such as the heading overshoot reached before the yawing tendency has been cancelled by the counter-~~rudder~~steering in a standard zig-zag manoeuvre.

.5 *Turning ability:*

Turning ability is the measure of the ability to turn the ship using hard-over ~~rudder~~steering. The result being a minimum "advance at 90° change of heading" and "tactical diameter" defined by the "transfer at 180° change of heading". Analysis of the final turning diameter is of additional interest.

.6 *Stopping ability:*

Stopping ability is measured by the "track reach" and "time to dead in water" realized in a stop engine-full astern manoeuvre performed after a steady approach at full test speed. Lateral deviations are also of interest, but they are very sensitive to initial conditions and wind disturbances.

1.3 Tests required by the Standards

1.3.1 Turning tests

A turning circle manoeuvre is to be performed to both starboard and port with ~~35° rudder~~declared steering angle ~~or the maximum design rudder angle permissible~~limit at the test speed. The ~~rudder~~steering angle is executed following a steady approach with zero yaw rate. The essential information to be obtained from this manoeuvre is tactical diameter, advance, and transfer (see figure 2).

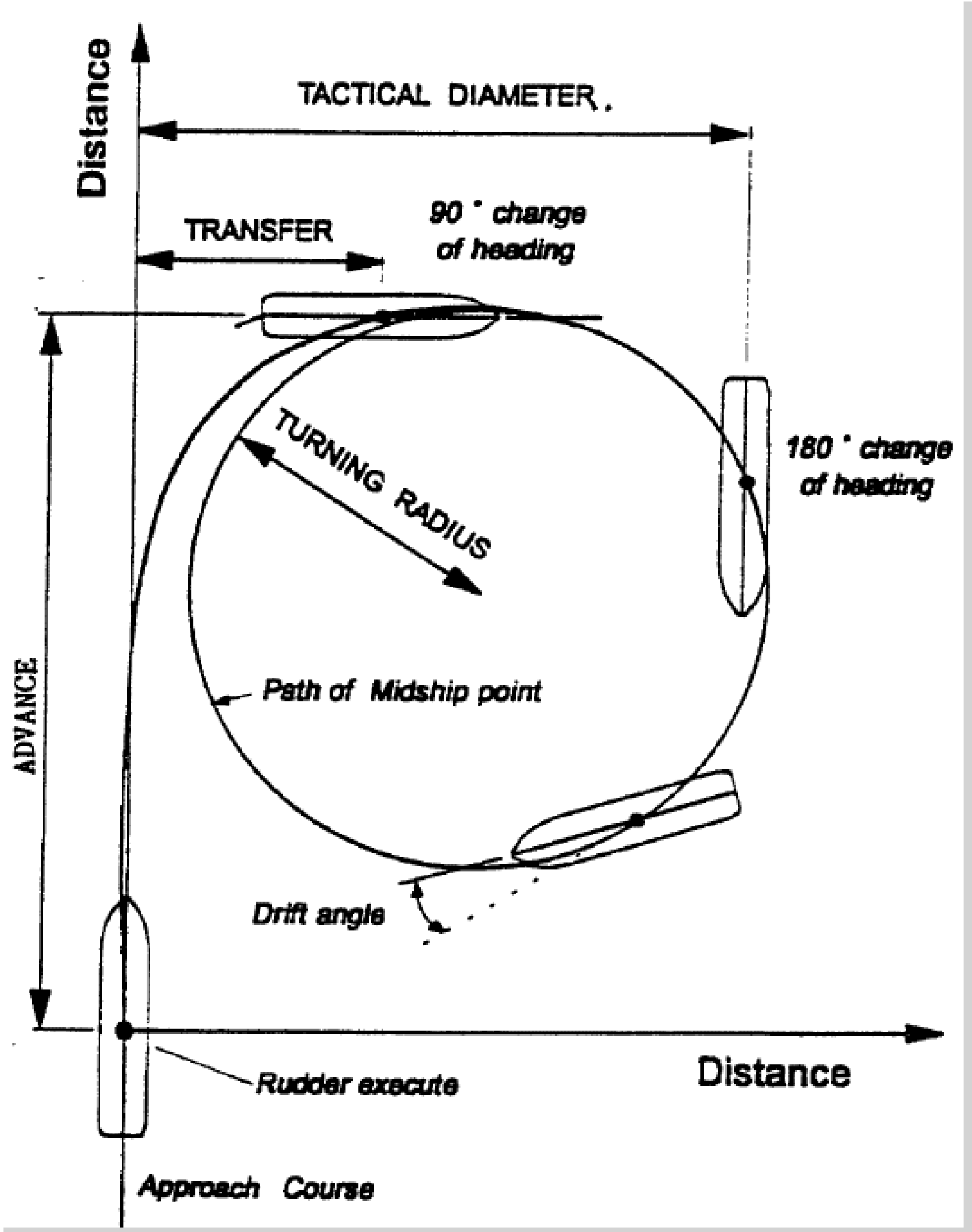
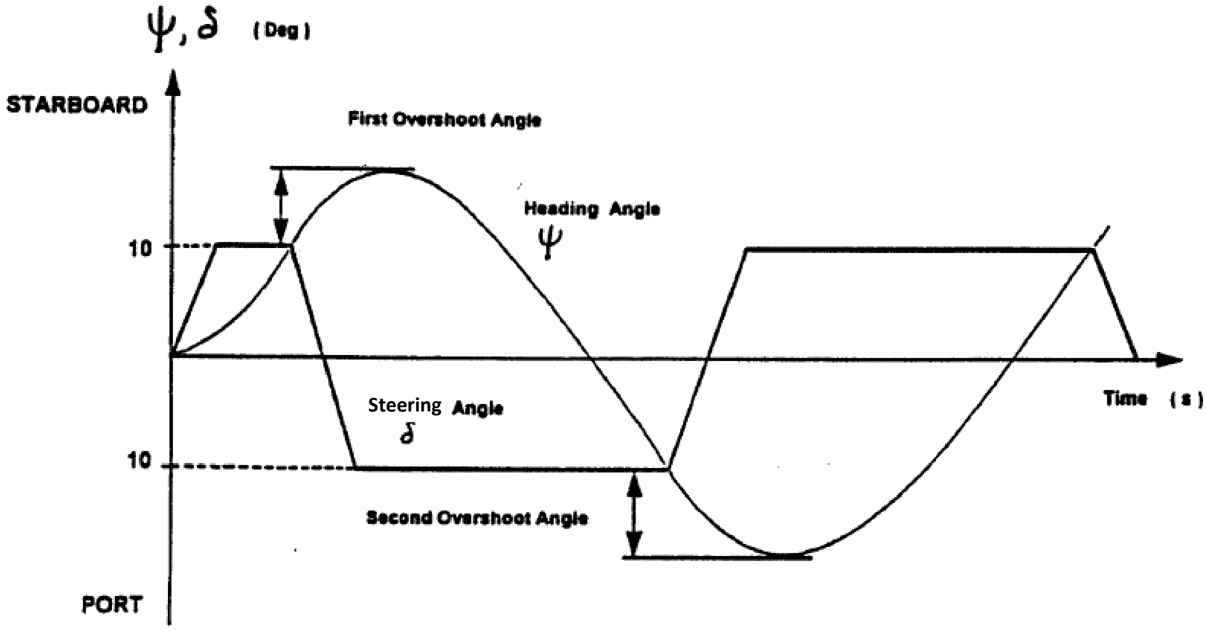


Figure 2 - Definitions used on turning circle test

1.3.2 Zig-zag tests

1.3.2.1 A zig-zag test should be initiated to both starboard and port and begins by applying a specified amount of ~~rudder~~steering angle to an initially straight approach ("first execute"). The ~~rudder~~steering angle is then alternately shifted to either side after a specified deviation from the ship' s original heading is reached ("second execute" and following) (see figure 3).



Zig-zag 10°/10° test

Figure 3

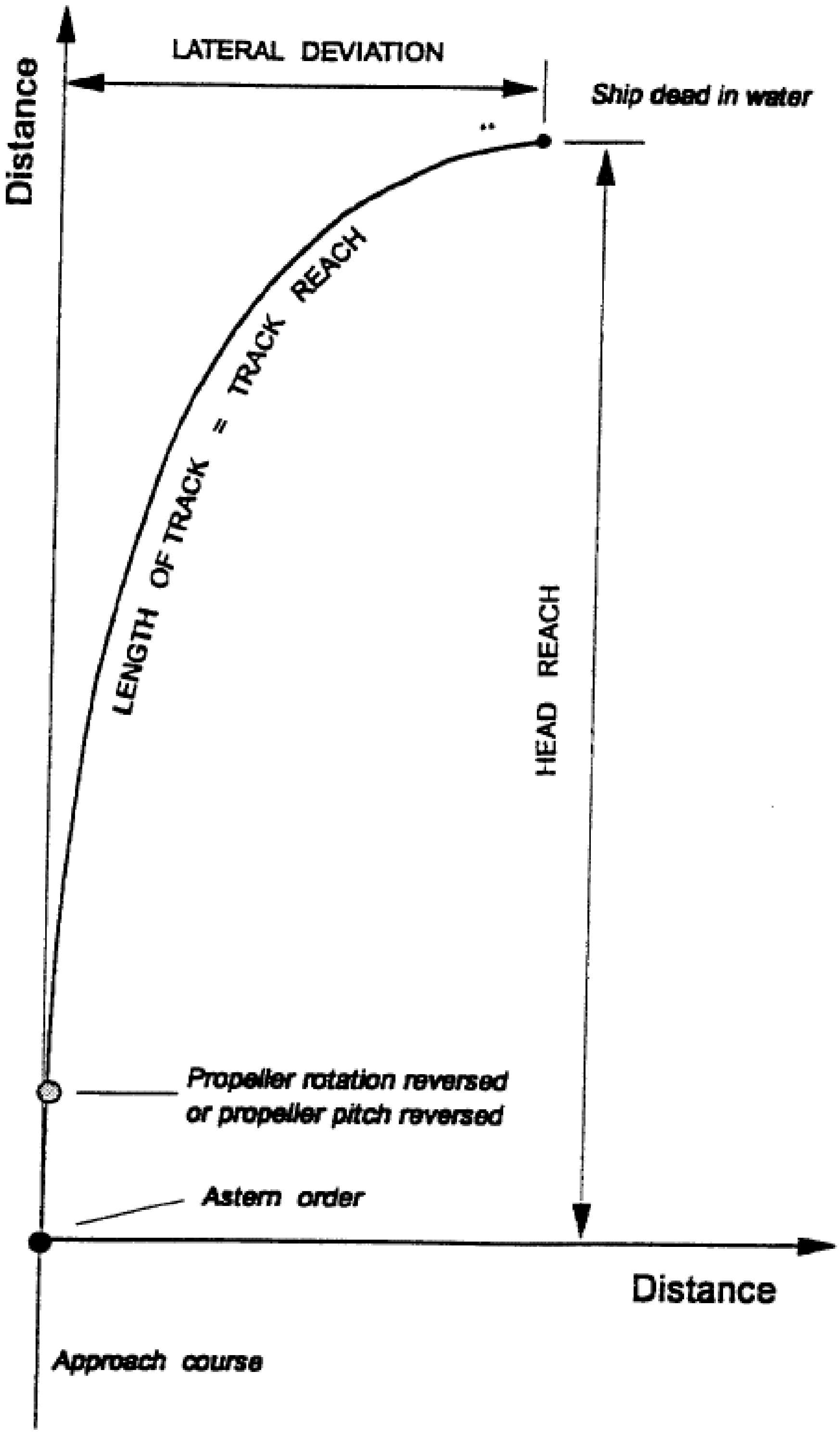
1.3.2.2 Two kinds of zig-zag tests are included in the Standards, the 10°/10° and 20°/20° zig-zag tests. The 10°/10° zig-zag test uses ~~rudder~~steering angles of ~~10°~~1/3 of the declared steering angle limit to either side following a heading deviation of 10° from the original course. The 20°/20° zig-zag test uses ~~20° rudder angles~~2/3 of the declared steering angle limit coupled with a 20° change of heading from the original course. The essential information to be obtained from these tests is the overshoot angles, initial turning time to second execute and the time to check yaw.

1.3.3 Stopping tests

A full astern stopping test is used to determine the track reach of a ship from the time an order for full astern is given until the ship is stopped dead in the water (see figure 4).

1.3.4 Heading keeping tests

A heading keeping test is used to verify that the ship yaw deviations from a preset heading, when running straight ahead for a minimum period of 30 minutes, do not exceed 2 degrees at any moment. The autopilot may be engaged.



Definitions used in stopping test

Figure 4

CHAPTER 2

GUIDELINES FOR THE APPLICATION OF THE STANDARDS

2.1 Conditions at which the Standards apply

2.1.1 General

2.1.1.1 Compliance with the manoeuvring criteria should be evaluated under the standard conditions in paragraph 5.2 of the Standards for ship manoeuvrability. The standard conditions provide a uniform and idealized basis against which the inherent manoeuvring performance of all ships may be assessed.

2.1.1.2 The Standards cannot be used to evaluate directly manoeuvring performance under non-standard, but often realistic, conditions. The establishment of manoeuvrability standards for ships under different operating conditions is a complex task that deserves ongoing research.

2.1.2 Deep, unrestricted water

Manoeuvrability of a ship is strongly affected by interaction with the bottom of the waterway, banks and passing ships. Trials should therefore be conducted preferably in deep, unconfined but sheltered waters. The water depth should exceed four times the mean draught of the ship.

2.1.3 Full load and even keel condition

2.1.3.1 The Standards apply to the full load and even keel condition. The term "fully loaded" refers to the situation where the ship is loaded to its summer load line draught (referred to hereafter as "full load draught"). This draught is chosen based on the general understanding that the poorest manoeuvring performance of a ship occurs at this draught. The full load draught, however, is not based on hydrodynamic considerations but rather statutory and classification society requirements for scantlings, freeboard and stability. The result being that the final full load draught might not be known or may be changed as a design develops.

2.1.3.2 Where it is impractical to conduct trials at full load because of ship type, trials should be conducted as close to full load draught and zero trim as possible. Special attention should also be given to ensuring that sufficient propeller immersion exists in the trial condition.

2.1.3.3 Where trials are conducted in conditions other than full load, manoeuvring characteristics should be predicted for trial and full load conditions using a reliable method (i.e. model tests or reliable computer simulation) that ensures satisfactory extrapolation of trial results to the full load condition. It rests with the designer/owner to demonstrate compliance at the final full load condition. Section 3.5 of Chapter 3 provides guidance on the subject.

2.1.4 Metacentric height

The Standards apply to a situation where the ship is loaded to a reasonable and practicable metacentric height for which it is designed at the full load draught.

2.1.5 Calm environment

Trials should be held in the calmest weather conditions possible. Wind, waves and current can significantly affect trial results, having a more pronounced effect on smaller ships. The environmental conditions should be accurately recorded before and after trials so that corrections may be applied. Specific environmental guidelines are outlined in 2.2.1.2.1.

2.1.6 Steady approach at the test speed

The required test speed is defined in paragraph 4.2.1 of the Standards for ship manoeuvrability.

2.2 Guidance for required trials and validation

2.2.1 Test procedures*

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* It should be noted that these procedures were developed for ships with conventional steering and propulsion systems.

2.2.1.1 General

The test procedures given in the following guidelines were established to support the application of the manoeuvring standards by providing to shipyards and other institutions standard procedures for the testing trials of new ships or for later trials made to supplement data on manoeuvrability. This guidance includes trial procedures that need to be performed in order to provide sufficient data for assessing ship manoeuvring behaviour against the defined criteria.

