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Part 04
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Author

Signed: ....

Name: Victor Pisaniello

Appointment:

Mechanical Engineer, DSME

Date: 10/11/06

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Signed: PF King ....

Name: Paul King

Appointment:

MRS – Configuration Management Authority

Date: 26 MARCH 07

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ASSISTANT DIRECTOR

Pass Technical Content

Signed: ....

Name: Andrew Gates

Appointment:

Principal Mechanical Engineer, DSME

Date: 7 DEC 2006

5 ↓

DIRECTOR

Approve Technical Content

Signed: ....

Name: Andrew Horobin

Appointment:

Director, DMSE

Date: 16 MArch 2007

6 →

DG NAVSYS

Authorise Release for ADO Use

Signed: P. Marshall ....

Name: ~~CDRE Richard Longbottom~~

Appointment: CDRE P. J. MARSHALL

Chief Naval Engineer

Date: 27 Aug 2007

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Issue No.	Issue Date	Description of Changes	Affected Pages	Sponsor's Name
1	27 Aug 2007	Original	All	Andrew Gates
2				
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PREFACE

1. This document was prepared by the Directorate of Submarine Engineering (DSME) and is an element of the DEF(AUST)5000 – ADF Maritime Materiel Requirements Set.

2. This document is Volume 9, Part 4, of the Standard Materiel Requirements for RAN Submarines.

3. This is the first version of the document, and will be updated to reflect improvements.

4. This standard details the minimum manoeuvring qualities required by RAN submarines, including test requirements and trials.

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LIST OF FIGURES/TABLES

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1 SCOPE

1.1 Life Cycle

This standard is to be applied in the acquisition of new equipment, in accordance with current Defence Instructions (Navy) on the Technical Regulation of Naval Materiel.

Acquisition contracts must either invoke this standard or alternative design and construction rules or standards that equate to this standard, as agreed by the Chief Naval Engineer (CNE) or his/her authorised delegate. The Chief Naval Engineer (CNE) or his/her authorised delegate may approve deviations from this standard, subject to provision of adequate documented justification by the proposer of this deviation.

This standard shall also be applied when upgrading components of an existing Royal Australian Navy submarine, to ensure the upgraded design will still satisfy the specified criteria.

1.2 What is Covered

This standard states the requirements for submarine manoeuvring and control, for both surfaced and fully submerged operations. This includes vertical and directional stability, depth and course keeping, turning, acceleration, deceleration, stopping, diving, surfacing, propulsion and emergency blow requirements.

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2 DOCUMENTS

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2.1 Referenced Documents

This standard is subject to periodic revision as improvements are proposed, changes in manoeuvring requirements are proposed or improved trial methods are introduced.

The shipbuilder or designer must ensure that he/she is in possession of the latest edition for each particular tender or contract. Inquiries in this regard should be made to the relevant authority within the Department of Defence.

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This standard shall take precedence over all documents quoted herein. Where anomalies occur in the documents quoted, these should be brought to the attention of the sponsor using the amendment proposal sheet for this standard.

When reference is made to documents, then the latest issue of that document shall apply unless otherwise stated.

The following documents were used in the development of this MRS. The appropriate information from these documents has been included and the authors are hereby acknowledged.

DEF(AUST)5000 – Vol 9 Pt 3 – Issue 1 – *Submarine Stability* (UNCLASSIFIED)

DEF(AUST)5000 – Vol 3 Pt 3 – Issue 1 – *Propulsion Performance* (UNCLASSIFIED)

DEF(AUST)5000 – Vol 3 Pt 7 – Issue 1 – *Ship Manoeuvrability Requirements and Analysis* (UNCLASSIFIED)

Joubert, Prof. P. N., 2004, *Some Aspects of Submarine Design Part 1. Hydrodynamics*, DSTO-TR-1622, DSTO Platforms Sciences Laboratory (UNCLASSIFIED)

Stenson, R. J., Hundley, L. L., 1991, *Performance and Special Trials on U.S. Navy Surface Ships*, DTRC/SHD-1320-02, David Taylor Research Center (UNCLASSIFIED)

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3 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

3.1 Definitions

Approval or **approved** means approval or approved by the Department of Defence.

Bow quartering seas. A heading of 135 degrees to the direction of the waves.

Full ahead is the submarine's top speed.

Full astern is the submarine's top astern speed.

Heading. The submarine's course relative to the predominant direction of travel of waves, wind, tidal streams or current, where so indicated.

Heel. Temporary angle due to temporary external force such as caused by the wind.

Hover. The condition where the submarine is at constant depth and zero speed.

Knot(s). The number of International Nautical Miles covered in one hour.

Nautical Mile. One International Nautical Mile corresponds to 1852 metres.

Pitch. Rotation of submarine about its transverse axis.

Propulsor. Device used to force a ship or submarine through the water.

Rudder or **rudder angle.** In this context, will refer to the horizontal component of the sum of aft control surface angles.

Shall, **is to be** or **are to be** indicate a mandatory requirement.

Shallow water. Water in which the ratio of depth to submarine draught is less than 1.2.

Should advises a preference.

Significant Wave Height. The mean value of the highest one-third of all the peak to trough wave heights, measured over a reasonable time period (say 10-20 minutes).

Snorting. Operation of diesel engines whilst submerged, utilising a snort-induction system to draw in air via an extended induction mast and expelling exhaust gases into the sea.

Sternplane. In this context, will refer to the vertical component of the sum of all aft control surface angles.

