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DESIGN CRITERIA

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25 July 2023

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TABLE OF CONTENTS

Table of Tables XII

Table of Figures XIV

PREFACE XV

CHAPTER 1 INTRODUCTION 1-1

1.1 Background 1-1

1.1.1 Aim and Objective of this Agreement 1-2

1.2 The Goal Based Approach and Mission Oriented Approach 1-3

1.2.1 Goal Based Approach 1-3

1.2.2 Mission Oriented Approach 1-4

CHAPTER 2 GUIDANCE FOR SPECIFYING MANOEUVRING REQUIREMENTS 2-1

2.1 Staff Requirements Formulation 2-1

2.2 Specifying Manoeuvring Performance 2-2

2.3 Assessing Manoeuvring Performance 2-3

CHAPTER 3 GENERAL DEFINITIONS 3-1

3.1 Definitions Of Speeds 3-1

3.2 Definition of Manoeuvring Abilities 3-1

3.3 Naval Mission/TASK Descriptions 3-3

3.3.1 Transit and Patrol 3-4

3.3.2 Harbour Manoeuvring and Towing 3-4

3.3.3 Anti Submarine Warfare 3-5

3.3.4 Anti Air Warfare 3-6

3.3.5 Anti Surface Warfare 3-6

3.3.6 Mine Warfare 3-7

3.3.7 Vehicle Interaction 3-8

3.3.8 Amphibious Warfare 3-9

3.3.9 Maritime Interdiction Operations 3-9

3.4 Conditions of application 3-9

3.4.1 Conditions Related to Mission Effectiveness 3-10

3.4.2 Conditions on the Use of Steering Equipment and Systems 3-10

3.4.3 Conditions on Mission Operability 3-11

CHAPTER 4 MANOEUVRING CRITERIA 4-1

4.1 Over-arching Goals 4-1

4.2 Functional Areas and Objectives 4-1

4.2.1 Safety Goals 4-1

4.2.2 Mission Effectiveness Goals 4-2

4.3 Maturity of Criteria 4-3

4.4 Safety Performance Requirements 4-4

4.4.1 Relevant Statutory Requirements 4-4

4.4.2 General Controllability Requirement 4-5

4.4.3 Controllability While Subject to Environmental Forces Requirement 4-5

4.4.4 Operator Guidance Requirement 4-5

4.4.5 Towing Capability Requirement 4-6

4.4.6 Directional Stability Requirement 4-6

4.4.7 Non-tactical Transit Requirements 4-7

4.4.8 Harbour Manoeuvring 4-8

4.5 Mission Performance Requirements 4-8

4.5.1 General Mission Controllability Requirement 4-8

4.5.2 Mission Heading Controllability Requirement 4-9

4.5.3 Mission Position Controllability Requirement 4-9

4.5.4 Tactical Transit in Formation Requirements 4-9

4.5.5 Anti Submarine Warfare Requirements 4-10

4.5.6 Mine Warfare Requirements 4-10

4.5.7 Anti Air Warfare Performance Requirements 4-14

4.5.8 Anti Surface Warfare Performance Requirements 4-15

4.5.9 Replenishment at Sea (RAS) Vehicle Interaction Performance Requirements .. 4-16

4.5.10 General Sea Vehicle Interaction Performance Requirements 4-17

4.5.11 Sea Vehicle Interaction at Stern Dock Performance Requirements 4-18

4.5.12 Air Vehicle Interaction Performance Requirements 4-18

4.6 Documentation of Manoeuvring Performance 4-18

CHAPTER 5 MANOEUVRING PERFORMANCE ASSESSMENT 5-1

5.1 Overview 5-1

5.2 Manoeuvring assessment Process through design phases 5-3

5.3 Numerical Modeling And Simulation Of Manoeuvring Performance 5-5

5.3.1 Simple Analytic Predictions 5-6

5.3.2 Detailed Simulations 5-6

5.4 Direct Physical Modelling Of Manoeuvring 5-8

5.5 Direct Measurement Using Full Scale Trials 5-10

5.6 Correlation Of Manoeuvring Performance Results 5-14

5.7 Additional Guidance On Manoeuvring Performance Assessment 5-14

APPENDIX A DISCUSSION OF DEVELOPMENT OF MANOEUVRING PERFORMANCE CRITERIA A-1

A.1 Course Keeping A-1

A.2 Track keeping A-1

A.3 Tactical Diameter A-1

A.4 Initial turning A-3

A.5 Yaw checking A-4

A.6 Accelerating Turning from Rest A-5

A.7 Turning at Rest A-6

A.8 Stopping A-6

A.9 Acceleration A-7

A.10 Astern Course Keeping A-7

A.11 Station Keeping A-7

A.12 Lateral transfer A-7

APPENDIX B SPECIFYING ENVIRONMENTAL CONDITIONS B-1

B.1 Overview B-1

B.2 Standardised wave and wind conditions for open ocean North Atlantic B-1

B.3 Wave information sources B-2

B.3.1 Hindcast Wave Data B-2

B.3.2 Wave Data from Visual Observations B-2

B.3.3 Wave Data from Direct Measurements B-2

APPENDIX C WARSHIP MANOEUVRING OPERABILITY ASSESSMENT C-1

C.1 Background C-1

C.2 Mission and Task Analysis C-1

C.3 Definition of Environment C-1

C.4 Overview of Manoeuvring Operability Assessment Process C-1

C.5 Determination of Performance Number for an Individual Criterion C-2

C.6 Determination of measure of effectiveness for a given mission C-3

APPENDIX D CORVETTE EXAMPLE D-1

D.1 Ship Dimensions and General Performance D-1

D.2 Manoeuvring performance requirements D-1

D.2.1 Non-tactical Transit Requirements D-2

D.2.2 Harbour Manoeuvring Requirements........D-3

D.2.3 Tactical Transit Requirements........D-3

D.2.4 Anti Submarine Warfare Requirements........D-4

D.2.5 Anti Air Warfare Requirements........D-4

APPENDIX E NOMENCLATURE........E-1

APPENDIX F REFERENCES........F-1

TABLE OF TABLES

Table 1: Manoeuvring Abilities ... 3-2

Table 2: Transit and Patrol (TaP) Operational Conditions ... 3-4

Table 3: Harbour Manoeuvring (HM) Operational Conditions ... 3-5

Table 4: Anti Submarine Warfare (ASW) Operational Conditions ... 3-5

Table 5: Anti Air Warfare (AAW) Operational Conditions ... 3-6

Table 6: Anti Surface Warfare (ASuW) Operational Conditions ... 3-6

Table 7: Mine Warfare (MIW) Operational Conditions ... 3-7

Table 8: Replenishment at Sea (RAS) Operational Conditions ... 3-8

Table 9 Vehicle Interaction Operational Conditions ... 3-8

Table 10: Maturity of Manoeuvring Performance Criteria ... 4-3

Table 11: IMO MSC.137(76) (2002) Manoeuvring Requirements ... 4-4

Table 12: Non-tactical Transit Criteria ... 4-7

Table 13: Harbour Manoeuvring Criteria ... 4-8

Table 14: Tactical Transit in Formation Criteria ... 4-9

Table 15: Anti Submarine Warfare (ASW) Criteria ... 4-10

Table 16: Mine Warfare (MIW) General Criteria ... 4-11

Table 17: Mine Warfare (MIW) Hunting Criteria ... 4-12

Table 18: Mine Warfare (MIW) Sweeping Criteria ... 4-13

Table 19: Mine Warfare (MIW) Mine Avoidance Criteria ... 4-14

Table 20: Anti Air Warfare (AAW) Performance Criteria ... 4-15

Table 21: Anti Surface Warfare (ASuW) Performance Criteria ... 4-16

Table 22: Replenishment at Sea (RAS) Vehicle Interaction Performance Criteria ... 4-17

Table 23: General Sea Vehicle Interaction Performance Criteria (Excluding RAS and Stern Dock) ... 4-17

Table 24: Sea Vehicle Interaction at Stern Dock Performance Criteria ... 4-18

Table 25: Air Vehicle Interaction Performance Criteria ... 4-18

Table 26: Manoeuvring Performance Recommended Measurements 5-2

Table 27: Manoeuvring Performance Assessment by Design Phase................................ 5-5

Table 28: Measurements for Free Running Model Manoeuvring Experiments 5-9

Table 29: Additional Measurements for Free Running Model Manoeuvring Experiments in a Protected Body of Water 5-10

Table 30: Measurements for Full Scale Trials.. 5-12

Table 31: Recommended Test Duration at Full Scale... 5-13

Table 32: NATO Sea States and Annual Statistics for North Atlantic B-1

Table 33: Ranking Factors for Mission Abilities C-4

Table 34: Non-tactical Transit Performance Requirements..D-2

Table 35: Harbour Manoeuvring Requirements D-3

Table 36: Tactical Transit Performance Requirements D-3

Table 37: Anti Submarine Warfare Performance Requirements D-4

Table 38: Anti Air Warfare Performance Requirements D-4

TABLE OF FIGURES

Figure 1: Ship Functional Areas in Design 1-1

Figure 2: Goal Based Approach 1-3

Figure 3: Application of Goal Based Principle, with Overarching Goals, Functional Objectives, and Performance Requirements with Associated Criteria 2-1

Figure 4: Typical Ship Design Process 5-4

Figure 5: Tactical Diameter Performance Criteria and Legacy Ship Manoeuvring Data A-3

Figure 6: Initial Turning Performance Criteria and Legacy Ship Manoeuvring Data for 20/20 Zig-Zag A-4

Figure 7: Yaw Checking Performance Criteria and Legacy Ship Manoeuvring Data for 20/20 Zig-Zag A-5

Figure 8: Stopping Performance Criteria and Legacy Ship Manoeuvring Data A-6

Figure 9: Calculation of Performance Number C-3

PREFACE

Strong ship manoeuvring performance is vital for the safe operation of all vessels. Safe ship manoeuvring enables vessels to avoid collisions with other vessels and running aground. Standards from agencies such as the International Maritime Organization and technical knowledge from the International Towing Tank Conference and other groups contribute to the design and operation of safe ships.

Naval ships, which must conduct various military missions, have additional demands for manoeuvring performance. Mine warfare requires avoidance of mines and strong performance for station keeping and track keeping. Naval warfare with opposing air, surface, and underwater entities requires strong high speed manoeuvring performance, including torpedo evasion. Replenishment at sea, air vehicle operations, and launch and recovery of water vehicles require strong course keeping performance.

STANREC 4721 and ANEP 70 Volumes I, II, and III provide a framework for design and operation of ships such that their manoeuvring performance will allow them to operate safely and to fulfill naval missions. ANEP 70 Volume I provides design manoeuvring criteria for naval ships and discusses methods for assessing whether ships meet design criteria. ANEP 70 Volume II provides guidance on the provision of ship manoeuvring performance information to ship operators, and includes much information regarding data to be measured during sea trials. ANEP 70 Volume III provides manoeuvring performance data for existing ships and results from surveys of naval operators, forming the basis for the design manoeuvring criteria of Volume I.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

1. Naval ships are designed and built for the purpose of conducting naval warfare at sea. In non-conflict operations naval ships must also be able to function in a safe manner, ensuring safety of ship/embarked assets, personnel and the environment. A number of basic abilities, or functional areas, are needed in order to accomplish necessary missions and tasks:

a. operate (fight);

b. sustain (move);

c. survive (float).

2. Andrews (1998) has illustrated the relationships among these, as shown in Figure 1.

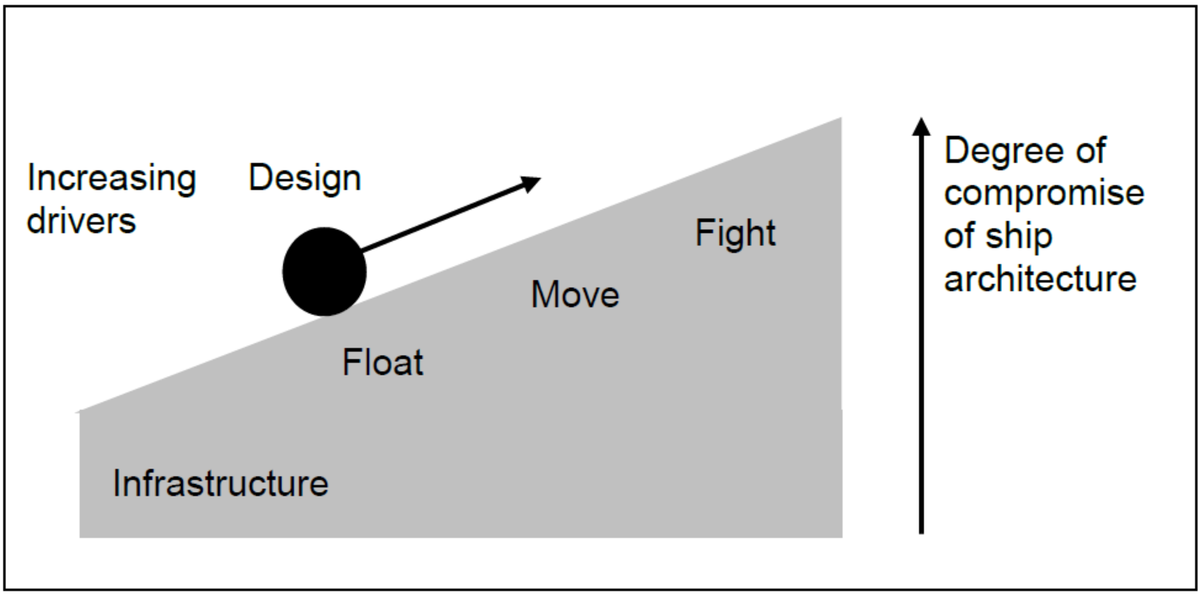

Figure 1: Ship Functional Areas in Design

3. For the ship, a number of basic characteristics are associated with maritime mobility. The ship shall be:

a. seaworthy;

b. designed to be able to effectively carry out its missions and associated support tasks/functions within its operational context and environmental boundaries, such as up to a specified sea state and for given ship conditions and operational scenarios;

c. controllable throughout the range of ship loading and environmental conditions specified to maintain its course and manoeuvre in a controlled and consistent manner.

4. The ship shall also:

   a. achieve the required degree of stability in calm water and in waves;

   b. be strong enough to withstand the loads imposed by severe weather and sea waves;

   c. move efficiently, meeting the required speed and endurance performance;

   d. maintain adequate seakeeping abilities up to a specified sea-state;

   e. maintain course and manoeuvre effectively, in both open water and confined waterways.

5. Other characteristics to be considered are:

   a. the navigational draught of the ship;

   b. transit underneath bridges with adequate clearance during high tide;

   c. transit/manoeuvring at slow speed through areas of ice.

6. This volume presents ship manoeuvrability design criteria developed using background information from ANEP-70 Vol. III. ANEP-70 Vol. II provides related guidance for preparation of onboard manoeuvring information.

7. The requirement of a naval platform to maintain a course and manoeuvre effectively at sea, as well as in confined waterways, will depend on the mission, tasks, and area of operations. It is important to define the required performance during the feasibility phase of a ship program. Verification of performance will require increasing detail through each phase from concept design through to delivery.

8. Introduction or alteration of manoeuvring requirements late in the design or during the build phase could result in a failure to meet those requirements. Likewise, the ability to improve the manoeuvring performance of an existing platform is generally limited to modification of high performance steering devices or the addition/reduction of skegs. Aspects such as hull shape and general configuration of propulsion and steering devices cannot easily be changed.

9. Most tabulated requirements in this ANEP address performance in calm environmental conditions as there is not widely available expertise to establish comprehensive quantitative requirements for adverse environmental conditions. However, manoeuvrability in higher sea states is required to meet certain mission objectives, which are mentioned specifically in Chapter 3 and Chapter 4.

1.1.1 Aim and Objective of this Agreement

1. The aim of the manoeuvring requirements in this ANEP is to provide a framework for naval surface ship safety and mission effectiveness, intended to embrace the controllability and interoperability of naval ships to be designed and operated by NATO members and their partners.

1.2 THE GOAL BASED APPROACH AND MISSION ORIENTED APPROACH

1.2.1 Goal Based Approach

1. The regulatory framework in this ANEP utilizes a goal based approach (see Figure 2) similar to the one used during the development of the Naval Ship Code (ANEP-77). The basic principle of the goal based approach is to define goals that represent the top tiers of a framework, against which a ship may be verified both at design and construction stages, and during ship operations.