2.2.1.2 Test conditions

2.2.1.2.1 Environment

Manoeuvring trials should be performed in the calmest possible weather conditions. The geographical position of the trial is preferably in a deep sea, sheltered area where accurate positioning fixing is possible. Trials should be conducted in conditions within the following limits:

.1 Deep unrestricted water: more than 4 times the mean draught.

.2 Wind: not to exceed Beaufort 5.

.3 Waves: not to exceed sea state 4.

.4 Current: uniform only.

Correction may need to be applied to the test results following the guidance contained in 3.4.2.

2.2.1.2.2 Loading

The ship should preferably be loaded to the full load draught and even keel, however, a 5% deviation from that draught may be allowed.

Alternatively, the ship may be in a ballast condition with a minimum of trim, and sufficient propeller immersion.

2.2.1.2.3 Ship speed

The test speed is defined in paragraph 4.2.1 of the Standards.

2.2.1.2.4 Heading

Preferably head into the wind during the approach run of the zig-zag tests and from the wind during the approach run of turning circle, heading keeping and full astern stopping tests.

2.2.1.2.5 Engine

Engine control setting to be kept constant during the trial if not otherwise stated in following procedures.

2.2.1.2.6 Approach run

The above-mentioned conditions must be fulfilled for at least two minutes preceding the test. The ship is running at test speed down wind (up wind for the zig-zag tests) with minimum ~~rudder~~steering to keep its course.

<u>2.2.1.3 Turning circle manoeuvre</u>

Trials shall be made to port and to starboard using ~~maximum rudder~~declared steering angle limit without changing engine control setting from the initial speed. The following general procedure is recommended:

.1 The ship is brought to a steady course and speed according to the specific approach condition.

.2 The recording of data starts.

.3 The manoeuvre is started by ordering the ~~rudder~~steering to ~~the maximum rudder~~declared steering angle~~. Rudder~~ limit. Steering and engine controls are kept constant during the turn.

.4 The turn continues until 360° change of heading has been completed. It is, however, recommended that in order to fully assess environmental effects a 720° turn be completed (3.~~4~~5.2 refers).

.5 Recording of data is stopped and the manoeuvre is terminated.

When testing a ship with the steering system in reduced service, the procedure shall be repeated in that condition and considering that, for ships provided with multiple steering systems, the least favorable steering system shall be out of operation. Reduction of propulsion on the propulsor associated with the faulty steering may only be done if operational restrictions apply. It is suggested to have the port system out of operation in a starboard turn and vice versa. The inoperative steering system shall be placed in neutral position.

<u>2.2.1.4 Zig-zag manoeuvre</u>

~~The given rudder and change of heading angle for the~~ The following procedure is ~~10°. This value can be replaced~~ for ~~alternative or combined zig-zag manoeuvres by other angles such as 20° for the other required~~the 10°/10° zig-zag test. Same procedure can be applied to other combinations of steering command and heading angle by replacing as appropriate. Trials should be made to both port and starboard. The following general procedure is recommended:

.1 The ship is brought to a steady course and. speed according to the specific approach condition.

.2 The recording of data starts.

.3 The ~~rudder~~steering is ordered to ~~10°~~1/3 of the declared steering angle limit to starboard/port.

.4 When the heading has changed by 10° off the base course, the ~~rudder~~steering is shifted to ~~10°~~1/3 of the declared steering angle limit to port/starboard. The ship's yaw will be checked and a turn in the opposite direction (port/starboard) will begin. The ship will continue in the turn and the original heading will be crossed.

.5 When the heading is 10° port/starboard off the base course, the ~~rudder~~steering is reversed as before.

.6 The procedure is repeated until the ship heading has passed the base course no less than two times.

.7 Recording of data is stopped and the manoeuvre is terminated.

2.2.1.5 Full astern Sstopping test

~~Full astern is applied and the rudder maintained at midship throughout this test.~~

The following general procedure is recommended:

.1 The ship is brought to a steady course and speed according to the specific approach condition.

.2 The recording of data starts.

.3 The manoeuvre is started by giving a stop order. The full astern ~~engine~~ order is applied.

.4 Data recording stops and the manoeuvre is terminated when the ship is stopped dead in the water.

For rudder-steered ships, the rudder shall be maintained at neutral position throughout the test.

When testing a ship with multiple propulsion lines, the procedure shall be repeated with the following modifications:

.1 The test is performed with one propulsion system and its corresponding steering system out of operation.

.1 The inoperative propeller may be allowed to windmill (depending on manufacturers specification and recommendation).

.2 The steering system corresponding to the inoperative propulsion line shall be placed at neutral position.

.3 The approach speed shall consequently be adjusted based on remaining available propulsion.

.2 For non-rudder-steered ships where the stopping in normal operational condition is done by turning the steering force units, the test in .1 shall be performed with all the propulsion systems active until the stop order is given. Consequently, the approach speed shall be the same as in normal operational condition.

2.2.1.6 Heading keeping test

The following general procedure is recommended:

.1 The ship is brought to a steady course and speed according to the specific approach condition.

.2 The recording of data starts.

.3 Recording of data is stopped and the manoeuvre is terminated.

When testing a ship with the steering system in reduced service, same related considerations as stated in 2.2.1.3 apply.

2.2.2 Recording

For each trial, a summary of the principal manoeuvring information should be provided in order to assess the behaviour of the ship. Continuous recording of data should be either manual or automatic using analogue or digital acquisition units. In case of manual recording, a regular sound/light signal for synchronization is advisable.

2.2.2.1 Ship's particulars

Prior to trials, draughts forward and aft should be read in order to calculate displacement, longitudinal centre of gravity, draughts and metacentric height. In addition the geometry, projected areas and steering particulars should be known. The disposition of the engine, propeller, ~~rudder~~steering, thrusters and other device characteristics should be stated with operating condition.

2.2.2.2 Environment

The following environmental data should be recorded before each trial:

.1 Water depth.

.2 Waves: The sea state should be noted. If there is a swell, note period and direction.

.3 Current: The trials should be conducted in a well surveyed area and the condition of the current noted from relevant hydrographic data. Correlation should be made with the tide.

.4 Weather: Weather conditions, including visibility, should be observed and noted.

2.2.2.3 Trial related data

The following data as applicable for each test should be measured and recorded during each test at appropriate intervals of not more than 20 s:

Position

Heading

Speed

~~Rudder~~Steering angle and rate of movement

Propeller speed of revolution

Propeller pitch

Wind speed

A time signal should be provided for the synchronization of all recordings. Specific events should be timed, such as trial starting-point, engine/helm change, significant changes in any parameter such as crossing ship course, ~~rudder~~steering to zero or engine reversal in operating condition such as ship speed and shaft/propeller direction.

2.2.2.4 Presentation of data

The recordings should be analysed to give plots and values for significant parameters of the trial. Sample recording forms are given in appendix 6. The manoeuvring criteria of the Standards should be evaluated from these values.

CHAPTER 3

PREDICTION GUIDANCE

3.1 General

3.1.1 To be able to assess the manoeuvring performance of a new ship at the design stage, it is necessary to predict the ship manoeuvring behaviour on the basis of main dimensions, lines drawings and other relevant information available at the design stage.

3.1.2 A variety of methods for prediction of manoeuvring behaviour at the design stage exists, varying in the accuracy of the predicted manoeuvres and the cost of performing the prediction. In practice most of the predictions at the design stage have been based on ~~three~~four methods.

3.1.3 The first and simplest method is to base the prediction on experience and existing data, assuming that the manoeuvring characteristics of the new ship will be close to those of similar existing ships.

3.1.4 The second method is to base the prediction on results from model tests. ~~At the time these notes were written, model tests must be considered the most reliable prediction method. However, it~~It may be said that traditionally the requirements with regard to accuracy have been somewhat more lenient in this area than in other areas of ship model testing. The reason for this has simply been the absence of manoeuvring standards. The feedback of full-scale trial results has generally been less regular in this area than in the case of speed trials. Consequently the correlation basis for manoeuvrability is therefore of a somewhat lower standard, particularly for hull forms that may present a problem with regard to steering and manoeuvring characteristics. ~~It is expected that this situation will improve very rapidly when it becomes generally known that a standard for ship manoeuvrability is going to be introduced.~~ Model tests are described in section 3.2.

3.1.5 The third method is to base the prediction on results from calculation/simulation using a mathematical model. Mathematical models are described in section 3.3.

3.1.6 The fourth method is to base the prediction on CFD simulations. CFD simulations could be considered as particular cases of mathematical model but, in view of their specifics, they are described separately in section 3.4.

3.2 Model tests

There are two commonly used model test methods available for prediction of manoeuvring characteristics. One method employs a free-running model moving in response to specified control input (i.e. helm and ~~propeller~~propulsion); the tests duplicate the full-scale trial manoeuvres and so provide direct results for the manoeuvring characteristics. The other method makes use of force measurements on a "captive" model, forced to move in a particular manner with controls fixed; the analysis of the measurements provides the coefficients of a mathematical model, which may be used for the prediction of the ship response to any control input.

3.2.1 Manoeuvring test with free-running model

3.2.1.1 The most direct method of predicting the manoeuvring behaviour of a ship is to perform representative manoeuvres with a scale model. To reduce costs by avoiding the manufacture of a special model for manoeuvring tests, such tests may be carried out with the same model employed for resistance and self-propulsion tests. Generally it means that a relatively large model will be used for the manoeuvring tests, which is also favourable with regard to reducing scale effects of the results.

3.2.1.2 The large offshore, sea-keeping and manoeuvring basins are well suited for manoeuvring tests with free-running models provided they have the necessary acquisition and data processing equipment. In many cases, conventional towing tanks are wide enough to allow the performance of the 10°/10° zig-zag test. Alternatively, tests with a free-running model can be conducted on a lake. In this case measuring equipment must be installed and the tests will be dependent on weather conditions. Both laboratory and open-air tests with free-running models suffer from scale effects, even if these effects to a certain extent will be reduced by using a large model for the tests. Sometimes it has been attempted to compensate for scale effects by means of an air propeller on board the model. Another improvement is to make the drive motor of the ship model simulate the characteristics of the main engine of the ship with regard to propeller loading.

3.2.1.3 Manoeuvres such as turning circle, zig-zag and spiral tests are carried out with the free-running model, and the results can be compared directly with the standard of manoeuvrability. There are however uncertainties in the results due to scale effects.

3.2.1.4 More recently, efforts have been made at deriving the coefficients of mathematical models from tests with free-running models. The mathematical model is then used for predicting the manoeuvring characteristics of the ship. Parameter identification methods have been used and this procedure has been combined with oblique towing and propulsion tests to provide some of the coefficients.

3.2.2 Manoeuvring tests with captive model

3.2.2.1 Captive model tests include oblique-towing tests in long narrow tanks as well as "circling" tests in rotating-arm facilities, but in particular such tests are performed by the use of a Planar Motion Mechanism (PMM) system capable of producing any kind of motion by combining static or oscillatory modes of drift and yaw. Generally, it may be said that captive model tests suffer from scale effects similar to those of the free-running tests, but corrections are more easily introduced in the analysis of the results.

3.2.2.2 In using captive model tests due account of the effect of roll during manoeuvring should be taken.

3.2.2.3 The PMM has its origin in devices operating in the vertical plane and used for submarine testing. The PMM makes it possible to conduct manoeuvring tests in a conventional long and narrow towing tank. The basic principle is to conduct various simpler parts of more complex complete manoeuvres. By analysis of the forces measured on the model the manoeuvring behaviour is broken down into its basic elements, the hydrodynamic coefficients. The hydrodynamic coefficients are entered into a computer based mathematical model and the results of the standard manoeuvres are predicted by means of this mathematical model.

3.2.2.4 A rotating arm facility consists of a circular basin, spanned by an arm from the centre to the circumference. The model is mounted on this arm and moved in a circle, varying the diameter for each test. The hydrodynamic coefficients related to ship turning as well as to the combination of turning and drift will be determined by this method. Additional tests often have to be conducted in a towing tank in order to determine hydrodynamic coefficients related to ship drift. As in the case of the PMM the manoeuvring characteristics of the ship are then predicted by means of a mathematical model using the coefficients derived from the measurements as input.

3.2.3 Model test condition

The Standards are applicable to the full load condition of the ship. The model tests should therefore be performed for this condition. For many ships the delivery trials will be made at a load condition different from full load. It will then be necessary to assess the full load manoeuvring characteristics of the ship on the basis of the results of manoeuvring trials performed at a condition different from full load. To make this assessment as reliable as possible the model tests should also be carried out for the trial condition, meaning that this condition must be specified at the time of performing the model tests. The assumption will be that when there is an acceptable agreement between model test results and ship trial results in the trial condition, the model test results for the loaded condition will then be a reliable basis for assessing the manoeuvring characteristics of the ship.

3.3 Mathematical model

A "mathematical model" is a set of equations which can be used to describe the dynamics of a manoeuvring ship. But it may be possible to predict the manoeuvrability for the conventional ship' s form with certain accuracy from the practical point of view using some mathematical models which have already been published. In this section, the method used to predict the manoeuvring performance of a ship at full load for comparison with the Standards is explained. The following details of the mathematical model are to be indicated:

.1 when and where to use;

.2 how to use;

.3 accuracy level of predicted results; and

.4 description of mathematical model

3.3.1 Application of the mathematical model

3.3.1.1 In general, the manoeuvring performance of the ship must be checked by a sea trial to determine whether it satisfies the manoeuvring standards or not. The Standards are regulated in full load condition from the viewpoints of marine safety. Consequently, it is desired that the sea trial for any ship be carried out in full load condition. This may be a difficult proposition for ships like a dry cargo ship, for which the sea trial is usually carried out in ballast or heavy ballast conditions from the practical point of view.

3.3.1.2 In such cases, it will be required to predict the manoeuvring performance in full load condition by means of some method that uses the results of the sea trial. As an alternative to scale model tests, usually conducted during the ship design phase, a numerical simulation using a mathematical model is a useful method for predicting ship manoeuvring performance in full load condition.

3.4 CFD simulations

A CFD simulation is a solution of the flow around the hull by dividing the fluid into many parts and solving equations for the water motions in these. There exist a large variety of CFD tools. Currently, most tools require the user to set key parameters significantly affecting the results. This particularly includes division into parts (mesh), time step and physical models (equations to be solved). This means that equally important as the accuracy of the tool itself is the choices made by the user. In order to ensure high accuracy, well founded choices need to be made. It is believed that adequately performed CFD simulations exceed the accuracy of model tests.

High accuracy in CFD simulations typically come at a significant computational cost. It is therefore relevant for the user to vary the accuracy depending on the need. This could e.g. be done by the choice of physical models, mesh and time step. A lot of useful information can be extracted from simplified simulations, however, if the simulation is to be used to provide proof of compliance with performance parameters, the needed accuracy is considerably higher. The following gives some general suggestions on what to include in CFD simulations used to document compliance with performance requirements.

