# INTERNATIONAL STANDARD

# IEC 62065

**Maritime navigation and radiocommunication equipment and systems –
Track control systems –
Operational and performance requirements,
methods of testing and required test results**

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First edition
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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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# SOMMAIRE

INTERNATIONAL ELECTROTECHNICAL COMMISSION
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## MARITIME NAVIGATION AND
## RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS –
## TRACK CONTROL SYSTEMS –

### Operational and performance requirements,
### methods of testing and required test results

## FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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International Standard IEC 62065 has been prepared by IEC technical committee 80: Maritime navigation and radiocommunication equipment and systems. It was developed in cooperation with ISO TC8 SC6.

The text of this standard is based on the following documents:

| FDIS | Report on voting |
|------|------------------|
| 80/331/FDIS | 80/339/RVD |

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A, G and I form an integral part of this standard.

Annexes B, C, D, E, F, H and J are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2006. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

# MARITIME NAVIGATION AND RADIOCOMMUNICATION EQUIPMENT AND SYSTEMS – TRACK CONTROL SYSTEMS –

## Operational and performance requirements, methods of testing and required test results

## 1 Scope

This International Standard specifies the minimum operational and performance requirements, methods of testing and required test results conforming to performance standards adopted by the IMO in resolution MSC.74(69) Annex 2 Recommendations on Performance Standards for Track Control Systems. In addition it takes into account IMO resolution A.694 to which IEC 60945 is associated. When a requirement of this standard is different from IEC 60945, the requirement in this standard shall take precedence.

NOTE   All text of this standard that is identical to that in IMO resolution MSC.74(69), Annex 2, is printed in *italics* and the resolution (abbreviated to – A2) and paragraph numbers are indicated in brackets i.e. (A2/3.3).

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60945, *Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results*

IEC 61108-1, *Global navigation satellite systems (GNSS) – Part 1: Global positioning system (GPS) – Receiver equipment – Performance standards, methods of testing and required test results*

IEC 61108-2, *Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) – Part 2: Global navigation satellite system (GLONASS) Receiver equipment – Performance standards, methods of testing and required test results*

IEC 61162-1, *Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 1: Single talker and multiple listeners*

IEC 61162-2, *Maritime navigation and radio communication equipment and systems – Digital interfaces – Part 2: Single talker and multiple listeners, high speed transmission*

ISO 9000, *Quality management and quality assurance standards*

IMO Resolution A.694(17), *General requirements for shipborne radio equipment performing part of the GMDSS and for electronic navigational aids*

IMO Resolution A.830(19), *Code on alarms and indicators*

IMO MSC.74(69) Annex 2, *Recommendations on performance standards for Track control systems*

## 3 Definitions and abbreviations

For the purposes of this standard, the following definitions and abbreviations apply.

### 3.1 Definitions

**3.1.1**
*active track*
*track activated for track control*

**3.1.2**
**alarm**
audio and visual signal announcing a condition requiring attention. The audio continues until acknowledged. The acoustic noise pressure of the alarm is at least 75 dBA but not greater than 85 dBA at a distance of 1 m (IEC 60945). The visual indication continues until the alarm condition is removed

**3.1.3**
**along track speed control**
automatic control of the ship's speed during track control based on a pre-planned track

**3.1.4**
**assisted turn**
manoeuvre of a ship from one straight leg to the next automatically controlled by a pre-set radius or rate of turn but not based on the ship's position

**3.1.5**
*back-up navigator*
*any individual, generally an officer, who has been designated by the ships master to be on call if assistance is needed on the bridge*

**3.1.6**
**consistent common reference system**
sensor input data, providing identical and obligatory reference pertaining to position, course, heading, bearing, speed, velocity, etc. and horizontal datum to different sub-systems within an integrated navigation system

**3.1.7**
**course**
for marine navigation, course is the horizontal direction in which a vessel is steered or intended to be steered, expressed as angular distance from north, usually 000° at north, clockwise through 360°.[1]

**3.1.8**
**course difference limit**
maximum difference between track course and heading before an alarm is activated

**3.1.9**
*cross track distance* **(also known as cross track error)**
*perpendicular distance of the ship from the track* including direction (negative if the ship is left of the intended track)

**3.1.10**
*cross-track limit*
*maximum cross track distance before an alarm is activated*

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[1] 360° is indicated as 000°.

**3.1.11**
*curved track*
*non-straight track between two straight legs*

**3.1.12**
**fall-back arrangements**
automatic reaction of the system to a failure to provide the best possible functionality

**3.1.13**
*FROM-waypoint*
*the last passed waypoint*

**3.1.14**
**great circle sailing**
sailing on the intersection of the earth surface and a plane containing the points A, B and the centre of the sphere

**3.1.15**
**heading**
the horizontal direction in which a ship actually points or heads at any instant, expressed in angular units from a reference direction, usually from 000° at the reference direction clockwise through 360° [2]

**3.1.16**
*heading control*
*control of the ship's heading*

**3.1.17**
*heading monitor* **function**
*Monitoring the actual heading sensor by an independent second source*

**3.1.18**
**indication**
visual display of any message to the user which may be accompanied by a low intensity acoustic signal to gain attention

**3.1.19**
*leg*
*line between two waypoints* defining the track

**3.1.20**
*main conning position*
*place on the bridge with a commanding view providing the necessary information and equipment for the conning officer to carry out his functions*

**3.1.21**
**minimum manoeuvring speed for track control**
lowest fore/aft speed through the water at which the track control system is capable of maintaining its performance within the specified accuracy limits. The value depends on the ship's design and loading and on the present environmental conditions

**3.1.22**
*NEXT-waypoint*
*the waypoint following the TO-waypoint*

_____

[2]   360° is indicated as 000°.

**3.1.23**
*override facility*
*a control to perform the override function*

**3.1.24**
*override function*
*an intentional fast change-over from automatic to temporary manual control*

**3.1.25**
*position monitor* **function**
*monitoring the actual position sensor by an independent second source*

**3.1.26**
**primary position-fixing system**
electronic position-fixing system (EPFS) used for track control and approved by the International Maritime Organization (see 4.1.1.3)

**3.1.27**
*radius of turn*
*radius of a curved track*

**3.1.28**
*rate of turn*
*change of heading per time unit*

**3.1.29**
**rhumb line sailing**
sailing on a line on the surface of the earth making the same angle with each meridian crossed

**3.1.30**
**ship manoeuvring characteristics**
these define the range-of-manoeuvre possible for the ship (for example, maximum turn rate, minimum turn radius, maximum turn acceleration and deceleration)

**3.1.31**
**single operator action**
an action which is directly accessible and immediately effected, for example by:

–  dedicated controls;

–  primary access in an associated menu;

–  alternative solutions which meet the functional requirements

**3.1.32**
**speed**
the absolute value of velocity. May either be the ship's speed through the water, or the speed made good over the ground

**3.1.33**
**steering mode selector**
a switch provided for the selection of manual steering modes and automatic steering devices

**3.1.34**
**temporary track**
a track that originates at the current position of the ship and joins the pre-planned track. The temporary track may include temporary waypoints which can be identified as different from the waypoints of the pre-planned track

**3.1.35**
*TO-waypoint*
*the waypoint which the ship is approaching*

**3.1.36**
*track*
*path to be followed over ground*

**3.1.37**
*track control*
*control of the ship's movement along a track,* where corrections made by the controller to compensate for wind, drift and other influences, are based on the cross track error and not only on the bearing to the destination waypoint (TO-waypoint)

**3.1.38**
*track course*
*the direction from one waypoint to the next*, a constant course on a rhumb line track and a varying course on a Great Circle track

**3.1.39**
**track planning**
preplanning of a track including waypoint data and optionally speed data, commonly referred to as passage planning or voyage planning

**3.1.40**
**waypoint**
a geographic position together with its associated data

**3.1.41**
*wheel-over-line*
*the line,* for example, perpendicular to the course line, *where the ship has to initiate a curved track* to eliminate the effect of any offset with respect to the new course, taking into consideration the distance required for the ship to build up the necessary turn rate

**3.2  Abbreviations**

| | |
|---|---|
| ~A | Not applicable for category A systems |
| CCA | Course change alarm |
| CCI | Course change indication |
| DGPS | Differential GPS |
| DR | Dead reckoning |
| ECCI | Early course change indication |
| ENC | Electronic navigational chart |
| EPFS | Electronic position fixing system |
| EUT | Equipment under test |
| GC | Great circle |
| GLONASS | Russian Ministry of Defence global navigation satellite system |
| GPS | Global positioning system |
| HSC | High speed craft |
| INS | Integrated navigation system |
| NA | (Back up) Navigator alarm |
| RL | Rhumb line |
| SDME | Speed and distance measuring equipment |
| WOT | Wheel-over time |

## 4  Requirements and application of this standard

a)  (A2/1)  *Track control systems in conjunction with their sources of position, heading and speed information are intended to keep a ship automatically on a pre-planned track over ground under various conditions and within the limits related to the ship's manoeuvrability. A track control system may additionally include* or be combined with

   –  *heading control;*

   –  along-track speed control (see annex B).

b)  Planning the track by waypoints may be performed

   –  as part of the track control system, or

   –  by importing waypoint or track data.

c)  This standard applies for track control systems which can exchange data with a heading sensor, speed sensor, EPFS and/or heading controller but excludes waypoint data exchange.

d)  If a track control system automatically receives additional data, including waypoints, from other navigational aids, the requirements of IEC 61924 for this data exchange shall also apply.

e)  If a track control system is integrated into an INS, the corresponding requirements of INS (as defined in IEC 61924), for example concerning

   –  track planning by waypoints,

   –  data transfer of safety-checked waypoints and

   –  monitoring of navigational safety for example by charts

   shall apply.

f)  Track control does not necessarily require that ENC or other geographic data such as shallow area information be taken into consideration by the track control system.

g)  (A2/2.1)  *These* IMO *Performance Standards are applicable for track control systems working*

   –  *at ship's speed from minimum manoeuvring speed up to 30 knots; and*

   –  *at ship's maximum rate of turn not greater than 10°/s.*

h)  These performance standards do not apply to HSC as defined by SOLAS chapter 10.

i)  (A2/2.2)  *Track control systems fitted on ships* shall *meet all requirements of the* IMO *Performance Standards* (MSC.74(69) Annex 2 Recommendations on Performance Standards for Track Control Systems) *relating to straight tracks. Systems fitted on ships requiring curved track control* shall *additionally meet all the requirements relating to curved tracks*.

j)  This standard applies to three categories of track control systems:

   Category A:     Single straight leg track control or multiple straight leg track control without assisted turns between legs;

   Category B:     Multiple straight leg track control with assisted turns between legs;

   Category C:     Full track control on straight legs and turns.

k)  Some requirements contained in this clause cannot be verified by objective measure-ments. The manufacturer shall declare that compliance to these requirements is achieved and shall provide relevant documentation. The declaration(s), documentation and, where necessary, the equipment shall be checked. The manufacturer shall also declare the general hardware and functional composition of the equipment and the relevant category of IEC 60945 for each unit.

## 4.1 Operational requirements

### 4.1.1 Functionality

#### 4.1.1.1 Track control steering modes

(A2/5.1.1)   *A track control system* shall *be able to steer the ship from its position*

.1   *to a single waypoint; or*

.2   *along a track containing a sequence of waypoints*

using rhumb line or great circle sailing*.*

#### 4.1.1.2 Starting requirements

(A2/5.1.2)   *The system* shall *allow the officer of the watch (user) to start or restart track control only if*

– the pre-planned track has been checked for plausibility and correctness of geometric and ship dependent limits before becoming the active track

and if

– *the ship's position* relative to the selected track,
– *the difference between track course and actual heading,*
– *the ship's manoeuvrability,*

*will result in a safe approach manoeuvre to the track.* A safe approach manoeuvre is a planned manoeuvre which is within the manoeuvring characteristics of the vessel and which does not result in an unexpected turning direction.

For this purpose, the system shall allow the user at least one of the following options:

a)  to select the TO-waypoint or a leg on a pre-planned track and to select the maximum allowable difference between the bearing to the TO-waypoint and the actual heading; or

b)  to define a temporary track to go to the pre-planned track. The temporary track shall meet all ship manoeuvring characteristics which apply to a pre-planned track (~A) .

#### 4.1.1.3 Primary position-fixing system

(A2/5.1.3)   *The primary position-fixing system used for track control* shall *be an electronic position-fixing system (EPFS) approved by the* International Maritime *Organization.*

#### 4.1.1.4 Position monitoring

(A2/5.1.4)   T*he ship's position* shall *be continuously monitored by a second* or additional *independent position source.* [3] If the ship is fitted with a second EPFS and position is available from this EPFS its position shall be used for position monitoring. Otherwise, estimated position by dead reckoning (DR) as a minimum shall be used as the second position source for position monitoring. The DR position shall be derived from a shipborne heading sensor and a speed and distance measuring equipment (SDME). Means shall be provided to adapt the acceptable deviation to the required steering accuracy. *This monitoring need not be an integral part of the track control system.*

#### 4.1.1.5 Early course change indication (~A)

A graphical description of the sequences described here is given in annex A.

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[3] For example, a secondary GPS may be used to monitor a primary GPS.

(A2/5.1.5)  *In the case of track control by a sequence of waypoints, a* confirmable *'early course change indication'* shall *be given* up to 5 min, and *no later than 1* min, *before the wheel-over line.*

*The system* shall *provide means for the officer of the watch* (user) *to confirm the* 'early *course change* indication*'* before *wheel-over.*

### 4.1.1.6  Actual course change and confirmation (~A)

A graphical description of the sequences described here is given in annex A.

a)  (A2/5.1.6.1)  *In the case of track control by a sequence of waypoints* and if the *'early course change indication'* was confirmed a confirmable course change indication shall be given at between 30 s to 1 min [4], at the earliest, before *the wheel-over line.*

If the *'early course change indication'* has not been confirmed, a confirmable course change alarm shall be given between 1 min [5] and no later than 30 s before the wheel-over line.

b)  (A2/5.1.6.2)  *The system* shall *provide means for the officer of the watch* (user) *to confirm* or acknowledge *the course change* indication or course change alarm at or before wheel-over.

c)  (A2/5.1.6.3)  *With or without the confirmation, the ship* shall *follow automatically the track.*

d)  (A2/5.1.6.1)  If the course change indication has not been confirmed by or *at wheel-over line* then *a* course change *alarm* shall *be given* instead.

e)  (A2/5.1.6.4*)  If the actual course change* indication or *the actual course change alarm is not confirmed by the officer of the watch* (user*) within 30 s* before or after the *wheel-over* line, *a back-up navigator alarm* shall *be given.*

### 4.1.1.7  Change of waypoints

(A2/5.1.7*)  In the case of track control by a pre-planned sequence of waypoints, it* shall *not be possible to modify the TO-waypoint, the FROM-waypoint and* (~A) *the NEXT-waypoint of* the active track and their relevant associated waypoint data *while in the track control mode without creating a new track and until:*

a)  the pre-planning of the new track is completed; and

b)  *the starting requirements* (4.1.1.2) *are fulfilled.*

### 4.1.1.8  Turn performance (~A)

(A2/5.1.8*)  The track control* shall *enable the ship to sail from one leg to another by turns based:*

a)  on a preset turn radius; or

b)  *on a radius calculated on the base of a preset rate of turn* and the planned speed; and

*within the turning capability of the ship.*

### 4.1.1.9  Adaptation to steering characteristics

(A2/5.1.9)  *The track control* shall *be capable of manual or automatic adjustment to different steering characteristics of the ship under various weather, speed and loading conditions.*

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[4]  The preceding indication shall last at least 15 s before this indication is triggered.

[5]  The preceding indication shall last at least 15 s before this indication is triggered.

### 4.1.1.10 Permitted tolerance

The quality of the track control shall be so that overshoot, oscillation and constant track deviation are within tolerable limits both for straight and curved tracks.

(A2/5.1.10) *Means* shall *be incorporated to prevent unnecessary activation of the rudder due to normal yaw or sway motion,* sensor data resolution *and statistically scattered position errors.*

For systems which include great circle sailing, the calculated great circle approximation of the planned track shall not differ by more than 250 m from the mathematical calculation based on geodetic solutions.

NOTE   Appropriate solutions may be found in – T. Vincenty, Direct and inverse solutions of geodesics on the ellipsoid, *Survey Review* No 176 April 1976 (pages 88-93) Published by: The Commonwealth Association of Surveying and Land Economy, c/o Faculty of the "Built" Environment, University of West England, Cold Harbour Lane, Bristol, BS16 1QY, UK.