Stern quartering seas. A heading of 45 degrees to the direction of the waves.

Tactical Diameter. The perpendicular distance in a turn from the point that a submarine has changed heading by 180 degrees, to the projection of the original course from the point of execution.

Track Reach. The length of the course traced by a ship or submarine in the water during a manoeuvre.

Yaw. Rotation of submarine around its vertical axis.

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3.2 Acronyms and Abbreviations

Δ	Displacement (tonnes)
Φ	Deviation from selected heading
DDD	Deep Diving Depth
$H_{1/3}$	Significant wave height
HP	High Pressure
Kn	Knots
L	Length of submarine in metres
m	Metres
MRS	Materiel Requirements Set
RAN	Royal Australian Navy
RPM	Revolutions Per Minute

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4 BACKGROUND

4.1 Significance to RAN

The purpose of this standard is to ensure that any new submarine acquired by the Royal Australian Navy will be able to perform satisfactorily in the areas of hydrodynamics, manoeuvrability and control.

4.2 Consequences of Poor Performance or Hazard

Poor performance in these areas can result in the inability to achieve mission requirements, or in the worst case, catastrophic loss of the submarine and/or crew.

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5 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

5.1 General Requirements

All RAN submarines shall satisfy manoeuvring requirements detailed in sections 5.2.1 to 5.3.16, at the full load displacement and the design trim. They should also be met at all other operational displacements and trims.

5.2 Surface Operations

5.2.1 Control Surface Actuators

The actuators shall be demonstrated to function without failure when driven from hard port to hard starboard at full ahead and full astern.

This requirement shall be demonstrated during sea trials by the Control Surface Actuators Trial outlined in section A.1.

5.2.2 Acceleration and Deceleration

Requirements for acceleration and deceleration will vary depending on submarine specifications.

However, once suitable requirements are known, they shall be demonstrated during sea trials using the Deceleration and Acceleration Trial outlined in section A.2.

5.2.3 Crash stop

Requirements for crash stop time and distance will vary depending on submarine specifications.

Once crash stop requirements are specified, the submarine shall satisfy the criteria in specified surface conditions.

This requirement shall be demonstrated at design stage through appropriate numerical simulation, and during sea trials by the Crash Stop Manoeuvre outlined in section A.3.

5.2.4 Heel angle during high speed turns

The maximum heel angle in a high speed turn both to port and to starboard will vary depending on submarine requirements. Once this angle is specified, the submarine shall satisfy the requirement in specified surface conditions.

This requirement shall be demonstrated during sea trials by the Manoeuvre to determine maximum heel angle during turn, outlined in section A.4.

5.2.5 Course keeping and yaw checking ability

The submarine shall demonstrate the ability to maintain zero rate of yaw in calm water with no more than 5 degrees of rudder.

This requirement shall be demonstrated by the Direct (Dieudonnè) or the Reverse (Bech) Spiral Manoeuvre (outlined in sections A.5 and A.6) at the design stage through model testing or appropriate numerical simulation, and during sea trials in calm seas with maximum nominal wind of 5 knots.

The submarine will be required to keep its course within a certain tolerance. This tolerance will vary depending on submarine specifications.

Controllability of the submarine shall be further demonstrated by conducting a 10-10 and 20-20 zig-zag manoeuvre at the design stage through model testing or appropriate numerical simulation, and during sea trials.

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During a 10-10 zig-zag manoeuvre, as outlined in section A.7 with the first execution both to port and to starboard, the first overshoot angle shall not exceed 10 degrees.

The second overshoot angle in the 10-10 zig-zag manoeuvre shall not exceed 15 degrees more than the first overshoot angle.

During a 20-20 zig-zag manoeuvre, with the first execution both to port and to starboard, the first overshoot angle shall not exceed 20 degrees.

5.2.6 Tactical Diameter

A minimum tactical diameter will be specified for the submarine, depending on the submarine operational requirements.

Once established, this tactical diameter must be demonstrated during sea trials using the Turning Circle Manoeuvre, detailed in section A.8.

5.2.7 Shallow water operation

The submarine shall be capable of manoeuvring to a satisfactory level in shallow water.

This requirement will be considered during the design phase, and demonstrated during sea trials.

5.2.8 Slow speed controllability

Submarines should have sufficient slow speed manoeuvrability to allow berthing and mooring without the aids of tugs in a current up to 4 knots and a steady wind speed of 21 knots. Both current and wind shall be considered to act from any direction. The berthing requirement may be achieved with the use of auxiliary propulsion systems while manoeuvring alongside.

This requirement should be considered during the design phase, and berthing ability demonstrated during sea trials.

5.3 Submerged Operations

5.3.1 Snorting

The submarine shall be capable of manoeuvring at a satisfactory level while snorting.

The submarine shall remain within a specified depth envelope whilst snorting, with minimum use of control surfaces. This envelope will be specified depending on the submarine operational requirements.

These requirements will be considered during the design phase, and demonstrated during sea trials.

5.3.2 Control Surface Actuators

The actuators shall be demonstrated to function without failure when driven from hard port to hard starboard, at full ahead and full astern, and hard rise to dive at safe speeds and depths, both ahead and astern. These safe speeds and depths must be decided upon by considering the emergency recovery measures and operating specifications of the submarine.

This requirement shall be demonstrated during sea trials by the Control Surface Actuators Trial outlined in section A.1.

5.3.3 Acceleration and Deceleration

Requirements for submerged acceleration and deceleration will vary depending on submarine specifications.