3.4.1 Suggested content of CFD simulations for compliance with performance requirements

The following geometries should be modelled:

.1 Hull

.2 Propulsion device
.3 Steering device
.4 Relevant appendices

The following can normally be excluded, but should be included if they are believed to have a significant effect on the maneuvering performance:

.1 Bow thrusters including openings
.2 Bilge keels
.3 Sea chests
.4 Pipe openings
.5 Super structure

The following physics should be included:

.1 The hull should be self-propelled, self-steered and free floating in 6 degrees of freedom
.2 The mass properties of the hull in terms of mass, center of gravity and radii of gyration
.3 The motion (translation and rotation) of the steering device relative to the hull should be modelled.
.4 The propulsion device should be moving (translation and rotation) relative to the hull as in real life (except for water jets for which a momentum source may be applied inside the duct)
.5 Shear forces on the geometries should be modelled at least by appropriate wall models
.6 Pressure forces on the geometries should be modelled
.7 The free surface waves generated by the geometries should be modelled in the vicinity of the hull
.8 Simplified engine model including torque and shaft speed

Cavitation should be included if it is believed to have a significant effect on the maneuvering performance.

The mesh should be of appropriate quality to resolve the above geometries and physic. The timestep should be chosen appropriate considering the mesh and fluid velocities.

The quality of CFD simulations used for documenting compliance with performance requirements should be to the satisfaction of the Administration and may need verification by third party.

3.5 Corrections from non-standard trial conditions

3.45.1 Loading condition

3.45.1.1 In the case for predicting manoeuvrability of a ship in full load condition using the mathematical model through the sea trial results in ballast or heavy, ballast condition, the following two methods are used in current practice.

Option 1:

3.45.1.2 The manoeuvring performance in full load condition can be obtained from the criteria of measured performance during the sea trial in ballast condition (T) and the interaction factor between the criteria of manoeuvrability in full load condition and in a trial condition (F/B), that is as given below;

$$R = TF/B$$

where,

B: the estimated performance in the condition of sea trial based on the numerical simulation using the mathematical model or CFD simulation or on the model test;

F: the estimated performance in full load condition based on the numerical simulation using the mathematical model or CFD simulation or on the model test;

T: the measured performance during the sea trial; and

R: the performance of the ship in full load condition.

3.~~4~~5.1.3 It should be noted that the method used to derive B and F should be the same.

Option 2:

3.~~4~~5.1.4 The manoeuvring performance in the condition of sea trial such as ballast or heavy ballast are predicted by the method shown in appendix 2, and the predicted results must be checked with the results of the sea trial.

3.~~4~~5.1.5 Afterwards it should be confirmed that both results agree well with each other. ~~The~~In that case, the performance in full load condition may be obtained by means of the same method ~~using the mathematical model~~shown in appendix 2.

3.~~4~~5.2 Environmental conditions

3.~~4~~5.2.1 Ship manoeuvrability can be significantly affected by the immediate environment such as wind, waves, and current. Environmental forces can cause reduced course-keeping stability or complete loss of the ability to maintain a desired course. They can also cause increased resistance to a ship' s forward motion, with consequent demand for additional power to achieve a given speed or reduces the stopping distance.

3.~~4~~5.2.2 When the ratio of wind velocity to ship speed is large, wind has an appreciable effect on ship control. The ship may be unstable in wind from some directions. Waves can also have significant effect on course-keeping and manoeuvring. It has been shown that for large wave heights a ship may behave quite erratically and, in certain situations, can lose course stability.

3.~~4~~5.2.3 Ocean current affects manoeuvrability in a manner somewhat different from that of wind. The effect of current is usually treated by using the relative velocity between the ship and the water. Local surface current velocities in the open ocean are generally modest and close to constant in the horizontal plane.

3.~~4~~5.2.4 Therefore, trials shall be performed in the calmest weather conditions possible. ~~In the case that the minimum weather conditions for the criteria requirements are not applied, the trial results should be corrected.~~

~~3.4.2.5 Generally, it is easy to account for the effect of constant current. The turning circle test results may be used to measure the magnitude and direction of current. The ship' s track, heading and the elapsed time should be recorded until at least a 720° change of heading has been completed. The data obtained after ship' s heading change 180° are used to estimate magnitude and direction of the current. Position~~ ~~(x_{li}' y_{li}' t_{li}) and (x_{2i}' y_{2i}' t_{2i})~~ ~~in figure 5 are the positions of the ship measured after a heading rotation of 360°. By defining the local current velocity~~ ~~V_i~~ ~~for any two corresponding positions as the estimated current velocity can be obtained from the following equation:~~

~~$\underline{v}_i = (x_{2i} - x_{1i}, y_{2i} - y_{1i})/(t_{2i} - t_{1i})$~~

~~the estimated current velocity can be obtained from the following equation:~~

~~$\underline{v}_c = (1/n) \sum \underline{v}_i = (1/n) \sum (x_{2i} - x_{1i}, y_{2i} - y_{1i})/(t_{2i} - t_{1i})$~~

~~3.4.2.6 If the constant time interval,~~ ~~$\delta t = (t_{2i} - t_{1i})$~~, ~~is used this equation can be simplified and written:~~

~~$\underline{v}_c = (1/n\delta t) \{\sum x_{2i} - \sum x_{1i}, \sum y_{2i} - \sum y_{1i}\}$~~

~~The above vector, $\underline{v}_c$, obtained from a 720º turning test will also include the effect of wind and waves.~~

~~3.4.2.7 The magnitude of the current velocity and the root mean square of the current velocities can be obtained from the equations:~~

~~$v_c = |v_c|$~~

~~$v_c(RMS) = [(1/n) \sum |\underline{v}_i - \underline{v}_c|^2]^{1/2}$~~

~~v_c(RMS) represents the non-uniformity of vi which may be induced from wing, waves, and non uniform current.~~

~~3.4.2.8 All trajectories obtained from the sea trials should be corrected as follows:~~

~~$x'(t) = x(t) - v_c t$~~

~~where~~

~~x(t) is the measured position vector and~~

~~x' (t) is the corrected one of the ship and~~

~~$x'(t) = x(t)$ at $t = 0$.~~

3.~~5~~6 Uncertainties

3.~~5~~6.1 Accuracy of model test results

3.~~5~~6.1.1 The model may turn out to be more stable than the ship due to scale effects. This problem seems to be less serious when employing a large model. Consequently, to reduce this effect model scale ratios comparable to that considered acceptable for resistance and self-propulsion tests should be specified for manoeuvring tests that use a free-running model. Captive model tests can achieve satisfactory results with smaller scale models.

3.~~5~~6.1.2 While the correlation data currently available are insufficient to give reliable values for the accuracy of manoeuvring model test results, it is the intent of the Standards to promote the collection of adequate correlation data.

3.~~5~~6.2 Accuracy of predicted results using the mathematical model

3.~~5~~6.2.1 The mathematical model that can be used for the prediction of the manoeuvring performance depends on the type and amount of prepared data.

3.~~5~~6.2.2 If there is no available data, under assumptions that resistance and self-propulsion factors are known, a set of approximate formulae for estimation of the derivatives and coefficients in the mathematical model will become necessary to predict the ship' s manoeuvrability.

3.~~5~~6.2.3 If there is enough experimental and accumulated data, it is desirable to use a detailed mathematical model based on this data. In most cases, the available data is not sufficient and a mathematical model can be obtained by a proper combination of different parts derived from experimental data and those obtained by the estimated formulae.

3.6.3 Accuracy of CFD simulations

Due to the large number of choices made when preparing a CFD simulation, the accuracy will vary depending on the program used, which geometries are included, how the fluid is subdivided (mesh), the chosen time step and physical models. It is believed that a lot of useful information can be extracted from simplified simulations, however if the simulation is to be used to provide proof of compliance with performance parameters, the simulation shall be performed according to 3.4.1.

APPENDIX 1

NOMENCLATURE AND REFERENCE SYSTEMS

1 The manoeuvres of a surface ship may be seen to take place in the xoyo-plane of a right-handed system of axes Oo(xoyozo) "fixed in space", the zo-axis of which is pointing downwards in the direction of gravity. For the present discussion let the origin of this system coincide with the position at time t = 0 of the midship point O of the ship, and let the xo-axis be pointing in the direction of ship's heading at the same moment, the yo-axis pointing to starboard. The future orientation of the ship in this system is given by its heading angle ψ, its angle of pitch θ, and its angle of roll ϕ (see figure A1-1).

2 In calm conditions with no tide or current ship speed through water (V) equals the speed over the ground, and the progress along the ship track is equal to the time integral

$$\int vdt.$$

3 This distance may conveniently be expressed by the number of ship lengths sailed (i.e. by the non-dimensional time):

$$t' = \int_o^t (V/L)dt.$$

4 In general the ship's heading deviates from the direction of the speed vector by the sideslip or drift angle β. The advance and transfer parallel to and at right angles to the original line of course (and ideal line of approach) are given by the integrals:

$$X_o(t) = \int_o^t V\cos(\psi-\beta)dt$$

$$Y_o(t) = \int_o^t V\sin(\psi-\beta)dt.$$

5 Mathematical models of ship dynamics involve expressions for the forces acting on the hull, usually separated in their components along the axes of a system 0(xyz) moving with the body. The full six-degrees-of-freedom motion of the ship may be defined by the three components of linear velocities (u,v,w) along the body axes, and by the three components of angular velocities (p,q,r) around these axes. Again, for the present discussion it is sufficient to consider the surface ship, moving with forward velocity u and sway velocity v in the 0(xy) plane, and turning with yaw velocity r around the z-axis normal to that plane (the yaw rate is also referred as *y* in section 1.2.2 of Chapter 1). On these assumptions the speed $V = (u^2+v^2)^{1/2}$, the drift angle $\beta = -\tan^{-1}(v/u)$ and the yaw rate r is equal to the time rate of change of heading angle ψ, i.e. $r = d/dt(-\psi) = y\psi$.

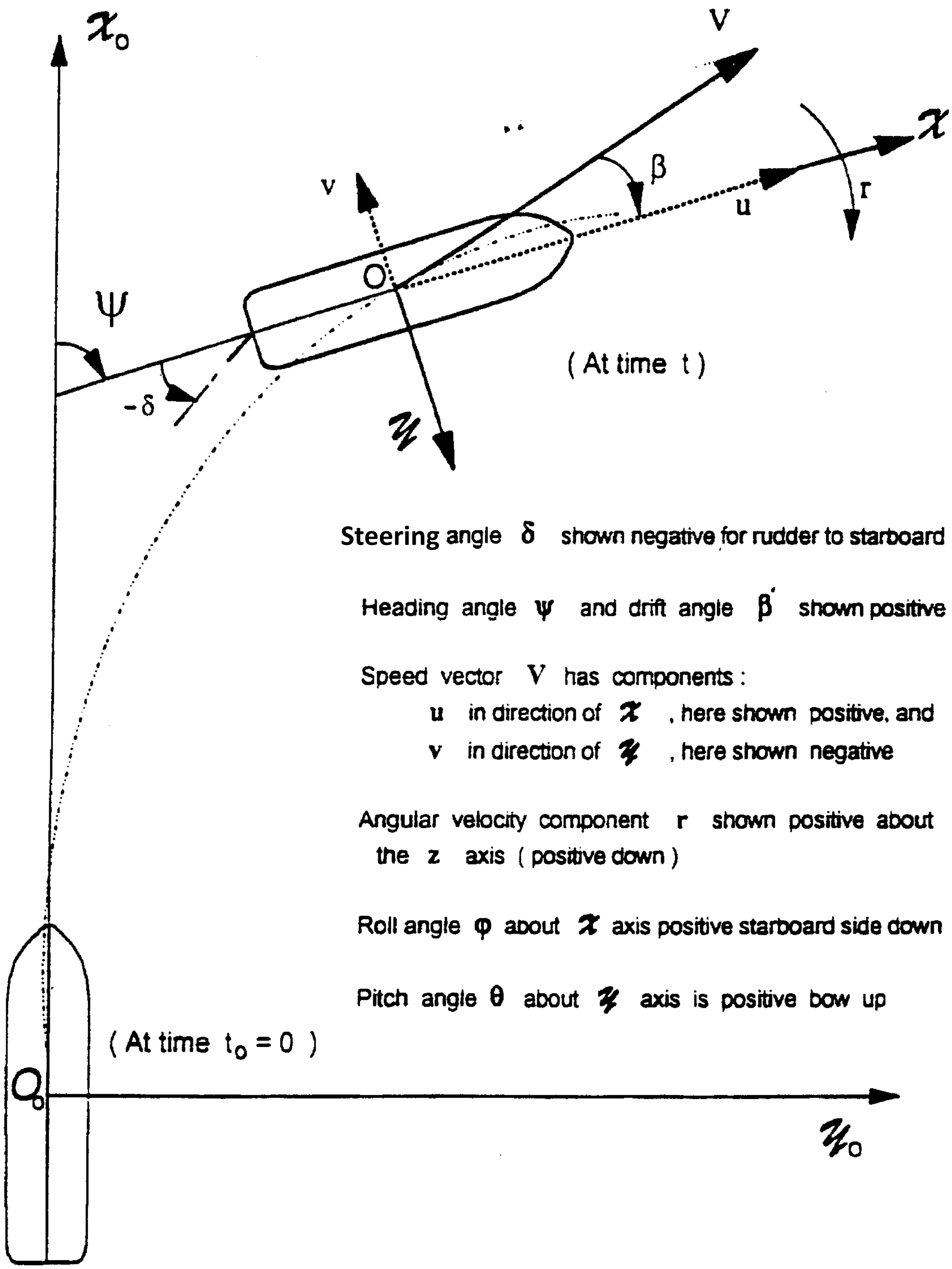
6 The non-dimensional yaw rate in terms of change of heading (in radians) per ship length sailed is

$$r' = d/dt'(-\psi) = y' = (L/V)y$$

which is also seen to be the non-dimensional measure of the instantaneous curvature of the path of this ship L/R.

7 Many ships will experience a substantial rolling velocity and roll angle during a turning manoeuvre, and it is understood that the mathematical model used to predict the manoeuvring characteristics should then include the more stringent expressions as appropriate.

8 Further information can be found in section 4.2 of the Standards for ship manoeuvrability.



Surface ship with body axes O(xyz) manoeuvring within space-fixed inertial frame with axes O_O ($x_o y_o z_o$)

Figure A1-1

APPENDIX 2

GENERAL VIEW OF PREDICTION OF MANOEUVRING PERFORMANCE

1 A mathematical model of the ship manoeuvring motion can be used as one of the effective methods to check whether a ship satisfies the manoeuvrability standards or not, by a performance prediction at the full load condition and from the results of the sea trial in a condition such as ballast.

2 Existing mathematical models of ship manoeuvring motion are classified into two types. One of the models is called a 'response model', which expresses a relationship between input as the control and output as its manoeuvring motion. The other model is called a "hydrodynamic force model", which is based on the hydrodynamic forces that include the mutual interferences. By changing the relevant force derivatives and interference coefficients composed of a hydrodynamic force model, the manoeuvring characteristics due to a change in the ship's form or loading condition can be estimated.

3 Furthermore, a hydrodynamic force model is helpful for understanding the relationship between manoeuvring performance and ship form than a response model from the viewpoint of design. Considering these situations, this Appendix shows the prediction method using a hydrodynamic force model. Certainly, the kind of mathematical model suitable for prediction of the performance depends on the kind of available data. There are many kinds of mathematical models.

