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INTERNATIONAL STANDARD

colour inside

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

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

FOREWORD

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International Standard IEC 62065 has been prepared by IEC technical committee 80: Maritime navigation and radiocommunication equipment and systems.

This second edition cancels and replaces the first edition published in 2002 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– alarms and warnings have been brought into line with the requirements for Bridge Alert Management;
– requirements for the category B system have been revised;

– the parameters of the ship models of Annex I have been adjusted to resemble more Newtonian-like behaviour and the tidal current has been modelled;

– a new Annex K has been added with interface requirements.

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

FDIS	Report on voting
80/716/FDIS	80/729/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 2.

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).

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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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

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 Recommendation on Performance Standards for Track Control Systems. In addition, it takes into account IMO resolution A.694(17) to which IEC 60945 is associated.

When a requirement of this standard is different from IEC 60945, the requirement in this standard takes precedence. Also it takes into account IMO resolution MSC.302(87) on bridge alert management (BAM).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 61162 (all parts), *Maritime navigation and radiocommunication equipment and systems – Digital interfaces*

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

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

IEC 61924-2, *Maritime navigation and radiocommunication equipment and systems – Integrated navigation systems – Part 2: Modular structure for INS – Operational and performance requirements, methods of testing and required test results*

IEC 62288, *Maritime navigation and radiocommunication equipment and systems – Presentation of navigation-related information on shipborne navigational displays – General requirements, methods of testing and required test results*

IEC 62616, *Maritime navigation and radiocommunication equipment and systems – Bridge navigational watch alarm system (BNWAS)*

IMO MSC.74(69) Annex 2*, Recommendation on Performance Standards for Track Control Systems*

IMO resolution A.694(17), *General requirements for shipborne radio equipment forming part of the Global Maritime Distress and Safety System (GMDSS) and for electronic navigational aids*

IMO MSC.302(87), *Performance standards for bridge alert management (BAM)*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this standard, the following terms and definitions apply

3.1.1
active track
track activated for track control

3.1.2
alarm
high-priority alert

Note 1 to entry: Condition requiring immediate attention and action by the bridge team, to maintain the safe navigation of the ship.

3.1.3
alert
announcement of abnormal situations and conditions requiring attention

Note 1 to entry: Alerts are divided in four priorities: emergency alarms, alarms, warnings and cautions.

Note 2 to entry: Alerts are additionally classified in two different categories for navigational purposes: category A and category B as described in IMO resolution MSC.302(87).

Note 3 to entry: An alert provides information about a defined state change in connection with information about how to announce this event in a defined way to the system and the operator.

3.1.4
along-track speed control
automatic control of the ship's speed during track control based on a pre-planned track

3.1.5
assisted turn
manoeuvre of a ship automatically controlled by a pre-set radius or rate of turn but not based on the ship's position to perform an approximation of a curved track

3.1.6
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

3.1.7
back-up navigator alarm
signal automatically sent from the TCS to call assistance to the bridge when the officer of the watch fails to acknowledge certain alarms within a defined time period

Note 1 to entry: Note that the back-up navigator alarm does not represent an alarm as defined in 3.1.2.

3.1.8
consistent common reference system
sub-system or function of a TCS for acquisition, processing, storage, surveillance and distribution of data and information providing identical and obligatory reference to sub-

systems and subsequent functions within a TCS and to other connected equipment, if available

3.1.9
course
for marine navigation, 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°

Note 1 to entry: 360° is indicated as 000°.

3.1.10
course difference limit
maximum difference between track course and heading before a warning is activated

3.1.11
cross-track distance
cross-track error
perpendicular distance of a predefined point on *the ship from the track* including direction (negative if the ship is left of the intended track)

3.1.12
cross-track limit
maximum cross-track distance before an alarm is activated

3.1.13
curved track
non-straight track between two legs

3.1.14
fall-back arrangements
automatic reaction of the TCS by using data, function or hardware of degraded quality in relation to the failed one

EXAMPLE Dead reckoning for position information, heading control in case of a failure of track control.

3.1.15
FROM-waypoint
last passed waypoint

3.1.16
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

3.1.17
heading
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°

Note 1 to entry: 360° is indicated as 000°.

3.1.18
heading control
control of the ship's heading

3.1.19
***heading monitor* function**
monitoring of *the actual heading sensor by an independent second source*

3.1.20
leg
straight *line between two waypoints* and/or curved track(s)

3.1.21
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

3.1.22
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

Note 1 to entry: The value depends on the ship's design and loading and on the present environmental conditions.