### 4.1.1.11 Override function

(A2/5.1.11)   A *track control system* shall *be able to accept a signal from the override facilities to terminate track control mode and switch to these override facilities.* After change-over to override, return to track control shall require user intervention (see 4.1.1.2).

### 4.1.1.12 Heading control mode

(A2/5.1.12)   A *track control system may be operated in heading control mode. In this case, the performance standards of heading control systems are to be applied.*

### 4.1.1.13 Manual change over from track control to manual steering

(A2/5.1.13.1)   *Change over from track control to manual steering* shall *be possible at any rudder angle.*

(A2/5.1.13.2)   *Change over from track control to manual steering* shall *be possible under any conditions, including any failure in the track control system.*

(A2/5.1.13.3)   *After change over to manual control, return to automatic control* shall *require operator* (user*) intervention* (see 5.3.5).

### 4.1.1.14 Manual change over from track control to heading control

This subclause only applies if the heading control is included in the track control system.

(A2/5.1.14.1)   *Any change over from track control to heading control* shall *be possible under all conditions* of normal operation.

(A2/5.1.14.2)   To maintain the course, *the heading control system* shall

– if sailing on a straight leg, *take over the actual heading as the preset heading,*

– if sailing on a curved path, *take over the actual heading as the preset heading.*

Optionally, if sailing on a curved path, based on an intended operator selection, the heading control system may take over the actual heading as the preset heading or complete the turn with the track course of the next straight leg as the preset heading (~A). This selection shall only be available after the turn has started and shall be clearly and unambiguously indicated.

(A2/5.1.14.3)   *Any switching back to track control* shall *require operator* (user) *intervention* (see 5.3.5).

#### 4.1.1.15  Steering mode indication

(A2/5.1.15)  *Adequate indication* shall *be provided to show which method of steering is in operation.* The indication of the steering mode is not required to be an integral part of the track control system, but shall be displayed at any work station of the track control system where the steering mode can be affected.

#### 4.1.1.16  Heading monitoring

(A2/5.1.16)  *Heading monitoring* shall *be provided to monitor the actual heading information by independent heading sources. The heading monitor is not required to be an integral part of the track control system.*

#### 4.1.1.17  End of track

a)   At the end of the pre-planned track, an 'end of track alarm' shall be generated.

b)   Until the user takes over, the system shall follow the track course of the final leg. As a minimum, the system shall maintain the actual heading.

For category A systems, the 'end of track alarm' shall be given at the end of each leg.

#### 4.1.2  Accuracy and performance constraint documentation

(A2/5.2.1)  *A short qualitative description of the effect of:*

   .1   *the accuracy of the sensors for position, heading and speed;*

   .2   *changes of course and speed;*

   .3   *actual speed through the water; and*

   .4   *environmental conditions*

*on the track control system* shall *be provided to the user in appropriate documentation*.

#### 4.1.3  Alarms and indications

All alarms and indications shall conform to the IMO code on alarms and indicators A.830(19). In addition, indications may be accompanied by a short low intensity acoustic signal.

#### 4.1.3.1  Failure or reduction in power supply

(A2/5.3.1)  *In case of failure or reduction of power supply to the track control system which effects its safe operation, an alarm* shall *be given*.

#### 4.1.3.2  Position monitoring alarm

(A2/5.3.2)  *An alarm* shall *be given when the position monitor detects a deviation* between the primary and secondary position-fixing system *beyond a preset limit*.

#### 4.1.3.3  Heading monitoring alarm

(A2/5.3.3)  *An alarm* shall *be given when the heading monitor detects a deviation beyond a preset limit.*

#### 4.1.3.4  Failure and alarm status of sensor

(A2/5.3.4)  *In the case of any failure or alarm status received from the position-fixing sensor, the heading sensor* or the speed sensor *in use:*

.1   *an alarm* shall *be generated at the track control system*;

.2   *the system* shall automatically *provide guidance to the user of a safe steering mode; and*

.3 *a back-up navigator alarm* shall *be given if a failure or alarm status is not acknowledged by the officer of the watch* (user) *within 30 s.*

*Fall-back procedures consequential to the failure and alarm conditions are stated in* 4.5.

### 4.1.3.5 Use of faulty signals

(A2/5.3.5*)* *It* shall *not be possible to select any sensor signal tagged with a fault or alarm status.*

### 4.1.3.6 Cross track alarm

(A2/5.3.6) *A cross-track alarm* [6]*,* shall *be provided when the actual position deviates from the track beyond a preset cross-track limit.*

### 4.1.3.7 Course difference alarm

(A2/5.3.7) A*n alarm* shall *be given if the actual heading of the ship deviates from the track course beyond a preset value.* The preset course difference limit shall be large enough to prevent unnecessary alarms.

### 4.1.3.8 Low speed alarm

(A2/5.3.8) *If speed through the water* in the fore/aft direction *is lower than a predefined limit necessary for steering the ship* under track control (minimum manoeuvring speed for track control) *an alarm* shall *be given.* This alarm is not required to be an integral part of the track control system.

### 4.1.3.9 End of track alarm

An alarm shall be given between 1 min and 5 min before the last waypoint of the active track is passed. A back-up navigator alarm shall be given if the alarm is not acknowledged within 30 s.

### 4.1.3.10 Track control stopped alarm

A track control stopped alarm shall be given if the system automatically switches over to heading control or is unable to continue operation. A back-up navigator alarm shall be given if the alarm is not acknowledged within 30 s (see 4.5.1).

## 4.2 Ergonomic criteria

### 4.2.1 Operational controls

### 4.2.1.1 Controls for track control

(A2/6.1.1) *Means* shall *be provided to:*

.1 *accept or calculate the course between subsequent waypoints; and*

.2 *adjust radius or rate of turn, all* user settable *track control related limits*, limits for *alarm functions and other control parameters*.

Means may include but are not limited to a keyboard, knob or input at a screen.

(See restrictions under 4.1.1.7.)

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[6] Category B systems shall monitor assisted turns. The cross-track deviation shall be measured at a minimum from the straight legs and cross-track alarms shall be given during manoeuvres. If this monitoring is not done, the system shall be a category A system and track control must stop at the end of the leg.

### 4.2.1.2 Change over controls

(A2/6.1.2.1)   *Track control to manual control*

*Changing over from track control to manual steering* shall *be possible by a single operator action.*

(A2/6.1.2.2)   *Track control to heading control*

*If the track control system can be operated with a heading control system, changing over from track to heading control* shall *be possible by a single operator action.*

(A2/6.1.2.3)   *Location of change over controls*

*The steering mode selector switch* or override facility, if installed, shall *be located at or in the immediate vicinity of the main conning position.*

### 4.2.2 Presentation of information

### 4.2.2.1 Continuously displayed information

(A2/6.2.1)   T*he following information* shall *be displayed clearly and continuously* in the vicinity of the main conning position; but not necessarily on a single display*:*

.1 *mode of steering;*

.2 *sources of actual* selected *position, heading and speed*;

.3 *status and failure* of selected heading, speed, and position *sensors (if any)* and their related monitoring functions*;*

.4 *track course and actual heading;*

.5 *actual position, cross track distance* including direction *and speed* over ground*;*

.6 *TO-waypoint and NEXT-waypoint;*

.7 *time and distance to TO-waypoint;*

.8 *next track course;*

.9 *selected track identification;* and

.10 optionally actual course over ground

For category B systems, an "assisted turn" indication shall be provided during course change manoeuvres.

*Items .4, .5, .7 and .8* shall *be displayed numerically.*

### 4.2.2.2 Information to be provided on demand

(A2/6.2.2)   *The following information* shall *be provided on demand:*

.1 *a list of pre-planned waypoints including*

  – *waypoint numbers,*

  – *co-ordinates,*

  – *courses and distances between waypoints,*

  – *turn radius or rates of turn* (~A)*;*

.2 *all user* settable *track control related limits and other preset control parameters*;

.3 geodetic datum in use.

The facility to provide the information in .1 is not required to be an integral part of the track control system.

### 4.2.2.3 Presentation

(A2/6.2.3) *Logically related values such as preset and actual values* shall *be displayed as a pair of data.*

## 4.3 Design and installation

The track control system shall be designed, manufactured and installed to approved international quality standards, such as ISO 9000.

## 4.4 Interfacing

Track control mode shall not be available unless required position and heading sensor data are valid and selected.

### 4.4.1 Sensors

(A2/7.1) *The track controller* shall *be connected to position, heading and speed sensors which meet the standards of the* International Maritime Organisation. *The heading measurement system* shall *be a gyro-compass* or equivalent.

### 4.4.2 Status information

(A2/7.2) *All connected sensors* shall *be able to provide status, including failure information.* The track control system shall check for received status and failure information. If a sensor used for track control does not provide status or failure information, the track control system shall perform corresponding plausibility checks.

### 4.4.3 Standards

(A2/7.3) *The track control system* shall *be capable of digital, serial communication with the ships navigation system and comply with the relevant international standards.*[7]

## 4.5 Fall-back arrangements

The associated alarms are stated in 4.1.3.

### 4.5.1 Failure of track control

If track control fails, a 'track control stopped' alarm shall be given.

(A2/8.1.1) *If the heading control is* installed and is *still available then the system* shall *automatically switch over to heading control and*

– if sailing on a straight leg, *take the actual heading as the preset heading for the heading control,*

– if sailing on a curved path, the turn shall be completed and the track course of the next straight leg shall be taken over as the preset heading (~A).

(A2/8.1.2) *If the heading control is not available the rudder angle* shall *be maintained,* i.e. stay in position. The rudder angle shall be set to a fixed angle in such a way that:

– if sailing on a straight leg, the actual heading shall be approximately maintained;

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[7] IEC 61162-1 and IEC 61162-2.

– if sailing on a curved path, the actual rate of turn shall be approximately maintained (~A).

For advice on failure of track control mode when dual heading controllers are installed, see annex C.

### 4.5.2 Failure of position sensor

If the primary position sensor has failed or is unavailable, then:

– the position sensor alarm shall be activated;
– the track control system shall automatically switch to heading control within 10 min of the failure having been detected and a "track control stopped" alarm shall be given. The system shall
    – if sailing on a straight leg, take the actual heading as the preset heading;
    – if sailing on a curved path, complete the turn and take the track course of the next straight leg as the preset heading (~A).

When at position failure condition and not switched to heading control system, then

– the track control system shall provide the estimated position of the ship by dead reckoning as a minimum and use it for track control;
– after 1 min or less, another alarm shall be activated giving the advice to switch to a valid and available position sensor, heading control or manual steering;
– even if acknowledged, this alarm shall be repeated every 2 min until action is taken by the user or the automatic change over has taken place.

### 4.5.3 Failure of the heading measuring system

If the heading sensor fails, then

– the 'track control stopped' alarm shall be activated, giving advice to the user to switch to manual control.
– (A2/8.2.1)   T*he actual rudder angle* shall *be maintained* (i.e. stay in position). The rudder angle shall be set to a fixed angle in such a way that
    – if sailing on a straight leg, the actual heading shall be approximately maintained;
    – if sailing on a curved path, the actual rate of turn shall be approximately maintained (~A).

### 4.5.4 Failure of the speed sensor

If the speed sensor in use has failed or is unavailable then

– the speed sensor alarm shall be activated;
– the track control system shall automatically switch to heading control within 10 min after the failure has been detected and a "track control stopped" alarm shall be given. The system shall
    – if sailing on a straight leg, take the actual heading as the preset heading;
    – if sailing on a curved path, complete the turn and take the track course of the next straight leg as the preset heading (~A).

When at speed failure condition and not switched to heading control

• the track control system shall provide the last plausible speed of the ship and use it for track control;
• after 1 min, or less, another alarm shall be activated giving the advice to switch to a valid and available speed sensor, heading control or manual steering;
• even if acknowledged, this alarm shall be repeated every 2 min until action is taken by the user or the automatic change over has taken place.

## 5  Test requirements and results

All tests in this section are intended to be executed in a laboratory environment with a simulator. Additional onboard tests may or may not be required.

### 5.1  General requirements

#### 5.1.1  Environmental tests

##### 5.1.1.1  General

The EUT shall meet the test requirements of IEC 60945. The equipment shall comply with the requirements of IEC 60945 that are appropriate to its category or alternatively, evidence of prior testing shall be supplied.

The manufacturer shall declare which equipment or units are ′protected′ or ′exposed′. The manufacturer shall declare any ′preconditioning′ required before environmental checks.

For the purposes of this standard, the following definitions shall apply for environmental tests:

**performance check**

a short functional check to show that the equipment under test is still operational without investigating all details of its functionality, for example power on equipment and activate any function

**performance test**

a detailed test of the equipment covering all functions provided. A performance test shall ensure that the full functionality is available under the present environmental conditions, power supply and input/output conditions, for example satisfactorily performing a subset of scenario 3

**inspection**

a visual check of the equipment or documentation

##### 5.1.1.2  Test site

Tests will normally be carried out at test sites, accredited by the type test authority. The manufacturer shall, unless otherwise agreed, set up the equipment and ensure that it is operating normally before type testing commences.

##### 5.1.1.3  Identification of the equipment under test (EUT)

The IMO performance standards for track control systems do not require distinct hardware components supporting distinct functions. It is up to the manufacturer to perform the different tasks for track control in possibly different physical and logical parts of its system. This may result in different layout solutions for the

– physical parts involved,

– logical parts involved,

– general data flow between physical and/or logical parts,

– sensor interfaces,

– locations of required functions,

– user access (human machine interface).

Therefore, the EUT′s special layout and its information flow have to be identified before it can be decided which tests are applicable. Identification should follow a functional approach in steps:

a) identify functions to perform different tasks of track control;

b) identify information flow between functions;

c) identify dependencies between functions;

d) identify in which parts of the system the required functions are performed.

Identification of functions can be taken from the functional model of an integrated navigation system that incorporates track control (track control affected parts in boxes with solid lines), see figure 1.



IEC 649/02
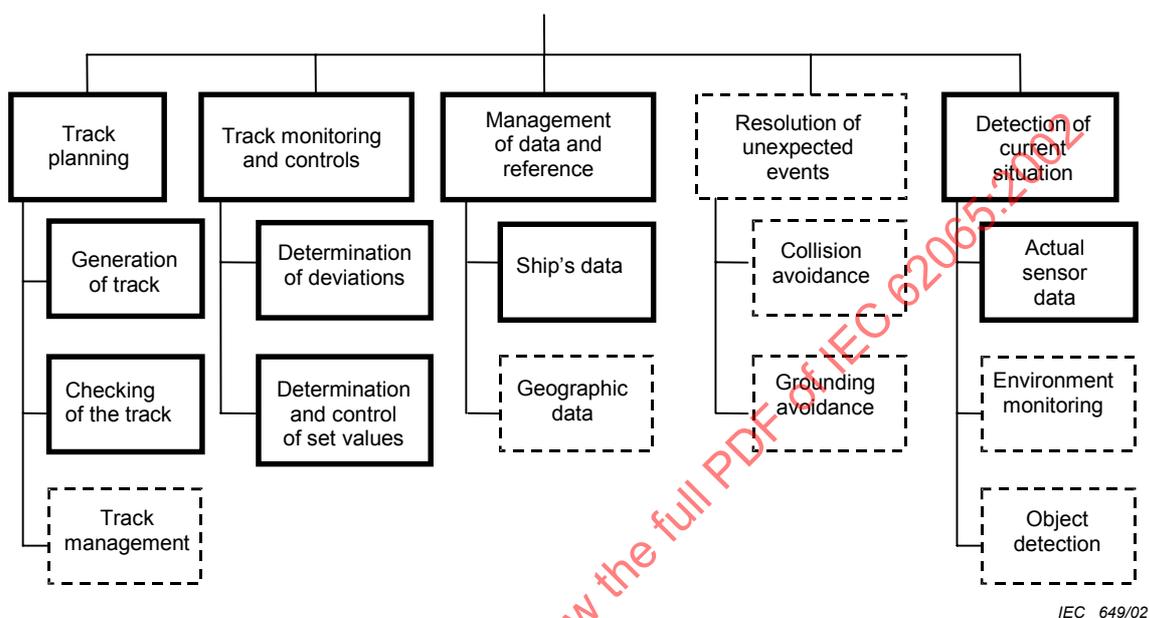
**Figure 1 – Functional model of track control as part of an integrated navigation system**

The information flow and the resulting dependencies between supported functions can be identified using the generic data flow diagram of the functional model (annex F). A general scheme of the EUT´s components should be used to apply functions and their information flow to physical parts of the system.

**5.1.1.4 Test of optional track control related modes**

All track control related modes offered by the manufacturer shall be exercised.

**5.1.2 Documentation**

**5.1.2.1 Equipment manuals**

Verify that adequate information is provided to enable suitable qualified members of the ship's crew to operate and maintain the equipment properly.