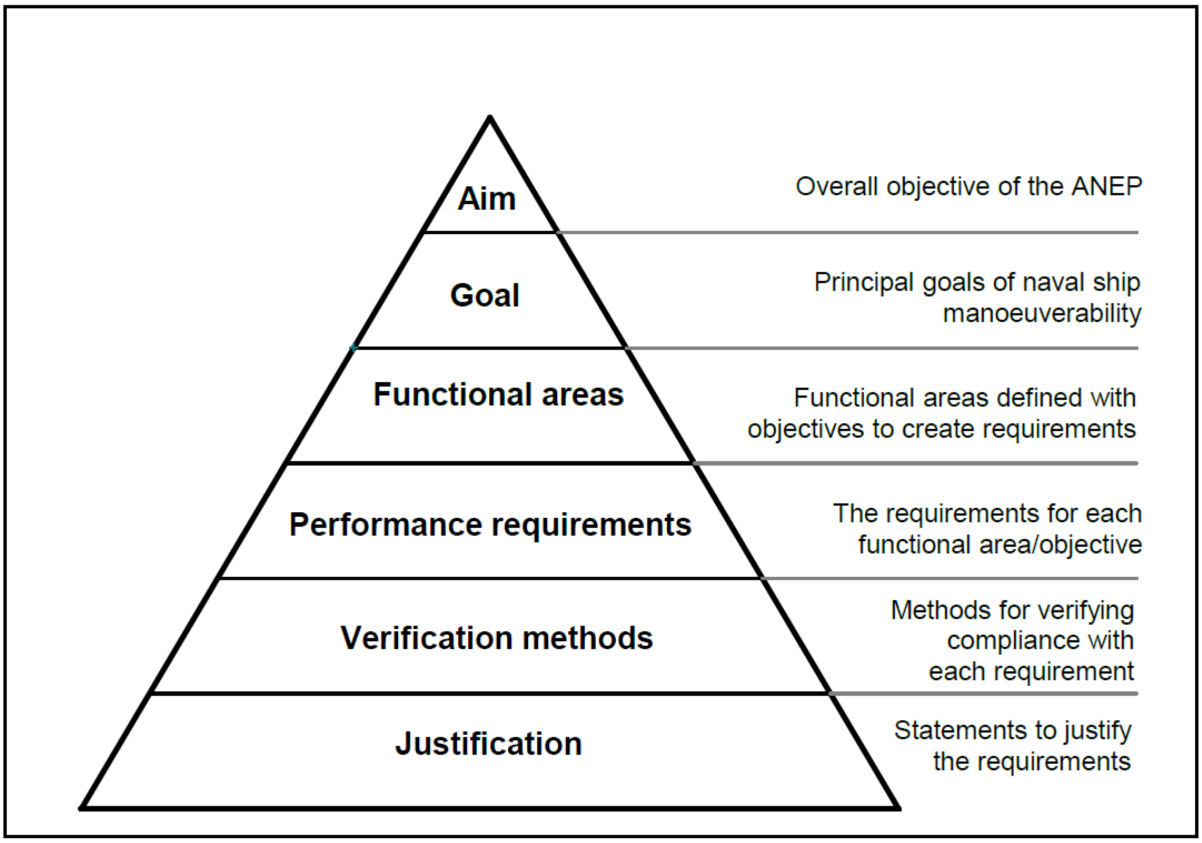

Figure 2: Goal Based Approach

2. This approach allows the requirements to vary widely in nature, as follows:

a. prescriptive (low level detail that acts to constrain and bound the solution);

b. focused on delivering a specified level of function and performance (allowing flexibility and solution innovation, but relying heavily on the ability to measure and verify the desired performance);

c. remain at a high level with reference to other standards;

d. a combination of the above.

3. This ANEP applies the goal based approach to determine ship manoeuvrability performance for both safety and mission oriented requirements of naval ships.

4. Goals, functional areas and objectives as well as performance requirements are found in Chapter 4. Verification is addressed in Chapter 5.

1.2.2 Mission Oriented Approach

1. This document also supports development of manoeuvrability criteria using a mission oriented approach. Surveys of naval operators were conducted to determine manoeuvrability requirements associated with various missions. Much of this knowledge is incorporated into ANEP-70 Vol. II (onboard manoeuvring documentation) and ANEP-70 Vol. III (manoeuvring requirements), and is referenced in this document.

CHAPTER 2 GUIDANCE FOR SPECIFYING MANOEUVRING REQUIREMENTS

2.1 STAFF REQUIREMENTS FORMULATION

1. In the area of controllability, the staff requirements or concept of operations of a naval platform should begin by including the goals and functional objectives of this ANEP. Figure 3 gives an overview of the process.

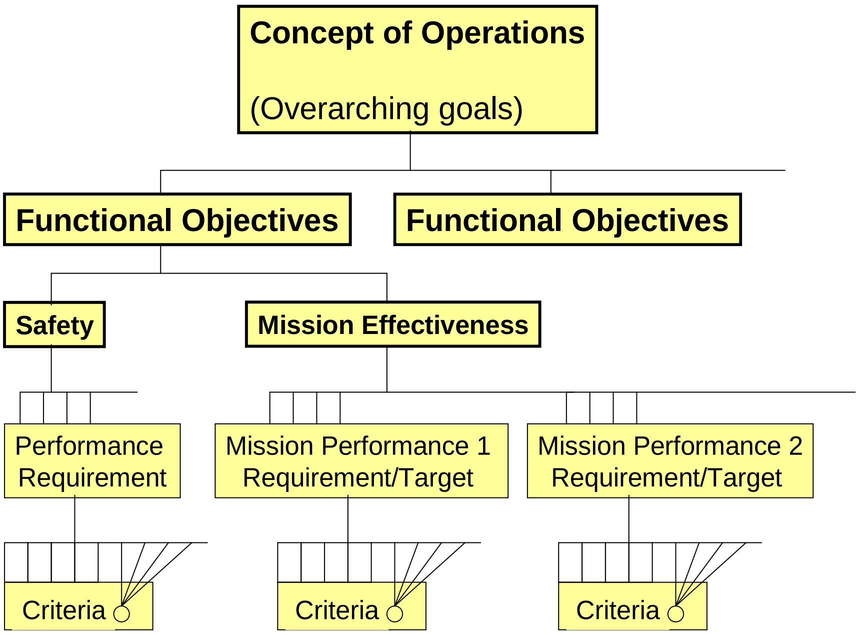

Figure 3: Application of Goal Based Principle, with Overarching Goals, Functional Objectives, and Performance Requirements with Associated Criteria

2. Following on from the goal and functional objectives, the primary drivers for mission effective manoeuvring requirements are the anticipated missions, resulting tasks and the areas of operation. These aspects must be defined by the naval staff in developing the concept of operation and will include the expected operating environment as well as required availability.

3. Once the relevant missions have been identified, this ANEP can be used to develop specific performance requirements and associated criteria that support the achievement of identified functional objectives and mission effectiveness requirements for a particular type of ship.

4. Regarding mobility, staff requirements normally stipulate as a minimum:

a. maximum speed;

b. minimum speed.

5. In addition, reasons may exist to require a ship to be capable to maintain other speeds.

6. During design work following requirements formulation, other speed requirements will be derived based on intended use, intended naval missions, and tasks. This ANEP defines typical speed ranges for each mission or task.

2.2 SPECIFYING MANOEUVRING PERFORMANCE

1. Having considered the staff requirements, the performance requirements can be established based on the mission specific requirements defined in this ANEP. By identifying the performance requirements, traceability to the goals and functional objectives will be maintained.

2. There are two main goals:

   a. safety;

   b. mission effectiveness.

3. Whilst some flexibility of requirements to allow for design optimisation should be maintained in the concept design phase, the required performance should be fixed by the time the options have been narrowed and preliminary design commences.

4. The following points outline at a high level the approach taken within this ANEP to assign the various manoeuvring performance requirements across the various naval ship types and roles:

   a. For ships with an operating profile that matches a merchant ship (fixed routes, weather routing, benign threat, etc.) navies may opt to conform to the requirements of IMO MSC.137(76) (2002) or specific national standards;

   b. Ships with limited mission requirements that do not fit the operating profile of a merchant ship should consider the naval safety requirements defined in this ANEP;

   c. Ships with specific mission requirements operating as naval ships should consider the naval safety requirements and the relevant mission effectiveness manoeuvring requirements defined in this ANEP.

5. Mission effectiveness requirements may have 2 metrics for any criterion. These will be designated “required performance” and “target performance”:

   a. “Required performance” is the level of performance that shall be achieved, and will provide the level of manoeuvring performance required for the mission.

   b. “Target performance” is the level of performance that exceeds the required performance and can be based on various inputs, including interviews with operators.

6. Metrics designated as “required performance” are considered essential for mission success and shall be satisfied, while those designated “target performance” are desirable, and will improve mission performance. Target performance requirements may need to be

substantiated and supported by analysis, in particular when a major cost-driving effect is anticipated.

7. Other factors which should be considered when developing manoeuvring requirements will include acoustic signature requirements, manoeuvrability of other fleet units, requirements for effective use of decoys, and required performance compared to adversary platforms such as submarines.

8. Environmental conditions should always be determined from the areas of operation and/or concept of operations document. For design verification, specification of wave heights, wave periods and spectra, and nominal (or gust) wind speed is required. Guidance for specifying environmental conditions is addressed in Appendix B of this ANEP.

2.3 ASSESSING MANOEUVRING PERFORMANCE

1. Manoeuvring performance shall be verified at each major stage of design, and validated during sea trials (see Chapter 5).

2. During the concept design phase, parametric assessment and simplified numerical methods will typically be adequate.

3. Preliminary design will require computational analysis to verify the platform configuration is adequate. Model tests should be conducted in this phase to provide preliminary validation of the computational analysis.

4. Detailed design may require further computations (of increasing fidelity) to verify design performance against requirements. Comparison with the model tests conducted during the preliminary design phase will validate the outcome. If model tests have not yet been undertaken, they should be completed in this phase.

5. Sea trials are an essential component of manoeuvring performance assessment, preferably to provide direct verification of ship performance or as a means of providing computational tool validation data for indirect performance verification.

6. Computations may be required to extend assessment to environmental conditions that are not encountered during trials. In such cases sea trials should provide sufficient data to allow final validation of computations.

7. Following sea trials, further trials on an opportunity basis may be required to provide the ship with a NATO/IP wheelhouse poster and pilot card as specified in ANEP-70 Vol. II.

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CHAPTER 3 GENERAL DEFINITIONS

1. This chapter provides definitions of ship manoeuvring properties. It also describes naval missions and conditions that can be used when specifying manoeuvring requirements.

3.1 DEFINITIONS OF SPEEDS

1. Speeds relevant for this ANEP are defined below:

   a. Mission speed: Speed (or speed range) that the ship is required to maintain during a mission or task normally derived from the use of a certain mission-specific equipment or system. A ship may have several mission speeds and/or speed ranges;

   b. Slow speed: The minimum steady speed at which the ship is self-controllable (function of sea state);

   c. Cruising speed (CS): Continuous sustained transit speed;

   d. Maximum continuous rating (MCR) speed: Speed corresponding to maximum safely sustainable continuous power from the power plant. Note that there can be more than one maximum continuous rating speed, depending on the number of engine configurations;

   e. Maximum design speed (MDS): Maximum design speed derived from the user requirements and/or derived from the operational context;

   f. Required verification speed: Speed at which mission/task performance criteria shall be verified.

3.2 DEFINITION OF MANOEUVRING ABILITIES

1. Manoeuvring abilities and their measures that are used to establish requirements are defined in Table 1.

2. Several criteria for course keeping and track keeping are specified based on RMS error, which includes contributions from both mean and oscillating components relative to the command heading or track. When developing RMS error values, the following equation based on Ochi (1973) for oscillation of time varying variable x with respect to a mean was utilized:

$$E(x_{max}) = \sigma_x \sqrt{2\ \ln\left(\frac{N}{\alpha}\right)}$$

where $E(x_{max})$ is expected maximum value of x, σ_x is standard deviation, N is number of cycles during a specified time, and α is exceedance probability. The following equations were then used to develop RMS error values based on initially prescribed values for x_{max}:

$$\sigma_x = 0.29\ x_{max} \text{ for } N = 20, \alpha = 0.05$$

$$\sigma_x = 0.26\, x_{max} \text{ for } N = 100, \alpha = 0.05$$

Table 1: Manoeuvring Abilities

Ability	Description	Definition
Course keeping Ψ (deg)	Accuracy with which the steered ship is able to maintain a predetermined heading without excessive oscillations of steering device or heading (see “3.4 Conditions of application”).	RMS course error during specified time and/or number of oscillations.
Track keeping (m)	Accuracy and effort with which the steered ship is able to maintain a specified track without excessive oscillations of steering device.	RMS track error during specified time and/or number of oscillations.
Tactical diameter y_{0180}/L_{PP}	Ability to turn the ship using optimum steering angle. Note: Roll stability requirements typically include a limitation of the heel angle during steady high-speed turning.	y_{0180} (m) is lateral distance of midship point from location where turn is initiated to where heading of 180 degrees has been achieved.
Initial turning $t_a/(L_{PP}/V_0)$	Ability is defined by the change-of-heading response to a moderate helm.	t_a (s) is time elapsed from order execute to achieve a specified heading change (e.g., 20 deg), with setting of propulsion unaltered and using a specified steering angle (e.g., 20 deg).
Yaw checking $t_{c1}/(L_{PP}/V_0)$	Response of a ship to check (stop) a certain rate of turning.	t_{c1} (s) is first time to check yaw in a zig-zag test (time elapsed from order execute to stop yaw).
Accelerating turning from rest t_{90} (s)	Accelerating turning from rest using most efficient and available steering and propulsion devices.	Time from order execute to turn to 90 degrees from rest.

Table 1: Manoeuvring Abilities (continued)

Ability	Description	Definition
Stopping s_F/L_{PP}	Stop from ahead describes the response of the ship using most efficient and available steering and propulsion devices.	s_F (m) is distance along track.
Acceleration time (s)	Acceleration time describes the ability to increase the speed either from zero or from a given initial speed to a given target speed.	Time to increase speed from initial to target speed.
Astern course keeping Ψ (deg)	Ability to maintain a predetermined heading within reasonable limits when going astern.	RMS course error during specified time and/or number of oscillations.
Station keeping (m), and/or Ψ (deg)	Ability to maintain a predetermined position and/or heading despite environment disturbances in form of current, wind and waves.	RMS station and/or heading error during specified time and/or number of oscillations.
Lateral transfer (knots)	Ability to change position by means of transverse motion at equilibrium angle with zero rate of turn.	Minimum required lateral transfer speed.
Standard deviation of navigational error (SDNE) (m)	SDNE is a measure of how accurately the ship is able to follow a prescribed track, which is often defined by waypoints.	RMS error of lateral distance from prescribed track.
Turning at rest t_{90} (s)	The ability to turn at rest with best available propulsion and manoeuvring means.	Time from order execute to turn to 90 degrees at rest. Required verification speed is zero knots. Limited position change is allowed.

3.3 NAVAL MISSION/TASK DESCRIPTIONS

1. The naval missions or tasks addressed herein are highly dependent on ship manoeuvring performance. This section provides a brief description of the relevant missions. Detailed descriptions of naval missions are provided in NATO standards, such as STANAG 1459.

2. Upper Sea State, as given in Table 3 to Table 9, is to be interpreted as normally accepted upper sea condition for the specific mission, and can be dependent on ship size and other variables. Appendix B gives definitions for sea states.

3. Wind speeds may be higher than those attributed to fully developed seas as operational areas may be fetch limited, or provide shelter from waves but not wind.

3.3.1 Transit and Patrol

1. Transit and Patrol (TaP) refers to the naval mission where the ship is moving from one place to another. Table 2 gives operational conditions for Transit and Patrol. Naval objectives may be limited to routine shipboard tasks, but could also include use of a variety of sensors to survey the surrounding environment, such as for Search and Rescue (SAR) missions. TaP may include the following tasks:

a. point to point;

b. Search and Rescue (SAR);

c. offshore patrol;

d. military surveillance.

Table 2: Transit and Patrol (TaP) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Non-tactical transit	In proportion to sea state	Maximum operational sea state for ship	Limited by sea
Tactical transit	In proportion to sea state	Maximum operational sea state for ship	Limited by sea

2. For the purpose of manoeuvrability performance criteria definition, all TaP variants are covered by the following two transit types:

a. non-tactical transit, which has no significant military objective;

b. tactical transit, which can have one or more military objectives.

3. Manoeuvrability is of concern for the following TaP tasks:

a. maintaining steady speed;

b. maintaining station in a formation (e.g., acceleration, change of heading);

c. uniform acceleration or deceleration for speed change in formation.

3.3.2 Harbour Manoeuvring and Towing

1. Harbour Manoeuvring (HM) refers to the naval mission of low speed manoeuvre approaching or leaving a position or area for anchoring, mooring or berthing or assisting/towing another ship, typically in confined waters. Table 3 gives operational conditions and subtasks for Harbour Manoeuvring.