3.1.23
NEXT-waypoint
waypoint following the TO-waypoint

3.1.24
override facility
control to perform the override function

3.1.25
override function
intentional fast change-over from automatic to temporary manual control

3.1.26
***position monitor* function**
monitoring of *the actual position sensor by an independent second source*

3.1.27
primary position-fixing system
electronic position-fixing system (EPFS) used for track control and approved by the International Maritime Organization (see 5.1.1.3)

3.1.28
radius of turn
radius of a curved track

3.1.29
rate of turn
change of heading per time unit

3.1.30
rhumb line sailing
sailing on a line on the surface of the earth making the same angle with each meridian crossed

3.1.31
ship manoeuvring characteristics
range-of-manoeuvre possible for the ship

Note 1 to entry: Examples of the range-of-manouvres are: maximum rate of turn, minimum radius of turn, maximum turn acceleration and deceleration.

3.1.32
single operator action
procedure achieved by no more than one hard-key or soft-key action, excluding any necessary cursor movements, or voice actuation using programmed codes

3.1.33
speed
absolute value of velocity

Note 1 to entry: May either be the ship's speed through the water, or the speed made good over the ground.

3.1.34
steering mode selector
switch provided for the selection of manual steering modes and automatic steering devices

3.1.35
surge
forward component of ship motion

3.1.36
sway
athwartships component of ship motion (positive to starboard)

3.1.37
temporary track
track that originates at the current position of the ship and joins the pre-planned track

Note 1 to entry: The temporary track may include temporary waypoints which can be identified as different from the waypoints of the pre-planned track.

3.1.38
TO-waypoint
waypoint which the ship is approaching

3.1.39
track
path to be followed over ground

3.1.40
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)

3.1.41
track course
direction from one waypoint to the next, a constant course on a rhumb line track and a varying course on a Great Circle track

3.1.42
warning
alert for condition requiring immediate attention, but no immediate action by the bridge team

Note 1 to entry: Warnings are presented for precautionary reasons to make the bridge team aware of changed conditions which are not immediately hazardous, but may become so if no action is taken.

3.1.43
waypoint
geographic position together with its associated data

3.1.44
wheel-over-line
WOL
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 rate of turn

3.1.45
wheel-over-time
WOT
point in time when the track control system initiates the planned course change

3.1.46
yaw
rate of turn (positive to starboard)

3.2 Abbreviations

~A	Not applicable for category A systems
ACCA	Actual course change alarm
ACCW	Actual course change warning
BAM	Bridge alert management
CCRP	Consistent common reference point
CCRS	Consistent common reference system
COG	Course over ground
DGPS	Differential GPS
DR	Dead reckoning
ECCA	Early course change alarm
ECCW	Early course change warning
ENC	Electronic navigational chart
EPFS	Electronic position fixing system
EUT	Equipment under test
GC	Great circle
GPS	Global positioning system
INS	Integrated navigation system
NA	(Back up) Navigator alarm
RL	Rhumb line
ROT	Rate-of-turn
SDME	Speed and distance measuring equipment
SWH	Significant wave height
TCS	Track control system
WOL	Wheel-over-line
WOT	Wheel-over-time

4 Application of this standard

The application of this standard is as follows.

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) The track control system shall ensure the integrity of the geodetic datum, the ship manoeuvring characteristics and the curved tracks of the imported data.

d) 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.

e) If a track control system automatically receives additional data, including waypoints, from other navigational aids, the requirements of IEC 61924-2 for this data exchange shall also apply.

f) If a track control system is integrated into an INS, the corresponding requirements of INS (as defined in IEC 61924-2) shall apply, for example concerning

   – route planning by waypoints,

   – data transfer of safety-checked waypoints and

   – monitoring of navigational safety for example by charts.

g) 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.

h) (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 kn; and*

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

i) These performance standards do not apply to High Speed Craft as defined by SOLAS chapter 10.

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

k) *Systems fitted on ships requiring curved track control* shall *additionally meet all the requirements relating to curved tracks* (category C)*.*

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

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

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

   Category C: Full track control on legs and turns.

Some requirements contained in this clause cannot be verified by objective measurements. 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.

5 Requirements

5.1 Operational requirements

5.1.1 Functionality

5.1.1.1 Track control steering modes

(See 6.4.3.2)

(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.

5.1.1.2 Starting requirements

(See 6.4.2.1, 6.4.2.2, 6.4.2.3, 6.4.2.4, 6.4.3.1)

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

– the required position, heading and speed sensor data are valid and selected.

– the pre-planned track has been checked for plausibility and correctness of geometric and ship-dependent limits (see Annex E) 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).