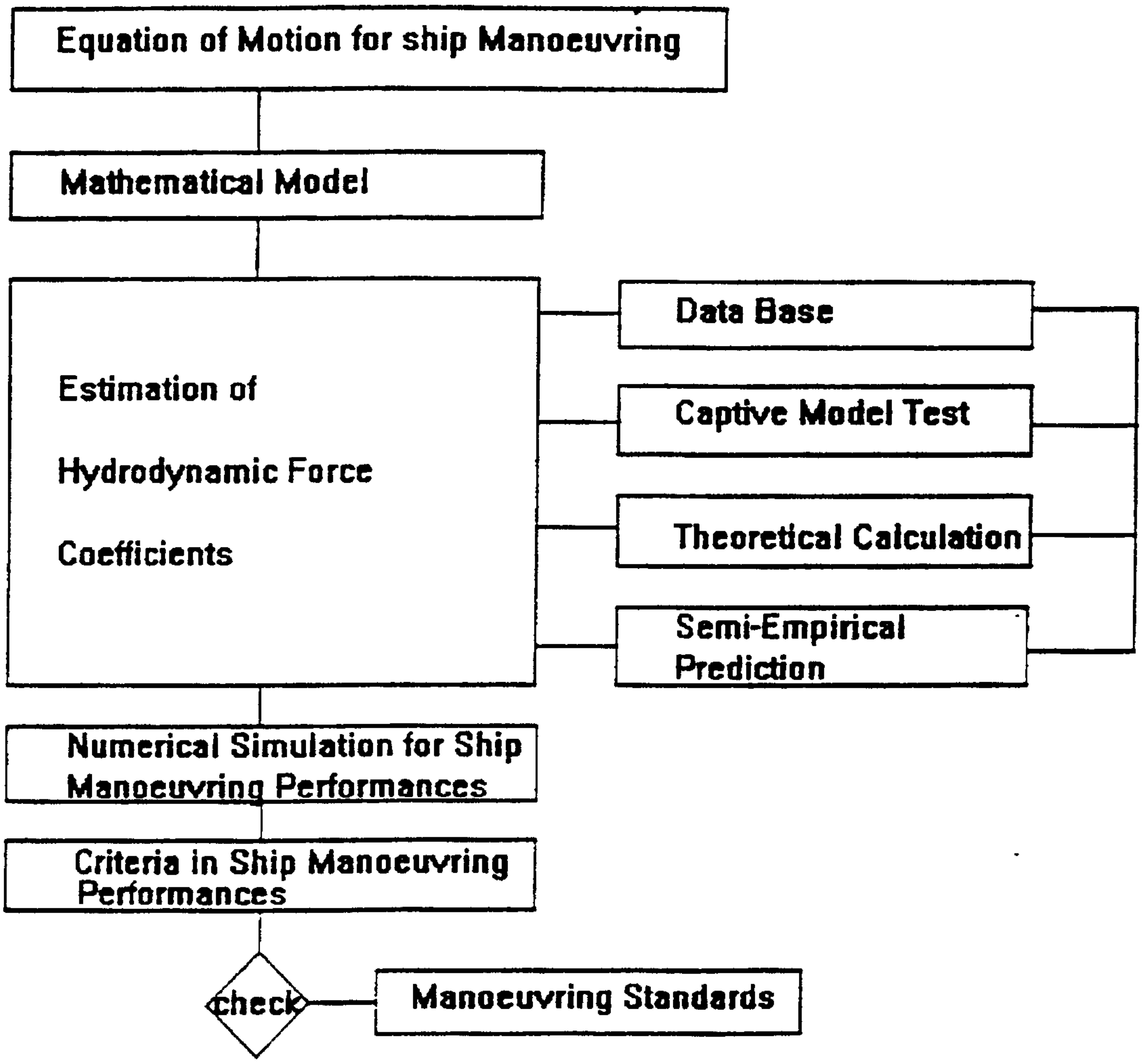
4 In figure A2-1, the flow chart of prediction method of ship manoeuvring performance using a hydrodynamic force model is shown. There are in general various expressions of a hydrodynamic force model in current practice, though their fundamental ideas based on hydrodynamic considerations have little difference. Concerning the hydrodynamic force acting on a ship in manoeuvring motion, they are usually expressed as a polynomial term of motion variables such as the surge, sway and angular yaw velocities.

5 The most important and difficult work in performance prediction is to estimate such derivatives and parameters of these expressions to compose an equation of a ship manoeuvring motion. These hydrodynamic force coefficients and derivatives may usually be estimated by the method shown in figure A2-1.

6 The coefficients and derivatives can be estimated by the model test directly, by data based on the data accumulated in the past, by theoretical calculation ~~and~~, by semi-empirical formulae based on any of these methods and by CFD simulations. There is also an example that uses approximate formulae for estimation derived from a combination of theoretical calculation and empirical formulae based on the accumulated data. The derivatives which are coefficients of hydrodynamic forces acting on a ship's hull, propeller and ~~rudder~~steering are estimated from such parameters as ship length, breadth, mean draught, trim and the block coefficient. Change of derivatives due to a change in the load condition may be easily estimated from the changes in draught and trim.

7 As mentioned above, accuracy of manoeuvring performance predicted by a hydrodynamic force model depends on accuracy of estimated results by hydrodynamic forces which constitutes the equation of a ship manoeuvring motion. Estimating the hydrodynamic derivatives and coefficients will be important to raise accuracy as a whole while keeping consistency of relative accuracy among various hydrodynamic forces.

8 A stage in which theoretical calculations can provide all of the necessary hydrodynamic forces with sufficient accuracy has not yet been reached. Particularly, non-linear hydrodynamic forces and mutual interferences are difficult to estimate with sufficient accuracy by pure theoretical calculations. Thus, empirical formulae and databases are often used, or incorporated into theoretical calculations.



Flow chart for prediction of ship manoeuvring performance

Figure A2-1

APPENDIX 3

STOPPING ABILITY OF VERY LARGE SHIPS

1 It is stated in the Standards for ship manoeuvrability that the track reach in the full astern stopping test may be modified from 15 ship lengths, at the discretion of the Administration, where ship size and form make the criterion impracticable. The following example and information given in tables A3-1, 2 and 3 indicate that the discretion of the Administration is only likely to be required in the case of large tankers.

2 The behaviour of a ship during a stopping manoeuvre is extremely complicated. However, a fairly simple mathematical model can be used to demonstrate the important aspects which affect the stopping ability of a ship. For any ship the longest stopping distance can be assumed to result when the ship travels in a straight line along the original course, after the astern order is given. In reality the ship will either veer off to port or starboard and travel along a curved track, resulting in a shorter track reach, due to increased hull drag.

3 To calculate the stopping distance on a straight path, the following assumptions should be made:

.1 the resistance of the hull is proportional to the square of the ship speed.

.2 the astern thrust is constant throughout the stopping manoeuvre and equal to the astern thrust generated by the propeller when the ship eventually stops dead in the water; and

.3 the propeller is reversed as rapidly as possible after the astern order is given.

4 An expression for the stopping distance along a straight track, in ship lengths, can be written in the form:

$$S = A \log_e (1 + B) + C,$$

where:

S : is the stopping distance, in ship lengths.

A : is a coefficient dependent upon the mass of the ship divided by its resistance coefficient.

R : is a coefficient dependent on the ratio of the ship resistance immediately before the stopping manoeuvre, to the astern thrust when the ship is dead in the water.

C : is a coefficient dependent upon the product of the time taken to achieve the astern thrust and the initial speed of the ship.

5 The value of the coefficient A is entirely due to the type of ship and the shape of its hull. Typical values of A are shown in table A3-1.

6 The value of the coefficient B is controlled by the amount of astern power which is available from the Dower plant. With diesel machinery, the astern power available is usually about 85% of the ahead power, whereas with steam turbine machinery this figure could be as low as 40%.

Table A3-1

Ship type	*Coefficient A*
Cargo ship	5-8
Passenger/car ferry	8-9
Gas carrier	10-11
Products tanker	12-13
VLCC	14-16

7 Accordingly the value of the coefficient B is smaller if a large amount of astern power and hence astern thrust, is available. Typical values of the coefficient B are given in table A3-2.

Table A3-2

Type of machinery	*Percentage power astern*	*Coefficient B*	*Log (1+B)*
Diesel	85%	0.6-1.0	0.5-0.7
Steam turbine	40%	1.0-1.5	0.7-0.9

8 The value of the coefficient C is half the distance travelled, in ship lengths, by the ship, whilst the engine is reversed and full astern thrust is developed. The value of C will be larger for smaller ships and typical values are given in table A3-3.

Table A3-3

Ship length (metres)	*Time to achieve astern thrust (s)*	*Ship speed (knots)*	*Coefficient C*
100	60	15	2.3
200	60	15	1.1
300	60	15	0.8

9 If the time taken to achieve the astern thrust is longer than 60 seconds, as assumed in table A3-3, or if the ship speed is greater than 15 knots, then the values of the coefficient C will increase pro rata.

10 Although all the values given for the coefficients A, B and C may only be considered as typical values for illustrative purposes, they indicate that large ships may have difficulty satisfying the adopted stopping ability criterion of 15 ship lengths.

11 Considering a steam turbine propelled VLCC of 300 metres length, travelling at 15 knots, and assuming that it takes 1 minute to develop full-astern thrust in a stopping manoeuvre, the results using tables A3-1, 2 and 3 are:

$A = 16$,

$B = 1.5$, and

$C = 0.8$

12 Using the formula for the stopping distance S, given above, then:

$$S = 16 \log_e (1 + 1.5) + 0.8$$

= 15.5 ship lengths,

which exceeds the stopping ability criterion of 15 ship lengths.

13 In all cases the value of A is inherent in the shape of the hull and so cannot be changed unless resistance is significantly increased. The value of B can only be reduced by incorporating more astern power in the engine, an option which is unrealistic for a steam turbine powered ship. The value of C would become larger if more than one minute was taken to reverse the engines, from the astern order to the time when the full-astern thrust is developed.

APPENDIX 4

ADDITIONAL MANOEUVRES

1 Additional methods to assess course keeping ability

1.1 The Standards note that additional testing may be used to further investigate a dynamic stability problem identified by the standard trial manoeuvres. This appendix briefly discusses additional trials that may be used to evaluate a ship's manoeuvring characteristics.

1.2 The Standards are used to evaluate course-keeping ability based on the overshoot angles resulting from the 10°/10° zig-zag manoeuvre. The zig-zag manoeuvre was chosen for reasons of simplicity and expediency in conducting trials. However, where more detailed analysis of dynamic stability is required some form of spiral manoeuvre should be conducted as an additional measure. A direct or reverse spiral manoeuvre may be conducted. The spiral and pullout manoeuvres have historically been recommended by various trial codes as measures that provide the comprehensive information necessary for reliably evaluating course-keeping ability. The direct spiral manoeuvre is generally time consuming and weather sensitive. The simplified spiral can be used to quickly evaluate key points of the spiral loop curve.

2 Spiral manoeuvres

2.1 Direct spiral manoeuvre

2.1.1 The direct spiral manoeuvre is an orderly sequence of turning circle tests to obtain a steady turning rate versus ~~rudder~~steering angle relation (see figure A4-2).

2.1.2 Should there be reasons to expect the ship to be dynamically unstable, or only marginally stable, a direct spiral test will give additional information. This is a time-consuming test to perform especially for large and slow ships. A significant amount of time is needed for the ship to obtain a steady rate of change of heading after each ~~rudder~~steering angle change. Also, the test is very sensitive to weather conditions.

2.1.3 In the case where dynamic instability is detected with other trials or is expected, a direct spiral test can provide more detailed information about the degree of instability that exists. While this test can be time consuming and sensitive to weather conditions, it yields information about the yaw rate/~~rudder~~steering angle relation that cannot be measured by any other test.

2.1.4 The direct spiral is a turning circle manoeuvre in which various steady state yaw rate/~~rudder~~steering angle values are measured by making incremental ~~rudder~~steering angle changes throughout a circling manoeuvre. Adequate time must be allowed for the ship to reach a steady yaw rate so that false indications of instability are avoided.

2.1.5 In cases where the ship is dynamically unstable it will appear that it is still turning steadily in the original direction although the ~~rudder~~steering is now slightly deflected to the opposite side. At a certain stage the yaw rate will abruptly change to the other side and the yaw rate versus ~~rudder~~steering angle relation will now be defined by a separate curve. Upon completion of the test the results will display the characteristic spiral loop as presented in figure A4-3.

2.1.6 A direct spiral manoeuvre can be conducted using the following general procedure:

.1 the ship is brought to a steady course and speed according to the specific initial condition;

.2 the recording of data starts;

.3 the ~~rudder~~steering is turned about ~~15°~~half the declared steering angle limit and held until the yaw rate remains constant for approximately one minute;

.4 the ~~rudder~~steering angle is then decreased in three approximately ~~5 degree~~equal increments~~.~~ towards zero steering angle. At each increment the ~~rudder~~steering is held fixed until a steady yaw rate is obtained, measured and then decreased again;

.5 this is repeated for different ~~rudder~~steering angles starting from large angles to both port and starboard; and

.6 when a sufficient number of points is defined, data recording stops.

2.2 Reverse spiral manoeuvre

2.2.1 The reverse spiral test may provide a more rapid procedure than the direct spiral test to define the instability loop as well as the unstable branch of the yaw rate versus ~~rudder~~steering angle relationship indicated by the dotted curve as shown in figure A4-2. In the reverse spiral test the ship is steered to obtain a constant yaw rate, the mean ~~rudder~~steering angle required to produce this yaw rate is measured and the yaw rate versus ~~rudder~~steering angle plot is created. Points on the curve of yaw rate versus ~~rudder~~steering angle may be taken in any order.

2.2.2 This trial requires a properly calibrated rate of turn indicator and an accurate ~~rudder~~steering angle indicator. Accuracy can be improved if continuous recording of rate of turn and ~~rudder~~steering angle is available for the analysis. Alternatively the test may be performed using a conventional autopilot. If manual steering is used, the instantaneous rate of turn should be visually displayed to the helmsman.

2.3 Simplified spiral manoeuvre

2.3.1 The simplified spiral reduces the complexity of the spiral manoeuvre. The simplified spiral consists of three points which can be easily measured at the end of the turning circle test. The first point is a measurement of the steady state yaw rate at the ~~maximum rudder~~declared steering angle limit. To measure the second point, the ~~rudder~~steering is returned to the neutral position and the steady state yaw rate is measured. If the ship returns to zero yaw rate the ship is stable and the manoeuvre may be terminated. Alternatively, the third point is reached by placing the ~~rudder~~steering in the direction opposite of the original ~~rudder~~steering angle to an angle equal to half the allowable loop width. The allowable loop width may be defined as:

0°	for	L/V < 9	seconds
~~3 +~~ (-1/~~3~~12 + 1/108 (L/V)) of declared steering angle limit	for	9 < L/V < 45	seconds
~~12°~~1/3 of declared steering angle limit	for	45 < L/V	seconds

When the ~~rudder~~steering is placed at half the allowable loop width and the ship continues to turn in the direction opposite to that of the ~~rudder~~steering angle, then the ship is unstable beyond the acceptable limit.

3 Pull-out manoeuvre

After the completion of the turning circle test the ~~rudder~~steering is returned to the midship position and kept there until a steady turning rate is obtained. This test gives a simple indication of a ship's dynamic stability on a straight course. If the ship is stable, the rate of turn will decay to zero for turns to both port and starboard. If the ship is unstable, then the rate of turn will reduce to some residual rate of turn (see figure A4-1). The residual rates of turn to port and starboard indicate the magnitude of instability at the neutral ~~rudder~~steering angle. Normally, pull-out manoeuvres are performed in connection with the turning circle, zig-zag, or initial turning tests, but they may be carried out separately.