Table 3: Harbour Manoeuvring (HM) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Mooring/ berthing	30 knots unaided	Sea State 2	Less than 5 knots
Anchoring	50 knots	Sea State 3	Less than 5 knots
Towing	15 knots	Sea State 3	Less than 10 knots

3.3.3 Anti Submarine Warfare

1. For the purposes of manoeuvrability, Anti Submarine Warfare (ASW) addresses both Proactive and Reactive ASW.

Table 4: Anti Submarine Warfare (ASW) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Proactive ASW	In proportion to sea state	Sea State 4 to Sea State 6	MDS and sonar operations speed
Reactive ASW	In proportion to sea state	Sea State 4 to Sea State 6	Up to MDS

2. Proactive ASW is the offensive ASW sub-task of detecting, identifying and tracking submarines and underwater objects, neutralising hostile submarines, and neutralising or diverting incoming underwater weapons. This includes manoeuvring abilities associated with launching of airborne assets, deploying towed sensors, target detection, target classification, launching torpedoes, launching and recovering unmanned vehicles, launching ASW grenades and target assessment.

3. Manoeuvrability is of concern during the following Proactive ASW tasks:

   a. sprint and drift ASW operations;

   b. operating sonar at speed below 10 knots;

   c. accelerating from sonar (signature) speed to MDS.

4. Reactive ASW is the defensive ASW sub-task of detecting, identifying, and tracking submarines and underwater objects. This includes underwater threat detection, threat classification, evasive manoeuvring, deployment of decoys and confirmation that the threat has been neutralised.

5. Manoeuvrability is of concern during the following Reactive ASW tasks:

   a. launch and recovery of equipment in water;

b. towing equipment in water (course keeping);

c. evasive manoeuvring (turning, acceleration).

3.3.4 Anti Air Warfare

1. Anti Air Warfare (AAW) refers to the naval mission of detecting, identifying, and tracking aircraft and missiles, neutralising hostile aircraft, and neutralising or diverting incoming missiles. Table 5 gives operational conditions for both Proactive and Reactive AAW.

Table 5: Anti Air Warfare (AAW) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Proactive AAW	In proportion to sea state	Sea State 4 to Sea State 6	Cruise speed to MDS
Reactive AAW	In proportion to sea state	Sea State 4 to Sea State 6	Cruise speed to MDS

2. Manoeuvring performance influences the following during AAW:

a. detecting, identifying and tracking air targets during day/night and clear/adverse weather using ship-based sensors and engaging targets with appropriate means;

b. deployment of countermeasures combined with evasive manoeuvring.

3.3.5 Anti Surface Warfare

1. Anti Surface Warfare (ASuW) refers to the naval mission of engagement of surface ships and other surface vehicles or objects. Manoeuvrability related to Anti Surface Warfare is primarily associated with Transit and Patrol (TaP) and Vehicle Interaction, which are both described above. Table 6 gives operational conditions for Anti Surface Warfare. Manoeuvring performance influences sensors and weapon systems that may be used.

Table 6: Anti Surface Warfare (ASuW) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
ASuW Ship to Ship	In proportion to sea state	Sea State 3 to Sea State 6	Cruise speed to MDS
ASuW Ship to Shore	In proportion to sea state	Sea State 3 to Sea State 6	Any speed - manoeuvring to maintain desired position and/or heading

3.3.6 Mine Warfare

1. Mine Warfare (MIW) refers to the naval mission associated with mines, with subtasks and operational conditions given in Table 7.

2. Mine hunting activities include the following:

a. deployment/recovery of towed equipment or unmanned vehicles;

b. transit over mine fields;

c. target detection, identification and classification;

d. deploying charges;

e. moving outside of mine range.

Table 7: Mine Warfare (MIW) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Mine hunting	Up to 30 knots	Sea State 1 to Sea State 4	0 - 6 knots
Mine sweeping	Up to 30 knots	Sea State 1 to Sea State 4	3 - 10 knots
Mine avoidance	In proportion to sea state	Sea State 1 to Sea State 6	0 -12 knots

3. Manoeuvring performance influences the following during mine hunting:

a. area search (slow speed, stopping, course keeping, track keeping);

b. navigation accuracy (course keeping, track keeping);

c. launch and recovery of unmanned vehicles (station keeping, track keeping);

d. handling and operation of unmanned vehicles (lateral transfer, astern course keeping);

e. underwater object interrogation (lateral transfer, astern course keeping);

f. underwater object detection and classification;

g. minimization of underwater signature.

4. Manoeuvring performance influences the following mine sweeping tasks:

a. deployment and recovery of sweep equipment or unmanned vehicles;

b. operation of sweep equipment or unmanned vehicles.

5. Manoeuvring performance influences the following mine avoidance tasks:

a. detection of underwater objects (slow speed);

b. avoidance of underwater objects (turning, astern course keeping).

3.3.7 Vehicle Interaction

1. Vehicle interaction includes replenishment at sea (RAS) tasks, air vehicle interaction, and sea vehicle interactions other than RAS. Table 8 gives operational conditions for RAS, and Table 9 gives operational conditions for vehicle interactions other than RAS.

Table 8: Replenishment at Sea (RAS) Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Abeam RAS	In proportion to sea state	Sea State 3 to Sea State 5	10-16 knots
Astern RAS	In proportion to sea state	Sea State 3 to Sea State 5	8-12 knots
Vertical RAS	In proportion to sea state	Sea State 3 to Sea State 5	10-15 knots

Table 9 Vehicle Interaction Operational Conditions

Mission/Task	Wind	Upper Sea State	Ship Speed
Air vehicle interaction	In proportion to sea state	Sea State 3 to Sea State 5	8 knots to MDS
Sea vehicle interaction	In proportion to sea state	Sea State 3 to Sea State 5	0-15 knots

2. Replenishment at sea refers to the naval support activity generally involving the transfer of fuel, ammunitions, supplies and personnel from one ship to another while ships are at sea.

3. Replenishment at sea is often conducted in between two ships, but can also involve additional ships. The "control" ship maintains steady course and speed. The other ships are referred to as "approach" ships, which come to station abeam the control ship and maintain that station throughout the replenishment. The replenishment course is normally dependent on sea state. Replenishments are routinely conducted in Sea State 4, and can be conducted in higher sea states if highly skilled personnel and suitable equipment are available.

4. Replenishment at sea demands the very best of helmsmanship. The operation involves an extended period of time during which two or more ships are in close proximity while at relatively high speeds. Unforeseen problems can necessitate immediate and timely disengagement.

5. Manoeuvrability performance influences the following during replenishment at sea:

   a. maintaining station and distance between ships (station keeping relative to the other vessel, acceleration);

   b. turning fast into wind (turning, acceleration).

6. It is assumed that adequate ability to keep course will enable the vessel to adequately station keep to another vessel during RAS.

7. Air vehicle interaction refers to the naval support activity generally involving helicopters, aeroplanes, and UAVs.

8. Sea vehicle interaction refers to general operations and stern dock operations.

9. Manoeuvrability performance influences the following during vehicle interaction:

   a. ability to launch vehicle;

   b. ability to recover vehicle;

   c. ability to transfer crew and/or equipment.

3.3.8 Amphibious Warfare

1. Manoeuvrability related to Amphibious Warfare is primarily associated with Transit and Patrol (TaP) and Vehicle Interaction, which are both described above.

3.3.9 Maritime Interdiction Operations

1. Naval ships intended for Maritime Interdiction Operations (MIO) may have to consider complex manoeuvring requirements to maximize safety and tactical advantage while in the presence of vehicles with unknown intentions. Safety distance could be guided by range of potential small calibre fire. Tactical advantage could be guided by range and dead angles of own weapons.

2. Manoeuvrability related to MIO is primarily associated with Transit and Patrol (TaP) and Vehicle Interaction, which are both described above.

3.4 CONDITIONS OF APPLICATION

1. The mission sea state is to be specified as the operational sea state for the specific mission or task in ship requirements.

2. A calm environment is defined as having wind, wave and current conditions as low as possible. In practice, the limits for calm conditions are normally defined as follows:

   a. The significant wave height (H_s) should not exceed 1% of L_{pp} (m), or H_s = 1.25 m (Sea State 3), whichever gives the smaller value;

b. The wind speed should not exceed the initial ship speed (or the mean ship speed if major speed changes occur) or 10 knots, whichever gives the smaller value.

3. Background information for specifying wind and wave environmental conditions for use with manoeuvrability criteria can be found in Appendix B.

4. Specific manoeuvrability requirements in waters of limited depth and in ice are not covered by this ANEP.

5. Criteria are only applicable for an intact fully operable ship. It is recognized that ship damage could potentially have a large impact on manoeuvring performance, but is not addressed in this ANEP.

6. In order to safeguard the quality of the assessment of manoeuvring performance, the following must be specified:

a. conditions related to mission effectiveness;

b. conditions on the use of steering equipment and systems.

3.4.1 Conditions Related to Mission Effectiveness

1. This ANEP recommends manoeuvring performance levels to ensure safety and mission effectiveness. However, mission effectiveness also depends on many other performance areas outside the scope of this document. Performance areas strongly linked to manoeuvring performance are:

a. speed;

b. signatures;

c. seakeeping.

2. Mission effectiveness and requirements derived from systems, equipment and operational procedures have been taken into account when specifying manoeuvring performance levels in this ANEP.

3. It is the intention of this ANEP that specified manoeuvring performance levels do not compromise performance in other areas.

4. Specified manoeuvring requirements can range from minimum acceptable ("required performance") to desirable ("target performance"). Although any performance level above the required is acceptable, the desirable level would represent excellent manoeuvring performance based on operator opinions, experience and analysis of existing ship performance.

3.4.2 Conditions on the Use of Steering Equipment and Systems

1. All equipment and systems related to steering shall be used unrestricted and within their normal operational boundaries and constraints during manoeuvrability assessment. No system shall be used in such a way that:

a. safety is degraded;

b. operational limits set for the system are exceeded;

c. wear and tear is increased to levels higher than normally acceptable.

2. However, within these limits, it is allowed to optimize the utilization of all systems in a way that manoeuvring performance is at its best.

3. The following specific conditions are set:

a. Steering device oscillations should not be excessive, which is interpreted as high frequency small motions and/or continuous peak-to-peak activity and/or steering command rate exceeding the mechanical capability of the steering gear.

b. In the case of an autopilot or other controller, settings may be tuned for each specific condition and manoeuvre, as long as this is also feasible on board during normal operation.

c. In principle, any steering and propulsion device can be used to obtain the best manoeuvre. The exception is when the use of a particular steering device may cause degradation in mission effectiveness, operational limits or signature. For example, the use of transverse thrusters could be restricted because of their potential impact on hydro-acoustic signature.

3.4.3 Conditions on Mission Operability

1. An operational profile in terms of heading against wind and wave directions shall be defined for each mission. The manoeuvrability requirements shall be fulfilled for all applicable headings within the operational profile.

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CHAPTER 4 MANOEUVRING CRITERIA

1. The goals, functional areas and objectives, as well as the performance requirements described in this chapter are in principle valid for all "normal" naval environmental conditions in accordance with the aim of this ANEP as stated in Chapter 1. The criteria stated in the performance tables are applicable for the manoeuvring abilities defined in Table 1.

2. It is assumed that adequate manoeuvring performance in calm conditions will also lead to adequate manoeuvring performance in waves.

4.1 OVER-ARCHING GOALS

1. This section defines over-arching goals that should be attained in order to meet the objective of this ANEP.

2. The ship shall be designed, constructed, and maintained to provide sufficient inherent and piloted controllability in all normal loading conditions, and under the influence of the specified environmental conditions in order to provide the required level of mission effectiveness.

3. The ship shall be designed, constructed, and maintained to provide sufficient inherent and piloted controllability in all normal loading conditions without introducing risk in the following areas:

a. ship handling;

b. operation of ship equipment;

c. ship motion;

d. capsizing;

e. collision;

f. grounding.

4.2 FUNCTIONAL AREAS AND OBJECTIVES

1. This ANEP considers the two following main functional areas:

a. safety;

b. mission effectiveness.

2. These functional areas and corresponding functional objectives are described in brief below.

4.2.1 Safety Goals

1. Controllability is a sub-set of safety of navigation which encompasses all aspects of at sea mobility and the ship's interaction with maritime environment including ships and naval

platforms in compliance with applicable regulations. The ship shall be capable of manoeuvring in order to prevent harm to the ship, persons on board, or third parties. Specific goals are given in the Naval Ship Code (ANEP-77 or comparable national standards concerning:

a. buoyancy;

b. stability;

c. controllability;

d. emergency steering.

2. The ship shall be able to manoeuvre to control its aspect to the prevailing environment.

3. The ship shall be able to manoeuvre to avoid collision with geostationary and moving objects as appropriate to its mission.

4. The ship shall be controllable with sufficient directional stability at all speeds, with the following provisions:

a. The minimum speed of which the ship is controllable shall be determined;

b. At speeds below the minimum ‘self-controllable’ speed, an assistance plan should be defined, (e.g., tug boats).

5. When applying the above goals, there shall be suitable levels of safety margins inherent within the ship design. In addition, appropriate operator guidance shall be provided.

4.2.2 Mission Effectiveness Goals

1. The term Measure of Effectiveness (MOE) in the context of a naval ship may be described as the extent to which a Naval Ship System may be expected to perform its tasks and mission requirements for its intended scenarios.

2. A Measure of Effectiveness is normally defined by and based on several Measures of Performance (MOP). MOPs are performance characteristics such as accuracy and time/range related parameters. Customer requirements are often expressed or established in MOEs in the form of a probabilistic value.

3. The importance of various manoeuvring abilities for each naval task was established through a survey among naval operators (ANEP-70 Vol. III).

4. For naval ships, functional objectives related to mission effectiveness shall apply. The ship shall be capable of manoeuvring in order to adequately perform its mission and ensure effective performance of its mission systems. Specific mission effectiveness goals are given immediately below.

5. The ship shall be able to maintain heading as appropriate for its mission, within the ship operational envelope.

6. The ship shall be able to manoeuvre to change its heading as appropriate for its mission, within the ship operational envelope.

7. The ship shall be able to manoeuvre to control its position as appropriate for its mission, within the ship operational envelope.

4.3 MATURITY OF CRITERIA

Sections 4.4 and 4.5 provide safety performance and mission effectiveness criteria, which have been developed primarily using data given in Appendix A. Table 10 provides a summary of maturity for the various criteria. It is recommended that caution be exercised when applying the criteria specified as being developmental.

Table 10: Maturity of Manoeuvring Performance Criteria

Manoeuvring performance criteria	Source of criteria			Limited data	Lack of data	Mature or developmental
	Numeric sim	Legacy data	Operator survey			
Course keeping	✓					D
Track keeping					✓	D
Tactical diameter (all missions except below)		✓	✓			M
►Tactical diameter (formation)				✓		D
►Tactical diameter (harbour)					✓	D
►Tactical diameter (MIW general)					✓	D
►Tactical diameter (MIW hunting)				✓		D
►Tactical diameter (MIW sweeping)				✓		D
Initial turning		✓	✓			M
Yaw checking		✓	✓			M
Accelerating turning from rest				✓		D
Turning at rest				✓		D
Stopping		✓	✓			D
Acceleration time					✓	D
Astern course keeping					✓	D
Station keeping					✓	D
Lateral transfer					✓	D

4.4 SAFETY PERFORMANCE REQUIREMENTS

1. This section has safety performance requirements that are generally applicable to all naval ships so that safety goals can be met. Safety goals may also be met by other criteria that are more applicable to the operational profile of the vessel. For example, harbour manoeuvring performance, whilst applicable to safety performance, may not be applicable for ships without a self-berthing requirement.

4.4.1 Relevant Statutory Requirements

1. For ships with an operating profile that matches a merchant ship (fixed routes, weather routing, benign threat, etc.) navies may opt to conform to the requirements of IMO MSC.137(76) (2002) given in Table 11, or specific national standards.

2. IMO MSC.137(76) (2002) sets a minimum manoeuvring performance requirement for all commercial ships with L_{pp} ≥ 100 m and all chemical or gas carriers. The purpose of the requirements is to reduce the probability of occurrence of marine casualties and pollution.