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Once suitable requirements are known, they shall be demonstrated during sea trials using the Deceleration and Acceleration Trial outlined in section A.2.

5.3.4 Crash stop

Requirements for crash stop will vary depending on submarine specifications.

Once crash stop requirements are specified, the submarine shall satisfy the criteria in calm conditions.

This requirement shall be demonstrated at design stage through appropriate numerical simulation, and during sea trials by the Crash Stop Manoeuvre outlined in section A.3.

5.3.5 Snap roll angle during high speed turns

The maximum snap roll angle in a high speed turn both to port and to starboard will vary depending on submarine specifications. Once this angle is known, the submarine shall satisfy this requirement.

This requirement shall be demonstrated during sea trials by the Manoeuvre to determine maximum heel angle during turn, outlined in section A.4.

5.3.6 Uncontrolled turn

A submarine is said to perform an uncontrolled turn when it only uses the horizontal component of control surfaces during a turn. The submarine must be able to stay within a specified depth range during the uncontrolled turn. This depth range will vary depending on submarine specification.

This requirement must be demonstrated at design stage by appropriate numerical simulation or model testing, and during sea trials using the Uncontrolled Turn Trial, detailed in section A.9.

5.3.7 Course keeping and yaw checking ability

The submarine shall demonstrate the ability to maintain zero rate of yaw in calm water with no more than 5 degrees of rudder.

This requirement shall be demonstrated by the Direct (Dieudonnè) or the Reverse (Bech) Spiral Manoeuvre (outlined in sections A.5 and A.6) at the design stage through model testing or appropriate numerical simulation, and during sea trials in calm seas with nominal wind of 5 knots.

The submarine will be required to keep its course within a certain tolerance. This tolerance will vary depending on submarine specifications.

Controllability of the submarine shall be further demonstrated by conducting a 10-10 and 20-20 zig-zag manoeuvre at the design stage through model testing or appropriate numerical simulation, and during sea trials.

During a 10-10 zig-zag manoeuvre, as outlined in section A.7 with the first execution both to port and to starboard, the first overshoot angle shall not exceed 10 degrees.

The second overshoot angle in the 10-10 zig-zag manoeuvre shall not exceed 15 degrees more than the first overshoot angle.

During a 20-20 zig-zag manoeuvre, with the first execution both to port and to starboard, the first overshoot angle shall not exceed 20 degrees.

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5.3.8 Depth keeping while on straight course at high speed

The submarine shall remain within a specified depth envelope whilst on straight course at high speeds, with minimum use of control surfaces. This envelope will be specified depending on the submarine operational requirements.

This requirement shall be demonstrated at design stage through model testing or appropriate numerical simulation, and during sea trials.

5.3.9 Depth keeping while on straight course at low speed

The submarine shall remain within a specified depth envelope whilst on straight course at low speeds with minimum use of control surfaces. This envelope will be specified depending on the submarine operational requirements.

This requirement shall be demonstrated at design stage through model testing or appropriate numerical simulation, and during sea trials.

5.3.10 Hovering at zero speed

The submarine shall be capable of remaining at constant depth (from zero depth to DDD) with zero speed.

This requirement shall be demonstrated during sea trials.

5.3.11 Tactical Diameter

A minimum submerged tactical diameter will be specified for the submarine, depending on the submarine operational requirements.

Once established, this tactical diameter must be demonstrated during sea trials using the Turning Circle Manoeuvre, detailed in section A.8.

5.3.12 Depth changing

The submarine shall have the ability to change depth rapidly and with a minimum overshoot. The overshoot will be specified depending on submarine operational requirements.

Once established, this requirement must be demonstrated at design stage by appropriate numerical simulation or model testing, and during sea trials using the Depth Changing Manoeuvre detailed in section A.10.

5.3.13 Trim control during submerged manoeuvres

During submerged manoeuvres, the submarine shall maintain an acceptable pitch angle, governed by the trim control. More detailed requirements will be specified, depending on submarine operational requirements.

This requirement shall be demonstrated during sea trials.

5.3.14 Critical speed

At low submarine speeds, the angle of downward pitch due to aft control surface operation can be less than the upward lift force on the aft control surfaces. At such a speed, the boat will pitch down but the dominant effect is an overall upward movement of the boat. Similarly for an upward submarine pitch, the overall movement of the boat will be downward. The critical speed is the speed at which the aft surfaces become ineffective for changing submarine depth. At speeds less than the critical speed it becomes necessary for forward hydroplanes to control the depth of the submarine.

This speed must be identified and demonstrated at design stage by appropriate numerical simulation or model testing, and during sea trials.

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5.3.15 Emergency ballast blow

The submarine must be capable of sufficient manoeuvrability and control to allow a safe ascent to the surface during an emergency ballast blow. During an emergency blow, HP air is blasted into the ballast tanks to rapidly displace the seawater, to allow the submarine to surface as quickly as possible.

This requirement must be demonstrated at design stage by appropriate numerical simulation or model testing, and during sea trials.

5.3.16 Aft control surface jam

Control surface jam trials shall be conducted to provide data for verification and/or modification of manoeuvring limitation diagram (see section 6.2.1), and control surface jam recovery procedures.

These trials are described in section A.11.