4 Very small zig-zag manoeuvre

4.1 The shortcomings of the spiral and 10°/10° zig-zag manoeuvres may be overcome by a variation of the zig-zag manoeuvre that quite closely approximates the behaviour of a ship being steered to maintain a straight course. This zig-zag is referred to as a Very Small Zig Zag (VSZZ), which can be expressed using the usual nomenclature, as 0°/5° zig-zag, where ψ is 0° and δ is ~~5º~~ 1/7 of the declared steering angle limit.

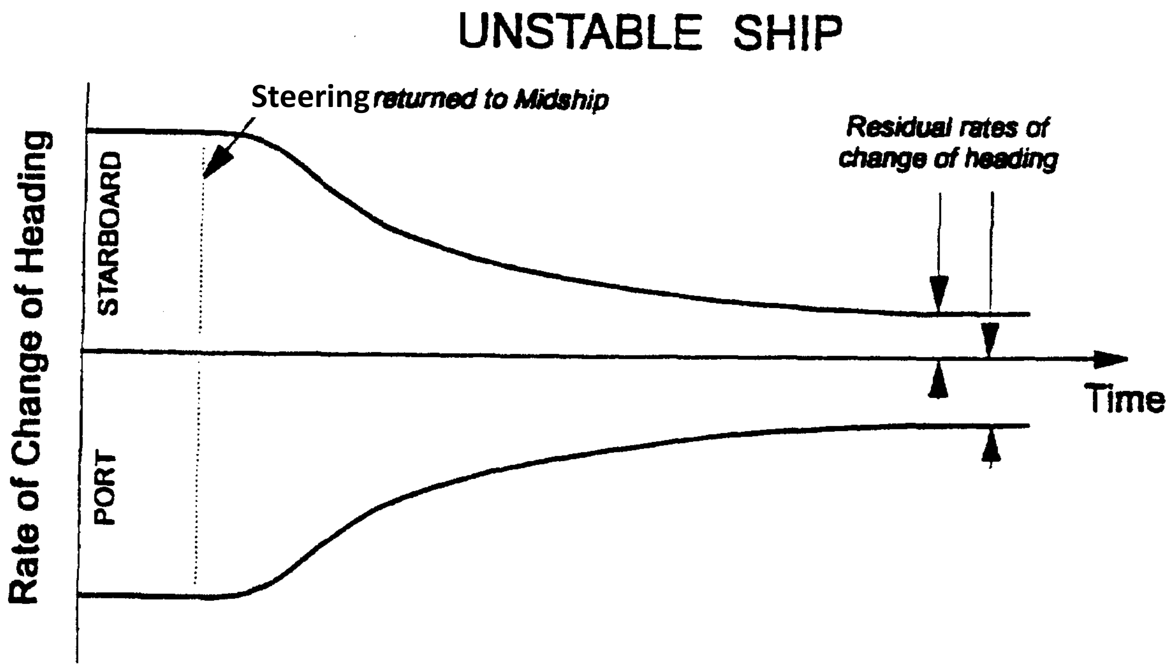
4.2 VSZZs characterized by 0°/5° are believed to be the most useful type, for the following two reasons:

.1 a human helmsman can conduct VSZZs by evaluating the instant at which to move the wheel while sighting over the bow, which he can do more accurately than by watching a conventional compass.

.2 a conventional autopilot could be used to conduct VSZZs by setting a large proportional gain and the differential gain to zero.

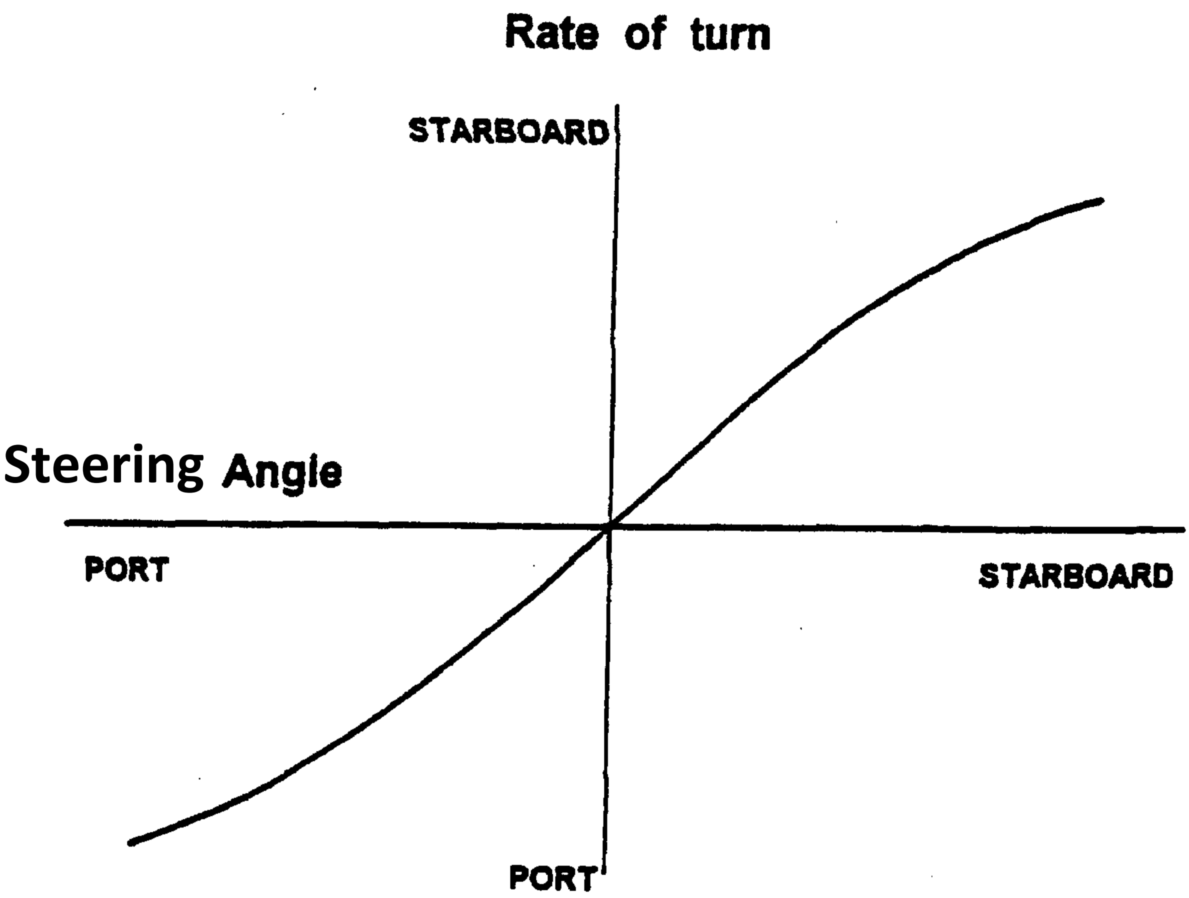
4.3 There is a small but essential difference between 0°/5° VSZZs and more conventional similar zig-zags, such as 1°/5° zig-zag. The 0°/5° zig-zag must be initialised with a non-zero rate-of-turn. In reality, this happens naturally in the case of inherently unstable ships.

4.4 A VSZZ consists of a larger number of cycles than a conventional zig-zag, perhaps 20 overshoots or so, rather than the conventional two or three, and interest focuses on the value of the overshoot in long term. The minimum criterion for course-keeping is expressed in terms of the limit-cycle overshoot angle for 0°/5° VSZZs and is a function of length to speed ratio.



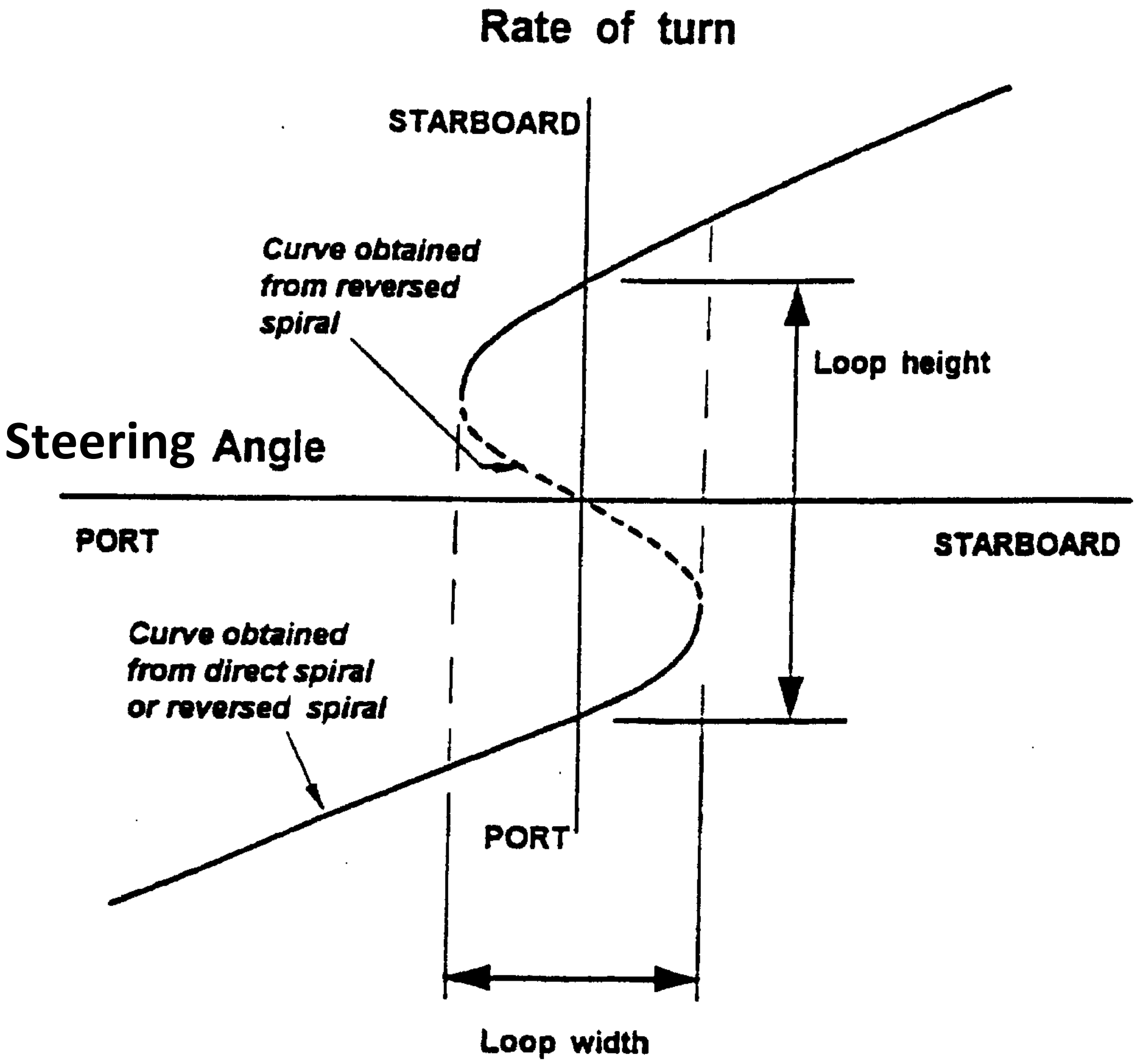
Presentation of pull-out test results

Figure A4-1



Presentation of spiral test results for stable ship

Figure A4-2



Presentation of spiral test results for unstable ship

Figure A4-3

APPENDIX 5

BACKGROUND AND BIBLIOGRAPHY

1 Background data

MSC/Circ.389 and MSC/Circ.644 invited Member Governments to submit ship manoeuvrability data for use in ship design and for establishing manoeuvrability standards. In response, ship trials data and other manoeuvring research and information were submitted to the Sub-Committee on Ship Design and Equipment by Member Governments. This data, along with other available information, were used in the development of the Standards for ship manoeuvrability (resolution MSC.137(76)) and Explanatory notes, as appropriate.

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31 Rhee, K. P., Kim, S. Y., Son, N. S. and Sung, Y. J.: Review of IMO Manoeuvring Standards in View of Manoeuvring Sea Trial Data, Proceedings of Mini Symposium on Prediction of Ship Manoeuvring Performance, Tokyo, Japan (2001).

APPENDIX 6

FORM FOR REPORTING MANOEUVRING DATA TO IMO

Administration: ______________________ **Reference No.*** [ ]

SHIP DATA: (FULL LOAD CONDITION)

Ship type*	[ ]	L/V	[sec]
L/B [ ]	B/T [ ]	C_B	[ ]
~~Rudder~~Steering/ rudder type*	[ ]		
	[ ]	Number of rudders	[ ]
Total rudder area/LT	[ ]	Trim	[ ]
Propeller type*	[ ]		
No. of propellers	[ ]	Ballast condition	[ ]
Engine type*			

TRIALS DATA: (ENVIRONMENTAL CONDITION)

Water depth/trial draught	[ ]
Wind: Beaufort number	[ ]
Wave: Sea state	[ ]

MANOEUVRING DATA:

Loading condition: Tested at Full load [ ] Tested at partial load and corrected [ ]

	TEST RESULTS PORT	STBD		**IMO CRITERIA**
Turning circle:	**PORT**	**STBD**		
Advance	[ ]	[ ]	Ship lengths	4.5
Tactical diameter	[ ]	[ ]	Ship lengths	5
Zig-Zag:				
10 deg/10 deg	**PORT**	**STBD**		
1st overshoot angle	[ ]	[ ]	deg	[ ]
2nd overshoot angle	[ ]	[ ]	deg	[ ]
20 deg/20 deg	**PORT**	**STBD**		
1st overshoot angle	[ ]	[ ]	deg	25
Initial turning:	**PORT**	**STBD**		
Distance to turn 10 deg with ~~10 deg rudder~~1/3 declared steering angle limit	[ ]	[ ]	Ship lengths	2.5
Stopping distance: Track reach	[ ]	[ ]	Ship lengths	15 to 20

REMARKS:

* See notes on the reverse of the page.

Form for reporting manoeuvring data to IMO

Notes:

1 Reference no. assigned by the Administration for internal use.

2 Ship type such as container ship, tanker, gas carrier, ro-ro ship, passenger ship, car carrier, bulk carrier, etc.

3 ~~Rudder~~Steering type such as azimuthing, water jet, cycloidal, full spade rudder, semi-spade rudder, high lift rudder, etc.

4 Propeller tune such as fixed pitch, controllable pitch, with/without nozzle, etc.

5 Engine type such as diesel, steam turbine, gas turbine, diesel-electric, etc.

6 IMO criteria for 10°/10° zig-zag test vary with L/V. Refer to paragraphs 5.3.3.1 and 5.3.3.2 of the Standards for ship manoeuvrability (resolution MSC.137(76)).

Resolution A.601(15)

Annex to Resolution A.601(15) is amended as follows:

ANNEX

RECOMMENDATION ON THE PROVISION AND THE DISPLAY OF MANOEUVRING INFORMATION ON BOARD SHIPS

1 INTRODUCTION

1.1 In pursuance of the ~~Recommendation on Data Concerning Manoeuvring Capabilities and Stopping Distances of Ships~~Standards for Ship Manoeuvrability, adopted by resolution ~~A.160(ES.IV~~MSC.137(76), and Part 4-1 ~~paragraph 10~~ of Section A-VIII/2 ~~regulation II/1~~ of the ~~International Convention on Standards of Training, Certification and Watchkeeping for Seafarers~~ STCW Code, ~~1978~~ 2010, Administrations are recommended to require that the manoeuvring information given herewith is on board and available to navigators.

1.2 The manoeuvring information should be presented as follows:

.1 Pilot card

.2 Wheelhouse poster

.3 Manoeuvring booklet.