Table 11: IMO MSC.137(76) (2002) Manoeuvring Requirements

Requirement	Test manoeuvre	Associated criteria
Turning ability	Turning circle manoeuvre	Advance ≤ 4.5 ship lengths
	Turning circle manoeuvre	Tactical diameter ≤ 5.2 ship lengths
Initial turning ability	10° - 10° zig-zag manoeuvre	With the application of 10° rudder angle, the ship should not have travelled more than 2.5 ship lengths by the time that the heading has changed more than 10° from the original heading.
Yaw-checking and course-keeping ability	10° - 10° zig-zag Manoeuvre	Value of the first overshoot should not exceed:
		10° if L_{pp} /V < 10 s
		20° if L_{pp} /V ≥ 30 s
		(5+0.5(L_{pp} /V)) degrees if 10 s ≤ L_{pp} /V < 30 s
		where V = IMO test speed
	10° - 10° zig-zag manoeuvre	Value of the second overshoot should not exceed:
		25° if L_{pp} /V < 10 s
		40° if L_{pp} /V ≥ 30 s
		(17.5 + 0.75(L_{pp} /V)) degrees, if 10 s ≤ L_{pp} /V < 30 s
		where V = IMO test speed
	20° - 20° Zig-Zag Manoeuvre	The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°
Stopping ability	Full astern stopping test	Track reach in the full astern stopping test should not exceed 15 ship lengths at the IMO test speed. This value may be modified by the regulatory authority in instances where a large ship displacement makes this impractical.

3. IMO resolution MSC.137(76) (2002) states that there are two routes for compliance with the regulations and 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:

a. 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

b. 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.

4.4.2 General Controllability Requirement

1. The ship shall be controllable to the extent required to perform manoeuvres essential to its safe operation.

2. When satisfying the general controllability requirement, the means of steering should enable the ship heading and direction of travel to be controlled without undue physical effort whilst operating within the ship operational envelope. Further, the manoeuvring performance should not be harmful to the crew and equipment.

4.4.3 Controllability While Subject to Environmental Forces Requirement

1. The ship should be provided with a means of directional control of adequate strength and design to ensure there is manoeuvring capability sufficient to overcome environmentally induced forces.

2. Consideration should include design features required to minimize damage and/or loss of stability including broaching, the ship being held beam on to seas or wind, wave damage to vulnerable areas in extreme seas, and other conditions. This includes aspects to both maintain the heading and change the heading as required. This will require a balance between the yaw characteristics of the ship and available yaw moment from control devices and propulsors to counter the environment.

4.4.4 Operator Guidance Requirement

1. The ship should be provided with an appropriate level of operator guidance to ensure safe operation of the ship and to assist with collision avoidance. A Pilot Card and Wheelhouse Poster as recommended by IMO Resolution A.601(15) (1987) should be considered as an integral part of what naval ships are to be provided with. See ANEP-70 Vol.II for a sample NATO Wheelhouse Poster and Pilot Card.

2. Instructions should be provided to persons onboard detailing manoeuvring performance including common manoeuvres, ship limitations and required actions following

prescribed failures. The manoeuvring capability of the ship under normal operating conditions and under equipment failure modes should be documented. This should include calm water manoeuvring performance, controllability in a seaway, operating limitations and procedures, actions in the event of prescribed failure, and limitations for safe operation subsequent to prescribed failures. When possible, all operator guidance should be validated by appropriate sea trials.

4.4.5 Towing Capability Requirement

1. The ship should have adequate ship-to-ship towing capability.

2. Ship-to-ship towing provides a means of moving ships to safety after becoming casualties as a result of enemy action or occurrences such as collision, grounding, fire or equipment failure. As a general rule warships and auxiliaries are provided with suitable towing points and a towing hawser so they are capable of towing a ship of similar size to themselves. To ensure a unified NATO ship-to-ship towing capability, it is recommended that naval ships have provision for standard towing equipment and that they conform to the towing pull requirement stipulated in ATP-43.

4.4.6 Directional Stability Requirement

1. The directional stability of the ship should be assessed to the extent required to ensure adequate heading control without excessive steering activity.

2. Excessive steering activity is defined as:

   a. continuous peak to peak operation of the steering gear;

   b. saturation such that the steering command over drives the steering gear response.

3. Controls-fixed directional stability should be assessed during the early design phase of new ships. Excessive directional stability is not necessarily considered as an advantage, as it makes the ship difficult to manoeuvre. The degree of directional stability may be a trade-off with powering and turning performance based on mission requirements.

4. Slightly unstable ships can be stabilized by the steering system; however, this may lead to excessive steering activity when emergency manual steering is required.

5. The pull-out test is a simple and time effective test that examines whether a ship is stable or not. The test is normally performed in connection with a turning circle test. The test is described in detail in IMO MSC/Circ.1053 (2002).

6. Alternatively, the spiral test is a more sophisticated directional stability test, but is more time consuming and weather sensitive than a pull-out test (IMO MSC/Circ.1053, 2002).

4.4.7 Non-tactical Transit Requirements

1. All naval ships should satisfy non-tactical transit safety goals. Recommended criteria are provided in Table 12.

Table 12: Non-tactical Transit Criteria

Mission speed range: Cruising speed – Maximum design speed Required verification speed: Maximum design speed, unless otherwise noted Required verification sea state: Calm, except where otherwise noted	
Ability	**Required performance**
Course keeping (deg)	≤1.3 deg RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	$\begin{cases} \leq 4.00 & \text{for } F_n \leq 0.2 \\ \leq 14.85\, F_n^{\,2} - 3.43\, F_n + 4.09 & \text{for } F_n > 0.2 \end{cases}$
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 3.90 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 2.00 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$
Stopping s_F/L_{pp}	$\begin{cases} \leq 5 & \text{for } K_E \leq 10^6 \\ \leq 3 + 2 \cdot 10^{-6} K_E & \text{for } 10^6 < K_E \leq 6 \cdot 10^6 \\ \leq 15 & \text{for } K_E > 6 \cdot 10^6 \end{cases}$ where K_E is kinetic energy calculated as $0.5 \cdot \Delta \cdot V^2$(tonne · knots^2)

4.4.8 Harbour Manoeuvring

1. All naval ships should satisfy harbour manoeuvring safety goals. Harbour manoeuvring performance, whilst applicable to safety performance, may not be applicable for ships without a self-berthing requirement. Table 13 gives recommended performance criteria for ships with an unassisted harbour manoeuvring requirement.

2. The turning at rest criterion was developed using data from ships with thrusters.

3. No criterion is defined for lateral transfer ability. As a possible reference, some national naval requirements stipulate the lateral transfer ability on the order of 1.5 knots for lateral transfer in calm conditions. This is estimated to be sufficient for self-berth in 30 knots wind condition + 1 knots current.

Table 13: Harbour Manoeuvring Criteria

Mission speed range: 0-10 knots Required verification speed: 4 knots, unless otherwise noted Required verification sea state: Calm, except where otherwise noted	
Ability	**Required performance**
Course keeping (deg)	≤ 1.0 deg RMS error in all mission sea states
Track keeping (m)	≤ 2.5 m RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	≤ 2.0 (optimum means permitted, including thrusters)
Initial turning $t_a/(L_{pp}/V_0)$	≤ 2.0
Yaw checking $t_{C1}/(L_{pp}/V_0)$	≤ 1.4
Turning at rest t_{90} (s)	≤ 180 s (recommended but not mandated)
Stopping s_F/L_{pp}	≤ 1.0
Astern course keeping (deg)	≤ 1.5 deg RMS error in all mission sea states
Lateral transfer (knots)	(recommended but not mandated)

4.5 MISSION PERFORMANCE REQUIREMENTS

1. This section has performance requirements relating to mission effectiveness.

4.5.1 General Mission Controllability Requirement

1. The ship shall be assessed to ensure there are suitable propulsion and control systems to ensure that heading and/or speed can be maintained as appropriate to its missions within the operational envelope.

4.5.2 Mission Heading Controllability Requirement

1. The ship shall be assessed to ensure there is a manoeuvring capability sufficient to overcome environmentally induced forces in order to maintain and change heading as appropriate to its missions.

2. Consideration is to be given to the provision of heading control when manoeuvring in harbour or high wind, including coming alongside unaided. Consideration should also be given to the ability to change heading if required by ship missions. This may include turning to expose the optimum above water signatures to an incoming missile, bringing guns to bear, and torpedo or mine avoidance.

4.5.3 Mission Position Controllability Requirement

1. The ship shall be able to manoeuvre to control its position as appropriate for its missions, within the ships operational environment.

2. Consideration is to be given to the provision of position control when manoeuvring in harbour or high wind, including coming alongside unaided. Consideration should also be given to the ability to adjust position in any direction if required by ship missions. This may include a station keeping requirement for mine hunting, submarine rescue, torpedo or other recovery operations, and some amphibious operations. The measures of performance for this requirement may vary for low and high-speed operations, and may apply in different environments.

4.5.4 Tactical Transit in Formation Requirements

1. Recommended criteria associated with tactical transit in formation are provided in Table 14.

Table 14: Tactical Transit in Formation Criteria

Mission speed range: 12-18 knots Required verification speed: 12 knots Required verification sea state: Calm, except where otherwise noted	
Ability	**Required performance**
Course keeping (deg)	≤ 1.3 deg RMS error in all mission sea states
Track keeping (m)	≤ 4.0 m RMS error in all mission sea states
Tactical diameter y_{0180} (m)	$\begin{cases} \leq 550\text{ m} & \text{for } L_{pp} < 137\text{ m} \\ \leq 730\text{ m} & \text{for } L_{pp} \geq 137\text{ m} \end{cases}$ Note: non-tactical transit criteria may be more stringent

4.5.5 Anti Submarine Warfare Requirements

1. Table 15 gives recommended performance criteria for Anti Submarine Warfare.

Table 15: Anti Submarine Warfare (ASW) Criteria

Mission speed range: Up to maximum design speed Verification speed: Maximum design speed, unless otherwise noted Required verification sea state: Calm, except where otherwise noted		
Ability	**Required performance**	**Target performance**
Slow course keeping (deg)	≤ 1.6 deg RMS error at 4 knots in all mission sea states	≤ 1.6 deg RMS error at 4 knots in all mission sea states
Course keeping (deg)	≤ 0.8 deg RMS error in all mission sea states	≤ 0.8 deg RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	$\begin{cases} \leq 3.5 & \text{for } F_n \leq 0.2 \\ \leq 13F_n^2 - 3F_n + 3.6 & \text{for } F_n > 0.2 \end{cases}$	$\begin{cases} \leq 3.0 & \text{for } F_n \leq 0.2 \\ \leq 11.14F_n^2 - 2.57F_n + 3.09 & \text{for } F_n > 0.2 \end{cases}$
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 2.92 - \frac{0.14}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 1.55 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$	$\begin{cases} \leq 2.64 - \frac{0.13}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 1.35 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$	$\begin{cases} \leq 1.8 - \frac{0.044}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.0 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$
Acceleration time (s)	To be determined by staff requirement	To be determined by staff requirement

4.5.6 Mine Warfare Requirements

1. Table 16 gives recommended performance criteria for Mine Warfare. Bryan and Davies (2008) give useful background information for standard deviation navigational error (SDNE), which is the RMS error based on lateral distance from a prescribed track, with the prescribed track often being described by waypoints.

Table 16: Mine Warfare (MIW) General Criteria

Mission speed: 0-12 knots Required verification speed: In accordance with specific MIW mission Required verification sea state: Calm, except where otherwise noted		
Ability	**Required performance**	**Target performance**
Standard deviation of navigational error (SDNE) (m)	< 50 m in all mission sea states	< 10 m in all mission sea states
Tactical diameter (m)	≤ 200 m	≤ 200 m
Stopping (m)	≤ 100 m	≤ 100 m
Station keeping (m)	< 10 m at zero speed in all mission sea states	< 5 m at zero speed in all mission sea states

2. For ships engaging in mine hunting, Table 17 provides additional required and target performance criteria.

Table 17: Mine Warfare (MIW) Hunting Criteria

Mission speed: 0-6 knots
Verification speed: 4 knots, unless otherwise noted
Required verification sea state: Calm, except where otherwise noted

Ability	Required performance	Target performance
Course keeping (deg)	≤ 0.8 deg RMS error in all mission sea states	≤ 0.8 deg RMS error in all mission sea states
Track keeping (m)	≤ 2.5 m RMS error in all mission sea states	≤ 1.3 m RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	≤ 2.0 (thrusters can be used)	≤ 2.0 (thrusters can be used)
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 3.9 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 2.0 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{s} \end{cases}$	$\begin{cases} \leq 3.42 - \frac{0.17}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 1.75 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$	$\begin{cases} \leq 1.8 - \frac{0.044}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.00 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$
Stopping s_F/L_{pp}	≤ 2.5	≤ 1.5
Astern course keeping (deg)	≤ 1.2 deg RMS error in all mission sea states	≤ 1.2 deg RMS error in all mission sea states
Station keeping (m)	≤ 2.5 m RMS at zero speed in all mission sea states	≤ 1.3 m RMS at zero speed in all mission sea states

3. Table 18 provides recommended performance criteria for mine sweeping. Due to variations among sweeping equipment from different nations, only target performance values are given.

Table 18: Mine Warfare (MIW) Sweeping Criteria

Mission speed: 3-10 knots Required verification speed: 8 knots Required verification sea state: Calm, except where otherwise noted	
Ability	**Target performance**
Course keeping (deg)	≤ 1.3 deg RMS error in all mission sea states
Track keeping (m)	≤ 4.0 m RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	≤ 6.0
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq\ 3.9 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10s \\ \leq\ 2.0 & \text{for } \frac{L_{pp}}{V_0} \geq 10s \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq\ 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19s \\ \leq\ 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19s \end{cases}$
Stopping s_F/L_{pp}	≤ 2.0

4. Table 19 provides recommended performance criteria for mine avoidance.

Table 19: Mine Warfare (MIW) Mine Avoidance Criteria

Mission speed: 0-12 knots
Verification speed: 8 knots, unless otherwise noted
Required verification sea state: Calm, except where otherwise noted

Ability	Required performance	Target performance
Slow speed course keeping (deg)	≤ 1.5 deg RMS error at 4 knots in all mission sea states	≤ 1.5 deg RMS error at 4 knots in all mission sea states
Course keeping (deg)	≤ 0.8 deg RMS error in all mission sea states	≤ 0.8 deg RMS error in all mission sea states
Track keeping (m)	≤ 4.0 m RMS error in all mission sea states	≤ 1.8 m RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	$\begin{cases} \leq 3.5 & \text{for } F_n \leq 0.2 \\ \leq 13F_n{}^2 - 3F_n + 3.6 & \text{for } F_n > 0.2 \end{cases}$	$\begin{cases} \leq 3.0 & \text{for } F_n \leq .2 \\ \leq 11.1F_n{}^2 - 2.57F_n + 3.09 & \text{for } F_n > .2 \end{cases}$
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 3.9 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10 \text{ s} \\ \leq 2.0 & \text{for } \frac{L_{pp}}{V_0} \geq 10 \text{ s} \end{cases}$	$\begin{cases} \leq 3.42 - \frac{0.17}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10 \text{ s} \\ \leq 1.75 & \text{for } \frac{L_{pp}}{V_0} \geq 10 \text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19 \text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19 \text{ s} \end{cases}$	$\begin{cases} \leq 1.8 - \frac{0.044}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19 \text{ s} \\ \leq 1.0 & \text{for } \frac{L_{pp}}{V_0} \geq 19 \text{ s} \end{cases}$
Accelerating turning from rest t_{90} (s)	≤ 60 s	≤ 30 s
Stopping s_F/L_{pp}	≤ 2.0	≤ 1.5
Astern course keeping (deg)	≤ 2.0 deg RMS error in all mission sea states	≤ 2.0 deg RMS error in all mission sea states
Station keeping (m)	≤ 3.0 m RMS error at zero speed in all mission sea states	≤ 1.5 m RMS error at zero speed in all mission sea states

4.5.7 Anti Air Warfare Performance Requirements

1. Table 20 provides recommended performance criteria for Anti Air Warfare.

Table 20: Anti Air Warfare (AAW) Performance Criteria

<table>
<tr><td colspan="3">Mission speed: Slow speed to maximum design speed
Verification speed: Maximum design speed
Required verification sea state: Calm, except where otherwise noted</td></tr>
<tr><th>Ability</th><th>Required performance</th><th>Target performance</th></tr>
<tr><td>Course keeping (deg)</td><td>≤ 1.3 deg RMS error in all mission sea states</td><td>≤ 1.3 deg RMS error in all mission sea states</td></tr>
<tr><td>Tactical diameter y_{0180}/L_{pp}</td><td>$\begin{cases} \leq 3.5 & \text{for } F_n \leq 0.2 \\ \leq 13F_n^2 - 3F_n + 3.6 & \text{for } F_n > 0.2 \end{cases}$</td><td>$\begin{cases} \leq 3.0 & \text{for } F_n \leq .2 \\ \leq 11.1F_n^2 - 2.57F_n + 3.09 & \text{for } F_n > .2 \end{cases}$</td></tr>
<tr><td>Initial turning $t_a/(L_{pp}/V_0)$</td><td>$\begin{cases} \leq 3.9 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 2.0 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$</td><td>$\begin{cases} \leq 3.42 - \frac{0.17}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 1.75 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$</td></tr>
<tr><td>Yaw checking $t_{C1}/(L_{pp}/V_0)$</td><td>$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$</td><td>$\begin{cases} \leq 1.8 - \frac{0.044}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.00 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$</td></tr>
<tr><td>Accelerating turning from rest t_{90} (s)</td><td>≤ 180 s</td><td>≤ 150 s</td></tr>
<tr><td>Acceleration time (s)</td><td>To be determined by staff requirement</td><td>To be determined by staff requirement</td></tr>
</table>

4.5.8 Anti Surface Warfare Performance Requirements

1. Table 21 provides recommended criteria for Anti Surface Warfare. These are the same as the non-tactical transit criteria.