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6 DESIGN AND PRODUCT CONSTRAINTS

6.1 Specific Design/Engineering Constraints

6.1.1 Hull design

The submarine hull shall be designed so as to maximise submarine manoeuvrability and control whilst on the surface, and submerged. During design, consideration must be given to the minimisation of hydrodynamic drag, and to hydrodynamic performance degradation due to fouling on the hull.

These requirements must be demonstrated at design stage by appropriate numerical simulation or model testing, and during sea trials.

Consideration must also be given to minimising acoustic noise originating from flow around the hull.

6.1.2 Aft control surfaces

Aft control surfaces shall be designed to enable all manoeuvres detailed in section 5 to be completed to specifications. Assessments shall also be conducted on noise and drag originating from aft control surfaces, their hydrodynamic effect on the propulsor, their contribution to submarine dynamic stability, and the reliability of the control surface actuators.

6.1.3 Forward hydroplanes

The hydroplanes shall be designed to enable all manoeuvres detailed in section 5 to be completed to specifications. Assessments shall also be conducted on noise and drag originating from the hydroplanes, their contribution to submarine dynamic stability, and the reliability of the hydroplane actuators.

6.1.4 Fin

The submarine fin shall be designed to enable all manoeuvres detailed in section 5 to be completed to specifications. Assessments shall also be conducted on noise and drag originating from the fin, and its contribution to submarine dynamic and static stability (in accordance with MRS Volume 9: Submarine System Requirements Part 3: Submarine Stability, Issue 1).

An assessment must be conducted on the impact of the fin on hull wake, and propulsion inflow.

6.1.5 Propulsion and propulsors

The submarine propulsor and propulsion system should be designed in accordance with MRS Volume 3: Hull System Requirements Part 3: Propulsion Performance, Issue 1. Assessment shall be conducted on effect of the propulsor on the manoeuvrability of the submarine.

6.1.6 Reserve propulsion system

Assessment shall be conducted on the manoeuvrability of the submarine under power of the reserve propulsion system.

Assessment shall be conducted on the manoeuvrability of the submarine under power of the reserve propulsion system.

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6.1.7 Emergency Blow System

The emergency blow system shall be designed to recover from DDD following a worst credible flood situation (for a flood of duration no less than 20 seconds). It shall be demonstrated that systems can detect, initiate and isolate the flood in a specified time period that allows recovery of the submarine. Determination of the maximum flood rate shall ignore pipe and fitting losses, and other minor flow losses. The determination of the emergency blow system capacity shall assume adiabatic conditions unless agreed otherwise.

6.2 Navy Practice Constraints

6.2.1 Manoeuvring Limitation Diagram (MLD)

Two of the most serious incidents that can occur in a submarine are aft control surfaces jamming hard to rise or dive, and uncontrolled flooding. To avoid the submarine getting into a situation from which recovery from the two said incidents is unlikely, a Manoeuvring Limitation Diagram (MLD) shall be constructed.

The MLD shall specify safe operating regions within which recovery from these scenarios would be possible. It shall present manoeuvring advice in the form of speed, depth and hydroplane and pitch restrictions. The MLD is to specify DDD and Flood Avoidance Zone (FAZ) for the submarine class.

The basis for the MLD development shall consider the following:

- Worst credible casualty scenarios determined from manoeuvring system safety studies
- Specification of initial conditions
- Recovery procedures including determination of reaction times to detect failure and initiate recovery actions.

Further information for the development of the MLD shall be gained using experience from existing and previous submarine classes, and data obtained from appropriate numerical simulation, model testing, and/or sea trials.

An example of an MLD is shown in Figure 6.1.

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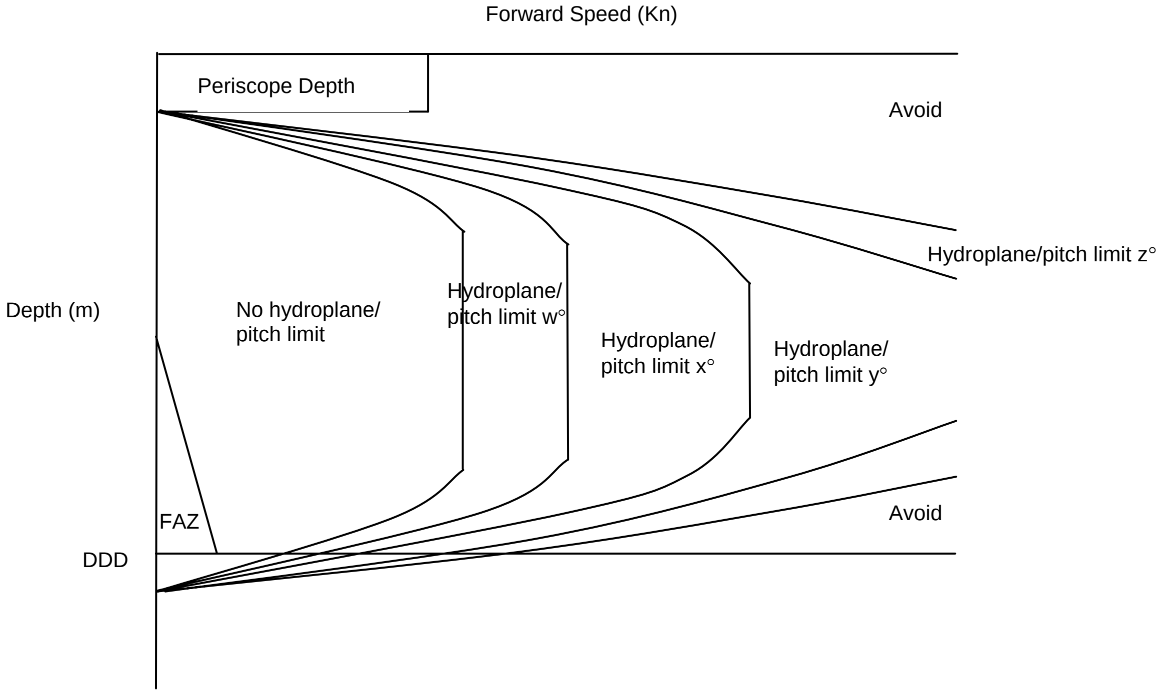