2 APPLICATION

2.1 The Administration should recommend that manoeuvring information, in the form of the models contained in the appendices, should be provided ~~as follows:~~for all new ships to which the requirements of the 1974 SOLAS Convention, as amended, apply.

~~.1 for all new ships to which the requirements of the 1974 SOLAS Convention, as amended, apply, the pilot card should be provided;~~

~~.2 for all new ships of 100 metres in length and over, and all new chemical tankers and gas carriers regardless of size, the pilot card, wheelhouse poster and manoeuvring booklet should be provided.~~

2.2 The Administration should encourage the provision of manoeuvring information on existing ships, and ships that may pose a hazard due to unusual dimensions or characteristics.

2.3 The manoeuvring information should be amended after modification or conversion of the ship which may alter its manoeuvring characteristics or extreme dimensions.

3 MANOEUVRING INFORMATION

3.1 Pilot card (appendix 1)

The pilot card, to be filled in by the master, is intended to provide information to the pilot on boarding the ship. This information ~~should~~shall describe the current condition of the ship, with regard to its loading, propulsion and manoeuvring equipment, and other relevant equipment. The contents of the pilot card are available for use without the necessity of conducting special manoeuvring trials.

3.2 Wheelhouse poster (appendix 2)

The wheelhouse poster ~~should~~shall be permanently displayed in the wheelhouse. It ~~should~~shall contain general particulars and detailed information describing the manoeuvring characteristics of the ship, and be of such a size to ensure ease of use. The manoeuvring performance of the ship may differ from that shown on the poster due to environmental, hull and loading conditions.

3.3 Manoeuvring booklet (appendix 3)

The manoeuvring booklet ~~should~~shall be available on board and should contain comprehensive details of the ship's manoeuvring characteristics and other relevant data. The manoeuvring booklet should include the information shown on the wheelhouse poster together with other available manoeuvring information. Most of the manoeuvring information in the booklet can be estimated but some should be obtained from trials. The information in the booklet may be supplemented in the course of the ship's life.

APPENDIX 1

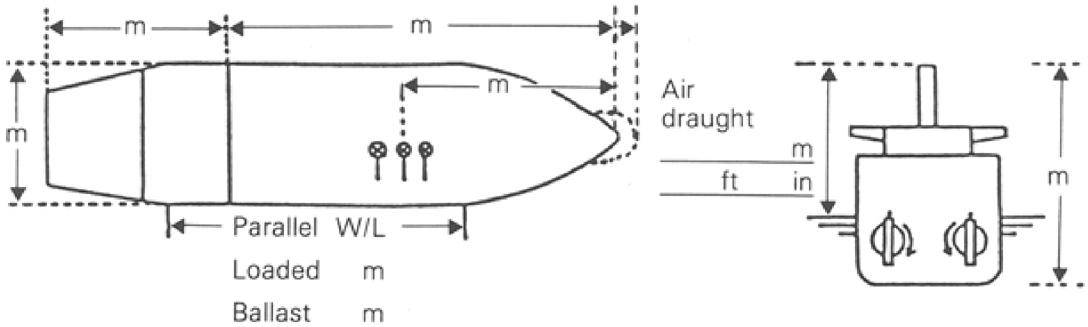
PILOT CARD

Ship's name ______________________________ Date ________________

Call sign __________ Deadweight __________ tonnes Year built ____________

Draught aft ______m/____ft ____in, Forward ______m/____ft ____in, Displacement ______tonnes

SHIP'S PARTICULARS		
Length overall ______m,	Anchor chain: Port ______shackles,	Starboard ______shackles,
Breadth ______m	Stern ______shackles	
Bulbous bow Yes/No	(1 shackle = ________m/________fathoms)	



Type of engine ________________		Maximum power ________kW (________HP)	
Manoeuvring engine order	Rpm/pitch	Speed (knots)	
		Loaded	Ballast
Full ahead			
Half ahead			
Slow ahead			
Dead slow ahead			
Dead slow astern		Time limit astern	________min
Slow astern		Full ahead to full astern	________s
Half astern		Max. no. of consec. starts	________
Full astern		Minimum RPM ________	________knots
		Astern power	________% ahead

STEERING PARTICULARS

Type of steering/ rudder ____________ Maximum angle ____________ °

Hard-over to hard-over ____________ s Declared steering angle limit: ______deg

Steering angle for neutral effect ____________ °

Thruster: Bow ________ kW (________ HP) Stern ________ kW (________ HP)

CHECKED IF ABOARD AND READY

Anchors ☐

Whistle ☐

Radar ☐ 3 cm ☐ 10 cm

ARPA ☐

Speed log ☐ Doppler: Yes/No

Water speed ☐

Ground speed ☐

Dual-axis ☐

Engine telegraphs ☐

Steering gear ☐

Number of power units operating ☐

Indicators:

Steering ☐

Rpm/pitch ☐

Rate of turn ☐

Compass system ☐

Constant gyro error ± ______ °

VHF ☐

Elec. pos. fix. system ☐

Type ____________

OTHER INFORMATION:

APPENDIX 2

WHEELHOUSE POSTER

Ship's name ______________________, Call sign __________, Gross tonnage __________, Net tonnage __________

Max. displacement ________tonnes, and Deadweight ________tonnes, and Block coefficient ________ at summer full load draught

Draught at which the manoeuvring data were obtained

Loaded	Ballast
Trial/Estimated	Trial/Estimated
____m forward	____m forward
____m aft	____m aft

STEERING PARTICULARS

Type of steering/ rudder ______________

Maximum steering angle ________ °

Time hard-over to hard-over
with one power unit ________ s
with two power units ________ s

Minimum speed to maintain course propeller stopped ______ knots

Steering angle for neutral effect ________ °

ANCHOR CHAIN

	No. of shackles	Max. rate of heaving (min/shackle)
Port		
Starboard		
Stern		

(1 shackle = ______m/______fathoms)

PROPULSION PARTICULARS

Type of engine ________, ____kW (____HP), Type of propeller ________

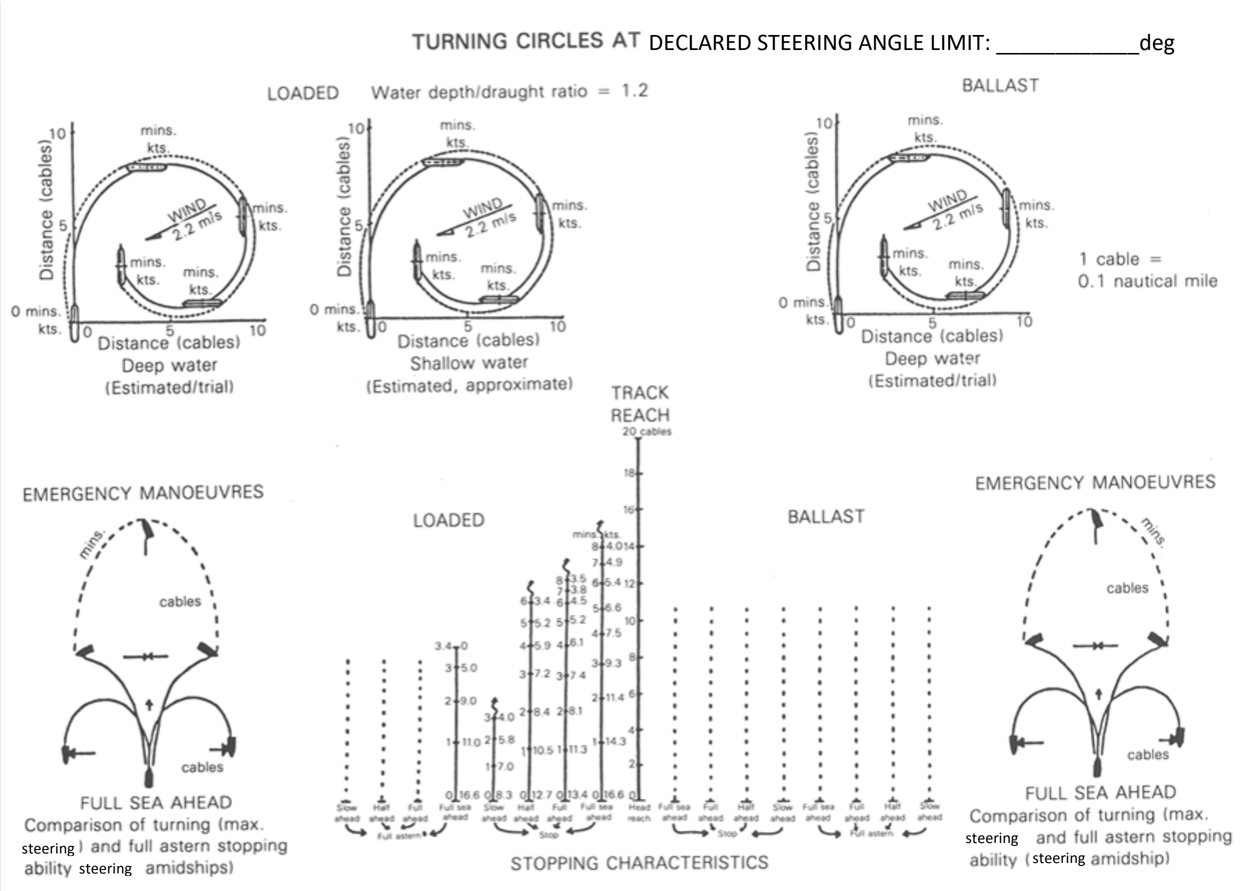
Engine order	Rpm/pitch setting	Speed (knots) Loaded	Speed (knots) Ballast
Full sea speed			
Full ahead			
Half ahead			
Slow ahead			
Dead slow ahead			
Dead slow astern		Critical revolutions ____rpm Minimum rpm ____ ____knots	
Slow astern		Time limit astern ____min Time limit at min. revs.____min	
Half astern		Emergency full ahead to full astern ____s Stop to full astern ____s	
Full astern		Astern power ____% ahead Max. no. of consecutive starts ____	

THRUSTER EFFECT at trial conditions

Thruster	kW (HP)	Time delay for full thrust	Turning rate at zero speed	Time delay to reverse full thrust	Not effective above speed
Bow		s	°/min	min s	knots
Stern		s	°/min	min s	knots
Combined		s	°/min	min s	knots

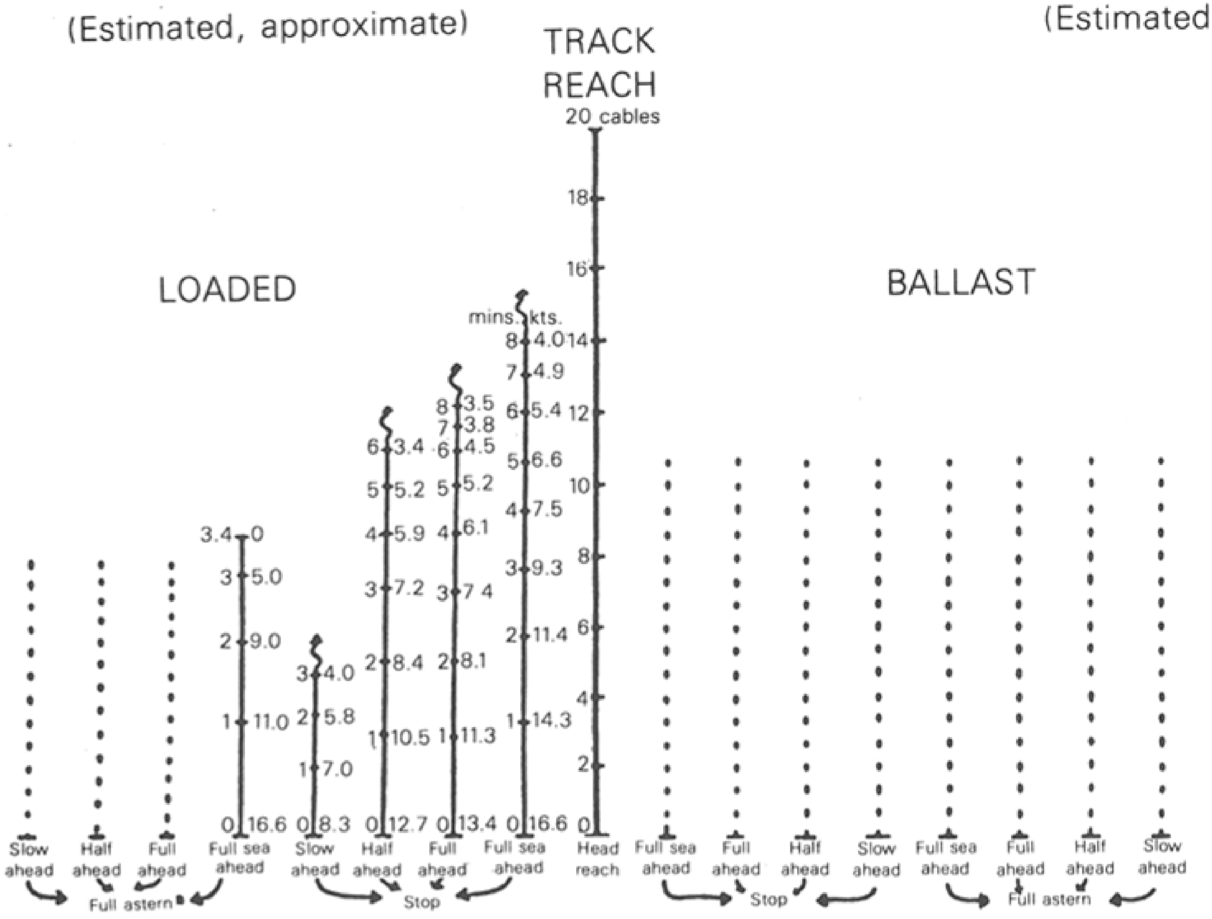
DRAUGHT INCREASE (LOADED)

Estimated Squat Effect			Heel Effect	
Under keel clearance	Ship's speed (knots)	Max. bow squat estimated (m)	Heel angle (degree)	Draft increase (m)
			2	
m			4	
			8	
			12	
m			16	

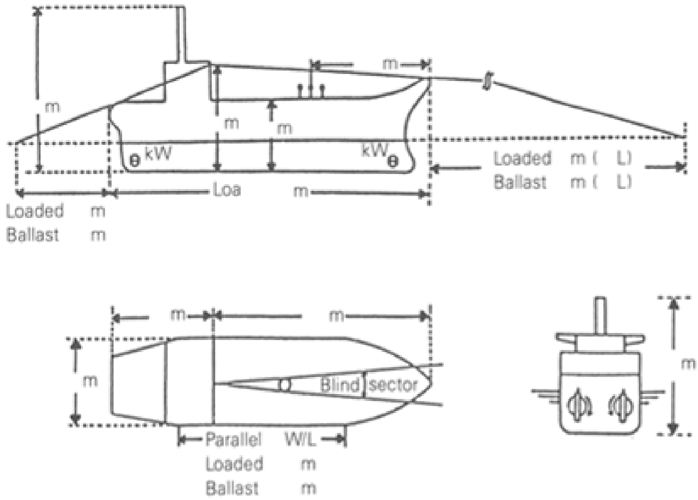

TURNING CIRCLES AT DECLARED STEERING ANGLE LIMIT: ____________deg
LOADED
Water depth/draught ratio = 1.2
BALLAST
Distance (cables)
mins.
kts.
WIND
2.2 m/s
0 mins.
kts.
Distance (cables)
Deep water
(Estimated/trial)
Distance (cables)
Shallow water
(Estimated, approximate)
Distance (cables)
Deep water
(Estimated/trial)
1 cable = 0.1 nautical mile
TRACK
REACH
20 cables
EMERGENCY MANOEUVRES
mins.
cables
cables
FULL SEA AHEAD
Comparison of turning (max. steering) and full astern stopping ability steering amidships)
LOADED
BALLAST
Slow ahead
Half ahead
Full ahead
Full sea ahead
Head reach
Full astern
Stop
STOPPING CHARACTERISTICS
EMERGENCY MANOEUVRES
mins.
cables
cables
FULL SEA AHEAD
Comparison of turning (max. steering and full astern stopping ability (steering amidship)