Table 21: Anti Surface Warfare (ASuW) Performance Criteria

Mission speed range: Cruising speed – Maximum design speed Required verification speed: Maximum design speed, unless otherwise noted Required verification sea state: Calm, except where otherwise noted	
Ability	**Required performance**
Course keeping (deg)	≤ 1.3 deg RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	$\begin{cases} \leq 4.00 & \text{for } F_n \leq 0.2 \\ \leq 14.85{F_n}^2 - 3.43F_n + 4.09 & \text{for } F_n > 0.2 \end{cases}$
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 3.90 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } < 10\text{ s} \\ \leq 2.00 & \text{for } \geq 10\text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } < 19\text{ s} \\ \leq 1.40 & \text{for } \geq 19\text{ s} \end{cases}$
Stopping s_F/L_{pp}	$\begin{cases} \leq 5 & \text{for } K_E \leq 10^6 \\ \leq 3 + 2 \cdot 10^{-6}K_E & \text{for } 10^6 < K_E \leq 6 \cdot 10^6 \\ \leq 15 & \text{for } K_E > 6 \cdot 10^6 \end{cases}$ where K_E is kinetic energy calculated as $0.5 \cdot \Delta \cdot V^2$(tonne · knots²)

4.5.9 Replenishment at Sea (RAS) Vehicle Interaction Performance Requirements

1. Table 22 provides recommended performance criteria for replenishment at sea (RAS) vehicle interaction.

Table 22: Replenishment at Sea (RAS) Vehicle Interaction Performance Criteria

Mission speed: 8 - 16 knots Verification speed: 12 knots, or Maximum design speed if slower than 12 knots Required verification sea state: Calm, except where otherwise noted		
Ability	**Required performance**	**Target performance**
Course keeping (deg)	≤ 1.0 deg RMS course error in calm water ≤ 3.0 deg RMS course error in all mission sea states	≤ 0.5 deg RMS course error in calm water ≤ 1.0 deg RMS course error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	$\begin{cases} \leq 3.5 & \text{for } F_n \leq 0.2 \\ \leq 13{F_n}^2 - 3F_n + 3.6 & \text{for } F_n > 0.2 \end{cases}$	$\begin{cases} \leq 3.0 & \text{for } F_n \leq .2 \\ \leq 11.1{F_n}^2 - 2.57F_n + 3.09 & \text{for } F_n > .2 \end{cases}$
Initial turning $t_a/(L_{pp}/V_0)$	$\begin{cases} \leq 3.9 - \frac{0.19}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 2.0 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$	$\begin{cases} \leq 3.42 - \frac{0.17}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 10\text{ s} \\ \leq 1.75 & \text{for } \frac{L_{pp}}{V_0} \geq 10\text{ s} \end{cases}$
Yaw checking $t_{C1}/(L_{pp}/V_0)$	$\begin{cases} \leq 2.52 - \frac{0.06}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.40 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$	$\begin{cases} \leq 1.8 - \frac{0.044}{s}\left(\frac{L_{pp}}{V_0}\right) & \text{for } \frac{L_{pp}}{V_0} < 19\text{ s} \\ \leq 1.00 & \text{for } \frac{L_{pp}}{V_0} \geq 19\text{ s} \end{cases}$
Acceleration time (s)	To be determined by staff requirement	To be determined by staff requirement

4.5.10 General Sea Vehicle Interaction Performance Requirements

1. Table 23 provides recommended performance criteria for general sea vehicle interaction (other than RAS or stern dock).

Table 23: General Sea Vehicle Interaction Performance Criteria (Excluding RAS and Stern Dock)

Mission speed: 0 – 15 knots Verification speed: 4 knots Required verification sea state: in all mission sea states		
Ability	**Required performance**	**Target performance**
Course keeping (deg)	≤ 1.3 deg RMS	≤ 0.8 deg RMS

4.5.11 Sea Vehicle Interaction at Stern Dock Performance Requirements

1. Table 24 provides recommended performance criteria for sea vehicle interaction at a stern dock.

Table 24: Sea Vehicle Interaction at Stern Dock Performance Criteria

Mission speed: 0 - 4 knots Verification speed: 2 knots unless otherwise noted Required verification sea state: in all mission sea states		
Ability	**Required performance**	**Target performance**
Course keeping (deg)	≤ 1.3 deg RMS	≤ 0.8 deg RMS
Station keeping (m)	≤ 8.0 m RMS	≤ 5.0 m RMS

4.5.12 Air Vehicle Interaction Performance Requirements

1. Table 25 gives recommended performance criteria for air vehicle interaction. These criteria are intended for ships other than aircraft carriers.

Table 25: Air Vehicle Interaction Performance Criteria

Mission speed: 8 knots to Maximum design speed Verification speed: Maximum design speed Required verification sea state: Calm, except where otherwise noted		
Ability	**Required performance**	**Target performance**
Course keeping (deg)	≤ 0.5 deg RMS error in all mission sea states	≤ 0.25 deg RMS error in all mission sea states
Acceleration time (s)	To be determined by staff requirement	To be determined by staff requirement

4.6 DOCUMENTATION OF MANOEUVRING PERFORMANCE

1. Ship manoeuvring performance shall be verified and documented. ITTC (2017) provides useful guidelines for manoeuvring trials.

2. A NATO/IP pilot card (ANEP-70 Vol. II) is strongly recommended.

3. A NATO/IP wheelhouse poster (ANEP-70 Vol. II) or similar poster is recommended.

4. A manoeuvring handbook (ANEP-70 Vol. II) is recommended.

CHAPTER 5 MANOEUVRING PERFORMANCE ASSESSMENT

5.1 OVERVIEW

1. This Chapter discusses theoretical methods, model tests, and full scale trials, to determine ship manoeuvring performance. The requirements for a new ship design identify the manoeuvring performance to be achieved. For each ship project, it has to be decided which part of the proof of performance is to be made by numerical methods, by model tests, or by full scale trials.

2. Proof of manoeuvring performance must follow a priority structure linked to the specific mission and mission speed criteria listed in detail in Chapter 4 of this document. Early stage design simulations and model experiments should include assessments that directly address 'required' conditions of the manoeuvring criteria.

3. The determination of manoeuvring performance process shall include verification and validation at critical project phases. Model verification is an assessment process used to ensure that a theoretical model or physical model correctly represents the ship design. These representations include hull form geometry, ship mass properties, and hull and appendage configuration. For example, hull form geometry of a physical model could be verified, relative to the ship design, through comparison of the physical model with templates or through laser measurement of the physical model. Validation is an assessment process used to ensure that physical behaviour is correctly represented in the evaluation of ship performance. For example, manoeuvring performance results from either numerical computations or physical model experiments can be validated through comparison of numerical or experiment results with full scale measurements. It is also acceptable to initially validate numerical results through comparisons with physical model experiments where the validation is qualified within the limits of the model experiment (e.g., scale effects).

4. The full scale manoeuvring trial provides final validation of manoeuvring performance. ITTC (2017a) provides recommended procedures for full scale manoeuvring trials.

5. The manoeuvring assessment process through full scale trials focusses on the first of class ship. Follow-on ships, without significant changes to hull form, appendages, loading condition or control systems, may not require rigorous performance assessment. A sister ship or ships with minor changes may be effectively evaluated during the design phase using a valid simulation tool and through acceptance trials for the as-built ship.

6. The manoeuvring performance of the ship should be assessed based on the manoeuvring parameters listed in Table 26. Mandatory measures are those which have to be assessed to verify compliance with manoeuvrability requirements in Chapter 4. Conditional measures are additional data which may be required for additional documentation.

7. Manoeuvres in waves cannot be strictly verified during full scale trials due to uncontrollability of environmental conditions.

Table 26: Manoeuvring Performance Recommended Measurements

Performance test	Manoeuvring ability	Mandatory measures	Conditional measures
Zig-zag	Initial turning Yaw checking	Initial turning time Yaw checking time	Overshoot angle Path width Period
Turning circle	Tactical diameter	Tactical diameter	Time to turn 90 deg Advance Transfer Loss of speed Path Heel angle Drift angle
Accelerating turning from rest	Accelerating turning from rest	Time to turn 90 deg	
Turning at rest	Turning at rest	Time to turn 90 deg	
Course keeping	Course keeping Astern course keeping	Heading deviation	Transverse path Yaw rate Steering angle
Track keeping	Track keeping	Transverse path Standard deviation of navigation error	
Station keeping	Station keeping	Radial distance and/or heading deviation	
Stopping	Stopping	Track reach	Path Time history
Acceleration/ deceleration	Acceleration	Acceleration/ deceleration time history	Path Time history
Spiral test, Pull-out test	Course keeping		Residual turning rate in pull-out Spiral hysteresis loop

5.2 MANOEUVRING ASSESSMENT PROCESS THROUGH DESIGN PHASES

1. The process to be used in assessing manoeuvring performance includes both analytical prediction and direct measurement. The process to be used in assessing manoeuvring performance is based upon maturity of the ship design. The design process applied to naval ship procurement consists of a step by step process from the original aim to provide a desired capability to meet the operational requirements. Figure 4 shows a typical ship design process.

2. The terminology and distribution for work undertaken in-house or by contractors varies among nations, and indeed among projects.

3. The level of effort, and effectively cost, of the assessment process employed can increase as the ship design matures. Table 27 shows the link between design stage and manoeuvring assessment process. Effort and cost of more detailed assessments can be controlled by applying knowledge gained from earlier assessments to focus the scope of test runs and model configurations.

4. The degree of analysis required to predict manoeuvring performance can be expressed in more detail by design timeline and performance parameters. Table 27 lists manoeuvring performance parameters that are relevant for the various design phases.

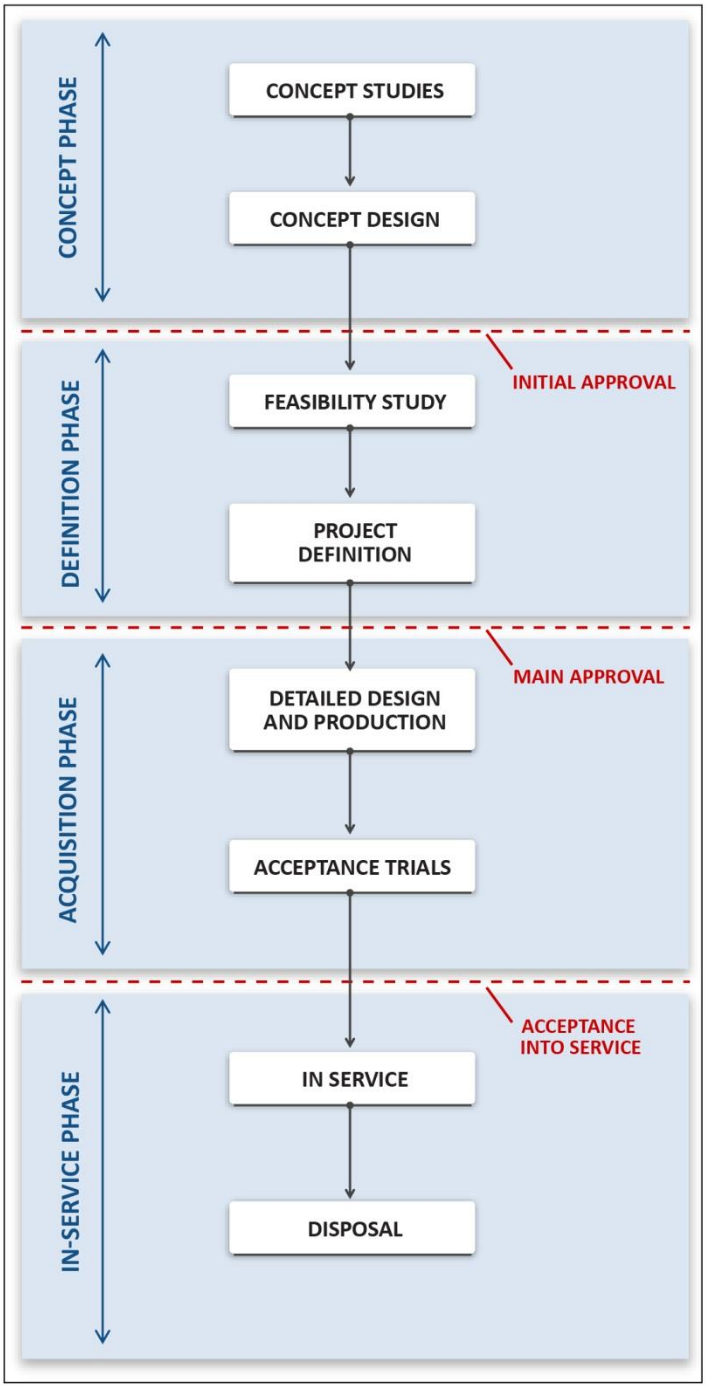

Figure 4: Typical Ship Design Process

Table 27: Manoeuvring Performance Assessment by Design Phase

Performance test	Concept design	Feasibility studies	Detailed design	Acceptance trials
Zig-zag	C	S	S, M	T
Turning	C	S	S, M	T, T2
Accelerating turning from rest			M	T
Turning at rest				T
Course keeping		S	S, M	T_i
Astern course keeping			M	T_i
Track keeping			S, M	T_i
Station keeping			S, M	T_i
Stopping test			S	T, T2
Acceleration/deceleration			S	T
Standard deviation of navigational error (SDNE)			S, M	T_i, $T2_i$
Pull-out or Spiral test		S	S, M	T

C = Calculation
S = Simulation
M = Model experiment
T = Trial (first of class)
T2 = Trial (follow-on-ships)
T_i = Trial for information, but not appropriate for strict verification due to uncontrollability of environmental conditions

5.3 NUMERICAL MODELING AND SIMULATION OF MANOEUVRING PERFORMANCE

1. A wide variety of numerical modelling and simulation methods is available for evaluation of manoeuvring performance. The choice of the methodology that is appropriate to use for a specific problem depends on the nature of the problem being addressed as well as the level of detail of the information available about the specific ship(s) or system(s) involved. This level of detail is directly related to the maturity and stage of the design.

5.3.1 Simple Analytic Predictions

1. Simple analytic predictions are the simplest and most cost effective means of estimating manoeuvring performance for a ship. Simple analytic predictions should be made at the Concept Design phase of the ship design cycle to provide a first order estimate of manoeuvring performance with respect to mission parameters.

Description

2. At the early stages of design where there is typically less well defined ship information with little or no physical model test data, simple models must be used to characterize manoeuvring behaviour. This type of modelling usually involves the use of low order, linearized governing equations, often supplemented by empirical relations that have been previously derived from other ship designs. These types of methods are relatively inexpensive in terms of time and complexity, and they tend to be quick and easy to use. However, the use of these lower order models, often with estimated parameters and empiricism, can lead to a potentially high margin of error. It is the responsibility of the analyst to understand the explicit and implicit assumptions inherent in the methods utilized and how the results of the methodology are impacted by the supporting available ship design data and/or empirical relations used.

Measurements

3. No measurements are performed for simple analytic predictions.

Procedures

4. Bertram (2012) and Lewandowski (2004) are useful references for simple analytic predictions.

Assumptions

5. This type of modelling usually involves the use of low order, linearized governing equations, often supplemented by empirical relations that have been previously derived from other ship designs.

Advantages

6. These types of methods are relatively inexpensive in terms of time and complexity, and they tend to be quick and easy to use.

Limitations

7. The use of these lower order models, often with estimated parameters and empiricism, can lead to a potentially high margin of error.

5.3.2 Detailed Simulations

1. The following approaches are available for detailed simulation of manoeuvring performance:

   a. Force coefficient based methods, with manoeuvring force coefficients provided by captive model tests or high fidelity computational fluid dynamics;

b. Direct simulation of manoeuvring using high fidelity computational fluid dynamics.

2. The present discussion focusses on methods using force coefficients provided by captive model tests. Application of high fidelity computational fluid dynamics for manoeuvring assessment continues to mature (ITTC 2017b).