**5.1.2.2 Technical documentation for type approval**

Manufacturers documentation shall include:

– a test certificate according to IEC 60945;

– documentation of all system components and all relevant internal parts (parts lists, parts numbers, drawings, pictures, etc) according to IEC 60945 test certificates;

– wiring diagrams of system components;

– data flow diagrams of system components;

– documentation of external interfaces available;

– documentation of sensor data use, derived sensor data validity, ships parameters and reference parameters in physical and logical system components;

– layout of the minimum system configuration and all other system configurations possible relevant to track control;

– identification of relevant system components including names and numbers;

– identification of relevant software revision numbers;

– documentation specified by the IEC 61162 series for all relevant system components;

– documentation of manufacturer test results based on this standard where appropriate.

### 5.1.3 Declarations

Some requirements cannot be verified by objective measurements.

Verify that

– the declaration and relevant documentation comply with the requirements in clause 4; and

– the general hardware and functional composition of the equipment and the relevant category of IEC 60945 for each unit is declared (see clause 4).

### 5.2 Environment setup

Prepare the test environment (see figure 2) including necessary simulators and install the interfaces to the EUT. Verify that the 3 ship classes described below (5.2.1) are available in the simulator. Prepare the scenarios by loading the test tracks into the planning system which is used by the EUT.
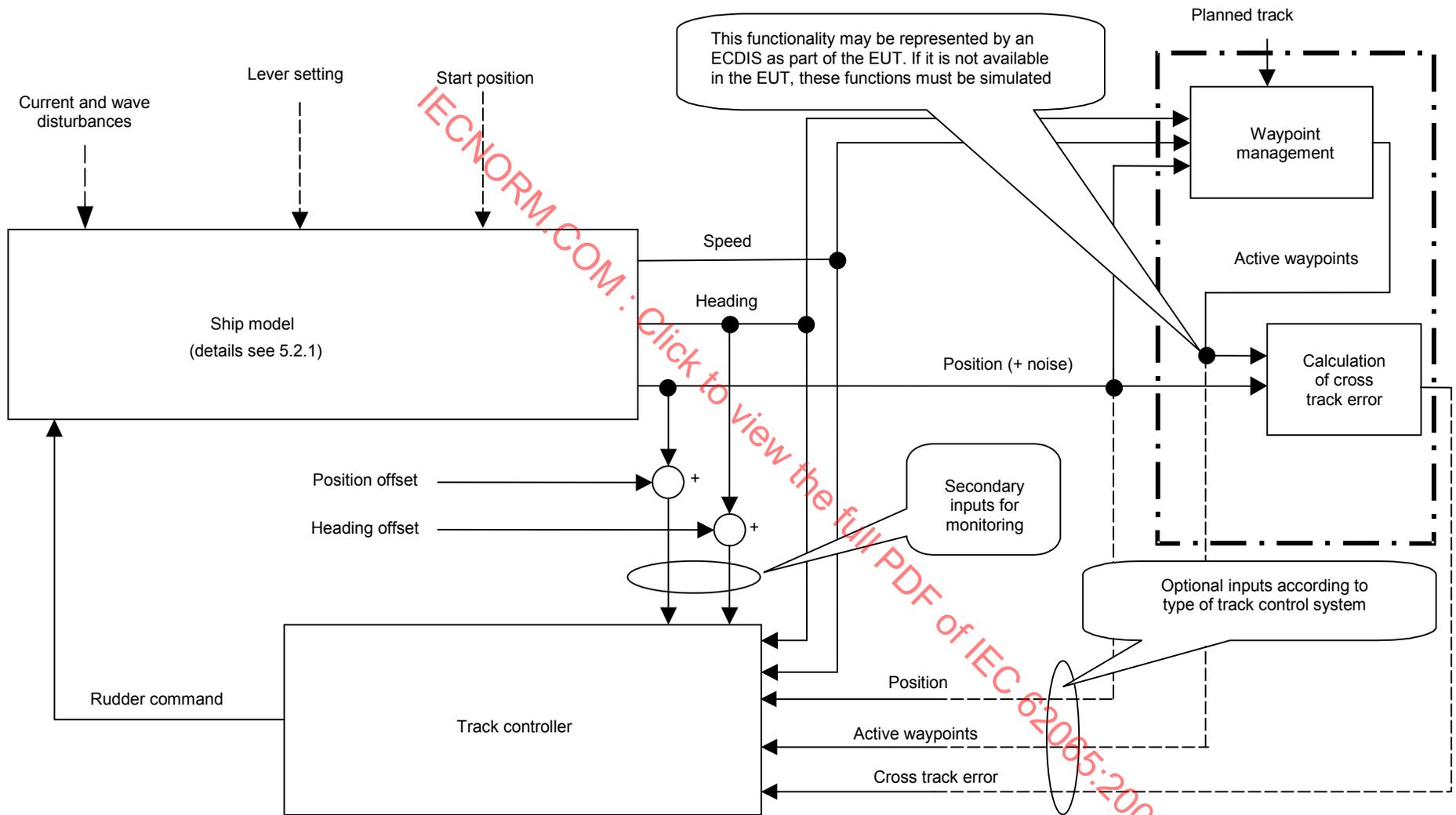
**Figure 2 – Block diagram**

### 5.2.1 Ship motion simulator

All functional tests of the track control system shall be performed using the ship motion simulator.

The ship's manoeuvrability shall be simulated in the range of

– ship class A: fast ferry, 30 knots,

– ship class B: container ship, 25 knots,

– ship class C: tanker, 10 knots.

The parameters of classes A, B and C are specified in annex I, table I.5.

These ship classes shall be used during the test of the track control system together with the scenarios defined in annex G.
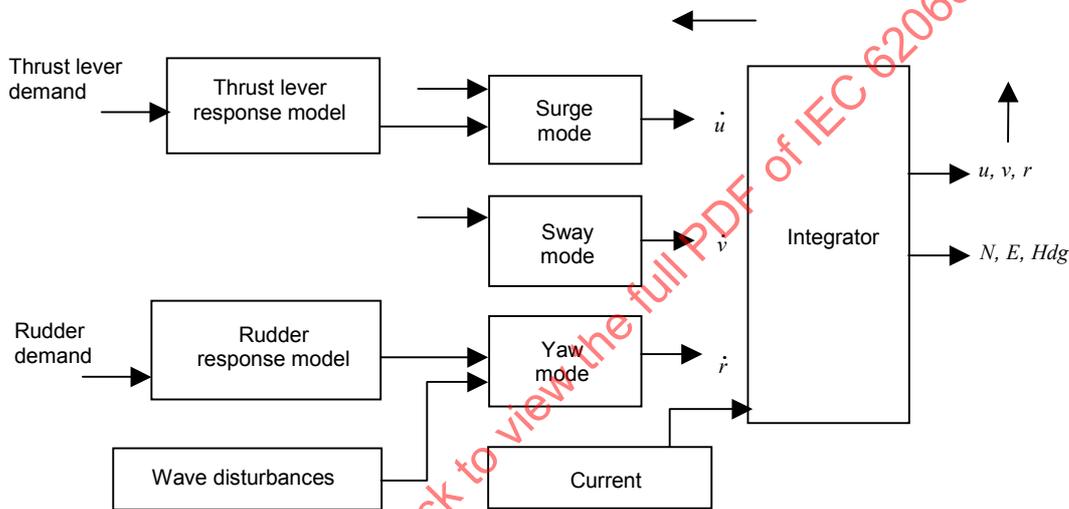


**Figure 3 – High level block diagram**

The mathematical model of the ship motion simulator is based on linear relationships between motions, propulsor and rudder control inputs, and the forces acting on the vessel. The model may be set up using eight coefficients, all of which are related in a simple way to ship characteristics which are readily measured. One of the parameters is a stability coefficient which allows the model to be set up to exhibit straight-line instability. Parameter lists to generate three different types of ships and a detailed description of the simulator is given in annex I.

The model shall accept data at a rate not less than specified in table 1:

**Table 1 – Simulator input rate**

| Input to simulator | |
|---|---|
| **Demand RPM** | **Demanded rudder** |
| 1 Hz | 10 Hz |

The model shall update data and produce messages at a rate no less than specified in table 2:

**Table 2 – Simulator output rate**

| Output of simulator | | | |
|---|---|---|---|
| **Position** | **Speed** | **Heading** | **Rudder feedback** |
| 1 Hz | 1 Hz | 10 Hz | 10 Hz |

Additional simulation facilities for the following signals and functions shall be provided for:

– position (second position source for monitoring, random noise model, failures),
– heading (second heading source for monitoring),
– steering mode selection, override tiller, alarm panel.

The noise model described in annex H shall be used for the simulation position.

The resolution and accuracy of the simulated signals shall be in accordance with the applicable IMO, IEC and ISO requirements. The signal simulation shall use the interface standard as defined in IEC 61162. Any other types of interfaces (for example, stepper or synchro, pulse log) shall also be tested.

### 5.2.2 Test scenarios

The following test scenarios shall be used for the performance test of the track control system.

**Scenario 1:**

Complex track at 0°N/0°E with ship class A.

**Scenario 2:**

Complex track at 0°N/180°E with ship class C.

**Scenario 3:**

Zigzag track at 65°N/0°E with ship class B.

**Scenario 4:**

Rhumb line/great circle Atlantic track (Boston to Rotterdam) with ship class B.

Details of the scenarios and graphs of the tracks are given in annex G.

### 5.2.3 Planning

The defined test scenarios shall be created by the planning system used by the EUT and transferred to the EUT or stored.

#### 5.2.3.1 Enter waypoints

Enter the waypoints of the test scenarios into the planning system. If necessary, they may be entered or transferred into other parts of the EUT.

### 5.2.3.2 Enter additional data

Enter additional data (limits, control data, ship's parameters, etc.) as defined in the operating manual of the EUT.

### 5.2.3.3 Store

Store the planned data so that they may be recalled and activated during execution of the test scenarios.

## 5.3 Test execution

All tests concerning track control on curved tracks shall only be executed with systems able to perform this function. Systems without curved track control (categories A and B) shall be tested performing the course changes manually according to the manufacturer's documentation.

### 5.3.1 Check the track

Before any track becomes the active track, perform a check of the track data according to the operating manual of the EUT.

### 5.3.1.1 Check the radius (4.1.1.2) (~A)

The purpose of this test is to verify that the track control system recognizes radius data that does not match the waypoint data (geometric check).

Method

Load the track data of scenario 1 and change or attempt to change the radius of waypoint 3 and 4 to 1,0 NM. Perform a check of the pre-planned track.

Result

Verify that indications are produced and that the changed track cannot be activated.

Restore the previous radius data and verify that no error messages are produced.

### 5.3.1.2 Check the waypoints (4.1.1.2, 4.1.1.7)

The purpose of this test is to verify that the track control system recognizes erroneous waypoint data (geometric check).

Method

Load the track data of scenario 1 and move or attempt to move the position of waypoint 3 to the position of waypoint 1. Perform a check of the pre-planned track.

Result

Verify that indications are produced and that the changed track cannot be activated.

Restore the previous waypoint data and verify that no error messages are produced.

### 5.3.1.3 Check against the ship dynamics (4.1.1.2) (~A)

The purpose of this test is to verify that the track control system detects a track that cannot be steered based on the ship's manoeuvrability (dynamic check).

Method

a) Configure the track control system to use ship class C parameters. Load the data of scenario 1 into the system. Perform a check of the pre-planned track.

b) Change the radius of waypoint 2 and 3 to 1,0 NM.

Result

a, b)   Verify that before or after activating track control, indications are produced that the track is not correct. Verify that no error messages are produced.

### 5.3.1.4 Invalidation of a modified track (4.1.1.7)

If the track control system has a facility to modify waypoints not included in the planning system or the planning system does not perform the check track function, this test applies.

Method

a) Change the radius of waypoint 8 in scenario 2 to 0,25 NM (~A).

b) Repeat for any other methods of changing the track, including any facility to replace the active track.

Result

a, b)   Verify that in all cases this modified track cannot become the active track.

### 5.3.1.5 Replace an active track without stopping track control (4.1.1.7)

If the track control system can replace the active track without stopping track control, this test applies.

Method

Place the ship's position between waypoint 6 and 7 of scenario 2 and activate track control.

Change a copy of scenario 2 by modifying the course between waypoints 6 and 7 so that the starting requirements are not fulfilled by the current ship's position.

Result

Verify that the system prevents the track copy from becoming active.

### 5.3.2 Execution of the scenarios

### 5.3.2.1 Start track control on the pre-planned track (4.1.1.2, 4.2.2)

This test only applies to systems that start track control directly, sailing on or near to the pre-planned track.

The purpose of this test is to verify that the track control system is able to activate a pre-planned track, to display the track-related data, to reject or to accept the activated track and to activate track control, if accepted.

### 5.3.2.1.1 Display of data

Method

a) Load the track of scenario 1 and set up the simulator accordingly. Set the simulated position on the leg between the first and second waypoint of the track. Set the ship's heading to 0° and the rudder to midships. Set the simulated speed according to the scenario.

b) Activate the pre-planned track.

Result

a, b)   Verify that graphic displays, if available, show the ship sailing on the first leg heading towards waypoint 2. Verify that specified information to be displayed continuously or on demand is presented correctly.

### 5.3.2.1.2 "Start track control" not accepted

Method

a) Set the heading to the track course and the simulated ship's position so that the cross-track difference to the track is beyond a preset limit.

b) Set the ship's position on the track and the simulated heading so that the course difference is beyond a preset limit.

c) If the EUT includes heading control, switch to heading control and repeat a).

Result

a, b, c)   Verify with each of the methods that track control cannot be started and that the system gives an indication of the reason.

### 5.3.2.1.3 "Start track control" accepted

Method

Set the simulated ship's position and heading in such a way that

– the cross-track difference to the track is below but close to the preset limit, and

– the course difference is below but close to the preset limit.

Result

Verify that the system accepts track control.

Verify that the track control system steers to the second waypoint. The system shall steer smoothly towards and then join the track.

### 5.3.2.1.4 Track modification (4.1.1.7)

Method

Attempt to modify the relevant data of the FROM-, TO- and (~A) NEXT-waypoint of the activated track during track control.

Result

Verify that this is not possible.

**5.3.2.2 Start track control using a temporary track (4.1.1.2, 4.2.2) (~A)**

This test only applies to systems capable of generating a temporary track.

The purpose of this test is to verify that the system or the user is able to generate a temporary track, to display the track-related data, to reject or to accept the temporary track and to start track control.

**5.3.2.2.1 Start track control and data display**

Method

a)  Load the track of scenario 1 and set up the simulator accordingly. Set the simulated position near but not on the track. Set the heading to 0° and the rudder to midships. Set the simulated speed according to the scenario.

b)  Activate the pre-planned track.

c)  Attempt to create a condition so that the temporary track does not fulfil the starting requirements and attempt to start track control.

d)  If track control has not been started, start track control with a temporary track which does fulfil the starting requirements.

Result

a)  Verify that the track control system or the user is able to generate a temporary track guiding to the pre-planned track. Verify that the system graphically displays the temporary track attaching to the pre-planned track. Verify that the temporary track can be accepted or rejected.

b)  Verify that the specified information to be displayed continuously or on demand is presented correctly.

c)  If this was successful, verify that track control cannot be started and the system gives an indication of the reason.

d)  Verify that

– track control can be started and that the system accepts the temporary track;

– the system turns towards the track course of the temporary track and then follows it;

– the track control system steers to and joins the pre-planned track.

**5.3.2.2.2 Temporary track modification (4.1.1.7)**

Method

Attempt to modify the FROM, TO and NEXT waypoint of the temporary track during track control along the temporary track.

Result

Verify that this is not possible.

**5.3.2.2.3 Pre-planned track modification (4.1.1.7)**

Method

Proceed along the temporary track on to the pre-planned track. Attempt to modify the relevant data of the FROM, TO and NEXT waypoint of the activated pre-planned track during track control.

Result

Verify that this is not possible.

### 5.3.2.3 Execute track control under undisturbed conditions

The following clauses define the details of the tests to be executed with each scenario under operationally normal and undisturbed conditions.

#### 5.3.2.3.1 Test using Scenario 1 (4.1.1.1, 4.2.2.1, 4.2.2.2)

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 1 with a class A ship and various turn rates/radii.

Method

Set the course difference limit to 15° and the cross-track limit to 35 m. Load the track of scenario 1 and set up the simulator and EUT accordingly. Start the simulation at the beginning of the first leg of the track.

Start track control and let the system follow the track until the last waypoint is passed.

At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows (~A).