Figure 6.1 Example of a Manoeuvring Limitation Diagram

6.2.2 Manoeuvring Handbook

A Manoeuvring Handbook shall be produced for the submarine. The contents of the handbook should contain details of the submerged and surfaced manoeuvring characteristics specified in this Materiel Requirements Set.

The manoeuvring handbook shall be revised after any modification to the submarine that impacts on manoeuvrability.

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7 DELIVERABLES (DIDs)

7.1 Tender Deliverables

A report demonstrating the manoeuvrability and control of the submarine shall be submitted. The report shall include performance data from sea trials on similar submarines, appropriate numerical simulations, model testing or other numerical methods or calculations shown to support the conclusions of the report.

7.2 During Contract Deliverables

During contract deliverables are deliverables required between signing of contract and delivery of reports confirming the submarine satisfies the requirements as demonstrated by sea trials.

A report demonstrating that the submarine meets the functional and performance requirements shall be submitted for the submarine design. This report shall contain results obtained from model testing, appropriate numerical simulation, or from other numerical methods or calculations shown to support the conclusions of the report.

A preliminary manoeuvring handbook shall be provided for the actual design, based on results of numerical simulations, model testing or other numerical methods or calculations.

7.3 Contract Deliverables

7.3.1 Sea Trials Report

A sea trials report shall be submitted. The report shall contain results of the sea trials described within this Materiel Requirements Set.

7.3.2 Manoeuvring Limitation Diagram (MLD)

A Manoeuvring Limitation Diagram (MLD) shall be submitted, which details operational limitations to prevent the submarine entering a situation from which recovery from a flood or control surface jam is unlikely (see section 6.2.1).

7.3.3 Manoeuvring Handbook

A Manoeuvring Handbook shall be produced for the submarine. The contents of the handbook should contain details of manoeuvring characteristics specified in this report.

7.4 Post Contract Deliverables

An updated sea trials report, MLD and Manoeuvring Handbook shall be submitted after any modification to the submarine that impacts on manoeuvrability.

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ANNEX A

SEA TRIALS

A.1 Control Surface Actuators Trial

The objective of this trial is to ensure the steering gear has the required strength and capacity to perform all necessary manoeuvres. It will demonstrate the mechanical functioning of the steering gear and its suitability to hold and move the control surfaces both in ahead and astern manoeuvres. Autopilots and other automatic course keeping systems are to be deactivated for this trial.

With the submarine travelling at full ahead, move control surfaces at the maximum rate from:

a) Neutral to hard over starboard and hold for 10 seconds.
b) Hard over starboard to hard over port and hold for 10 seconds.
c) Hard over port to hard over starboard and hold for 10 seconds.
d) Return to neutral.
e) Repeat the actions whilst at full astern.

With the submarine travelling ahead at safe speed and depth, move control surfaces at the maximum rate from:

f) Neutral to hard dive and hold for 10 seconds.
g) Hard dive to hard rise and hold for 10 seconds.
h) Hard rise to hard dive and hold for 10 seconds.
i) Return to neutral.
j) Repeat the actions whilst travelling astern at safe speed and depth.

The following data shall be recorded:

a) Power unit in use and motor rated amperes and RPM.
b) Time required for each control surface movement. The exact moment of reaching hard over is not easily established because of the slow decelerating motion at these high angles. Most positive control surface timing can be made by starting the stop watch as the control surfaces begin to move from the hard over position, and stopping it as the control surfaces pass some agreed angle near hard over on the other side (usually 5 degrees before the ordered angle). The average rate of the control surfaces per second can then be determined.
c) Maximum control surface angles.
d) Maximum hydraulic oil pressure on the rams.
e) Servo pressure, replenishing pressure, and pump stroke at maximum demand, if available from the submarine's instruments.
f) Steering gear motor idle and maximum amperes and RPM for each control surface movement.
g) Propeller shaft torque, RPM, and hence power at start and finish of each movement.

A.2 Acceleration and Deceleration Trial

The objective of these trials is to determine time and distance to change speed for submarine manoeuvring purposes.

For the deceleration trial, the submarine is to be progressively slowed over speed ranges equivalent to:

a) Full ahead to 50% speed.
b) 50% to 25%.
c) 25% to 5%.

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For the acceleration trial, the submarine speed is increased from zero to full ahead. Additional acceleration data should be recorded for:

a) 5% to 25%.
b) 25% to 50%.
c) 50% to full ahead.

The following data shall be recorded or calculated from recorded data:

a) Shaft torque and RPM immediately prior to the next order.
b) Shaft torque, RPM, shaft power, submarine speed and position at constant time intervals throughout the trial.

A.3 Crash Stop Manoeuvre

The crash stop is to be performed with the submarine at full load. The submarine is held on a constant heading at full ahead.

a) The signal “Full Astern” is given.
b) The control surfaces should be used to maintain heading and course as long as possible.