3. Captive model experiments can be conducted using either a rotating arm in a basin or a planar motion mechanism in a towing tank. Detailed simulations based on physical model experiments can provide more fidelity than simple analytical predictions and should be completed by the end of the Feasibility Study phase of the ship design cycle.

Description

4. As the level of detail of a ship design increases in the later stages of the design process, more detailed, complex, and/or rigorous analysis methods may be used. Typically at this stage, physical model tests are also performed. Captive physical model tests performed using a rotating arm facility or horizontal planar motion mechanism with a linear basin both provide the forces and moments acting on a vessel over a range of operating conditions. Multiple approaches to reducing the measured data can be used, depending on how that data will be used with a particular mathematical model and/or analysis method. A commonly used approach is to reduce the measured data into a coefficient model form that can be used to express the forces and moments on a vessel in terms of the vessel states (position, orientation, velocity, etc.). The resulting hydrodynamic manoeuvring coefficients and/or cross-flow drag coefficients are often used for time domain simulations.

Measurements

5. In a rotating arm experiment, a ship model is attached to the rotating arm carriage by sensors that measure the forces and angles (trim, heel, control surfaces) on the model.

6. A planar motion mechanism is a device that oscillates a ship model in a prescribed manner as the model is towed down a linear basin. As with the rotating arm experiment, the model is attached using sensors that measure the forces and angles (trim, heel, control surfaces) on the model.

Procedures

7. Parametric variations in the model orientation, speed, propulsion settings, and/or steering angles are performed and the forces measured.

Assumptions

8. It is assumed that scale effects are small during model tests.

Advantages

9. Both the rotating arm and planar motion tests are relatively easy to perform, and provide physical model based coefficients to support detailed computation of manoeuvring performance.

Limitations

10. The rotating arm experiment is conducted at a steady state condition and cannot provide pure sway or the acceleration terms needed for definition of the added mass coefficients.

11. The planar motion test involves more complex data reduction procedures, but can provide the pure sway condition and the acceleration terms. Extrapolation must be done to obtain the zero frequency acceleration terms.

12. Model tests are subject to scaling issues and model defects, as well as uncertainties associated with physical model test set-up and execution.

5.4 DIRECT PHYSICAL MODELLING OF MANOEUVRING

1. Manoeuvring performance results can be determined by direct measurement of free running model experiments. Manoeuvring performance parameters given earlier in Table 26 are measured directly with this approach, and can offer a level of fidelity greater than calculations or simulations. Manoeuvring performance should be defined using free running models prior to the end of the Contract Design phase of the ship building cycle. Past work from analytical predictions should be used to develop test matrices to address manoeuvring performance issues and maximize efficiencies associated with the conduct of the physical model experiments.

2. Operational envelopes associated with each mission shall be used to develop the test matrix of speeds and relative wave headings.

Description

3. Free running model experiments can be conducted using either a towing/manoeuvring basin or an outdoor protected body of water. Free-running model experiments can be conducted with a radio controlled autonomous model or a tethered configuration such that the tether apparatus will not impact the manoeuvring performance of the model. A free-running physical manoeuvring model must be configured to represent the hull form, propulsors, and appendages. The physical model shall be ballasted to represent the load condition of interest, with the centre of gravity of the model accurately represented. Model scale shall be selected with respect to the modelling of lifting surfaces such as propellers and rudders. Manoeuvres as listed in Table 26 shall be performed in the experiment using the physical model to define manoeuvring performance in each of the specific manoeuvres.

Measurements

4. For experiments conducted in an indoor manoeuvring basin, the parameters to be measured during each manoeuvre are listed in Table 28.

5. For experiments conducted in a protected body of water, such as a lake or harbour, the parameters to be measured during each manoeuvre include those listed in Table 28, with the addition of measurements listed in Table 29 to quantify the environment.

6. Online continuous recording is recommended for all performance measurements, with manual recording of some of the test environment conditions being acceptable. Sampling for

continuously recorded data should be at least 4 samples per second. ITTC (2008) gives more detail on sampling requirements.

Procedures

7. Procedures for conducting each specific test manoeuvre should follow those procedures specified in ITTC (2008). Model conditions, such as steady yaw rate and model speed, on both the approach and exit of each specific manoeuvre are considered a part of the manoeuvre, and should be recorded as part of the manoeuvre.

Table 28: Measurements for Free Running Model Manoeuvring Experiments

Measurement	Mandatory	Conditional
Heading angle	X	
Steering angle	X	
X-Y position/track at CG or midships	X	
Course angle	X	
Propulsion shaft speed	X	
Ship speed over water	X	
Ship speed over ground		X
Yaw rate	X	
Roll/heel angle	X	
Pitch/trim angle		X
Heave/sinkage		X
Drift angle		X

Table 29: Additional Measurements for Free Running Model Manoeuvring Experiments in a Protected Body of Water

Measurement	Mandatory	Conditional
Ship speed over ground	X	
Wind speed and direction	X	
Current speed and direction*		X
Wave height		X
Water temperature		X
Water density		X

* If applicable

Assumptions

8. The primary assumption is that the physical model and its appendages accurately represent the geometry of the full scale ship design. Model geometry should be verified using techniques such as laser scanning or other methods.

Advantages

9. The advantages of the free running physical model experiment are centred on direct measurement of manoeuvring performance. Manoeuvres that will be conducted on the full scale ship are conducted in an identical manner using a free running model.

Limitations

10. The limitations of the free running physical model experiment are mainly due to scale effects. Model lifting surfaces such as rudders and propellers, along with resistance characteristics of the hull form, are subject to Reynolds number effects. The model propulsion system may also be a limitation in that fluctuations in power may not be representative of the ship power plant. Typically, model experiments are conducted with a ‘constant shaft speed’ approach rather than modelling ‘shaft torque’. Consequently, loading of the power plant and associated changes in speed may not be modelled precisely.

5.5 DIRECT MEASUREMENT USING FULL SCALE TRIALS

1. Manoeuvring performance can be determined by direct measurement of ship manoeuvres derived from the execution of specific manoeuvres using the full scale ship. The manoeuvring performance parameters defined in Table 26 should be assessed through full scale trials as a part of the Acceptance Trials in the ship design cycle. Past work from analytical predictions and model experiments should be used to develop test matrices to address manoeuvring performance issues and maximize efficiencies associated with the conduct of the trial. Operational envelopes associated with each mission shall be used to develop the test matrix of speeds and relative wave headings.

Description

2. Full scale trials can be conducted on a test range, a protected body of water, or open water conditions. The physical condition of the ship must be noted for each trial event. Ship conditions such as displacement, draught, centre of gravity, and hull bottom condition (clean/dirty) must be recorded. Manoeuvres as listed in Table 26 shall be performed in the full scale trial to quantify manoeuvring performance in each of the specific manoeuvres.

Measurements

3. For direct measurement of full scale manoeuvring performance, the parameters to be measured during each manoeuvre are listed in Table 30.

4. Online continuous recording is recommended for all performance measurements, with manual recording of some of the test environment conditions being acceptable. Sampling for continuously recorded data shall be at least 1 sample per second.

Procedures

5. ITTC (2017a) provides guidance for full scale trials. Basic manoeuvres for full scale trials include turning test, zig-zag test, stopping test, and accelerating turning test. Guidance on durations for course keeping tests is provided by ITTC (2017c).

6. Course/track keeping is carried out by keeping a steady speed and course/track while steering appropriately.

7. Station keeping is carried out by using appropriate means of steering devices to maintain position and heading (provided heading is a requirement).

8. Table 31 lists recommended durations for the different performance tests, with ITTC (2017a, 2017c) providing useful background information.

Table 30: Measurements for Full Scale Trials

Measurement	Mandatory	Conditional
Heading angle	X	
Steering angle	X	
X-Y position/track at CG or midships	X	
Course angle	X	
Propulsion shaft speed	X	
Ship speed through water	X	
Yaw rate	X	
Roll/heel angle	X	
Pitch/trim angle	X	
Heave/sway/surge acceleration		X
Ship speed over ground	X	
Wind speed and direction	X	
Current speed and direction*		X
Wave height	X	
Water depth	X	
Water temperature*		X
Water density*		X
Propeller pitch (if CPP), Waterjet bucket position etc.		X
Drift angle		X

* if applicable

Table 31: Recommended Test Duration at Full Scale

Performance test	Test duration
Zig-Zag	At least 5 executions
Turning circle	Two 540° turns, on each of port and starboard
Accelerating turning	Two 180° turns, one each of port and starboard
Turning at rest	Two 180° turns, one each of port and starboard
Course keeping	Require either 100 oscillations or 30 minute duration
Astern course keeping	Require either 20 oscillations or 10 minute duration
Track keeping	Require either 100 oscillations or 30 minute duration
Station keeping	At least 30 minutes
Stopping test	One head wind and one downwind
Acceleration/ deceleration	One head wind and one downwind
Standard deviation of navigational error (SDNE)	Derived from track keeping and navigational accuracy
Pull out or Spiral test	Port and starboard

Assumptions

9. The primary assumption is that the ship load condition is well defined, and the condition of the hull is clean. Correlation of model and full scale manoeuvring performance results will depend upon matching conditions between the physical model and the full scale ship.

Advantages

10. The advantages of the full scale trial are centred on direct measurement of manoeuvring performance. Manoeuvres that will be conducted on the full scale ship are conducted in an identical manner using a free running model, allowing correlation of full scale and model scale manoeuvring performance results.

Limitations

11. The limitations of the full scale trial can be addressed with respect to baselining the performance of the hull and producing trial results for correlation. From this view point limitations can be found in both the condition of the ship and the condition of the trial site. The condition of the ship must be well defined, where the displacement and centre of gravity are known at the time of the trial. Also, the hull bottom, propulsor(s), and steering appendages must be clean. The condition of the trial site must be well understood. Should the parameters of the test environment be too dynamic, or the condition of the hull be fouled, the baseline manoeuvring performance parameters for the ship may be skewed. Differences in ship condition and trial site from those of model experiments and analytical predictions can limit the fidelity of correlation assessments.

5.6 CORRELATION OF MANOEUVRING PERFORMANCE RESULTS

1. Correlation across manoeuvring performance results determined through calculation, simulation, model experiments, and full scale trials should be conducted at the end of the ship design cycle. Figure 4 depicts the time line of manoeuvring performance assessment with respect to the ship design cycle.

5.7 ADDITIONAL GUIDANCE ON MANOEUVRING PERFORMANCE ASSESSMENT

1. In order to ensure reliable and consistent verification data, criteria are set for verification methodologies. An overview of the most important aspects is given here.

2. All manoeuvring abilities should be verified during sea trials in deep water, which is defined such that the mean water depth h_M in the trials area satisfies both conditions below:

a. $h_M \geq 5 \cdot T$

b. $h_M \geq 4 \cdot V^2/g$

where V stands for the maximum speed during the trials and T stands for mean draught.

3. For turning, initial turning, yaw-checking, accelerating turning from rest, lateral transfer and turning at rest, turns should be executed to both starboard and port side in order to reveal asymmetries in the design or model. Averaged measured results based on multiple runs should be used to compare with required performance criteria.

4. Ideally, runs should be repeated for both model tests and sea trials so that uncertainties can be quantified and understood. However, this is not a strict requirement since the environment, which is erratic by nature, has a smaller role for manoeuvring performance.

5. Manoeuvring abilities must be verified in correspondence to mission loading conditions, to be agreed with naval staff (customer).

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APPENDIX A DISCUSSION OF DEVELOPMENT OF MANOEUVRING PERFORMANCE CRITERIA

1. Almost all of the manoeuvrability performance criteria are based on input from naval operators which were collected in a multi-national survey investigation. Comparisons of operator input with existing ship manoeuvring data indicated that desired performance levels in many cases would be too difficult to achieve within available economic and technical constraints.

2. Subsequent development of realistic manoeuvring performance criteria was achieved by reviewing the following:

   a. national performance levels;

   b. performance levels stipulated or derived from various other NATO manuals or standards;

   c. common best practices;

   d. existing manoeuvring data for naval ships.

3. In the present Appendix, a short summary of explanations and justifications of the selected manoeuvrability performance criteria for some abilities is presented. Justification has been made mainly through comparison of criteria with legacy data (data from existing ships). These data were obtained from standard testing results. Consequently, it has been possible to apply the process only for a limited number of manoeuvring abilities, while for other criteria no validation could be performed. For cases with existing manoeuvring data, the data often did not cover whole mission speed ranges, with data at low speeds being most commonly unavailable. The legacy database was very limited or totally absent for missions such as Mine Warfare (MIW) and Harbour Manoeuvring (HM).

4. During the development of the present ANEP, simulations indicated that course keeping and track keeping criteria may be very problematic, and in some cases not feasible, at lower speed ranges. Application of the criteria requested would imply the use of bow/stern thrusters, which may be in contrast with some nations practice for certain types of ships (e.g., frigates and corvettes); thus, care must be taken when developing naval ship requirements for course keeping and track keeping.

A.1 COURSE KEEPING

1. Course keeping requirements were validated using numerical simulations.

A.2 TRACK KEEPING

1. Track keeping requirements were not validated due to lack of available data.

A.3 TACTICAL DIAMETER

1. Initial performance criteria for non-dimensional tactical diameter for several missions were based on the operator survey, and had no dependence on ship speed.

2. Subsequent review of legacy ship manoeuvring data led to the development of criteria that are dependent on ship speed, as shown in Figure 5.

3. Analyses were performed to ensure that horizontal accelerations arising from the tactical diameter criteria would be acceptably small. It was found that the criteria led to horizontal accelerations that were always less than 0.25 g, comparing very favourably with the following limiting criteria from the International Code of Safety for High-Speed Craft (IMO MSC.97(73), 2000):

  a. 1.00 g: hazardous;

  b. 0.45 g: the average person may fall out of seat if not wearing a seatbelt;

  c. 0.25 g: maximum load at which the average person can keep balance when holding on points of attachment;

  d. 0.15 g: the average person will keep balance when holding on points of attachment.

4. The tactical diameter criterion for Mine Warfare Hunting ($y_{0180}/L_{pp} \leq 2$) is based on limited data; thus, further validation is recommended.

5. The tactical diameter criterion for Harbour Manoeuvring ($y_{0180}/L_{pp} \leq 2$) is considered suitable because velocity is very limited and any steering device may be adopted.

6. Tactical diameter criteria for Mine Warfare Sweeping ($y_{0180}/L_{pp} \leq 6$ target) were not validated against any legacy data; thus, care should be taken when developing associated ship requirements.

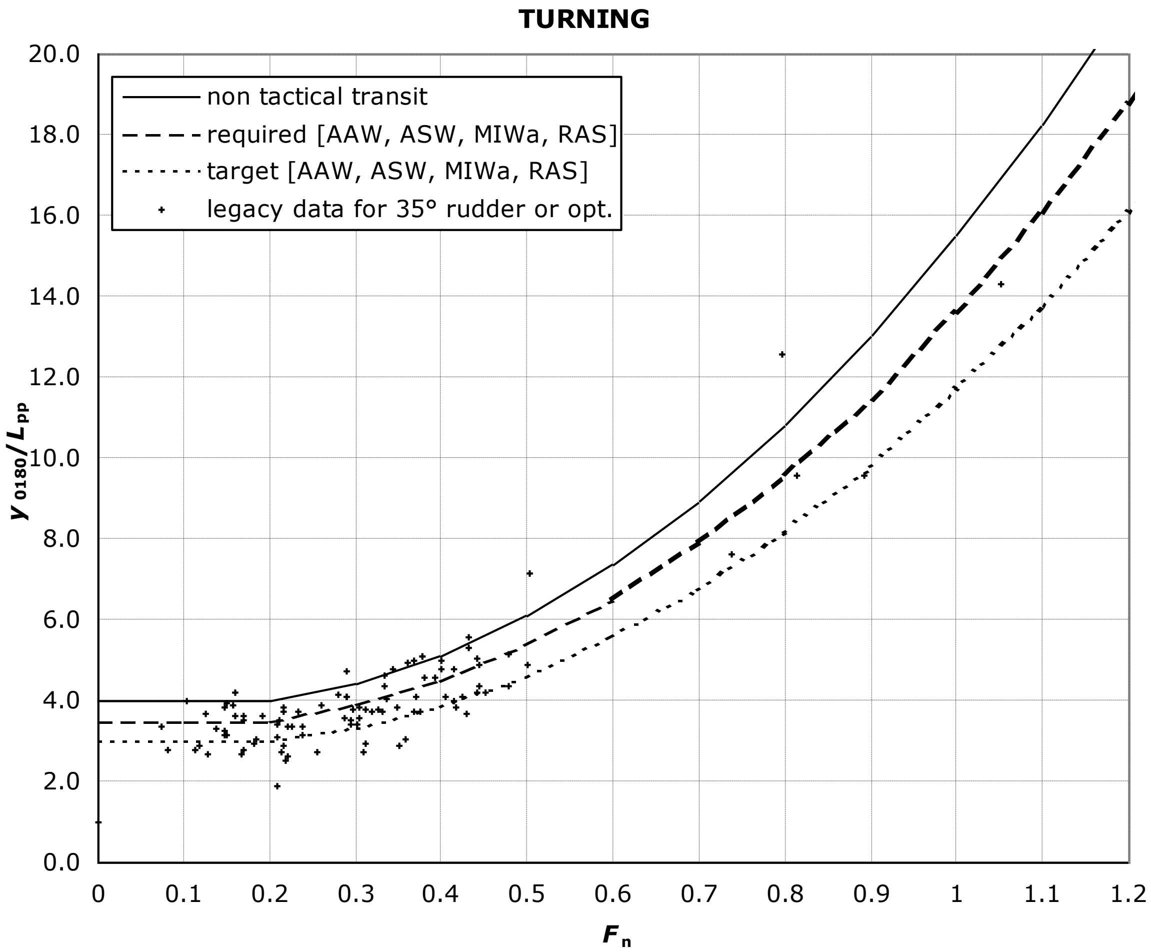

Figure 5: Tactical Diameter Performance Criteria and Legacy Ship Manoeuvring Data

A.4 INITIAL TURNING

1. Figure 6 gives initial turning performance criteria and legacy manoeuvring data for naval ships. The criteria are based on a 20/20 zig-zag. Initial turning requirements suggested by the operator survey were found to be unrealistically stringent.