Result

As the ship proceeds along the track, verify that:

– the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;
– the graphic screens, if available, display the ship sailing on the track;
– the displayed information is presented correctly, referencing the activated track and switch from leg to leg automatically;
– the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6 (~A);
– at the end of the track the system proceeds as required under 4.1.1.17.

Furthermore, if the system supports track control along curved tracks, verify that:

– the track graphics include the curved tracks presenting the correct radii;
– the course changes are executed using the correct radii.

#### 5.3.2.3.2 Test using scenario 2

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 2 with a class C ship and various turn rates/radii.

Method

Set the course difference limit to 15° and the cross-track limit to 100 m. Set up the simulator and the EUT according to scenario 2. Start the simulation at the beginning of the first leg. Start track control and let the system follow the track until the last waypoint is passed. At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows (see also 5.3.4.9) (~A).

Result

As the ship proceeds along the track, verify that:

– the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;

– the graphic screens, if available, display the ship sailing on the track;

– the displayed information is presented correctly, referencing the activated track and switch from leg to leg automatically;

– the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6 (~A);

– at the end of the track the system proceeds as required under 4.1.1.17.

Furthermore, if the system supports track control along curved tracks, verify that:

– the track graphics include the curved tracks presenting the correct radii;

– the course changes are executed using the correct radii.

### 5.3.2.3.3  Test using scenario 3

The purpose of this test is to verify that the EUT is able to perform track control according to scenario 3 with a class B ship and various turn rates/radii.

Method

Set the course difference limit to 15° and the cross-track limit to 60 m. Set up the simulator and the EUT according to scenario 3. Start the simulation at the beginning of the first leg. Start track control and let the system follow the track until the last waypoint is passed. At the end of each leg confirm/acknowledge the course change indications and alarms within the assigned time windows.

Result

As the ship proceeds along the track, verify that

– the ship's actual course and position do not deviate from the pre-planned track beyond the preset limits;

– the graphic screens, if available, display the ship sailing on the track;

– the displayed information is presented correctly, referencing the activated track and switch from leg to leg automatically;

– the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6 (~A);

– at the of the track the system proceeds as required under 4.1.1.17.

Furthermore, if the system supports track control along curved tracks, verify that:

– the track graphics include the curved tracks presenting the correct radii;

– the course changes are executed using the correct radii.

### 5.3.2.3.4  Test using scenario 4 rhumb line (RL)

The purpose of this test is to verify that the EUT is able to perform long term track control according to scenario 4 with a class B ship in rhumb line (RL) mode.

Method

Set the course difference limit to 25° and the cross-track limit to 200 m. Set up the simulator and the EUT according to scenario 4.

a) Start track control on the first leg in RL mode and let the system follow the track until waypoint 9 is passed. Confirm/acknowledge the course change indications and alarms within the assigned time windows (~A).

b) Let the system follow the leg from waypoint 9 to waypoint 10 (this can be done unattended). Stop track control before or at waypoint 10.

Result

a) Verify

   – the correctness of information on graphic displays, if available,

   – the correctness of specified track-related data during the test;

   – that the course change indications/alarms are given as specified in 4.1.1.5, 4.1.1.6 (~A).

b) Verify by recording or observation that the ship proceeds from waypoint 9 to waypoint 10 along a constant track course with a cross track deviation not greater than 50 m.

### 5.3.2.3.5 Test using scenario 4 great circle (GC)

This test is restricted to systems able to steer along a track in great circle (GC) mode.

The purpose of this test is to verify that the EUT is able to perform long term track control according to scenario 4 with a class B ship in great circle mode and that the system is able to switch over from rhumb line to great circle mode and vice versa.

Method

Set the course difference limit to the maximum specified by the manufacturer and the cross-track limit to 1 000 m. Set up the simulator and the EUT according to scenario 4. Set the leg from waypoint 13 to waypoint 14 to great circle mode.

a) Start track control at the end of the leg from waypoint 12 to waypoint 13 in rhumb line mode and let the system follow the track until waypoint 13. If the system does not switch automatically to great circle mode, select great circle mode manually.

b) Continue great circle track control for a minimum of 4 h.

c) Restart track control on the four great circle positions between waypoint 13 and waypoint 14.

d) Restart track control after setting the position before and the heading along the end of the great circle leg between waypoint 13 and waypoint 14 and let the system pass way-point 14. If the system does not switch automatically to rhumb line mode, select rhumb line mode manually.

Result

a) Verify

   – that the switch over from rhumb line to great circle is performed;

   – the correctness of the graphic displays, if available;

   – the indicated track-related data during the test are correct.

b) Verify that

- the course changes while the ship is sailing on the great circle leg;
- the tested part of the leg is sailed on a great circle according to the calculated courses of scenario 4 without track deviations greater than the test cross-track limit (by recording or observation).

c) Verify that

- the courses on the great circle approximation are correct.
- the calculated great circle approximation of the planned track does not differ by more than 250 m from the mathematically correct solution based on annex E.

d) Verify that

- the system is able to switch over from great circle to rhumb line mode automatically or manually after waypoint 14 has been passed;
- the tested part of the leg between waypoint 14 and waypoint 15 is sailed on a rhumb line according to the calculated course and with a cross-track deviation not greater than 50 m.

## 5.3.3 Execution of additional tests

### 5.3.3.1 Adaptation (4.1.1.9)

The purpose of this test is to verify that the EUT is able to adapt by manual or automatic means to varying speed and weather conditions. Note that the performance of the above tests covers the verification of system capabilities for different loading conditions. For systems requiring preconditioning, provide sufficient adaptation to the ships model in use before the test scenarios are performed.

The effects of speed variations and weather conditions to be tested are:

- influence of speed change during the turn;
- influence of current change on a straight leg;
- influence of current during the turn;
- influence of sea state during the turn;
- influence of sea state change on a straight leg.

Method

Load the track of scenario 3 and set up the simulator accordingly.

**Adaptation to intended speed change**

a) Set the simulated ship on the first leg at a distance of 2 NM to 3 NM from WP2 sailing a course of 040° at 10 knots. Start track control. After the turn has been initiated, increase the commanded speed to 20 knots.

b) Restart track control on the second leg at a distance of 3 NM to 4 NM from WP3 sailing a course of 140° at 20 knots. After the turn has been initiated, decrease the commanded speed to 7 knots.

**Adaptation to current change**

c) Restart track control on the second leg sailing a course of 140° at 20 knots. When the simulated ship is 4 NM to 5 NM from WP3, induce a simulated current of 5 knots perpendicular to the track.

d) Restart track control on the first leg at a distance of 2 NM to 3 NM from WP2 sailing a course of 040° at 20 knots. In the middle of the turn induce a simulated current of 5 knots northwards.

e) Restart track control on the second leg at a distance of 3 NM to 4 NM from WP3 sailing a course of 140° at 20 knots. In the middle of the turn, induce a simulated current of 5 knots northwards.

**Adaptation to sea state**

f) Restart track control on the first leg at a distance of 2 NM to 3 NM from WP2 sailing a course of 040° at 20 knots. Set the simulated sea state to 2 and complete the turn.

g) Restart track control on the second leg at a distance of 2 NM to 3 NM from WP3 sailing a course of 140° at 20 knots at sea state 2. In the middle of the leg, induce a simulated sea state of 5.

**Adaptation to loading conditions**

h) Check that the manufacturer's documentation includes the method for adaptation to different loading conditions and exercise this method on one leg of scenario 3.

Result

a to h) Verify that the track control system is able to adapt to the varying conditions by automatic or manual means and that it follows the track without exceeding the cross-track limit after the adaptation has been applied.

### 5.3.3.2 Rudder activity (4.1.1.10)

The purpose of this test is to verify that the EUT is able to prevent unnecessary activation of the rudder due to normal yaw motion, sensor data resolution and statistically scattered position errors.

Method

Load the track of scenario 3 and set up the simulator accordingly.

Set the simulated ship after waypoint 2 sailing a course of 140° at 20 knots.

Start track control and perform the following tests individually.

– Induce a periodical yaw motion using a sinus function with $f$ = 0,1 Hz and an amplitude of ±4° into heading input of the track control.
– Induce the following reduced resolution sensor inputs, one at a time
  - heading        1/6°,
  - speed          1/2 knots,
  - position data   1/100 min (18 m).
– Induce statistically scattered position errors as per annex H.

Result

Verify that the track control system is able to adapt to the disturbed environment by automatic or manual means and that it is following the track within the test track limit and without excessive activation of the rudder.

### 5.3.3.3 Ship steering bias (4.1.1.9)

The purpose of this test is to verify that the EUT is able to compensate for ship steering bias, such as asymmetries like hull flow and propeller effects.

Method

Load the track of scenario 3 and set up the simulator accordingly. Set the rudder offset to +2° simulating a steering bias. Set the simulated ship just after WP1 sailing a course of 040° at 15 knots. Start track control. Stop track control after 20 min.

Result

Verify by observation that the track control system is able to compensate for the ship steering bias.

### 5.3.4  Monitoring and alarms

All tests of operational alarms shall verify that these alarms, if acknowledged, remain as an indication while the alarm condition exists, and comply with 4.1.3.

After each test in this section, re-establish normal operation conditions for EUT.

### 5.3.4.1  Failure or reduction in power supply (4.1.3.1)

This test may be combined with environmental tests in section 5.1.1.

Method

a) Reduce the power supply of each component of the track control system successively below the limit specified by the manufacturer as the minimum for safe operation. In the absence of such data, limits according to IEC 60945 shall be used.

b) Switch off the power supply of each component of the track control system successively.

Result

Verify that an alarm is triggered by the track control system.

### 5.3.4.2  Position monitoring alarm (4.1.3.2)

Method

Supply a pair of position data to the position monitoring function (4.1.1.4) to be used with the track control system. Modify the primary data or secondary data in such a way that the positions differ from each other by more than the preset alarm limit.

Result

Verify that a corresponding alarm is given.

### 5.3.4.3  Heading monitoring alarm (4.1.3.3)

This test applies only if the heading monitoring function is an integral part of the track control system.

Method

Supply a pair of heading data to the heading monitoring function (4.1.1.16) to be used with the track control system. Modify the primary or secondary heading in such a way that the headings differ from each other by more than the preset alarm limit.

Result

Verify that a corresponding alarm is given.

### 5.3.4.4  Failure and alarm status of sensors (4.1.3.4, 4.4.2)

Method

Successively modify input data from the position-fixing sensor, the heading sensor and speed sensor in use for track control to simulate a sensor failure or an alarm status. If the EUT can accept position, heading or speed data from a sensor which does not provide status or failure information, modify the input data to a non-plausible value.

Result

Verify that an alarm sequence and corresponding indications are generated as specified in 4.1.3.4.

(See also test of fall-back procedures defined in 5.3.5.)

### 5.3.4.5  Use of faulty signals (4.1.3.5)

Method

Successively provide input data from the position-fixing sensor, the heading sensor, the speed sensor and any other sensor provided for track control in the system so that it is tagged with a failure status. Attempt to select the faulty sensor.

Result

Verify that it is not possible to select the sensor for track control purposes and that a status indication is generated.

### 5.3.4.6  Cross-track alarm (4.1.3.6)

Method

a) Modify the selected position so that a cross track distance greater than the preset cross-track alarm limit is generated.
b) Acknowledge the alarm and modify the selected position so that the preset cross-track alarm limit is not exceeded.

Result

a) Verify that a corresponding alarm is given.
b) Verify that the alarm status and its indication are cleared.

### 5.3.4.7  Course difference signal (4.1.3.7)

Method

a) Modify the selected heading input so that the preset course difference alarm limit is exceeded.
b) Acknowledge the alarm and modify the selected heading input so that the preset course difference alarm limit is not exceeded.

Result

a) Verify that a corresponding alarm is given.
b) Verify that the alarm status and its indication are cleared.

**5.3.4.8  Low speed alarm (4.1.3.8)**

This test applies only to systems in which the low speed alarm is an integral part of the EUT.

Method

a)  Reduce the selected speed input below the minimum speed for track control.
b)  Acknowledge the alarm and set the selected speed input to a value higher than the minimum speed for track control.

Result

a)  Verify that a corresponding alarm is given.
b)  Verify that the alarm status and its indication are cleared.

**5.3.4.9  End of track alarm (4.1.3.9)**

This test may be carried out simultaneously with other tests (see 5.3.2.3).

Method

Follow a pre-planned track until the last waypoint is passed with and without acknowledging the 'end of track alarm'.

Result

Verify that corresponding alarms are given as described in 4.1.3.9.

**5.3.4.10  Track control stopped alarm (4.1.3.10)**

Each of these tests is to be carried out in track control mode.

Method

a)  Create a failure condition other than sensor failures in the track control part of the system by any means which causes the system to switch automatically to heading control or renders it unable to continue in track control.
b)  Disconnect the selected position input from the track control system or define it as invalid.
c)  Disconnect the selected heading input from the track control system or define it as invalid.

Result

a, b, c)   Verify that a track control stopped alarm is given after application of each method by the track control system itself or that an external alarm device is triggered by the track control system as described in 4.1.3.10.

**5.3.4.11  Course change indications and alarms (4.1.1.5 and 4.1.1.6) (~A)**

The purpose of the following sequence of tests is to fully exercise the course change indication and alarm conditions (see 4.1.1.5, 4.1.1.6 and annex A).

The test shall be carried out using scenario 2.

After each test, normal operating conditions shall be re-established. Irrespective of any alarm sequence, the pre-planned track shall be maintained.

Method and result

### 5.3.4.11.1  First leg under test

With no confirmations of indications and no acknowledgements of alarms, verify that:

a)  ECCI occurs between WOT – 5 min and WOT – 1 min.
b)  CCA occurs at between WOT – 1 min and WOT – 30 s latest.
c)  NA is triggered at WOT + 30 s.

### 5.3.4.11.2  Second leg under test

Confirm ECCI before WOT – 30 s and verify that:

a)  CCI occurs at WOT – 30 s latest, do not confirm.
b)  CCA occurs at WOT, acknowledge before WOT+ 30 s.
c)  NA is not triggered.

### 5.3.4.11.3  Third leg under test

Confirm ECCI before WOT – 30 s and verify that:

a)  CCI occurs at WOT – 30 s latest, confirm before WOT.
b)  CCA does not start and NA is not triggered.

### 5.3.4.11.4  Fourth leg under test

Do not confirm ECCI and verify that:

a)  CCA starts at WOT – 30 s latest.
b)  Acknowledge CCA before WOT + 30 s.
c)  NA is not triggered.

### 5.3.4.11.5  Fifth leg under test

Confirm ECCI at once after it occurred and verify that:

a)  CCI starts at WOT – 30 s latest, do not confirm.
b)  CCA starts at WOT, acknowledge.
c)  NA is not triggered.

### 5.3.4.11.6  Sixth leg under test

Confirm ECCI before WOT – 30 s and verify that:

a)  CCI starts at WOT – 30 s latest, do not confirm.
b)  CCA starts at WOT do not acknowledge.
c)  NA is triggered at WOT + 30 s.

### 5.3.5  Fallback and manual change over

### 5.3.5.1  Failure of track control (4.5.1)

If a physically separated heading controller is included, the following tests shall be repeated with and without failure of heading control.

Method

a) Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and create a failure condition other than sensor failures that renders the track control system inoperative.

b) Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre and then switch off the power supply of the track control system or render it inoperative by any other means.

Result

a, b)　Verify that the system reacts as specified in 4.5.1.

### 5.3.5.2  Failure of position sensor (4.5.2)

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and perform the following tests.

Restart track control using scenario 3 and repeat the tests during a course change manoeuvre (~A).

Method

a) Switch off the selected position.

b) Tag the selected position input as invalid.

Result

a, b)　Verify that the system reacts as specified in 4.5.2.

### 5.3.5.3  Failure of the heading measurement system (4.5.3)

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a straight leg and perform the following tests.

Restart track control using scenario 3 and repeat the tests during a course change manoeuvre (~A).

Method

a) Switch off the selected heading sensor.

b) Tag the selected heading input as invalid.

Result

a, b)　Verify that the system reacts as specified in 4.5.3.

### 5.3.5.4  Failure of the speed sensor (4.5.4)

Select scenario 3 and start track control.

Method

a) Switch off the selected speed sensor.

b) Tag the selected speed input as invalid.

Result

a, b)　Verify that the system reacts as specified in 4.5.4.

### 5.3.5.5  Manual changeover from track control to manual steering (4.1.1.13, 4.2.1.2) (~A)

Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre for each of the following tests.

Method

a)  Switch over to manual steering. Repeat this test with a manoeuvre to the opposite direction.

b)  Create a failure condition which renders the track control system inoperative. Then switch over to manual steering. After 3 min with manual steering, remove the failure condition of the track control system.