The following data shall be recorded or calculated from recorded data:

a) Shaft torque and RPM immediately prior to the “Full Astern” order.
b) Shaft torque, RPM, ship’s heading, ship’s position and control surface angles at constant time intervals throughout the manoeuvre.
c) Time shaft stops
d) Time shaft starts astern
e) Time to reach maximum astern RPM
f) Time to stop submarine dead in the water.

A.4 Manoeuvre to determine maximum snap roll angle during turn

Heel angle trials are undertaken with the submarine on the surface. When the submarine is submerged, this trial may be carried out to find maximum snap roll during a turn.

With the submarine travelling at full ahead speed, move control surfaces at maximum rate from:

a) Centre to hard over starboard, and hold until the submarine reaches a steady heel/roll angle.
b) Hard over starboard to hard over port and hold until the roll motion steadies.
c) Return to centre.

Repeat the trial using the opposite control surface movements to the previous run. In subsequent runs, execute the second control surface movement when:

a) The submarine’s heel/roll reaches an initial maximum.
b) The first control surface movement reaches hard over.

The following data shall be recorded or calculated from recorded data:

a) Maximum rudder angles.
b) Maximum heel/roll angles.
c) Submarine initial speed.

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A.5 Direct (Dieudonnè) Spiral Manoeuvre

The direct spiral is an orderly sequence of turning circle tests to obtain a constant rate of turn versus control surface angle relation, provided the submarine has straight-line stability. This will demonstrate directional stability. The submarine's speed should be normal cruising speed.

This manoeuvre should only be carried out in winds less than 5 knots and significant wave heights less than 0.5 or L/200 metres, whichever is less. Obviously, submerged trials will not be affected by wind or wave conditions.

To perform the test,

a) Bring the submarine onto a constant heading at the designated speed.
b) Move the rudder to 20 degrees starboard and hold until the submarine changes heading at a constant rate.
c) Progressively move the rudder through the following settings, holding at each setting until a constant rate of turn is obtained.

20S, 15S, 10S, 5S, 3S, 1S, 0, 1P, 3P, 5P, 10P, 15P, 20P, 15P, 10P, 5P, 3P, 1P, 0, 1S, 3S, 5S, 10S, 15S, 20S.

A constant rate of turn is deemed to have been reached when at least six consecutive readings of the submarine heading at equal time intervals show an essentially constant difference in heading. Once a constant rate of turn has been reached, the rudder will be ordered to the next setting.

The following data shall be recorded or calculated from recorded data:

a) Submarine initial speed.
b) Rate of change of heading.
c) Rudder angle.
d) Submarine heading (to nearest degree) every 10 seconds.

A.6 Reverse (Bech) Spiral Manoeuvre

The advantage of the reverse spiral manoeuvre is that it will provide the shape of the hysteresis loop if the submarine is directionally unstable. In this manoeuvre, the submarine is held at a constant rate of turn and the mean control surface angle required to produce this rate of turn is measured. It is best to follow a predetermined pattern of turns for this trial.

This manoeuvre should only be carried out in winds less than 5 knots and significant wave heights less than 0.5 or L/200 metres, whichever is less. Obviously, submerged trials will not be affected by wind or wave conditions.

To perform the manoeuvre,

a) Bring the submarine to a constant rate of turn.
b) Adjust control surfaces to maintain this rate of turn.
c) Repeat this process for a variety of yaw rates requiring rudder angles between port and starboard 20 degrees.

The following data shall be recorded or calculated from recorded data:

a) Submarine initial speed.
b) Rate of change of heading once steady at each stage.
c) Rudder angle once steady rate of turn achieved.
d) Submarine heading (to nearest degree) every 10 seconds.

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A.7 Zig-zag Manoeuvre

The two zig-zag manoeuvres that may be completed are the 10/10 and 20/20 manoeuvres.

To perform the 10/10 manoeuvre, maintain cruising speed and bring the submarine to a constant heading.

a) Move the rudder from centre to 10 degrees starboard at maximum rate and hold until the submarine's heading has changed to 10 degrees starboard of original heading.
b) Move the rudder from 10 degrees starboard to 10 degrees port at maximum rate and hold until the submarine's heading has changed to 10 degrees port of original heading.
c) Reverse the rudder as before.
d) Once the original heading has been passed four times, resume a constant heading.

A 20/20 manoeuvre is completed with the same method as above, but with 20 degree heading changes rather than 10 degrees.

Control surface effectiveness at various speeds may be investigated by performing additional manoeuvres at different speeds.

For a sample of zig-zag manoeuvres the above procedure should be repeated with application of opposite helm to those listed. The objective of these tests being to confirm that the behaviour is similar regardless of the direction of the initial control surface application.

The following data shall be recorded or calculated from recorded data:

a) Time when control surfaces are moved, including start and stop of actual surface movement.
b) Time the control surfaces are held in position.
c) Submarine heading to nearest degree every 10 seconds.
d) Rate of change of heading.

A.8 Turning Circle Manoeuvre

A surface and submerged turning circle test shall be performed at cruising speed to both port and starboard with control surfaces hard over. This trial will give information on tactical diameter. The time, position, and speed of submarine at 10, 30, 45, 60, 90, 180, 270, 360 and 450 degrees change of heading, the steady yaw rate, steady turning speed and steady turning diameter shall also be determined.