2. The dependence of initial turning criteria on ship speed is supported by legacy manoeuvring data.

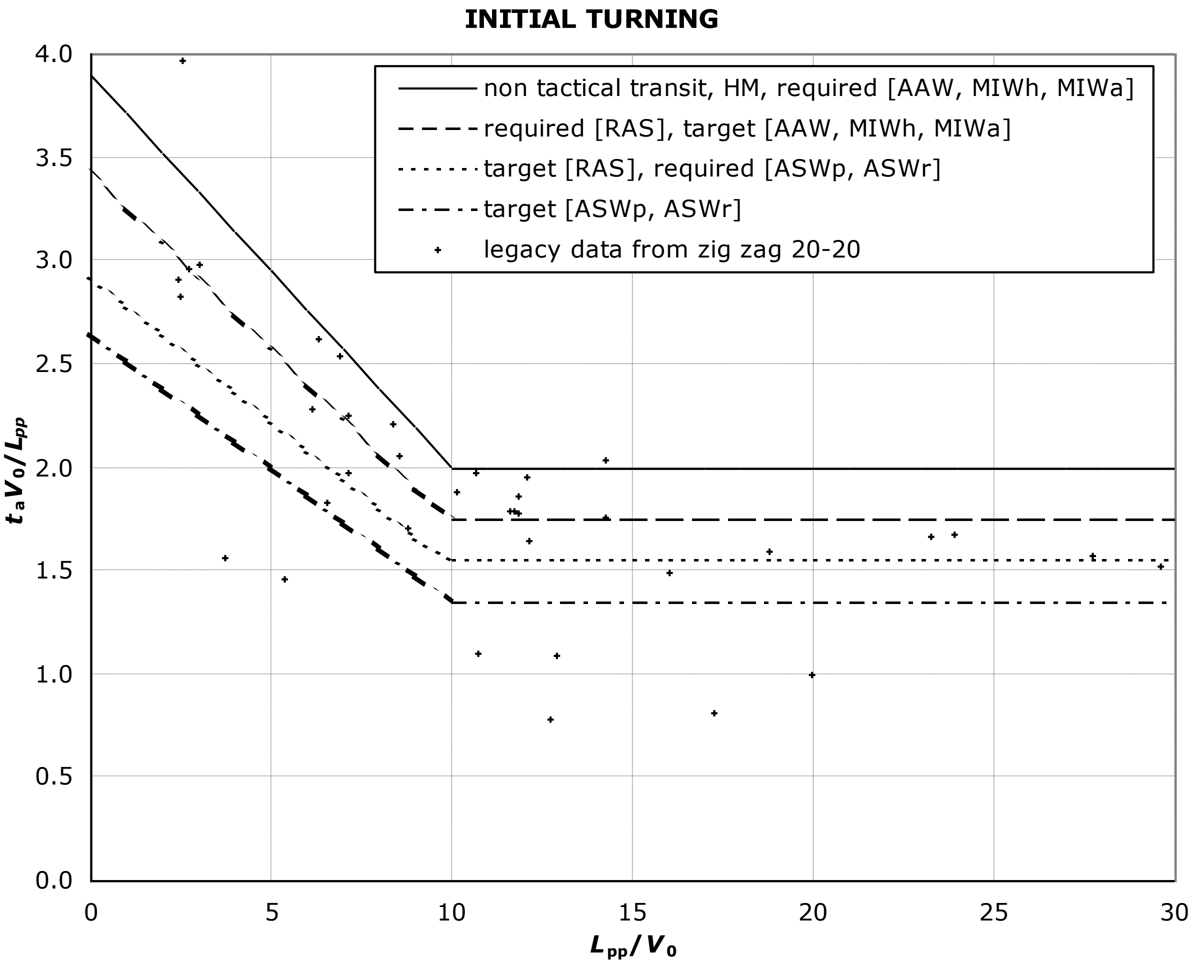

Figure 6: Initial Turning Performance Criteria and Legacy Ship Manoeuvring Data for 20/20 Zig-Zag

A.5 YAW CHECKING

1. Figure 7 gives yaw checking performance criteria and legacy manoeuvring data for naval ships. The criteria are based on a 20/20 zig-zag. Yaw checking turning requirements suggested by the operator survey were found to be unrealistically stringent.

2. The dependence of initial turning criteria on ship speed is supported by legacy manoeuvring data.

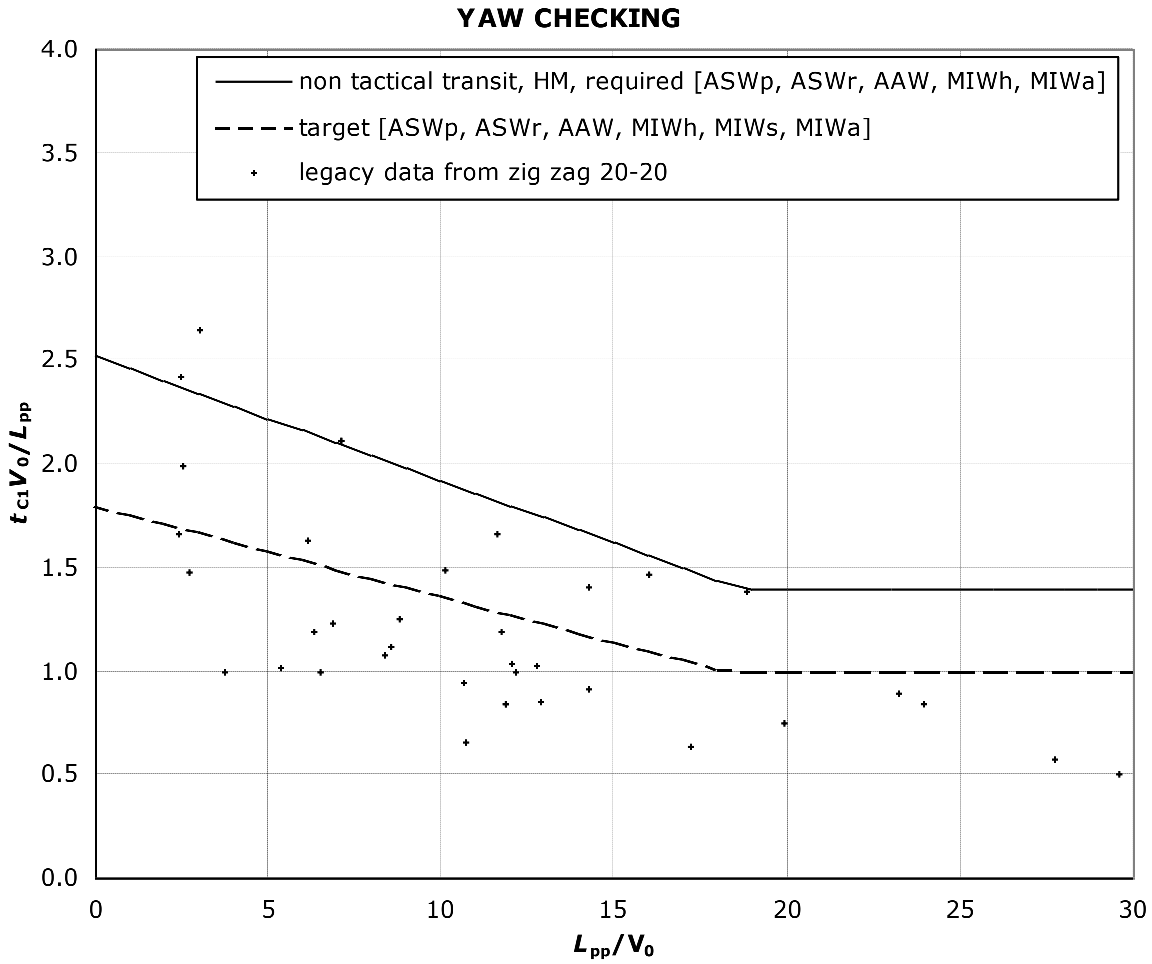

Figure 7: Yaw Checking Performance Criteria and Legacy Ship Manoeuvring Data for 20/20 Zig-Zag

A.6 ACCELERATING TURNING FROM REST

1. The turning from rest criteria for Anti Air Warfare, $t_{90} \leq 180$ s required and $t_{90} \leq 150$ s target, were developed using simulation data for a single frigate; thus, care should be exercised when using these criteria.

2. The turning from rest criteria for Mine Warfare – Avoidance, $t_{90} \leq 60$ s required and $t_{90} \leq 30$ s target, have not been validated with legacy manoeuvring data; thus, care should be exercised when using these criteria.

A.7 TURNING AT REST

1. The turning at rest criterion for Harbour Manoeuvring, $t_{90} \leq 180$ s, was developed using data from only 6 ships manoeuvring with thrusters; thus, care should be exercised when using this criterion.

A.8 STOPPING

1. Figure 8 gives stopping performance criteria for non-tactical transit and legacy data for naval ships.

2. Note that very high displacement ships are not included in the legacy data. Furthermore, most of the legacy data are for crash stop manoeuvres from high speed.

3. Additional stopping criteria for Harbour Manoeuvring and Mine Avoidance were developed based on the operator survey.

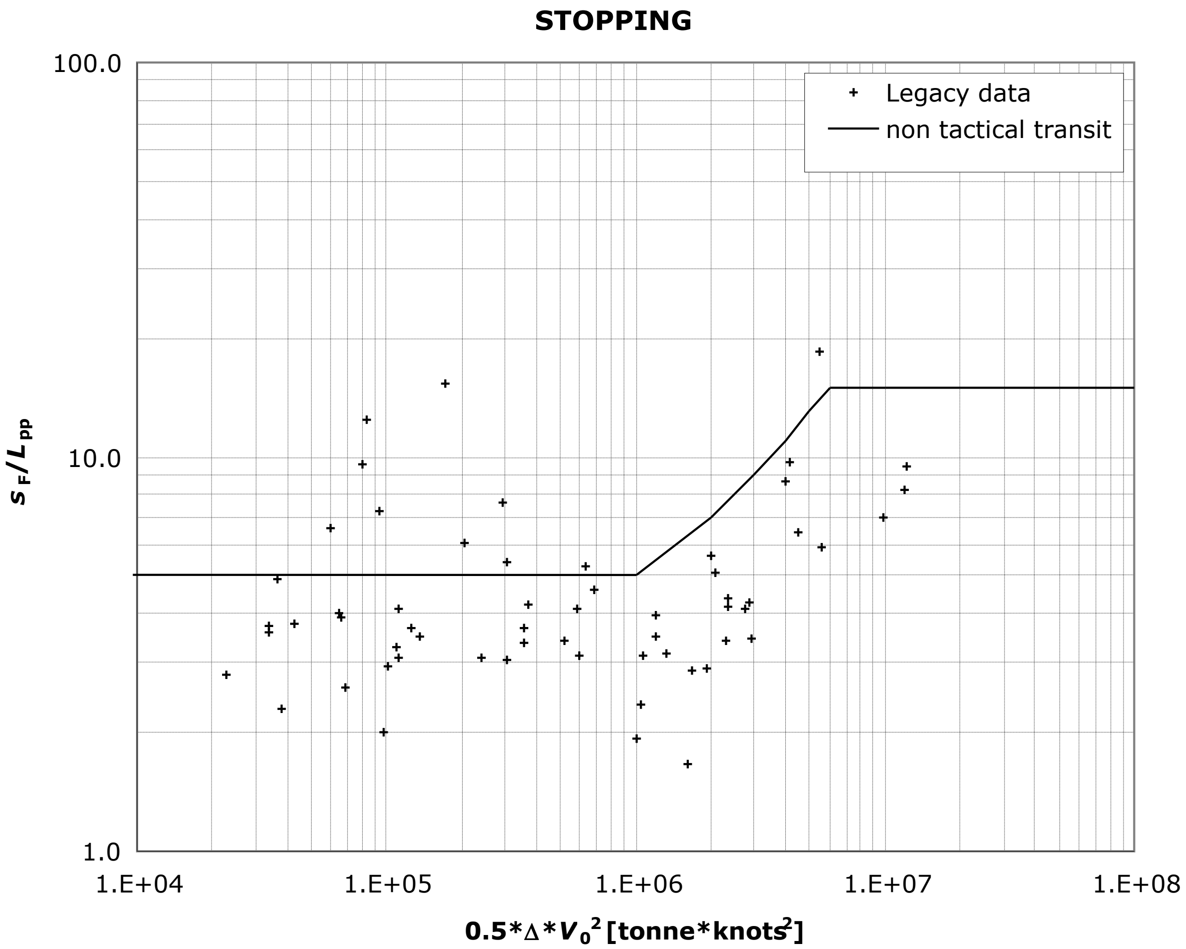

Figure 8: Stopping Performance Criteria and Legacy Ship Manoeuvring Data

A.9 ACCELERATION

1. Acceleration criteria were not determined due to a lack of available data.

A.10 ASTERN COURSE KEEPING

1. Astern course keeping criteria were not validated due to a lack of available data.

A.11 STATION KEEPING

1. Station keeping criteria were not validated due to a lack of available data.

A.12 LATERAL TRANSFER

1. Lateral transfer criteria were not determined due to a lack of available data.

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APPENDIX B SPECIFYING ENVIRONMENTAL CONDITIONS

B.1 OVERVIEW

1. This Appendix provides reference information on wave and wind environmental conditions.

2. STANAG 4194 provides detailed information on wave and wind environmental conditions.

B.2 STANDARDISED WAVE AND WIND CONDITIONS FOR OPEN OCEAN NORTH ATLANTIC

1. Table 32 gives NATO sea states and statistics for the open ocean North Atlantic.

Table 32: NATO Sea States and Annual Statistics for North Atlantic

Sea State Number	Significant Wave Height (m)		Sustained Wind Speed (knots) *		Percentage Probability of Sea State	Peak Wave Period [s]	
	Range	Mean	Range	Mean		Range**	Most Probable***
0 – 1	0 – 0.1	0.05	0 – 1	0.5	0	–	–
2	0.1 – 0.5	0.3	1 – 6	3.5	7.2	3.3 – 12.8	7.5
3	0.5 – 1.25	0.88	7 – 10	8.5	22.4	5.0 – 14.8	7.5
4	1.25 – 2.5	1.88	17 – 21	19	28.7	6.1 – 15.2	8.8
5	2.5 – 4	3.25	22 – 27	24.5	15.5	8.3 – 15.5	9.7
6	4 – 6	5	28 – 47	37.5	18.7	9.8 – 16.2	12.4
7	6 – 9	7.5	48 – 55	51.5	6.1	11.8 – 18.5	15.0
8	9 – 14	11.5	58 – 63	59.5	1.2	14.2 – 18.6	16.4
>8	> 14	> 14	> 63	> 63	< 0.05	15.7 – 23.7	20.0

* Ambient wind sustained at 19.5 m above surface to generate fully developed seas. To convert to another altitude, H_2, apply $V_2 = V_1 (H_2/19.5)^{1/7}$.

** Minimum is 5 percentile and maximum is 95 percentile for period's given wave height range.

*** Based on periods associated with central frequencies included in Hindcast Climatology

2. As indicated in STANAG 4194, Table 32 is valid for open ocean North Atlantic conditions only. Sea state number provides an indication of significant wave height; however, peak wave periods and probabilities of occurrence will vary with geographical location and season. It is recommended that sea conditions be specified by at least two parameters (e.g., significant wave height and peak wave period).