Result

a, b)    Verify that

– the system reacts as specified in 4.1.1.13,

– track control cannot be resumed without user intervention, and

– that this can be done by a single operator action.

### 5.3.5.6  Manual changeover from track control to heading control (4.1.1.14, 4.2.2)

This test is only required for systems which include heading control.

Method

Select scenario 3 and start track control. Wait until the ship is performing a course change manoeuvre and then switch over to heading control. For category A systems, perform this test on a straight leg.

Result

Verify that

– the system reacts as specified in 4.1.1.14 including any options provided,

– track control shall not be resumed without user intervention, and

– this can be done by a single operator action.

### 5.3.6  Display of information

These tests may be combined with and verified during execution of the normal mode and failure mode tests.

### 5.3.6.1  Continuously displayed information (4.1.1.15, 4.2.2.1, 4.2.2.3)

Method

Locate the display of the information listed in 4.2.2.1.

Result

– Verify that the appropriate steering mode is displayed on any workstation of the EUT where the steering mode can be affected.

– Verify that an appropriate indication is displayed during assisted turns (category B).

- Verify that all information is displayed clearly and continuously on the main conning position.
- Verify that the items listed in 4.2.2.1 subclauses .4, .5, .7 and .8 are displayed numerically.
- Evaluate the layout of the information displayed.
- Verify that logically related values, such as preset and actual or all TO-/NEXT- data, are displayed as a pair of data or in logically related groups. [8]

### 5.3.6.2 Information to be provided on demand (4.2.2.2)

The information may be displayed on associated equipment.

Method

Locate the display of the information listed in 4.2.2.2.

Result

Verify that that this information is available on demand.

### 5.3.7 Operational controls (4.2.1.1, 4.2.1.2)

The previous tests have verified that the requirements of 4.2.1.1 have been met.

Method

Check the installation manual for intended locations of change over controls.

Result

Verify that the location complies with 4.2.1.2 (see also 5.3.5.5, 5.3.5.6).

---

[8] This is a subjective judgement and should only be used to point out severely illogical data arrangement, and should not be used to evaluate differences in implementation.

**Annex A**
(normative)
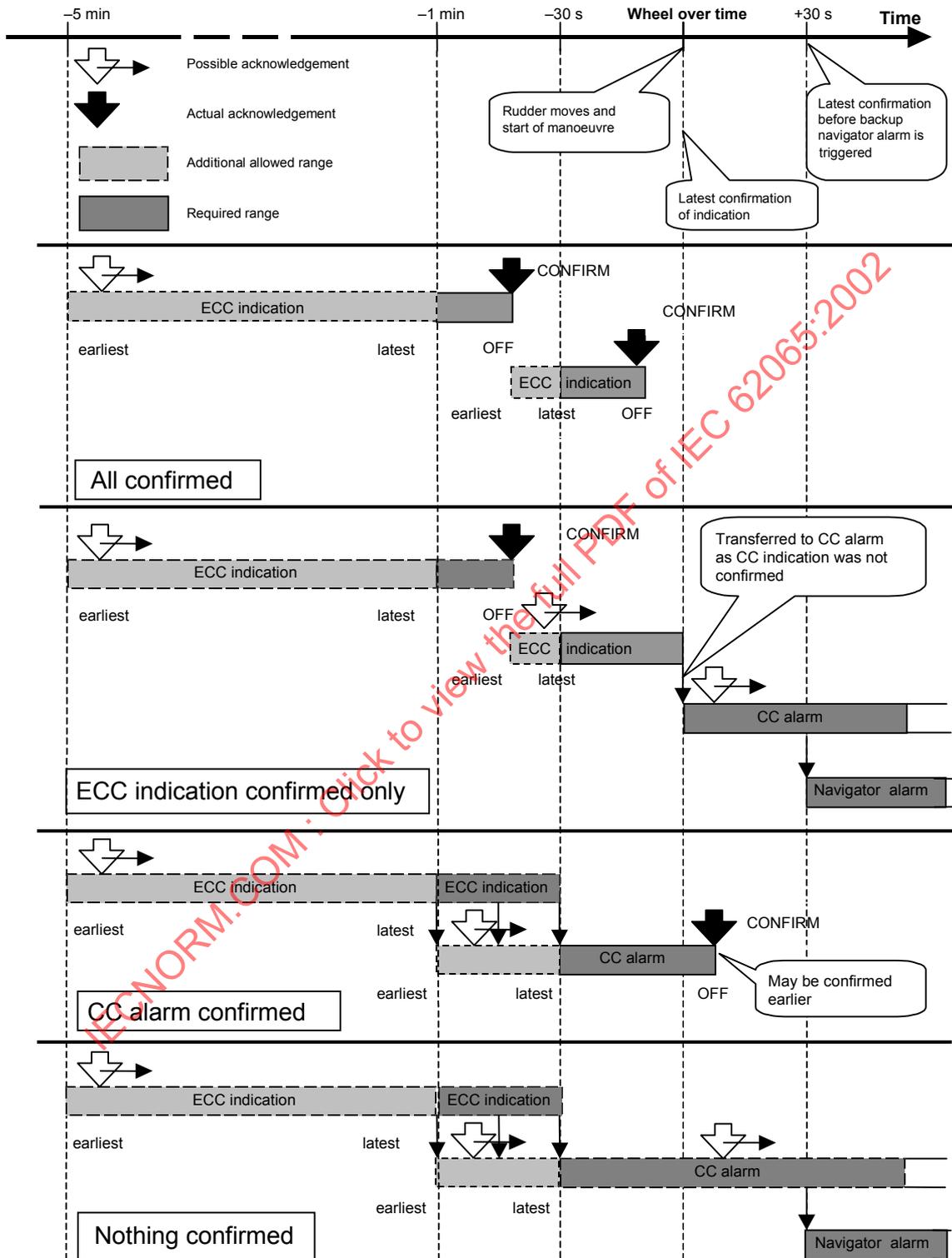


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NOTE   The CC alarm is triggered 30 s earlier when the ECC indication was not confirmed

**Figure A.1 – Sequence of course change indications and alarms (~A)**

## Annex B
(informative)

## Speed control

### B.1    General

A track control system may be augmented by speed control. Speed control uses the speed/time profile from a route plan to dynamically determine the commanded speed of the ship during the execution of the route. If an interface to the propulsion system is available, this commanded speed should be effected automatically.

Speed control may be applied without route information where the operator manually specifies the commanded speed.

If no propulsion system interface is available, speed control should be used in an advisory manner. It should determine and display actual speed-of-advance and the required speed-of-advance to meet the route's speed/time profile.

Track control systems including speed control shall be compliant with the relevant international standards.

### B.2    Planning

Speed control for a route requires that a speed/time profile be specified for the route. This may be in a variety of forms but is generally given by specifying leg speeds and/or waypoint arrival/departure times. If one or more arrival/departure time is specified along with leg speeds, the route has an absolute time reference. This is most often given as a departure time from the initial waypoint or an arrival time at the final waypoint.

For each leg, a minimum and maximum speed should be specified which would limit the acceptable speeds for that leg. Reasonable defaults for these are: the minimum speed allowed by track control and the full-ahead speed, respectively. The planning system should ensure that the specified speed/time profile be consistent and not violate the ship's allowed speed range.

### B.3    Execution – commanded speed generation

#### B.3.1    Required speed-of-advance

From the track control position source, the system may compute a speed-of-advance along the track. If the route has an absolute time reference, speed control should automatically determine adjustments to the planned speed required to satisfy the time profile. These adjustments would be constrained by the acceptable speed range for each leg. The resulting value is the required speed-of-advance. This should be used in an advisory mode or as an input to the propulsion control system.

#### B.3.2    Leg speed

From the route speed, profile leg speed should be used directly as the commanded speed.

### B.3.3    Operator-specified speed

The operator might wish to control speed apart from any route information. In this case, a manually-entered commanded speed would be specified.

## B.4    Execution – propulsion control

### B.4.1    Open-loop propulsion control

Using the commanded speed, an open-loop control would use an internal conversion function to determine the corresponding propulsion control order. No feedback of measured speed would be made to adjust the order.

### B.4.2    Closed-loop propulsion control

Using the commanded speed, a closed-loop control would use measured speed to adjust the propulsion control order until the commanded speed is attained.

## B.5    Execution – speed monitor

During execution where propulsion control is used, the actual speed should be monitored against the commanded speed.

## B.6    Displays

Speed control should display commanded speed, actual speed, source of actual speed, and, when a route is present, speed of advance.

## B.7    Failure and alarms

### B.7.1    Loss of speed sensor

A valid speed sensor is crucial to closed-loop propulsion control. An alarm should be given upon loss of the speed sensor and the system should fall back to open-loop propulsion control.

### B.7.2    Speed not controlled

If the speed monitor indicates that the actual speed deviates significantly from the commanded speed, an alarm should be given and closed-loop control should fall back to open-loop control.

### B.7.3    Time profile infeasible

If the speed required to satisfy the route time profile exceeds the leg speed constraints, an alarm should be given.

## B.8    Changeover controls and termination of automatic speed control

Changing from automatic to manual speed control should be possible under any condition, including failure in the automatic control system. The changeover controls should be located at or in the vicinity of the main steering position.

# Annex C
(informative)

## Track control systems with dual heading controllers

This annex includes specific advice for track control systems which include a primary heading controller and a back-up heading controller, both capable of being used for track control.

### C.1 Change over from active to back-up heading controller

– A change over from track control using the active heading controller to track control using the back-up heading controller should be possible at any time, including a failure of the active heading controller.

– The track control system should ensure that or be installed so that, the back-up heading controller affects a smooth take over. The back-up heading controller should not use any accumulated rudder bias or other parameter established prior to activation.

### C.2 Failure of track control

If the track controller fails, then a 'track control stopped alarm' should be given.

– If the active heading controller is still available, the system should automatically switch over to heading control using the active heading controller as in the corresponding paragraph of 4.5.1.

– If the active heading controller is not available, the system should allow a manual or automatic switch over to heading control using the back-up heading controller, when available, proceeding as in 4.5.1.

However, if the active heading controller fails in a system with a separate track controller and the back-up heading controller is still available, an alarm advising operator to switch to the back-up heading controller or manual mode should be given. If the operator switches to the back-up heading controller within 1 min, track control may continue. If the operator does not switch to the back-up heading controller before the timeout, a 'track control stopped alarm' should be given. Automatic switch over to the back-up heading controller may be provided with an appropriate indication to the operator.

## Annex D
(informative)

## Management of static and dynamic data

According to the functional model of track control (5.1.1.3 and annex F), the management of static and dynamic data comprises the handling of

– geographic (chart) data,

– ship´s data and reference parameters,

– planning data,

– control data,

– sensor data.

Track control requires a 'consistent common reference system' for all these types of data and information. The following guidelines are based on this condition.

### D.1    Management of geographic (chart) data

Geographic data which are processed by different functions within the system should be identical in amount, content and date of issue for the same area or if not, these should be marked as different, in one or more of these categories.

The geodetic datum of the geographic data used for voyage planning/track control, the geodetic datum of the position sensor used and the geodetic datum of other position-based functions should be identical or, if not, suitable functions to transform different position data into one common geodetic datum should be provided.

### D.2    Management of ships data and reference parameters

The different locations of antennas and other sensor receiving units should be transformed to a common reference location on the ship. This location should be predefined by the manufacturer or adaptable to the special conditions of each ship. In order to align different location information to a common reference location information, the consistent common reference system should be established.

All functions should use identical values for reference parameters of the same type.

### D.3    Management of track-related data (planning and control)

Depending on the capabilities of the used planning tool, different options for handling pre-planned and actual track limits are possible:

a)  all track-related data defined by means of the planning tool, are equal for all waypoints and legs and are unchangeable/changeable during track control;

b)  track-related data defined individually for different waypoints or legs by means of the planning tools and are individually changeable/unchangeable during track control;

c)  all track-related data defined by means of the planning tool are overruled by the track-related data defined by track control functions or may be changed during track control;

d)  the pre-planned track does not carry any additional track-related data, but these are defined by track control functions or may be changed during track control.

The track control system should be designed in such a way that the user gets full information about the sources of the track-related data in use for track control in every situation. Dependent on the solution used, any change of track-related data should be harmonized for all system components affected and displayed accordingly. If local track-related data of one or more of the system components are overruled by track-related data settings by other components, this should be brought to the attention of the user by appropriate means.

## D.4   Management of sensor data

Any kind of sensor data can be described by the following items:

– method of measurement and/or source of data (sensor or derived from different sources in a filter process),
– measured value,
– time of measurement,
– reference systems,
– validity of measured value,
– pre-processing of the measured value (for example smoothed values),
– error characteristics.

A data message should in general carry all of the items stated above except in configurations which use identical data for one particular item in each part of the system (note that this is not fully supported by the applying interface standard IEC 61162 series). The processing of sensor data should take all of these items into consideration as far as necessary for the particular task.

# Annex E
(informative)

## Limits

**Table E.1 – Limits**

| Clause/subclause | Item | Required | Recommended |
|---|---|---|---|
| 4 | Maximum manoeuvring speed | ≤30 knots | |
| 4 | Maximum rate of turn | ≤10°/s | |
| 4.1.1.2 | Ship's position relative to selected track for starting | | ≤1 NM |
| 4.1.1.2 | Course difference limit for starting | | ≤60° |
| 4.1.3.2 | Maximum position monitoring difference | | ≤1 NM |
| 4.1.3.3 | Maximum heading monitoring difference | | ≤25° |
| 4.1.3.6 | Maximum cross-track limit (for alarm) | | ≤5 NM |
| 4.1.3.7 | Maximum course difference limit (for alarm) | | ≤60° |

Additional parameters and limits are to be set by the manufacturer or the user taking safety related values into consideration. Those values which are the responsibility of the user shall have appropriate defaults where possible. Otherwise they shall be enforced by the system and/or clearly documented.

**Annex F**
(informative)

**Data flow diagram**



Outside of the Track Control System
—— Boundary ——
Inside the Track Control System

Sources for meteorological data

Sources for hydrographic data

Global meteorological data

Global hydrographic data

Shipping company

Global commercial voyage plan

Voyage planning 1

In use voyage plan

In use voyage plan

In use voyage plan

VTS

VTS Instructions

Set value rudder

Steering gear device

Voyage monitoring and control 2

Set value speed

Machinery

In use voyage plan

Corrections to voyage plans

In use parameters, geographical data

Preplanned own ship state variables

Preplanned parameters, geographical data

In use parameters, geographical data

Set values (collision avoidance, etc)

In use voyage plan

Resolving of unexpected events 4

Environment data, local objects

VTS - and / or AIS- Information

Own ship state variables

In use parameters, geographical data

Environment data, local objects

VTS - and / or AIS- Information

Own ship state variables

External data receivers
display devices, AIS, etc

Own ship state variables

Sensor data, local object data, etc

Own ship state variables

External data sources
radar / ARPA, sensors, AIS, etc

Weather conditions

Actual weather data

Sources for vessel parameters

Ships dimensions, manoeuvring characteristic etc

Sensor and system parameters

Management of data and reference parameters 3

Own ship state variables

Detection of the actual situation 5

Actual sea conditions

Sea conditions

Sources for navigational reference parameters

Geographical data

Sources for geographical data (nautical charts etc)

Parameter, geographical data

Local objects (direct visual observation)

Local environment

VTS Information

VTS

●······▶ No direct data transmission link required by this standard

●- - -▶ No direct access to control loops available

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# Annex G
(normative)

# Scenario definitions and plots

**Table G.1 – Scenario 1**

| Scenario 1: Complex track at 0/0 with ship class A (20 knots) | | | | | | |
|---|---|---|---|---|---|---|
| Waypoint No. | Latitude | Longitude | Track [deg] | Distance [NM] | Radius [NM] | Estimated R.o.T. [deg/min] |
| 001 | 00°01,000′ S | 000°01,000′ W | 000,0 | 2,00 | 0,25 | 80 |
| 002 | 00°01,000′ N | 000°01,000′ W | 090,0 | 2,00 | 0,25 | 80 |
| 003 | 00°01,000′ N | 000°01,000′ E | 315,0 | 1,41 | 0,10 | 200 |
| 004 | 00°02,000′ N | 000°00,000′ E | 225,0 | 1,41 | 0,20 | 100 |
| 005 | 00°01,000′ N | 000°01,000′ W | 135,0 | 2,83 | 0,60 | 33 |
| 006 | 00°01,000′ S | 000°01,000′ E | 270,0 | 2,00 | 0,20 | 100 |
| 007 | 00°01,000′ S | 000°01,000′ W | 045,0 | 2,83 | 0,25 | 80 |
| 008 | 00°01,000′ N | 000°01,000′ E | 180,0 | 2,00 | 0,40 | 50 |
| 009 | 00°01,000′ S | 000°01,000′ E | | | | |