The complete trial shall include a turn through 720 degrees to port and to starboard. This enables identification of any asymmetry and correction for any drift caused by current or wind (if on surface). To perform the manoeuvre,

a) Maintain cruising speed and bring the submarine onto a constant heading (zero yaw).
b) Move rudder to hard over starboard at maximum rate and hold until the submarine heading has changed at least 720 degrees.
c) Resume a constant heading and restore speed.
d) Move rudder to hard over port at maximum rate and hold until the submarine's heading has changed at least 720 degrees.
e) Resume original constant heading.

Propulsion setting should not be changed during the test.

Further exploration of turning circle characteristics shall be investigated by performing additional tests at different speeds and rudder angles. Typically, speeds of 25%, 50% and 75% of full speed, and 10 and 20 degrees rudder angles should be considered.

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The following data shall be recorded or calculated from recorded data:

a) Rudder angle used.
b) Submarine heading to nearest degree every 10 seconds.
c) Rate of change of heading.
d) Time elapsed from “execution” of manoeuvre.
e) Submarine speed and position at suitable intervals.

In the final report, corrections for drift as outlined in Appendix B shall be made.

A.9 Uncontrolled Turn Trial

This manoeuvre will be used to investigate the tendency of the submarine to change depth in a turn.

To perform the manoeuvre,

a) Establish steady conditions of speed, course and depth. Throttle positions should remain constant during these runs.
b) Move rudder angle to 15 degrees starboard, whilst keeping hydroplanes and sternplanes at neutral angle. Rudder angle is to be held throughout the turn.
c) Continue turn for 360 degrees if feasible.
d) Continue to execute the sequence of turns as shown below:

25S, 35S, 15P, 25P, 35P, 15S, 25S, 35S, 15P, 25P, 35P, 15S, 25S, 35S, 15P, 25P, 35P.

The following data shall be recorded or calculated from recorded data:

a) Submarine initial speed.
b) Time elapsed from ‘execution’ of manoeuvre.
c) Shaft RPM.
d) Submarine depth and heading.
e) Submarine pitch and roll.
f) Aft control surface angles.
g) Hydroplane angles.

A.10 Depth Changing Manoeuvre

This manoeuvre will determine vertical overshoot of the submarine in either rise or dive.

To perform the manoeuvre,

a) Maintain cruising speed and bring the submarine onto a constant heading, pitch, and depth, with all control surfaces in neutral position.
b) Move sternplanes to the required value as shown below in Table A1.
c) Hold until the required pitch (Table A1) is reached.
d) Once the pitch has been reached, change sternplane deflection to the equal and opposite value with respect to the neutral angle.
e) Hold until the rate of change of depth has passed through zero.
f) Continue to execute the sternplane angles shown in Table A1.

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The following data shall be recorded or calculated from recorded data:

a) Submarine initial speed.
b) Time elapsed from 'execution' of manoeuvre.
c) Shaft RPM.
d) Submarine depth and heading.
e) Submarine pitch and roll.
f) Aft control surface angles.
g) Hydroplane angles.

Sternplane Entrance Angle (deg)	Execute Pitch Angle (deg)	Sternplane Checking Angle (deg)
10D	5	10R
10D	10	10R
10D	15	10R
20D	5	20R
20D	10	20R
20D	15	20R
20R	5	20D
20R	10	20D
20R	15	20D
10D	5	10R
10D	10	10R
10D	15	10R
20D	5	20R
20D	10	20R
20D	15	20R
20R	5	20D
20R	10	20D
20R	15	20D
5D	5	5R
5D	10	5R
5D	15	5R
8D	5	8R
8D	10	8R
8D	15	8R
8R	5	8D
8R	10	8D
8R	15	8D

(R = Rise, D = Dive)

Table A1: Depth Changing Manoeuvre Angles

A.11 Control Surface Jam Trials

These trials have the potential of bringing the submarine close to its operational limits. Caution must be exercised to ensure the submarine remains within the MLD at all times (with a margin of safety for further security). Appropriate control surface jam angles and time delays should be agreed upon prior to trials.

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To perform the manoeuvre,

a) Establish neutral buoyancy and level trim at operating depth for the trials.
b) Establish steady speed, heading and approach depth.
c) Move the aft control surfaces to the scheduled jam angle and hold for duration of the run.
d) When the appropriate time delay is reached, the command is given to commence the scheduled recovery. Continue the recovery measures for duration of the run.
e) The run will end when depth change has been stopped and recovery is assured.
f) Continue to execute the remaining the dive, rise and/or rudder jams.

The following data shall be recorded or calculated from recorded data:

a) Submarine initial speed.
b) Time elapsed from ‘execution’ of manoeuvre.
c) Shaft RPM.
d) Submarine depth.
e) Submarine pitch and roll.
f) Dive/rise/rudder angle.
g) Aft control surface angles.
h) Hydroplane angles.

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ANNEX B

CORRECTING TURNING CIRCLE PLOT FOR DRIFT

B.1 Introduction

The turning circle plot obtained from global positioning systems, or underwater tracking ranges, show the submarine's course over the ground or sea floor. This course will consist of the actual manoeuvring of the submarine and the effect on the submarine by current.

The drift effect must be removed, so as to obtain the actual course undertaken by the submarine.