3. Bretschneider wave spectra can be used to model open ocean conditions. Short-crested seas can be modelled using a cosine-squared spreading function.

4. For modelling of wind conditions, McTaggart and De Kat (2000) developed the following based on data for the North Atlantic:

$$V_{WT} = 1.823/s \cdot H_S + 3.45 \text{ m/s}$$

where V_{WT} is the true wind velocity in m/s at a height of 19.5 m and H_S is significant wave height.

5. The wind direction is typically assumed to be collinear with the predominant wave direction. This assumption is generally incorrect but is conservative in most cases.

B.3 WAVE INFORMATION SOURCES

1. Wave information is available from various sources. The following should be considered when selecting wave information sources:

   a. accuracy;

   b. geographical area;

   c. availability of seasonal data;

   d. availability of wave direction data.

B.3.1 Hindcast Wave Data

1. For naval ship studies, hindcast data are commonly used and are considered to have acceptable accuracy.

2. ANEP-11 has extensive hindcast data for NATO operational areas. ANEP-14 has additional data for the North Sea.

B.3.2 Wave Data from Visual Observations

1. Visual observations from ships have been used extensively for developing wave climate data (British Maritime Technology Limited, 1986).

2. When using wave data from visual observation, attention should be given to accuracy of wave heights and periods.

B.3.3 Wave Data from Direct Measurements

1. Wave conditions can be measured directly using technologies such as wave buoys, radars, and satellites. The geographical coverage and accuracy of these sources continue to advance.

APPENDIX C WARSHIP MANOEUVRING OPERABILITY ASSESSMENT

C.1 BACKGROUND

1. Operational effectiveness in the context of manoeuvring is a measure of the ability of the ship to satisfy specified manoeuvring requirements. The methods outlined in this Appendix are a way to assess whether a ship is suitable for its intended role, and to perform comparative assessment of design alternatives.

2. The following are used for assessing overall manoeuvring performance:

   a. defined manoeuvring requirements, including mission scenarios;

   b. tools for evaluating manoeuvring performance in the specified environment;

   c. an approach for condensing the detail information to an overall manoeuvring measure of performance (MOP).

3. Chapter 4 discusses definition of manoeuvring performance requirements. Chapter 5 discusses manoeuvring assessment methods. This Appendix proposes a possible method for condensing the detailed information into a global measure of manoeuvring performance.

C.2 MISSION AND TASK ANALYSIS

1. The distribution of expected missions and tasks must be determined. Various missions and tasks may have different degrees of importance and may be associated with different performance criteria.

C.3 DEFINITION OF ENVIRONMENT

1. Most manoeuvring performance assessment is performed for ships in calm environmental conditions. In some cases, it is preferable to specify non-calm conditions. For example, course keeping, track keeping, and station keeping can be significantly influenced by wind and wave conditions.

2. If multiple environmental conditions are specified for a given performance criterion, then weighting factors can be applied to the different environmental conditions.

C.4 OVERVIEW OF MANOEUVRING OPERABILITY ASSESSMENT PROCESS

1. After definition of manoeuvring requirements and evaluation of manoeuvring capabilities for individual criteria, the operability assessment proceeds by evaluating quantities in the following sequence:

a. Performance numbers (PN) based on achieved performance are evaluated for individual criteria;

b. Measure of effectiveness (MOE) values are evaluated for individual missions using weighted summation of performance number (PN) values;

c. Overall measure of performance (MOP) is evaluated using weighted summation of measure of effectiveness (MOE) values.

C.5 DETERMINATION OF PERFORMANCE NUMBER FOR AN INDIVIDUAL CRITERION

1. A performance number with nominal range from 0 percent to 100 percent is assigned to each manoeuvring performance criterion for each mission. Note that many manoeuvring characteristics (e.g., tactical diameter) can be associated with multiple missions, thus requiring multiple evaluations of associated performance numbers.

2. Figure 9 gives an example approach for assignment of performance number. A value of 100 percent is assigned if the manoeuvring performance is equal to the required performance. The performance number decreases linearly to 0 percent if the performance is less than 75 percent of the required performance. The performance number can increase linearly from 100 percent to a maximum of 125 percent if the achieved performance exceeds the required performance.

3. The scoring process described above must be revised if better performance for a given criterion is indicated by a decreasing achieved value (e.g., tactical diameter).

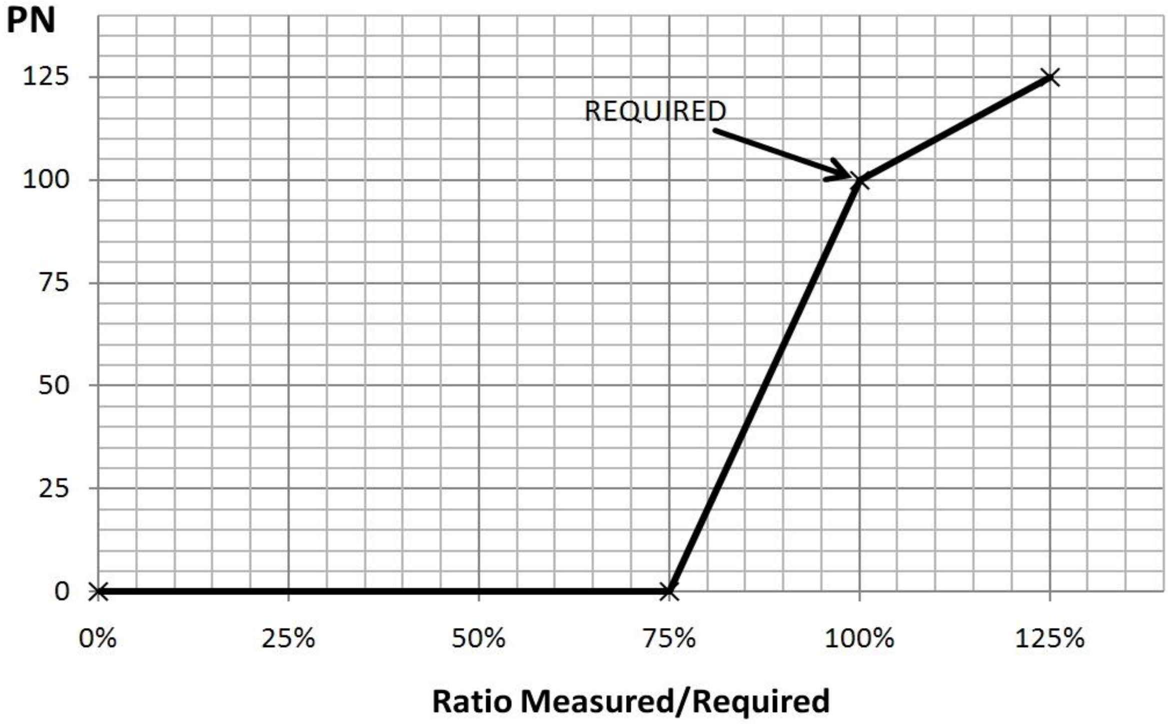

Figure 9: Calculation of Performance Number

C.6 DETERMINATION OF MEASURE OF EFFECTIVENESS FOR A GIVEN MISSION

1. The measure of effectiveness (MOE) for each mission is determined using the following weighted summation:

$$MOE(mission) = \frac{\sum_{abilities} PN(ability, mission) \cdot RF(ability, mission)}{\sum_{abilities} RF(ability, mission)}$$

2. The above equation requires that a ranking factor RF be specified for each manoeuvring ability associated with the mission.

3. Table 33 gives recommended ranking factors for mission abilities.

Table 33: Ranking Factors for Mission Abilities

Ability	Non-Tactical Transit	Tactical Transit	HM	ASW	AAW	MIW hunt	MIW sweep	MIW mine avoidance	RAS	Air Vehicle Interaction
Course keeping	1.80	1.80	1.90	1.90	1.80	1.90	1.90	1.00	1.00	1.00
Track keeping		1.00	1.80			2.00	1.00	1.00		
Tactical diameter	1.60	1.60	1.90	1.90	1.80	1.70	1.50	1.00	1.00	
Initial turning	1.60		1.80	1.80	1.70	1.90	1.90	1.00	1.00	
Yaw checking	1.60		1.80	1.80	1.70	1.80	1.80	1.00	1.00	
Accelerating turning from rest					1.90			1.00		
Turning at rest			2.00							
Stopping	1.00		1.90			1.50	1.00	1.00		
Acceleration				1.80	1.00				1.00	1.00
Astern course keeping			1.80			1.00		1.00		
Station keeping						1.00		1.00		

C.7 DETERMINATION OF OVERALL MEASURE OF PERFORMANCE

1. The total measure of performance can be evaluated using the following equation:

$$MOP = \frac{\sum_{missions} MOE(mission) \cdot MF(\ mission)}{\sum_{missions} MF(mission)}$$

2. The above equation uses a mission factor *MF* for each mission. Separate overall measures of performance can be evaluated for safety and for mission effectiveness. Alternatively, a single overall measure of performance can be determined. It is recommended that safety related missions and primary missions be assigned mission factor values of 1.0. For secondary missions, a mission factor of 0.30 is recommended.

APPENDIX D CORVETTE EXAMPLE

1. This Appendix gives an example of development of manoeuvring requirements for a corvette.

D.1 SHIP DIMENSIONS AND GENERAL PERFORMANCE

1. The ship under consideration is a corvette type of ship. The ship shall have full Anti Submarine Warfare capability and Anti Air Warfare (self-defence) capability. The ship will also have a role in escort missions; thus, Tactical Transit capability is required.

2. The main dimensions are as follows:

    a. Length overall: 90 m;

    b. Length between perpendiculars: 85 m;

    c. Beam: 13.5 m;

    d. Draught: 3.4 m;

    e. Full load displacement: 1600 metric tonnes.

3. The general performance parameters are as follows:

    a. Maximum design speed: 23.0 knots;

    b. Endurance: 7 days.

D.2 MANOEUVRING PERFORMANCE REQUIREMENTS

1. The established missions/tasks and requirements demand that the ship fulfil manoeuvrability performance criteria for the following:

    a. Non-tactical Transit;

    b. Harbour Manoeuvring;

    c. Tactical Transit;

    d. Anti Submarine Warfare;

    e. Anti Air Warfare.

2. The following ship parameters are used for development of manoeuvring criteria:

a. L_{pp} = 85m;

b. MDS speed = 23 knots;

c. $V_{0,(MDS=23kn)}$= 11.88 m/s;

d. F_n= 0.41;

e. $L_{PP}/V_{0,(MDS=23kn)}$= 7.18 s;

f. K_E= 0.423*10^6 tonnes•knots^2.

D.2.1 Non-tactical Transit Requirements

1. Table 34 gives Non-tactical Transit performance requirements developed from Table 12.

Table 34: Non-tactical Transit Performance Requirements

Verification speed: Maximum design speed, 23 knots	
Ability	**Required**
Course keeping	≤ 1.3 deg RMS error in mission sea state
Tactical diameter y_{0180}/L_{pp}	≤ 5.18
Initial turning $t_a/(L_{pp}/V_0)$	≤ 2.53
Yaw checking $t_{C1}/(L_{pp}/V_0)$	≤ 2.09
Stopping s_F $/L_{pp}$	≤ 5

D.2.2 Harbour Manoeuvring Requirements

1. Table 35 gives Harbour Manoeuvring performance requirements developed from Table 13.

Table 35: Harbour Manoeuvring Requirements

Verification speed: 4 knots, unless otherwise noted	
Ability	**Required**
Course keeping	≤ 1.0 deg RMS error in all mission sea states
Track keeping	≤ 2.5 m RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	≤ 2.0 (optimum means permitted, including thrusters)
Initial turning $t_a/(L_{pp}/V_0)$	≤ 2.0
Yaw checking $t_{C1}/(L_{pp}/V_0)$	≤ 1.4
Turning at rest t_{90}	≤ 180 s (nominal speed zero knots, recommended but not mandated)
Stopping s_F /L_{pp}	≤ 1.0
Astern course keeping	≤ 1.5 deg RMS error in all mission sea states
Lateral transfer	(recommended but not mandated)

D.2.3 Tactical Transit Requirements

1. Table 36 gives Tactical Transit performance requirements developed from Table 14.

Table 36: Tactical Transit Performance Requirements

Verification speed: 12 knots	
Ability	**Required**
Course keeping	≤ 1.3 deg RMS error in all mission sea states
Track keeping	≤ 4.0 m RMS error in all mission sea states
Tactical diameter y_{0180}	≤ 550 m

D.2.4 Anti Submarine Warfare Requirements

1. Table 37 gives Anti Submarine Warfare requirements based on Table 15.

Table 37: Anti Submarine Warfare Performance Requirements

Verification speed: Maximum design speed, 23 knots, unless otherwise noted Required verification sea state: Calm, except where otherwise noted		
Ability	**Required**	**Target**
Slow course keeping	≤ 1.6 deg RMS error at 4 knots in mission sea state	≤ 1.6 deg RMS error at 4 knots in mission sea state
Course keeping	≤ 0.8 deg RMS error in mission sea state	≤ 0.8 deg RMS error in mission sea state
Tactical diameter y_{0180}/L_{pp}	≤ 4.55	≤ 3.91
Initial turning $t_a/(L_{pp}/V_0)$	≤ 1.91	≤ 1.71
Yaw checking $t_{C1}/(L_{pp}/V_0)$	≤ 2.09	≤ 1.48

D.2.5 Anti Air Warfare Requirements

1. Table 38 gives Anti Air Warfare requirements based on Table 20.

Table 38: Anti Air Warfare Performance Requirements

Verification speed: Maximum design speed, 23 knots Required verification sea state: Calm, except where otherwise noted		
Ability	**Required**	**Target**
Course keeping	≤ 1.3 deg RMS error in all mission sea states	≤ 1.3 deg RMS error in all mission sea states
Tactical diameter y_{0180}/L_{pp}	≤ 4.55	≤ 3.91
Initial turning $t_a/(L_{pp}/V_0)$	≤ 2.53	≤ 2.20
Yaw checking $t_{C1}/(L_{pp}/V_0)$	≤ 2.09	≤ 1.48
Accelerating turning from rest t_{90}	≤ 180 s	≤ 150 s

APPENDIX E NOMENCLATURE

ACRONYMS

	Full term
AAW	Anti air warfare
AAWp	Anti air warfare, proactive
AAWr	Anti air warfare, reactive
ACT	Allied Command Transfer
AJP	Allied joint publication
ANEP	Allied naval engineering publication
ASuW	Anti surface ship warfare
ASW	Anti submarine warfare
ASWp	Anti submarine warfare, proactive
ASWr	Anti submarine warfare, reactive
ATP	(NATO) Allied tactical publication
Circ.	(IMO) Circular
CPP	Controllable pitch propeller
HM	Harbour manoeuvring
HSC	High speed craft (code)
IMO	International Maritime Organisation
ITTC	International Towing Tank Conference
LPD	Landing platform dock
MCR	Maximum continuous rating of propulsion power, associated with sustained safe operation of propulsion system
MDS	Maximum design speed
MIO	Maritime interdiction operation
MIW	Mine warfare
MIWa	Mine warfare avoidance
MIWh	Mine warfare hunting
MIWs	Mine warfare sweeping
MOE	Measure of effectiveness
MOP	Measure of performance
MSC	(IMO) Maritime Safety Committee
NATO	North Atlantic Treaty Organisation
PN	Performance number
PfP	Partner for Peace

	Full term
RAS	Replenishment at sea
RF	Relevance factor
SAR	Search and Rescue
SDNE	Standard deviation of navigational error
SS	Sea state
STANAG	Standardisation agreement
TaP	Transit and patrol
UW	Under water

SYMBOLS

Symbol	Term and definition
a_{max}	Maximum acceleration (longitudinal)
F_n	$= V/\sqrt{g \cdot L_{pp}}$, Froude number
g	Acceleration due to gravity
H_S	Significant wave height
h_M	Mean water depth during the trial
K_E	$= 0.5 \cdot \Delta \cdot V_0^2$, Kinetic Energy
L_{PP}	Length between perpendiculars
s_F	Stopping distance (until the ship is dead in the water)
T	Draught
T_P	Spectral peak wave period
t_{C1}	First time to check yaw (in zig-zag test)
t_a	Initial turning time (in zig-zag test)
t_{90}	Time to turn through 90°
V	Ship speed (through the water)
V_{WT}	True wind velocity
V_0	Initial speed (of the individual test run)
y_{0180}	Tactical diameter
ψ	Heading deviation
Δ	Displacement mass
deg	Angular degrees
m	Metres
ft	Feet
kn	Knots
s	Seconds

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