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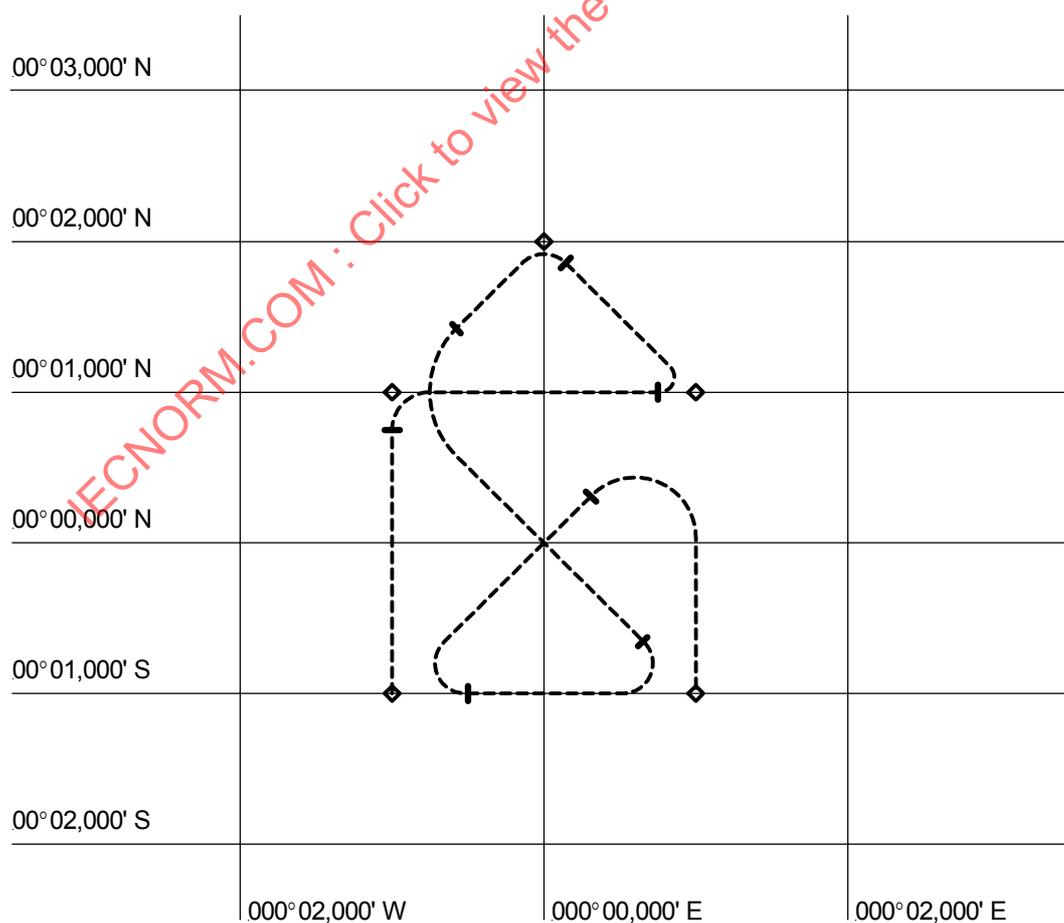
**Figure G.1 – Scenario plot 1**

**Table G.2 – Scenario 2**

| Waypoint No. | Latitude | Longitude | Track [deg] | Distance [NM] | Radius [NM] | Estimated R.o.T. [deg/min] |
|---|---|---|---|---|---|---|
| **Scenario 2:    Complex track at 0/180 with ship class C (10 knots)** | | | | | | |
| **001** | 00°03,000′ S | 179°57,000′ W | 000,0 | 6,00 | 1,00 | 10 |
| **002** | 00°03,000′ N | 179°57,000′ W | 270,0 | 6,00 | 1,00 | 10 |
| **003** | 00°03,000′ N | 179°57,000′ E | 045,0 | 4,24 | 0,50 | 20 |
| **004** | 00°06,000′ N | 180°00,000′ W | 135,0 | 4,24 | 1,00 | 10 |
| **005** | 00°03,000′ N | 179°57,000′ W | 225,0 | 8,49 | 1,50 | 7 |
| **006** | 00°03,000′ S | 179°57,000′ E | 090,0 | 6,00 | 1,00 | 10 |
| **007** | 00°03,000′ S | 179°57,000′ W | 315,0 | 8,49 | 0,75 | 13 |
| **008** | 00°03,000′ N | 179°57,000′ E | 180,0 | 6,00 | 1,25 | 8 |
| **009** | 00°03,000′ S | 179°57,000′ E | | | | |



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**Figure G.2 – Scenario plot 2**

**Table G.3 – Scenario 3**

| | Scenario 3:   Zigzag track at 65/0 with ship class B (20 knots) | | | | | |
|---|---|---|---|---|---|---|
| **Waypoint No.** | **Latitude** | **Longitude** | **Track [deg]** | **Distance [NM]** | **Radius [NM]** | **R.o.T. [deg/min]** |
| **001** | 65°00,000′ N | 000°20,000′ W | 040,2 | 6,54 | 0,50 | 40 |
| **002** | 65°05,000′ N | 000°10,000′ W | 139,8 | 13,09 | 1,0 | 20 |
| **003** | 64°55,000′ N | 000°10,000′ E | 040,2 | 6,55 | 2,0 | 10 |
| **004** | 65°00,000′ N | 000°20,000′ E | | | | |
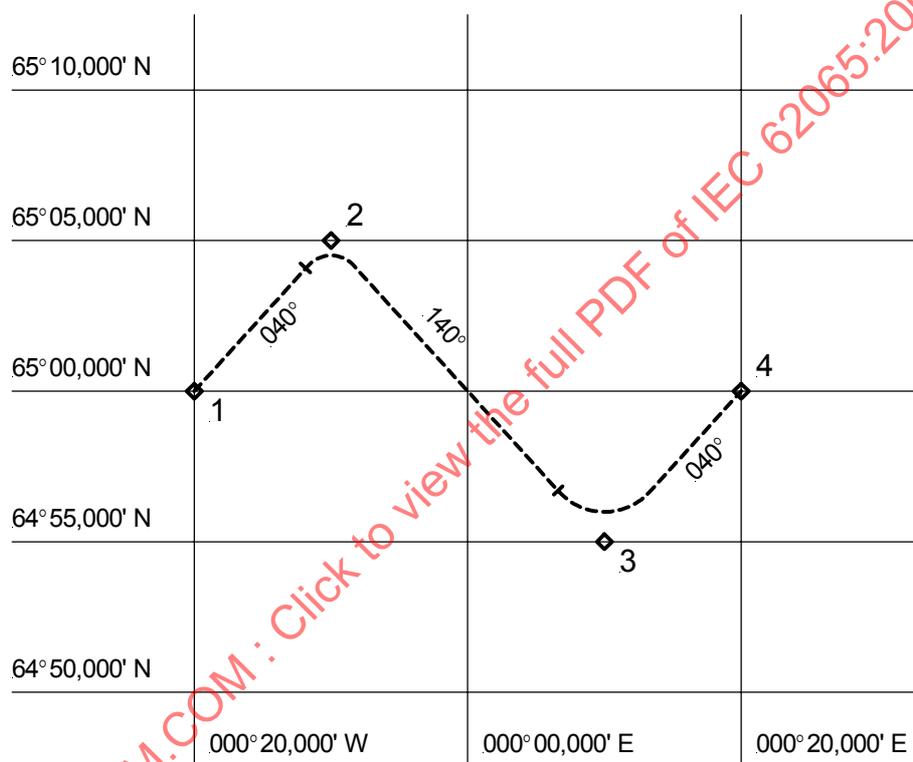


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**Figure G.3 – Scenario 3 plot**

**Table G.4 – Scenario 4**

| Scenario 4:   Rhumb line/great circle Atlantic track (Boston to Rotterdam) with ship class B (20 knots) | | | | | | |
|---|---|---|---|---|---|---|
| **Waypoint No.** | **Latitude** | **Longitude** | **Track** [deg] | **Distance** [NM] | **Radius** [NM] | **R.o.T.** [deg/min] |
| **001** | 42°20,639′ N | 071°00,786′ W | 132,1 | 0,82 | 0,5 | 40 |
| **002** | 42°20,090′ N | 070°59,964′ W | 112,1 | 0,40 | 0,5 | 40 |
| **003** | 42°19,940′ N | 070°59,465′ W | 087,0 | 1,44 | 0,5 | 40 |
| **004** | 42°20,015′ N | 070°57,525′ W | 063,6 | 0,93 | 0,5 | 40 |
| **005** | 42°20,429′ N | 070°56,397′ W | 026,6 | 1,77 | 0,5 | 40 |
| **006** | 42°22,011′ N | 070°55,325′ W | 065,9 | 0,90 | 0,5 | 40 |
| **007** | 42°22,380′ N | 070°54,210′ W | 079,5 | 4,92 | 0,5 | 40 |
| **008** | 42°23,275′ N | 070°47,663′ W | 065,1 | 9,53 | 1,0 | 20 |
| **009** | 42°27,287′ N | 070°35,953′ W | 088,2 | 126,4 | 1,0 | 20 |
| **010** | 42°31,223′ N | 067°44,616′ W | 085,4 | 272,9 | 0,0 | 20 |
| **011** | 42°53,045′ N | 061°34,463′ W | 065,2 | 202,7 | 1,0 | 20 |
| **012** | 44°17,923′ N | 057°20,346′ W | 067,1 | 307,8 | 1,0 | 20 |
| **013** Great circle approximation | 46°17,898′ N 48°47′ N 50°05′ N 50°29′ N 50°01′ N | 050°37,294′ W 40°00′ W 30°00′ W 20°00′ W 10°00′ W | 067,1 075,0 082,5 090,0 098,0 | 1761,2 | 1,0 | 20 |
| **014** | 49°38,074′ N | 006°25,031′ W | 084,5 | 147,4 | 1,0 | 20 |
| **015** | 49°52,252′ N | 002°37,903′ W | 074,5 | 144,2 | 1,0 | 20 |
| **016** | 50°30,788′ N | 000°59,106′ E | 049,7 | 18,33 | 1,0 | 20 |
| **017** | 50°42,637′ N | 001°21,152′ E | 016,3 | 13,03 | 1,0 | 20 |
| **018** | 50°55,140′ N | 001°26,929′ E | 038,1 | 19,59 | 1,0 | 20 |
| **019** | 51°10,551′ N | 001°46,164′ E | 041,5 | 15,62 | 1,0 | 20 |
| **020** | 51°22,252′ N | 002°02,706′ E | 041,6 | 46,69 | 1,0 | 20 |
| **021** | 51°57,145′ N | 002°52,725′ E | 084,9 | 13,15 | 1,0 | 20 |
| **022** | 51°58,304′ N | 003°13,980′ E | 082,4 | 24,71 | 1,0 | 20 |
| **023** | 52°01,567′ N | 003°53,769′ E | 112,1 | 7,20 | 1,0 | 20 |
| **024** | 51°58,858′ N | 004°04,605′ E | | | | |
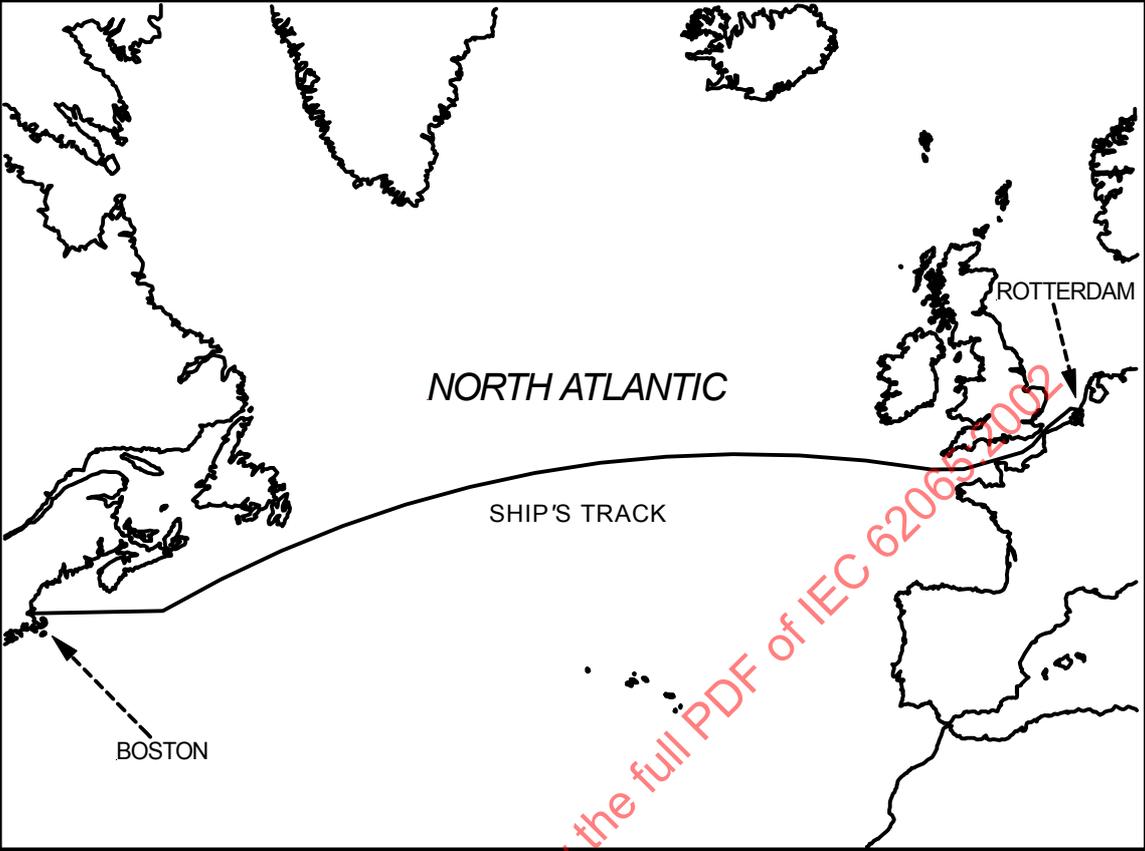
**Figure G.4 – Scenario 4 plot**

## Annex H
### (informative)

## Sensor errors and noise models

### H.1    Simulation of position sensor errors

For the purpose of this standard, the simulator should generate 'noise free true position data' as well as 'disturbed position data'. The latitude and longitude shall be disturbed independently. The disturbances should be within the permitted tolerance as specified by the appropriate standards for position fixing devices, for example:

GPS          IEC 61108-1          ±100 m (95 % confidence level)

GLONASS      IEC 61108-2          ±45 m (95 % confidence level)

DGNSS        IEC 61108-4 [9]      ±10 m (95 % confidence level)

### H.1.1    Noise model for simulated position data

The noise superimposed on position data should be calculated in accordance with the model below or any equivalent.

#### GPS Error model

Define Rand = random[0,1] (top-hat distribution)

For each component of position the error is the sum of $N$ sinusoids, $N = 4$;
The amplitudes are equal (20 metres for GPS)
F0 = 0,004 Hz

At each step

- Check whether to jump

- If jumping, calculate time for next jump: period between jumps = $-760 \times \log_e(\text{Rand})$

New frequency = F0 $\times$ Rand (independently for each sinusoid)
Phase step = $0,4\pi \times$ Rand (independently for each sinusoid)

- At each step

For each sinusoid: Phase step = deltaTime $\times$ Frequency

Position error = Amplitude $\times$ sum of {cos(Phase)} over all sinusoids

The standard deviation should be between

- 20 and 30 metres for GPS

- 2 and 3 metres for DGPS

---

[9]  Under consideration.

The position error spectrum should conform to the following distribution:

Let $x(t)$ be the values of position error as a function of time.

Let $y(f)$ be the frequency spectrum of $x$.

Let Y1 be the average of $y(f)$, over the range zero to 0,005 Hz.

Let Y2 be the average over the range 0,005 Hz to 0,010 Hz.

Let Y3 be the average over the range 0,010 Hz to 0,100 Hz.