B.2 Method

a) Determine turning circle as detailed in section A.8.
b) The turning circle test procedure requires that the test be continued until the heading changes 720 degrees. This provides 360 degrees of overlapped course. Part of this overlap will have a steady turning rate for both tracks.
c) For the heading change with time data, identify the points with a heading change of 170, 340, 530, and 700 degrees. Also, determine the time to reach these points and plot them on the original turning circle plot as shown in Figure B1.
d) Connect the plotted points. The length of the connections will be proportional to the distance the ship drifted during a full turn. The proportionality constant will be the scale of the plot.
e) The direction of the connection between the points will be the direction of drift relative to the base course. This should be indicated on the plot along with the drift distance.
f) To determine the rate of drift, calculate the time difference between the connected points (time to turn 360 degrees). Then divide the drift distance by the time difference to obtain the rate of drift expressed in millimetres of plot per second.
g) To plot the corrected turning circle, determine the elapsed time since “execute” for each plotted point of the original track.
h) Multiply the elapsed time from “execute” by the drift rate to obtain the drift distance for each point.
i) Using the “execute” point as the origin, lay off a line extending from each original point in a direction opposite the direction of drift for point after ”execute” and in the direction of drift for points before execute.
j) Mark off on these lines a distance representing drift for each point. The drift distance for each plot is equal to the drift velocity (mm/s on the plot) multiplied by the time elapsed since the “execute” command was called to reach the given point. These are the new points defining the track corrected for drift.
k) Determine the best fit centre for the new points that are in the portion of track that has a steady turning rate.
l) Draw the best fit circle about this centre.
m) Fair a line through the remaining points including ta few prior to “execute” to redefine the base course.
n) From the scaled plot, determine all necessary dimensions as required by the test procedure.

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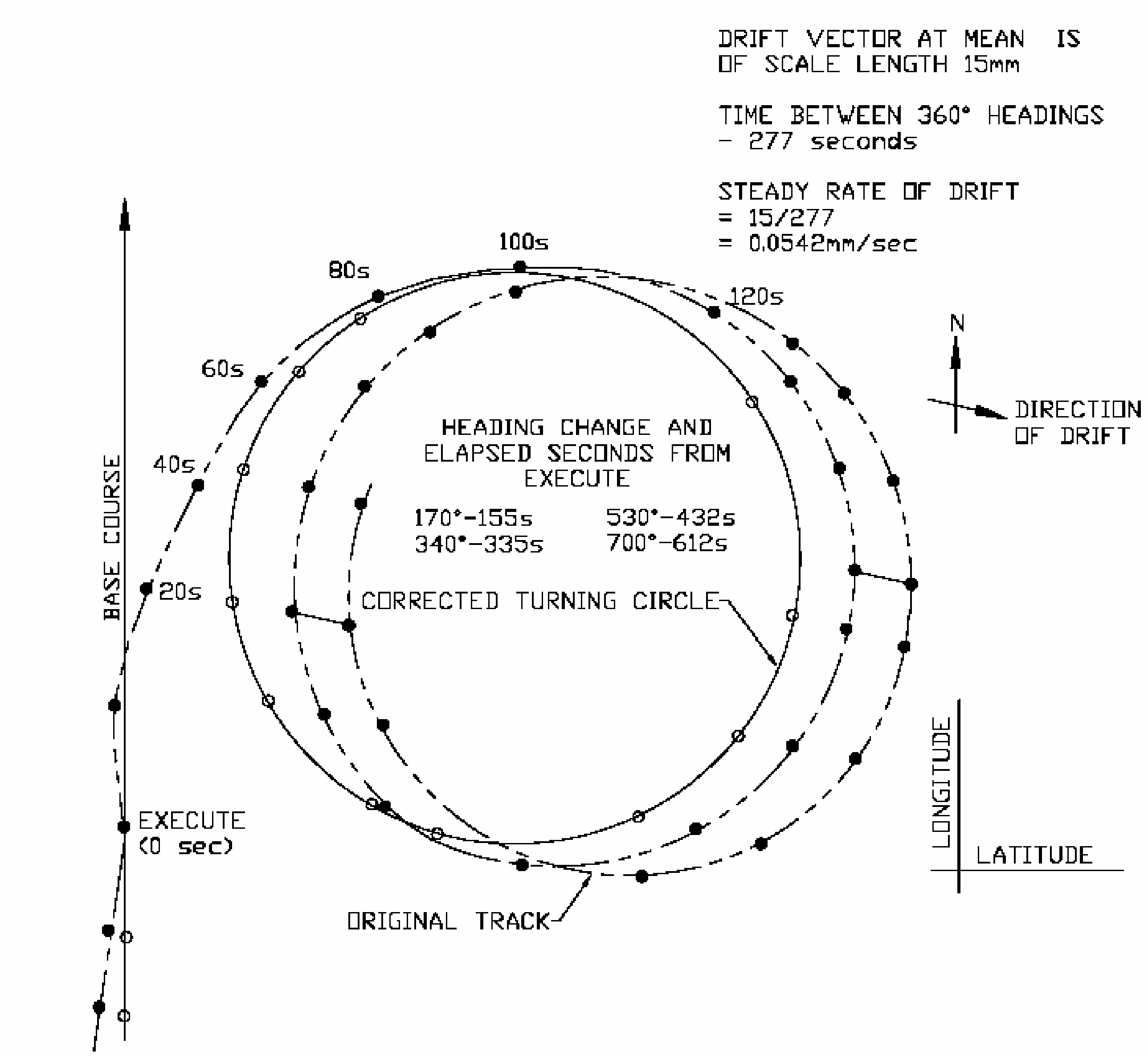

Figure B1: Correcting Turning Circle For Drift

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