(Estimated, approximate)

(Estimated/



STOPPING CHARACTERISTICS



MAN OVERBOARD
RESCUE MANOEUVRE

SEQUENCE OF ACTIONS TO BE TAKEN:

- TO CAST A LIFEBUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK-OUT

Insert a recommended turn

Prepared by ________________

Date ________________

PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENTAL, HULL AND LOADING CONDITIONS

APPENDIX 3

RECOMMENDED INFORMATION TO BE INCLUDED IN THE MANOEUVRING BOOKLET

CONTENTS

1 General description
  - 1.1 Ship's particulars
  - 1.2 Characteristics of main engine

2 Manoeuvring characteristics in deep water
  - 2.1 Course change performance
  - 2.2 Turning circles in deep water
  - 2.3 Heading keeping test in deep water
  - 2.4 Accelerating turn
  - 2.~~4~~5 Yaw checking tests
  - 2.~~5~~6 Man-overboard and parallel course manoeuvres
  - 2.~~6~~7 Lateral thruster capabilities

3 Stopping and speed control characteristics in deep water
  - 3.1 Stopping ability
  - 3.2 Deceleration performance
  - 3.3 Acceleration performance

4 Manoeuvring characteristics in shallow water
  - 4.1 Turning circle in shallow water
  - 4.2 Squat

5 Manoeuvring characteristics in wind
  - 5.1 Wind forces and moments
  - 5.2 Course-keeping limitations
  - 5.3 Drifting under wind influence

6 Manoeuvring characteristics at low speed

7 Additional information

1 General description

1.1 Ship's particulars

1.1.1 General

Ship's name, distinctive number or letters, year of build

1.1.2 Gross tonnage and other information

Gross tonnage, deadweight and displacement (at summer draught)

1.1.3 Principal dimensions and coefficients

Length overall, length between perpendiculars, breadth (moulded), depth (moulded), summer draught, normal ballast draught, hull coefficients at summer load and normal ballast condition

Extreme height of the ship's structure above the keel

1.1.4 Main engine

Type, number of units and power output

1.1.5 ~~Propeller~~Propulsor

Type, number of units, diameter, pitch, direction of rotation, propeller immersion

1.1.6 ~~Rudder~~Steering

Type, number of units, declared steering angle limits (Res. MSC.137(76))

For rudders also: total rudder area, rudder area ratio (full load and normal ballast)

1.1.7 Bow and stern thrusters

Type, number of units, capacities and location

1.1.8 Bow and stern profiles

1.1.9 Forward and after blind zones with dimensions specified (full load and normal ballast)

1.1.10 Other hull particulars

Projected areas of longitudinal and lateral above-water profiles (full load and normal ballast)
Length of parallel middle body for berthing (full load and normal ballast)

1.2 Characteristics of main engine

1.2.1 Manoeuvring speed tables (trial or estimated, at the full load and ballast conditions)

Engine revolutions, ship speed and thrust (at ahead) corresponding to engine orders

1.2.2 Critical revolutions

1.2.3 Time for effecting changes in engine telegraph settings as in 3.1.2 for both routine and emergency conditions

1.2.4 Time limit astern

1.2.5 Minimum operating revolutions (for diesel engines) and corresponding ship speed

1.2.6 Maximum number of consecutive starts (for diesel engines)

2 Manoeuvring characteristics in deep water

2.1 Course change performance

2.1.1 Initial turning test results (trial or estimated, at the full load and ballast conditions), test conditions, diagrams of heading angle versus time and ship's track

2.1.2 Course change test results (trial or estimated, at full load and ballast conditions)

Curves of course change distance and point of initiation of counter rudder for the necessary course change angle (for both full load and ballast conditions)

2.2 Turning circles in deep water (trial or estimated, at the full load and ballast conditions)

2.2.1 Turning circle test results

Test conditions, test results (advance and transfer) and turning track at full sea speed ahead

2.2.1.1 Turning circles in both full load, both in normal operational condition and with the steering system in reduced service, and ballast conditions (stern track should be shown)

2.2.1.2 The data presented should refer to the case of starboard turn only (unless there is significant difference for port turn)

2.2.1.3 The initial speed of the ship should be full sea speed ahead

2.2.1.4 Times and speeds at 90, 180, 270 and 360 degrees turning should be specifically shown together with an outline of the ship

2.2.1.5 The ~~rudder~~steering angle used in the test should be the ~~maximum rudder~~declared steering angle limit

2.3 Heading keeping test in deep water

Heading keeping test at full load, both in normal operational condition and with the steering system in reduced service. The maximum yaw deviation during the heading keeping test is to be reported.

2.~~3~~4 Accelerating turn (trial or estimated)

Data are to be presented for both full load and ballast conditions in the same manner as 2.2 for turning circles. The ship accelerates from rest with the engine full manoeuvring speed ahead and the ~~maximum rudder~~declared steering angle limit

2.~~4~~5 Yaw checking tests (trial or estimated)

2.~~4~~5.1 Results of the zig-zag and pull-out manoeuvre tests at the full load or ballast condition shown as diagrams of the heading changes and ~~rudder~~steering angle

2.~~5~~6 Man-overboard and parallel course manoeuvres

2.~~5~~6.1 Man-overboard manoeuvre (trial)

Diagrams for cases of both starboard and port turns should be shown for both full load and ballast conditions

2.~~5~~6.2 Parallel course manoeuvre (estimated)

Diagrams showing lateral shift to a parallel course using ~~maximum rudder~~declared steering angle limit

2.~~6~~7 Lateral thruster capabilities (trial or estimated)

2.~~6~~7.1 Diagrams of turning performance at zero forward speed in the full load or ballast condition should be shown, for bow and stern thrusters acting separately and in combination

2.~~6~~7.2 Diagrams showing the effect of forward speed on turning performance should be included

2.~~6~~7.3 Information on the effect of wind on turning performance should be given

3 Stopping and speed control characteristics in deep water

3.1 Stopping ability

3.1.1 Stopping test results (trial)

Test conditions, ship's tracks, rpm, speed, track reach, head reach and side reach

Two or more tests should be carried out including a test of full astern from full sea speed ahead and a test of full astern from full ahead speed. For ships provided with multiple propulsion lines, additional tests should be carried out while any one of the propulsion systems and its corresponding steering system is out of operation.

3.1.2 Stopping ability (estimated)

Information and diagrams should be given of the track reach, head reach, side reach, time required and track reach deceleration factor (distance/one knot reduction) of a ship in both full load and ballast conditions covering the following modes of stopping manoeuvres:

- full astern from full sea speed ahead
- full astern from full ahead speed
- full astern from half ahead speed
- full astern from slow ahead speed
- stop engine from full sea speed ahead
- stop engine from full ahead speed
- stop engine from half ahead speed
- stop engine from slow ahead speed

3.2 Deceleration performance (estimated)

3.2.1 Deceleration ability (estimated)

Information and diagrams should be given concerning the track reach, time required and deceleration factor of the ship in both full load and ballast conditions for the following engine orders:

- full sea speed to "stand by engines"
- full ahead to half ahead
- half ahead to slow ahead
- slow ahead to dead slow ahead

3.3 Acceleration performance (estimated)

3.3.1 Information and diagrams should be given for track reach and time for the ship to achieve full sea speed ahead, from zero speed

4 Manoeuvring characteristics in shallow water

4.1 Turning circle in shallow water (estimated)

4.1.1 Turning circle in the full load condition (stern track to be shown)

4.1.2 The initial speed of the ship should be half ahead

4.1.3 Times and speeds at 90°, 180°, 270° and 360° turning should be specifically shown, together with an outline of the ship

4.1.4 The ~~rudder~~steering angle should be the ~~maximum~~declared steering angle limit and the water depth to draught ratio should be 1.2

4.2 Squat (estimated)

4.2.1 Curves should be drawn for shallow water and infinite width of channel, indicating the maximum squat versus ship speed for various water depth/draught ratios

4.2.2 Curves should be drawn for shallow and confined water, indicating the maximum squat versus speed for different blockage factors

5 Manoeuvring characteristics in wind

5.1 Wind forces and moments (estimated)

5.1.1 Information should be given on the wind forces and moments acting on the ship for different relative wind speeds and directions in both full load and ballast conditions, to assist in berthing

5.2 Course-keeping limitation (estimated)

5.2.1 Information should be given for both full load and ballast conditions, showing the effect of wind on the ability of the ship to maintain course

5.3 Drifting under wind influence (estimated)

5.3.1 Information should be given on the drifting behaviour under wind influence with no engine power available

6 Manoeuvring characteristics at low speed (trial or estimated)

6.1 Information on the minimum operating revolutions of the main engine and corresponding ship's speed should be given

6.2 Information on the minimum speed at which the ship can maintain course while still making headway after stopping engines

7 Additional information

7.1 Any other relevant additional information should be added to the contents of the booklet, particularly information concerned with the operation of the bridge manoeuvring controls.

Circular MSC.1/Circ. XXXX: Goals, functional requirements and expected performance criteria for SOLAS Regulations II-1/28 & 29 and V/25 & 26

The following Annex to a tentative draft MSC Circular is proposed:

1. Scope

This circular describes the goals and establish the functional requirements that the rules for the design and construction of ship's steering and propulsion systems shall be conform to.

The Appendix A contains the goals, functional requirements and expected performance criteria as such; while Appendix B establishes the cross check between them and the SOLAS regulations II–1/28 & 29 and V/25 & 26 as relevant requirements for ship's steering and propulsion systems.

2. Definitions

For the purpose of this Circular, unless expressly provided otherwise, the terms used have the meanings defined in the following paragraphs. Terms used, but not defined below, are to be interpreted as they are defined in the relevant SOLAS regulations.

Term	Explanation
Cold redundancy	Cold redundancy is for non-critical processes where time is not a high priority and human intervention is acceptable
Declared steering angle limits	Declared steering angle limits are the operational limits in terms of maximum steering angle, or equivalent, according to manufacturer's guidelines for safe operation, also taking into account the ship's speed or propeller torque/speed or other limitations.
Environmental load	Any kind of load due to weather, wind, wave etc.
Expected performance	Part of functional requirement (MSC.1Circ.1394/Rev.2) providing the criterion for verification of compliance
Fail-safe	A concept which is incorporated into the design of a product such that, in the event of a failure, it enters or remains in a safe state (EN 50129)
Failure	An occurrence in which a part, or parts of a system ceases to perform the required function, i.e. a state of inability to perform a normal function
Failure mode	Inability to perform intended function and manifestation
Functional requirement	Functional requirements provide the criteria to be complied with in order to meet the goals. (MSC.1Circ.1394/Rev.2)

Goal	High-level objectives to be met that addresses the issue(s) of concern and reflect the required level of safety
Hazard	A potential to threaten human life, health, property or the environment
Hot redundancy	Warm & hot redundancy are similar in arrangement, but hot redundancy offers instant process correction when a failure is detected
Insufficient performance	Performance does not meet the expectations for safe steering and manoeuvring
Load	Any kind of load acting in or on a system or component of system such as mechanical, hydraulic or electrical
Malfunctioning/malfunction	System or component blocked, broken down, output deviates from design intent
Mode	Manifestation, form or arrangement of being
Normal service	A system fully functional and provides intended performance
Operational profile	Conditions a vessel operates in, e.g. wind, waves, temperature, loading etc.
Overload	Load outside loads considered for design
Reduced service	Service of system in the event of a failure not causing complete loss, i.e. system delivers limited performance compared to normal service
Redundancy	Ability of a system to maintain its function when one failure has occurred
Steering actuating system	Steering actuating system is the equipment provided for supplying power to turn the steering force unit, i.e. comprising steering gear power unit, actuator and the system connecting them (e.g.: transmission or piping system).
Steering actuator	Steering actuator is a component which converts energy into mechanical motion to turn the steering force unit (e.g. hydraulic cylinder, piston, etc.).
Steering control system	Steering control system is the equipment by which orders are transmitted to the steering actuating system(s). Steering control systems comprise all components from the user input device to the receivers, including transmitters, controllers, piping, cables and data networks, hydraulic control pumps

	and their associated motors, motor controllers and solenoid valves, as appropriate.
Steering force unit	Steering force unit is the element generating the forces required to control the vessel (i.e. rudder and stock, rudder propeller, thruster, pod), including all parts up to the interface to the steering gear.
Steering gear	Steering gear is the machinery, actuating system(s) and ancillary equipment to direct the steering force unit for the purpose of steering the ship. The steering gear may include various combinations of steering actuating systems and tiller or equivalent component.
Steering gear power unit	Steering gear power unit is: .1 in the case of electric steering gear, an electric motor and its associated electrical equipment; .2 in the case of electrohydraulic steering gear, an electric motor and its associated electrical equipment and connected pump; or .3 in the case of other hydraulic steering gear, a driving engine and connected pump.
Steering system	Steering system(s) is the ship's mean(s) of directional control, including steering gear, steering control and monitoring system and steering force unit, as well as all means connecting to power supply
Warm redundancy	When time and response to a failure is more important but not critical, a warm redundancy strategy may suffice if a temporary outage is acceptable. The cycle can tolerate certain minutes of interruption, but the process must be restored quickly and automatically to avoid any integrity issues.