Then Y1, Y2, Y3 should fall within the following bounds:

**Table H.1 – Histogram limits**

|    | From frequency Hz | To frequency Hz | Min. | Max. |
|----|-------------------|-----------------|------|------|
| Y1 | 0                 | 0,005           | 100  | 200  |
| Y2 | 0,005             | 0,010           | 10   | 50   |
| Y3 | 0,010             | 0,100           | 0    | 10   |

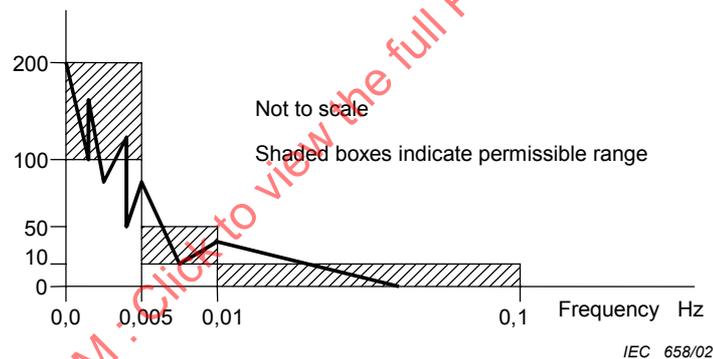This is illustrated in figure H.1:



**Figure H.1 – Spectral distribution of modelled GPS errors**

## H.2   Simulation of heading and speed information

The simulated heading and speed information should be noise free, since constant sensor errors (except heading and speed sensor failure) and dynamic sensor errors do not have a considerable effect on the test results.

## H.3    Simulation of sea state

### H.3.1    General

This paragraph describes a mathematical sea state model. The model has been constructed for use with the ship model simulation described in detail in annex I. The purpose of this sea state model is to generate disturbances which may be applied to the ship model, to simulate the effects of waves. Other models may be used but should give results equivalent to those described below.

A real sea state is generally complicated since the spectrum, directionality, and wave profiles (shapes) vary with conditions of depth, fetch (the uninterrupted distance travelled by waves), wind, current and so on. It is not the intention to reproduce all of these factors here, but to generate a representative model which fulfils the following requirements:

– simplicity;

– applicability to the ship model in annex I;

– some relationship to recognizable sea states.

With regard to the second criterion, the ship model needs a time-sequence of numbers which represent the instantaneous 'turning action' of the waves, expressed as an equivalent rudder angle at a standard L/V condition. If at a given time the wave disturbance is +0,01, this is defined to be equivalent to rudder hard over top starboard when the ship forward speed (in metres per second) is 0,01 times its length overall (in metres).

As for the third criterion, sea states 2 and 5 must be supplied for the tests, in terms of relevant parameters in the model.

The following model is derived, indirectly, from the Bretschneider sea state spectrum, used by the International Towing Tank Committee (ITTC), which describes the dominant frequency and the significant wave height (SWH) and the distribution of energy among a range of frequencies, for a fully developed sea.

### H.3.2    Definitions and abbreviations

Within the scope of this annex, the following definitions and abbreviations apply:

**surge**
forwards component of ship motion

**sway**
athwartships component of ship motion (positive to starboard)

**yaw**
rate of turn (positive to starboard

SWH    Significant Wave Height

### H.3.3    Model description

The model generates a square wave disturbance, using a random number generator which produces a flat probability distribution between –1 and +1:

The sea state is generated from a sequence of half-waves. Each half-wave has a duration $T_i$ and a height $H_i$.

Define $Rand_b$ = random[–1,+1] (top-hat distribution).

Duration:

$T_i = 0,5 \times T_0(SS) \times (1 + T_r \text{ x Rand}_b)$ where $T_r = 0,5$;

$T_0(SS)$ is a time constant characteristic of the sea state SS, listed in the table below.

The overall factor of 0,5 reflects the fact that this time applies to just half of the full wave period.

Height:

$H_i = H_0(SS) \times (1 + H_r \text{ x Rand}_b) \times$ alternating signs, i.e. ±1 where $H_r = 0,5$;

$H_0(SS)$ is the SWH characteristic of the sea state SS, listed in the table below.

The table below gives values for the characteristic time constant and SWH for sea states 2 and 5. These are related to the Bretschneider spectrum as follows:

– the time constant is half the typical wave period, since this sequence is expressed in terms of half-waves;
– the height is equal to that which is suggested by the Bretschneider spectrum.

**Table H.2 – Heights and periods for half-waves**

| Sea state (SS) | Period $T_0(SS)$ s | Height $H_0(SS)$ m |
|---|---|---|
| 2 | 5,0 | 0,5 |
| 5 | 14,0 | 4,0 |

The resulting sequence, and the characteristic spectrum are illustrated in the figures below for sea state 5. It may be seen that the spectrum peaks at about 0,07 Hz, which corresponds to a full wave period of 14 s.
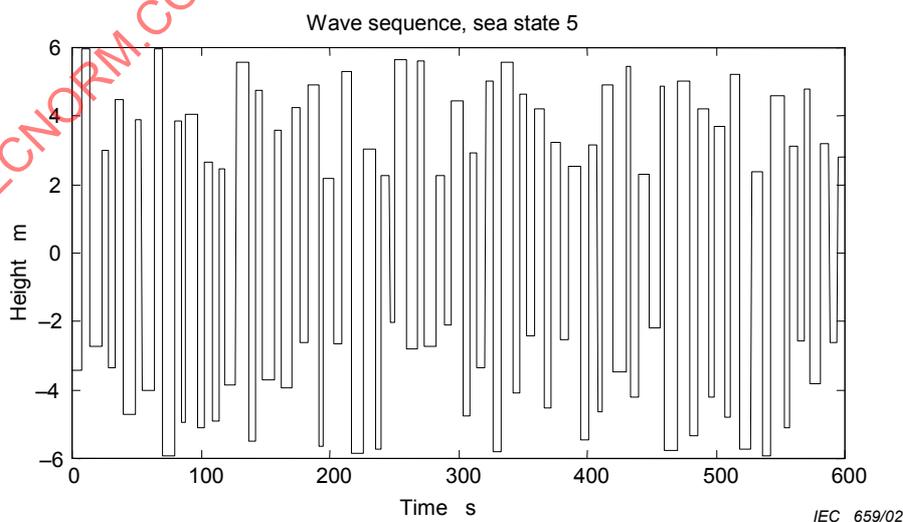


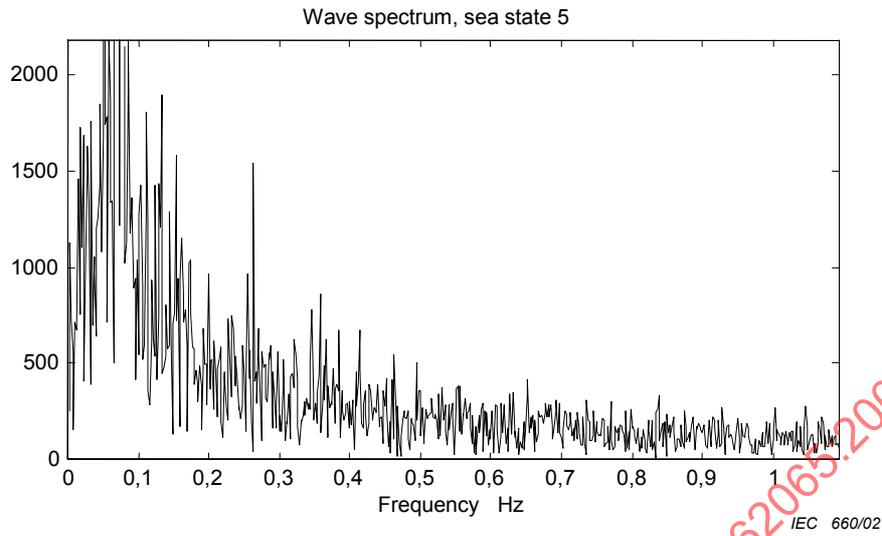Figure H.2 – Wave sequence – sea state 5

Wave spectrum, sea state 5



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**Figure H.3 – Wave spectrum – sea state 5**

### H.3.4    Model implementation

The sea state model may be incorporated directly into the ship model by means of a scaling factor which relates the 'turning action' to the wave height. A scaling factor of 20,0 gives results as illustrated below for the supertanker, container and fast ferry models.

In the case of the fast ferry model, the instability coefficient, $\gamma$, was set to zero for the test (equivalent to drifting at very low speed) so as to avoid entering a self-sustaining turn.
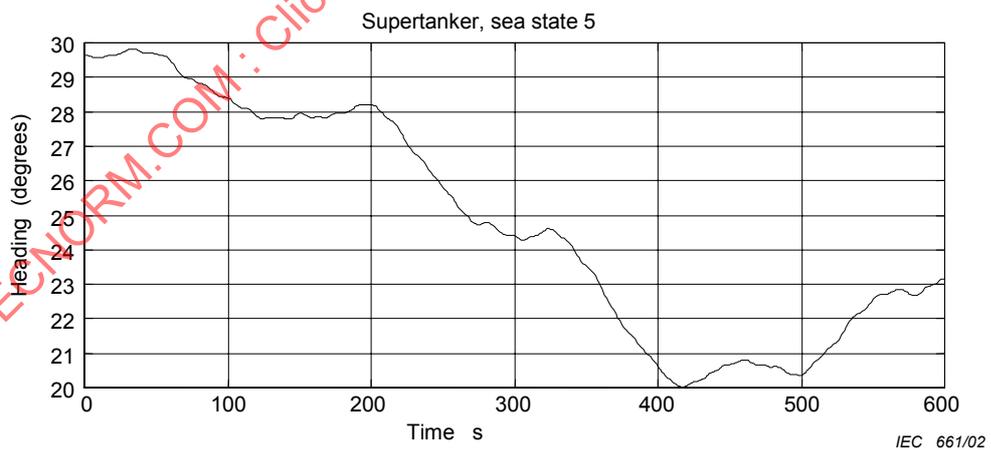
Supertanker, sea state 5



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**Figure H.4 – Supertanker – sea state 5**

Container, sea state 5



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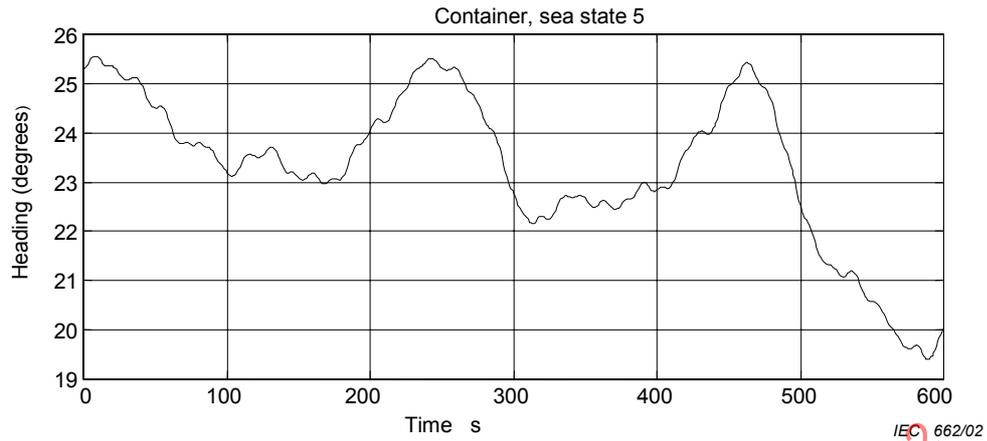
**Figure H.5 – Container ship – sea state 5**

Fast ferry, gamma zero, sea state 5



IEC 663/02
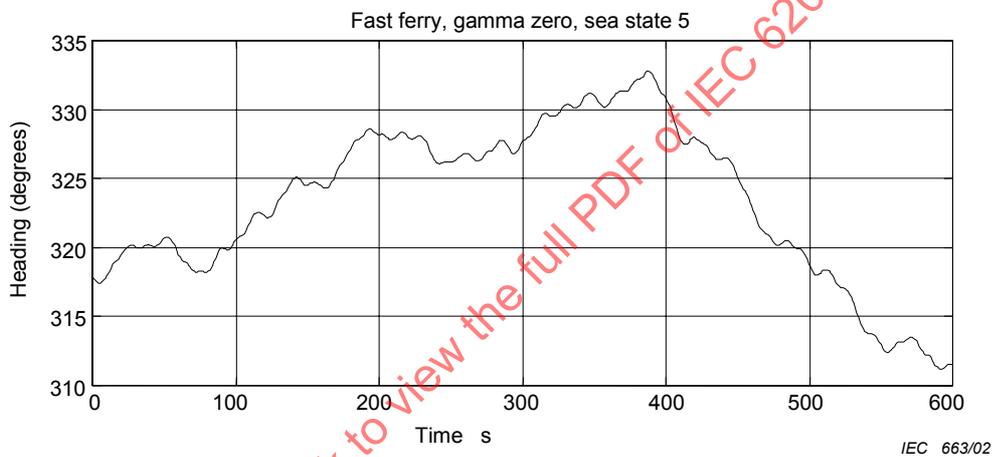
**Figure H.6 – Fast ferry – sea state 5**

Graphs for sea state 2 will give similar results albeit on a greatly reduced scale since both the amplitude and the characteristic time scale are reduced to levels where, for these vessels, the induced heading variations are very small (and are impractical to measure independently of other factors). As an example, the following figure illustrates the behaviour of the container class in sea state 2:

Container, sea state 2



IEC 664/02

**Figure H.7 – Container ship – sea state 2**

## Annex I
### (normative)

## Ship model specification

### I.1    General

All functional tests of the track control system shall be performed using the described ship motion simulator. The different ship′s and their manoeuvrability can be simulated by using parameter sets as listed in clause I.7 of this annex.

### I.2    Definitions

Within the scope of this annex, the following definitions apply:

**surge**
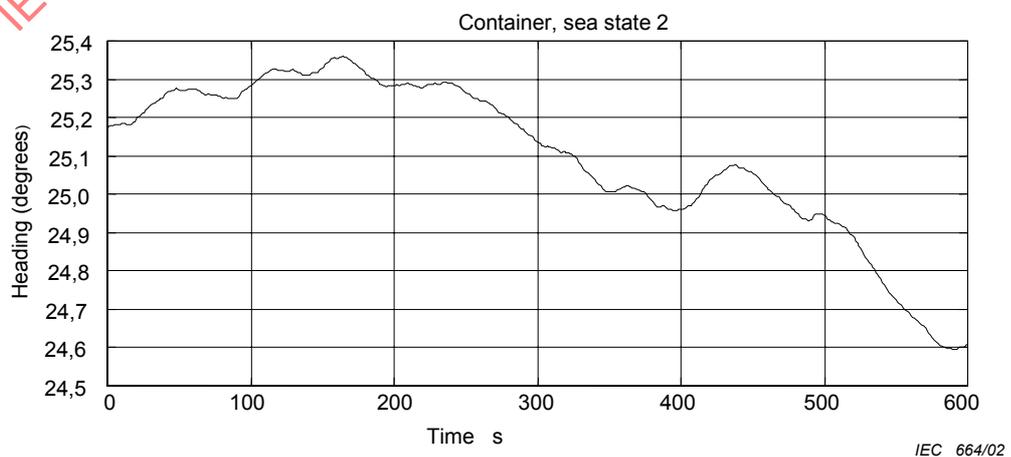forwards component of ship motion

**sway**
athwartships component of ship motion (positive to starboard)

**yaw**
rate of turn (positive to starboard);

### I.2.1    Symbols

| | |
|---|---|
| $C$ | Cosine of heading; |
| $E$ | Position East; |
| $Hdg$ | Heading; |
| $I_z$ | Effective moment of inertia for yawing motion; |
| $K_u$ | Coefficient of thrust; |
| $K_r$ | Coefficient of rudder effectiveness; |
| $K_r'$ | Normalized coefficient of rudder effectiveness; |
| $L$ | Length overall; |
| $M_u$ | Effective mass for forward motion; |
| $M_v$ | Effective mass for athwartships motion; |
| $N$ | Position North; |
| $P_a$ | Thrust lever setting (achieved); |
| $P_d$ | Thrust lever setting (demanded); |
| $P_{max}$ | Maximum thrust lever setting; |
| $P_a'$ | Normalized thrust lever setting (achieved); |
| $P_d'$ | Normalized lever setting (demanded); |
| $R_\delta$ | Rudder (achieved) rate of change; |
| $R_\delta'$ | Normalized rudder (achieved) rate of change; |

$R_\mathrm{p}$       Thrust lever (achieved) rate of change;

$R_\mathrm{p}{}'$      Normalized thrust lever (achieved) rate of change;

$R_\mathrm{u}$       Resistance coefficient for forwards motion (surge, $u$);

$R_\mathrm{v}$       Resistance coefficient for athwartships motion (sway, $v$);

$R_\mathrm{r}$       Resistance coefficient for rotational motion (yaw, $r$);

$S$       Sine of heading;

$T_\delta$       Rudder hard-over time (limit to limit);

$T_\mathrm{p}$       Thrust lever ramp time;

$T_\mathrm{E}$       Tidal current east;

$T_\mathrm{N}$       Tidal current north;

$V_\mathrm{GE}$       Velocity component east, relative to ground;

$V_\mathrm{GN}$       Velocity component north, relative to ground;

$V_\mathrm{WE}$       Velocity component east, relative to water;

$V_\mathrm{WN}$       Velocity component north, relative to water;

$W$       Wave disturbance;

$W'$       Normalized wave disturbance;

$X$       Thrust;

$X_\mathrm{max}$       Maximum thrust;

$X'$       Thrust (normalized);

$r$       Yaw rate;

$u$       Surge (forwards) velocity component (with respect to water);

$v$       Sway (athwartships) velocity component (with respect to water);

$z$       The vertical axis (downwards);

$\Delta$       Rudder offset (normalized);

$\delta_\mathrm{a}$       Rudder setting (achieved);

$\delta_\mathrm{d}$       Rudder setting (demanded);

$\delta_\mathrm{a}{}'$       Normalized rudder setting (achieved);

$\delta_\mathrm{d}{}'$       Normalized rudder setting (demanded);

$\gamma$       Stability coefficient;

$\tau_\mathrm{u}$       Time constant for forwards motion (surge, $u$);

$\tau_\mathrm{v}$       Time constant for athwartships motion (sway, $v$);

$\tau_\mathrm{r}$       Time constant for rotational motion (yaw, $r$).