Appendix A. Final goals and functional requirements for steering and manoeuvring

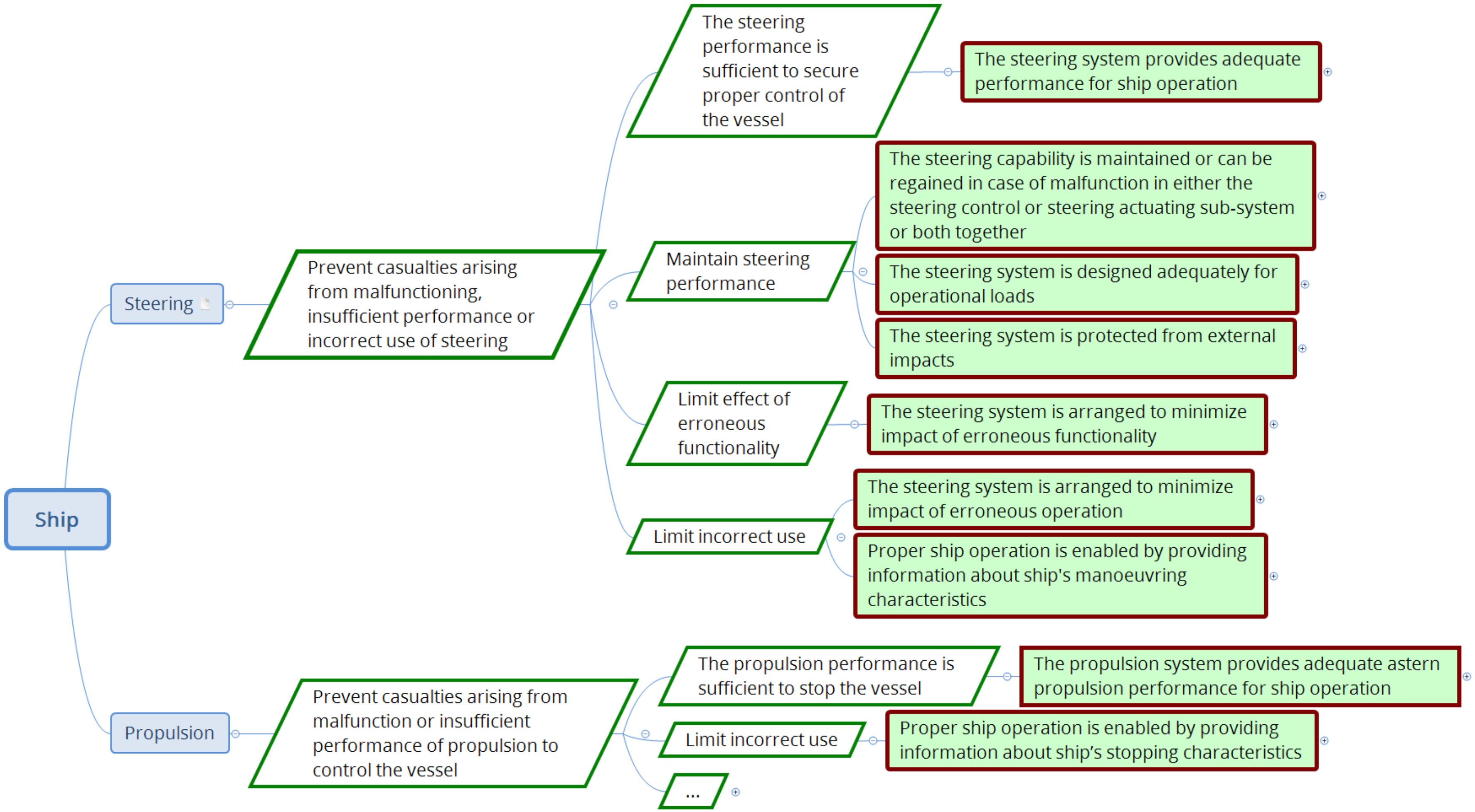


Figure 1 Structure of goals and functional requirements

Top goal and individual goals for steering

Top goal for steering: Prevent casualties arising from malfunctioning, insufficient performance or incorrect use of steering

- Individual goal 1: The steering performance is sufficient to secure proper control of the vessel
- Individual goal 2: Maintain steering performance
- Individual goal 3: Limit effect of erroneous functionality
- Individual goal 4: Limit incorrect use

Top goal and individual goals for propulsion

Top goal for propulsion: Prevent casualties arising from malfunctioning or insufficient performance of astern propulsion to control the vessel

- Individual goal 1: The propulsion performance is sufficient to stop the vessel
- Individual goal 2: Limit incorrect use

Function I: The steering system provides adequate steering performance for ship operation

Expected performance:

- The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 30 minutes. Applicable for both normal and reduced service.
- Ability to turn/change course. Performance during Turning circle manoeuvre:
  - In normal service: advance within 4.5 ship lengths, tactical diameter within 5 ship lengths.
  - In reduced service: advance within 5.6 ship lengths, tactical diameter within 6.25 ship lengths.
- Steering gear performance

  Each steering gear can turn the steering force unit both to port and starboard with the following performance at scantling draft:
  - In Normal service, running ahead at maximum ahead service speed:
    - from declared steering angle limit on one side to declared steering angle limit on the other side
    - from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 28 seconds
  - In Reduced service (only applicable to ships with single steering system):
    - from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 56 seconds, running ahead at maximum ahead service speed
    - For tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and every other ship of less than 70,000 gross tonnage, the requirement may be reduced to:

      from 50% of declared steering angle limit on one side to 50% of declared steering angle limit on the other in not more than 60 seconds, running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.

Function II: The steering capability is maintained or can be regained in case of malfunction in either the steering control or steering actuating sub-systems or both together

Expected Performance:

- Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained;
    - For passenger ships of 70,000 gross tonnage and upwards, normal service performance is maintained
    - and for all other ships, at least reduced service performance is maintained
    - For multiple steering-propulsion systems, redundancy can be realized on ship level
- Malfunction of steering control system will not lead to complete loss of steering capability;
    - Reduced service steering capability is maintained.
    - Steering system can be operated from navigation position.
    - Steering force unit angle indicated independent of control system
    - Indication of steering force unit angle in all locations the steering gear can be operated from
- Normal service capability is available without steering remote control system
- Steering capability (either normal or reduced) will be speedily regained;
    - For tanker, chemical tanker and gas carrier of 10,000 gross tonnage and upwards within 45 s (e.g. by warm redundancy)
    - For all other ships within 15 min. (e.g. by cold redundancy)
    - Automatic restart of steering system when electrical power is regained after failure in electrical power supply
- Availability and performance of steering system continuously monitored and indicated on navigation position
- Loss of availability and overload is indicated by an alarm

Function III: The steering system is designed adequately for operational loads

Expected Performance:

- Components have adequate strength for ship operation and specified design life, considering:
    - All mechanical, hydraulic and electrical loads
    - Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice, maximum speed ahead/astern)
    - Safety factor adequate to address uncertainty in load determination and material/component properties
    - Actuating system is protected from overloads resulting from malfunctioning of the system
- Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality
- System operable under ship motion and environmental conditions
- Steering system availability is not hampered by safety devices
- Inspection concept adequate for steering system design

Function IV: The steering system is protected from external impacts

Expected Performance:

- Steering control system and actuator system are separated from other ship systems, and their electrical power supply arranged as separate circuit
- Electrical power supply maintained after malfunction in electric circuit
- Steering system is protected from external impacts by fire;
    - Separate routing of cabling for power supply and control system
    - No routing through areas of high risk of fire
    - Separate steering gear compartment from other machinery spaces
- Actuating system is protected from overloads, respectively;
    - Overloads due to external forces
    - Overloads resulting from erroneous operation

Additionally, passenger ships of 120 m in length or more or having three or more main vertical zones:

- Fire: reduced service steering capability available after loss of any space of origin
    - up to the nearest A class boundaries protected by fixed fire extinguishing system; or,
    - adjacent spaces up to nearest A class boundaries outside the space of origin

- Flooding: reduced service steering capability available after flooding of any single watertight compartment

Function V: The steering system is arranged to minimize impact of erroneous functionality

Expected Performance:

- Steering system shall be arranged with a fail-safe behaviour in case of failures
- Malfunction in data communication and programmable systems are automatically detected
- Consequences of malfunction in data communication and programmable systems are limited and do not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained
- Earth fault does not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained

Function VI: The steering system is arranged to minimize impact of erroneous operation

Expected Performance:

- Minimize possibilities of steering system operation threatening ship safety:
    - Limit possibility of erroneous input
        - Declare safe operational limits for steering system considering at least speed and stability
    - Limit effect of erroneous input

Function VII: Proper ship operation is enabled by providing information about ship’s manoeuvring characteristics

Expected Performance:

- Provide information about ship’s manoeuvring characteristics adequate for all persons involved in navigation and available at all navigation positions;
    - Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)
    - Comprehensive details of manoeuvring characteristics per MSC.137 shall be readily available to the operator

- Provide familiarisation of ship’s manoeuvrability characteristics (drills and training)

Function VIII: The propulsion system provides adequate astern propulsion performance for ship operation

Expected Performance:

- Ship can be brought to rest with stopping distance within 15 ship lengths
- In reduced service, ships provided with multiple propulsion-steering systems can be brought to rest with stopping distance within 20 ship lengths

Function IX: Proper ship operation is enabled by providing information about ship’s stopping characteristics

Expected Performance:

Provide information about ship´s stopping characteristics adequate for all persons involved in navigation and available at all navigation positions

Appendix B. Cross reference functions and SOLAS regulation

Steering system

Function	Expected Performance	Reference SOLAS Ch. II-1
I. The steering system provides adequate steering performance for ship operation	• The ship can maintain a straight course with yaw oscillations less than ±2 degrees for 30 minutes. Applicable for both normal and reduced service.	Reg.29.4
	• Ability to turn/change course. Performance during Turning circle manoeuvre: ○ In normal service: advance within 4.5 ship lengths, tactical diameter within 5 ship lengths. ○ In reduced service: advance within 5.6 ship lengths, tactical diameter within 6.25 ship lengths.	Reg.29.4
	• Steering gear performance Each steering gear can turn the steering force unit both to port and starboard with the following performance at scantling draft: ○ In Normal service, running ahead at maximum ahead service speed: ▪ from declared steering angle limit on one side to declared steering angle limit on the other side	Reg.29.8

Function	Expected Performance	Reference SOLAS Ch. II-1
	▪ from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 28 seconds ○ In Reduced service (only applicable to ships with single steering system): ▪ from declared steering angle limit on one side to 85% of declared steering angle limit on the other in not more than 56 seconds, running ahead at maximum ahead service speed ▪ For tanker, chemical tanker or gas carrier of less than 10,000 gross tonnage and every other ship of less than 70,000 gross tonnage, the requirement may be reduced to: from 50% of declared steering angle limit on one side to 50% of declared steering angle limit on the other in not more than 60 seconds, running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.	

Function	**Expected Performance**	**Reference SOLAS** **Ch. II-1**

II. The steering capability is maintained or can be regained in case of malfunction in either the steering control or steering actuating or both together	• Malfunction of steering gear will not lead to complete loss of steering capability and at least reduced service performance is maintained;
	  ○ For passenger ships of 70,000 gross tonnage and upwards, normal service performance is maintained
	  ○ and for all other ships, at least reduced service performance is maintained
	  ○ For multiple steering-propulsion systems, redundancy can be realized on ship level
		Ch.V Reg.25
		
		Reg.29.4,
		Reg.29.7, Reg.29.10.1 4)

	• Malfunction of steering control system will not lead to complete loss of steering capability;
	  ○ Reduced service steering capability is maintained.
	  ○ Steering system can be operated from navigation position.
	  ○ Steering force unit angle indicated independent of control system
	  ○ Indication of steering force unit angle in all locations the steering gear can be operated from
		Reg.29.7
		
		Reg.29.9
		Reg.29.9.2.3
		Reg.29.9.4.1

Function	Expected Performance	Reference SOLAS Ch. II-1
	• Normal service capability is available without steering remote control system	Reg.29.9.2.3
	• Steering capability (either normal or reduced) will be speedily regained; ○ For tanker, chemical tanker and gas carrier of 10,000 gross tonnage and upwards within 45 s (e.g. by warm redundancy) ○ For all other ships within 15 min. (e.g. by cold redundancy) ○ Automatic restart of steering system when electrical power is regained after failure in electrical power supply	Reg.29.4.4 Reg. 29.7.3.2 Reg.29.4.5 Reg.29.7.3.1 Reg.29.9.4.2
	• Availability and performance of steering system continuously monitored and indicated on navigation position	Reg.29.9.3
	• Loss of availability and overload is indicated by an alarm	Reg.29.9.3.3 Reg.29.10.1 2)

Function	Expected Performance	Reference SOLAS Ch. II-1
III. The steering system is designed adequately for operational loads	• Components have adequate strength for ship operation and specified design life, considering: ○ All mechanical, hydraulic and electrical loads ○ Characteristic loads resulting from operation of steering system considering ship operation and environment (e.g. waves, ice, maximum speed ahead/astern) ○ Safety factor adequate to address uncertainty in load determination and material/component properties ○ Actuating system is protected from overloads resulting from malfunctioning of the system	Reg.29.6 Reg.29.10.2 Reg.29.10.1 3)
	• Steering system is designed with margins such that normal wear and degradation will have negligible effect on functionality	Reg.29.6.1
	• System operable under ship motion and environmental conditions	Reg.29.6.1
	• Steering system availability is not hampered by safety devices	Reg.29.11.7
	• Inspection concept adequate for steering system design	Reg.29.12.2 Ch.V Reg.26

Function	Expected Performance	Reference SOLAS Ch. II-1
IV. The steering system is protected from external impacts	• Steering control system and actuator system are separated from other ship systems, and their electrical power supply arranged as separate circuit	Reg.29.9.2.4, Reg.29.9.5, Reg.29.11
	• Electrical power supply maintained after malfunction in electric circuit	Reg.29.9.5, Reg.29.11
	• Steering system is protected from external impacts by fire; ○ Separate routing of cabling for power supply and control system ○ No routing through areas of high risk of fire ○ Separate steering gear compartment from other machinery spaces	Reg.29.11 Reg.29.9.2.2 Reg.29.12.1

Function	Expected Performance	Reference SOLAS Ch. II-1

	• Actuating system is protected from overloads, respectively;
	  ○ Overloads due to external forces
	  ○ Overloads resulting from erroneous operation
		Reg.29.6.4,
		Reg.29.6.5,
		Reg.29.6.6
		Reg.29.10.1 3)

For Pax of 120 m in length or more or having three or more main vertical zones: Steering capability available after loss of any A-bounded space	• Fire: reduced service steering capability available after loss of any space of origin
	  ○ up to the nearest A class boundaries protected by fixed fire extinguishing system; or,
	  ○ adjacent spaces up to nearest A class boundaries outside the space of origin
		II-2/21, II-1/8-1.3

	• Flooding: reduced service steering capability available after flooding of any single watertight compartment	
V. The steering system is arranged to minimize impact of erroneous functionality	• Steering system shall be arranged with a fail-safe behaviour in case of failures	Reg.29.7, Reg.29.9.3.2,
	• Malfunction in data communication and programmable systems are automatically detected	Reg.29.7, Reg.29.9.3.2,

Function	**Expected Performance**	**Reference SOLAS** **Ch. II-1**
	• Consequences of malfunction in data communication and programmable systems are limited and do not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained	Reg.29.9.3.2, Reg.29.9.6
	• Earth fault does not render the system inoperable or with insufficient performance, and at least reduced service performance is maintained	Reg.29.9.3.2

VI. The steering system is arranged to minimize impact of erroneous operation	• Minimize possibilities of steering system operation threatening ship safety:
	  ○ Limit possibility of erroneous input
	    ▪ Declare safe operational limits for steering system considering at least speed and stability
	  ○ Limit effect of erroneous input
		Reg.29.9.3.2, Reg.29.9.6

VII. Proper ship operation is enabled by providing information about ship's manoeuvring characteristics	• Provide information about ship's manoeuvring characteristics adequate for all persons involved in navigation and available at all navigation positions;
	  ○ Condensed format for easy use summarising main manoeuvring characteristics (pilot card, wheelhouse poster)
	  ○ Comprehensive details of manoeuvring characteristics per MSC.137 shall be readily available to the operator
		Reg.29.5

Function	**Expected Performance**	**Reference SOLAS** **Ch. II-1**
	• Provide familiarisation of ship's manoeuvrability characteristics (drills and training)	Ch. V Reg. 26

Propulsion system

Function	**Expected Performance**	**Reference SOLAS** **Ch.II-1**
VIII**.** The propulsion system provides adequate astern propulsion performance for ship operation	• Ship can be brought to rest with stopping distance within 15 ship lengths	Reg.28.5.1
	• In reduced service, ships provided with multiple propulsion-steering systems can be brought to rest with stopping distance within 20 ship lengths	Reg.28.5.2
IX: Proper ship operation is enabled by providing information about ship's manoeuvring characteristics	• Provide information about ship's stopping characteristics adequate for all persons involved in navigation and available at all navigation positions	Reg.28.5.5

About DNV

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