## I.3    Related documents

ISO/IEC 16329, *Ships and Marine Technology – Heading control systems for high-speed craft*

## I.4    Introduction – background and requirements

This annex describes a mathematical model which has been designed to provide a simple means of testing track control equipment. The requirements of the model are the following:

a)  It should be representative of the essential features of ship motion, including:

 –  the reaction of the propulsor machinery to a command,

 –  the reaction to a propulsive force,

 –  straight-line resistance,

 –  the reaction of the rudder machinery to a command,

 –  the reaction of the vessel to the achieved rudder position,

 –  the sideslip motion of the vessel during a turn.

b)  The model should be capable of demonstrating the behaviour of a ship which is unstable in straight-line motion, i.e. where the ship may achieve a self-sustaining turn even with the rudder amidships, so that a rudder action opposing the turn direction becomes necessary to eliminate an unwanted turn.

c)  The model should be capable of being interfaced to commercial off-the-shelf vessel controller systems without special modification. This means that the inputs to the model should be obtainable from the standard equipment, and the outputs of the model should be suitable as direct inputs to the standard equipment.

d)  The model should be simple, so that test houses worldwide may interpret the equations without ambiguity, and build the mathematical equations into computer simulators with minimum difficulty.

As a result of item c) in this list, the rudder model has been defined with two options, option A and option B, to allow connection either to a direct follow-up system or a standard actuator output using feedback.

## I.5    The model – derivation

The model has been derived from Newton's laws of motion using linear equations to relate the hydrodynamic forces to the respective motions in the horizontal plane. A top-level block diagram of the model is illustrated in figure I.1.
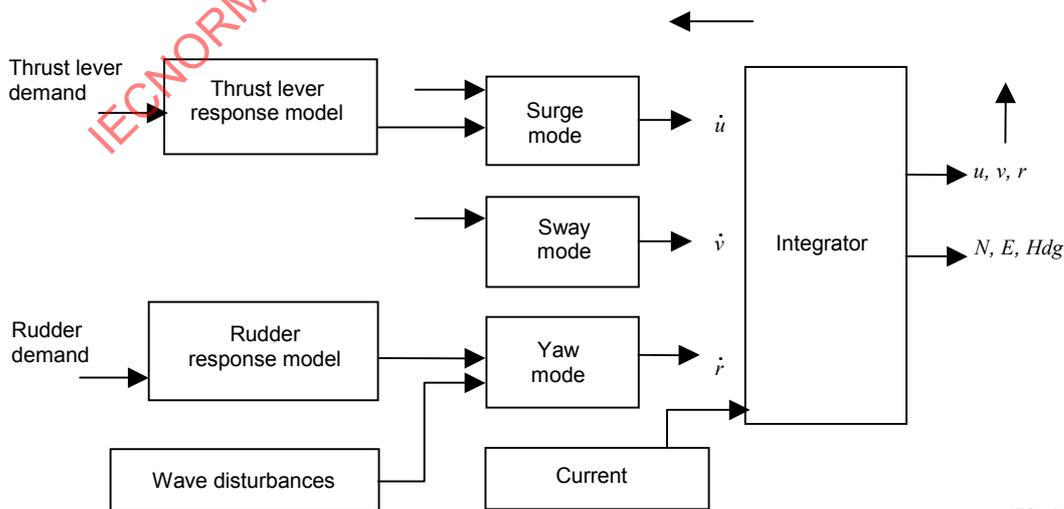


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**Figure I.1 – High level model block diagram**

The individual components of the model are discussed individually in the following sections. In each section, a physically meaningful equation is presented and explained; this is transformed into an alternative form, which is more convenient for the purpose of defining readily measurable parameters and for computation.

The model inputs and outputs are summarized in clause I.6, with a full block diagram, where guidance is given as to methods for determining the values of the ship parameters for various classes of vessel and for application under various conditions.

### I.5.1 Thrust lever response model

#### I.5.1.1 Derivation

This model has one input, the demand setting, and two outputs which are the last achieved lever position setting and the thrust. The last achieved setting is fed back internally in the lag calculation. The rate of change is constant, so that the achieved lever position will ramp linearly towards the setpoint and then remain constant.

The thrust is related to the achieved lever position by a linear equation:

$$\dot{P_a} = \begin{cases} + R_p & P_a < P_d \\ 0 & P_a = P_d \\ - R_p & P_a > P_d \end{cases} \tag{I.1}$$

This is subject to minimum and maximum limits imposed on $P_a$.

$$X = const \times P_a \tag{I.2}$$

where

$P_a$      is the achieved lever setting, and the dot denotes the time-derivative;

$P_d$      is the demanded lever setting;

$R_p$      is the lever response rate;

$X$      is the thrust.

#### I.5.1.2 Transformed equation

The lever settings and rate are normalized with respect to the maximum value $P_{max}$:

$$P' = P / P_{max}, \quad \text{and} \quad R'_p = R_p / P_{max}$$

The normalized rate $R'_p$ may be expressed in terms of the time taken for the lever achieved setting to ramp from one extreme to the other, $T_p$:

$$T_p = 2 / R'_p$$

The thrust is also normalized with respect to its maximal value:

$$X' = X / X_{max}$$

The equations used in computation are then:

$$\dot{P}_a' = \begin{cases} + 2 / T_p & P_a' < P_d' \\ 0 & P_a' = P_d' \\ - 2 / T_p & P_a' > P_d' \end{cases} \tag{I.3}$$

where $P_a'$ is constrained within the range –100 % to +100 %; and

$$X' = P_a' \tag{I.4}$$

Constant parameters to be entered by the user:

$T_p$    Lever ramp time (full astern – full ahead), in seconds;

$P_a'$    Also, the initial value of $P_a'$ should be specified or taken as zero by default (see below).

Run-time inputs:

$P_d'$ Lever demand, normalized (–100 % to +100 %).

Run-time outputs:

$P_a'$    Lever achieved setting, normalized (–100 % to +100 %);

$X'$    The thrust, normalized with respect its maximal value (–100 % to 100 %).

### I.5.2 Rudder response model

### I.5.2.1 Derivation

The fundamental derivation of the rudder response model is identical to the lever response model, in so far as it represents a mechanism which drives at a given rate of change, towards a setpoint. The rudder model is related to the lever model by the following translation in the algebraic notation:

**Table I.1 – Relationship between thrust lever and rudder models**

| Thrust lever | | Rudder | |
|---|---|---|---|
| $P_a$, $P_d$, etc. | Lever settings | $\delta_a$, $\delta_d$, etc. | Rudder settings |
| $R_p$ | Lever rate | $R_\delta$ | Rudder rate |
| $T_p$ | Lever time | $T_\delta$ | Rudder hard-over time |
| $X$ | Thrust | – | (see yaw model) |

One difference between the rudder and lever response models is that the rudder response model needs to be adaptable to various possible track control systems. To allow for the different systems which may be tested, the rudder model should be capable of accepting alternative methods of input, namely the demand setpoint (as for the lever model) or a run-time rate input, i.e. a demanded rate-of-change instead of an absolute setpoint. These two methods are presented below as option A and option B, although it should be noted that the underlying model is fundamentally the same, and the model presented here is a single model with two options for input connections.

Another significant difference between the rudder and lever models is that the rudder model includes an offset. This offset, $\Delta$, represents the effect of miscalibration of the follow-up mechanism. In practice, this will result in the ship initiating a turn when the rudder setpoint is amidships, and the control system needs to detect and counteract this offset in order to steer a straight course in the desired direction.

Finally, the rudder does not, in itself, produce a force: the turning moment only arises when the achieved rudder position is combined with water flow. This calculation is deferred to the yaw model, so the output of the rudder response model is only an achieved position.

The equations used in computation are

$$\dot{\delta}_a' = \begin{cases} +2/T_\delta & \delta_a' < \delta_d' + \Delta \\ 0 & \delta_a' = \delta_d' + \Delta \\ -2/T_\delta & \delta_a' > \delta_d' + \Delta \end{cases} \text{ (input option A)} \tag{I.5}$$

or

$$\dot{\delta}_a' = R_\delta' \text{ (input option B)} \tag{I.6}$$

In both cases, the achieved setting is limited by endstops so that $\delta_a$ is limited to the range –100 % to +100 %.

Constant parameters to be entered by the user:

$T_\sigma$    Rudder ramp time (full port – full starboard), in seconds (option A);

$\Delta$    Rudder follow-up offset (–100% to +100 %) (option A; irrelevant for option B);

also, initial value of $\delta_a'$ should be specified or may be defined to be zero by default (see below).

Run-time inputs:

$\delta_d'$    rudder demand, normalized (–100 % to +100 %) (option A);

$R_\delta'$    demanded rate of change of normalized rudder setting (% per second) (option B).

Run-time output:

$\delta_a'$    rudder achieved setting, normalized (–100 % to +100 %).

### I.5.3    Surge response model

### I.5.3.1    Derivation

The surge response model calculates the forwards acceleration which is brought about by the thrust $X$ (provided by the propulsor) and the hydrodynamic resistance to forwards motion, which is assumed to vary linearly with forward speed. There is also a term which describes the effect of sideways motion coupled with rotation (yaw); essentially this term takes into account the fact that the ship axes are rotating and do not constitute an inertial frame of reference.

$$M_u \dot{u} = X + M_u vr - R_u u \tag{I.7}$$

where

$M_u$     is the mass associated with forwards acceleration;

$u$       is the forwards component of ship velocity, and the dot denotes the time-derivative;

$X$       is the forward thrust imparted by the propulsor;

$v$       is the lateral component of ship velocity (positive to starboard);

$r$       is the yaw, or rate of turn about the vertical axis (positive to starboard);

$R_u$     is the linear coefficient of hydrodynamic resistance.

### I.5.3.2    Transformed equation

The equation is transformed by first dividing by $M_u$, and then defining parameters

$$\tau_u = M_u / R_u \tag{I.8}$$

$\tau_u$   is the time constant of the linear response model;

$$u_{max} = X_{max} / R_u \tag{I.9}$$

$$K_u = u_{max} / \tau_u \tag{I.10}$$

$K_u$   is the coefficient of thrust, relating the maximum forward speed to the time constant. Note that the value of $K_u$ is derived from easily measured or defined quantities.

The equation used in computation then becomes

$$\dot{u} = K_u X' + vr - u / \tau_u \tag{I.11}$$

Constant parameters to be entered by the user:

$u_{max}$   maximum speed, metres per second;

$\tau_u$   acceleration time constant, seconds;

also, the initial value of $u$ should be specified or taken as zero by default.

Run-time inputs:

$X'$      thrust (normalized with respect to its maximum value) (–100 % to +100 %);

$u,v$     components of velocity, metres per second;

$r$       rate of turn (yaw), radians per second.

Run-time output:

$\dot{u}$   time-derivative of $u$, metres per second per second.

### I.5.4    Sway response model

### I.5.4.1    Derivation

The sway response model is directly analogous to the surge response model, albeit with a few notable differences. The sway response model calculates the lateral acceleration, which is brought about by the lateral hydrodynamic forces acting on the hull.

A simplifying assumption is that the lateral force imparted by the rudder is ignored, i.e. the rudder is effectively placed at the centre of gravity. This assumption does not have any significant impact on the resulting motion of the vessel other than a subtle lateral movement of the centre of gravity which may be observed, on a real vessel, as a turn is initiated: the simplified model does not exhibit this effect. While it would be a simple matter to introduce this effect, it would not afford any benefits in terms of the purpose of this model for testing track control systems.

The hydrodynamic resistance to sideways motion is assumed to vary linearly with sideways speed. There is also a term which describes the effect of forward motion coupled with rotation (yaw); as above, essentially this term takes into account the fact that the ship axes are rotating and do not constitute an inertial frame of reference.

$$M_V \dot{v} = -M_V u r - R_V v \qquad (I.12)$$

where

$M_V$ is the mass associated with sideways acceleration;

$v$ is the sideways component of ship velocity, and the dot denotes the time-derivative, (positive is to starboard);

$u$ is the forwards component of ship velocity;

$r$ is the yaw, or rate of turn about the vertical axis (positive to starboard);

$R_V$ is the linear coefficient of hydrodynamic resistance to lateral motion.

### I.5.4.2    Transformed equation

The equation is transformed by first dividing by $M_V$, and then defining a parameter

$$\tau_V = M_V / R_V \qquad (I.13)$$

$\tau_V$ is the time constant of the linear response model.

The equation used in computation then becomes:

$$\dot{v} = -ur - v / \tau_V \qquad (I.14)$$

Constant parameters to be entered by the user:

$\tau_V$ is the acceleration time constant, in seconds;

Furthermore, the initial value of $v$ should be specified or taken as zero by default.

Run-time inputs:

$u, v$ components of velocity, metres per second;

r    rate of turn (yaw), radians per second.

Run-time output:

$\dot{v}$ time-derivative of $v$, metres per second per second.

### I.5.5    Yaw response model

### I.5.5.1    Derivation

The yaw response model calculates the rate of change of the rate of turn about the vertical axis (yaw) which is brought about by the turning moment. The turning moment is provided by a combination of the rudder achieved position, $\delta_a$, and the water flow over the rudder. The water flow over the rudder is dominated by the effect of the propeller, in the regimes of interest to this model, and is represented by the term $K_u X' \tau_u$ which represents the forward speed which is achieved, in equilibrium straight line motion, for a (normalized) thrust $X'$.

The turn is opposed by the hydrodynamic resistance to rotational motion, which is assumed to vary linearly with the rate of turn.

There is also a term which describes the effect of sideways motion coupled with the lever arm distance which may exist between the centre of lateral pressure and the centre of gravity. If the lateral resistance force acts aft of the centre of gravity, the slipping motion in the turn will tend to generate an opposing moment, so that the vessel will tend to straighten out, i.e. it is stable in a straight line. If, on the other hand, the lateral resistance force acts forward of the centre of gravity, the sideslip will tend to aggravate the turn. Clearly this effect will be more pronounced at speed, and there is a point where the vessel will become unstable in straight-line motion. If the centre of lateral pressure coincides with the centre of gravity, the vessel is neutrally stable; there remains some positive stability from the simple resistance to turning motion.

$$I_z \dot{r} = K_r \left( \delta_a \frac{K_u X' \tau_u}{L} + W \right) + \gamma L R_v (v - \gamma L r) - R_r r \tag{I.15}$$

where

| | |
|---|---|
| $I_z$ | is the moment of inertia associated with rotation about the z axis (which points vertically downwards), i.e. yaw; |
| $r$ | is the rate of turn, i.e. yaw rate, and the dot denotes the time-derivative; |
| $K_r$ | is a constant of proportionality; |
| $\delta_a$ | is the achieved rudder position; |
| $u$ | is the forwards ship speed; |
| $K_r \delta_a K_u X' \tau_u / L$ | is the turning moment imparted by the rudder, which is dependent on the rudder achieved position and the speed of water flow; |
| $K_r W$ | is the turning moment imparted by wave disturbances; |
| $\gamma$ | is the stability coefficient, i.e. the distance of the centre of pressure aft of the centre of gravity, normalized to the ship length $L$; |
| $L$ | is the ship length; |
| $R_v$ | is the linear coefficient of hydrodynamic resistance to lateral motion; |
| $(v - \gamma L r)$ | is the lateral component of ship velocity (positive to starboard), measured at the centre of hydrodynamic pressure; |
| $R_r$ | is the linear coefficient of hydrodynamic resistance to rotation (yaw); |
| $r$ | is the yaw, or rate of turn about the vertical axis (positive to starboard). |