5.1.1.3 Primary position-fixing system

(See 6.2.2.2)

(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.*

5.1.1.4 Position monitoring

(See 6.4.5.3)

(A2/5.1.4) T*he ship's position* shall *be continuously monitored by a second* or additional *independent position source.* 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.*

5.1.1.5 Early course change warning (~A)

(See 6.4.5.12)

A graphical description of the sequences described here is given in Annex A Figure A.1.

(A2/5.1.5) *In the case of track control by a sequence of waypoints, an 'early course change* warning*'* shall *be given* up to 6 min, and *no later than* 3 min, *before the wheel-over* time*.*

If the early course change warning is not acknowledged within 30 s, at the latest 2 min 30 s before the wheel-over-time, the alert priority shall change from warning to alarm.

The early course change alarm is defined to be associated with NA activation (see 5.1.3.11).

5.1.1.6 Actual course change warning (~A)

(See 6.4.5.12)

A graphical description of the sequences described here is given in Annex A Figure A.1.

(A2/5.1.6.1) *In the case of track control by a sequence of waypoints an* actual course change warning shall *be given* 30 s before *the wheel-over* time.

If the actual course change warning is not confirmed/acknowledged by the officer of the watch (user) within 30 s the alert priority shall change from warning to alarm.

NOTE This warning is superfluous, if the NA from the unacknowledged early course change alarm is already active.

(A2/5.1.6.2) *The system* shall *provide means for the officer of the watch* (user) *to confirm*/acknowledge *the* actual *course change* alerts.

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

(A2/5.1.6.4*) If the actual course change alarm is not confirmed/*acknowledged *by the officer of the watch* (user*) within 30 s* of *wheel-over a back-up navigator alarm* shall *be given* as fully described in 5.1.3.11.

5.1.1.7 Change of waypoints

(See 6.4.2.2, 6.4.2.3, 6.4.2.4, 6.4.2.5, 6.4.3.1.6, 6.4.3.1.8, 6.4.3.1.9)

(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* (5.1.1.2) *are fulfilled*.

5.1.1.8 Turn performance (~A)

(See 6.4.3.2)

(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 radius of turn;

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.

The planned track shall be checked for plausibility and correctness of geometry and of ship-dependent limits before becoming the active track.

5.1.1.9 Adaptation to steering characteristics

(See 6.4.4.1, 6.4.4.3)

(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*.

5.1.1.10 Permitted tolerance

(See 6.4.4.2)

(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.*

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.

Category B TCS shall comply with the requirements for curved track TCS, except that, after having passed the wheel-over, the actual cross-track distance is merely used for monitoring until completion of the automatic course change manoeuvre. Manual or automatic means shall be provided to adapt to variable drift and speed changes during a turn (e.g. facilitating manual adjustments of rate of turn or radius of turn).

5.1.1.11 Override function

(See 6.4.6.5, 6.4.8)

(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 5.1.1.2).

5.1.1.12 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*.

NOTE The IMO performance standards for heading control are given in IMO resolution MSC.64(67) annex 3 and these are incorporated into ISO 11674.

5.1.1.13 Manual change over from track control to manual steering

(See 6.4.6.5)

(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*.

5.1.1.14 Manual change over from track control to heading control

(See 6.4.6.6)

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 leg, *take over the actual heading as the preset heading,*

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

Optionally, if sailing on a curved track, based on an intended operator selection, the heading control system may complete the turn with the track course of the next 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*.

5.1.1.15 Steering mode indication

(See 6.4.7.1)

(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.

5.1.1.16 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.*

NOTE This is an installation issue which is not covered by this standard.

5.1.1.17 End of track

(See 6.4.5.10)

At the end of the pre-planned track, an 'end of track warning' shall be generated.

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 warning' shall be given at the end of each leg.

5.1.2 Accuracy and performance constraint documentation

(See 6.2.2.1)

(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*.

5.1.3 Alerts

5.1.3.1 Failure or reduction in power supply

(See 6.4.5.2)

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

5.1.3.2 Position monitoring alert

(See 6.4.5.3)

(A2/5.3.2) *A* warning shall *be given when the position monitor detects a deviation* between the primary and secondary position-fixing system *beyond a preset limit*. See Annex E.

5.1.3.3 Heading monitoring alert

(See 6.4.5.4)

(A2/5.3.3) *A* warning shall *be given when the heading monitor detects a deviation beyond a preset limit.* See Annex E.

5.1.3.4 Failure and alert status of sensor

(See 6.4.5.5)

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

.1 in case of a performance reduction of the track control process an alert of an appropriate priority 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* alert *status* of priority alarm *is not acknowledged by the officer of the watch* (user) *within 30 s* as fully described in 5.1.3.11.

Fall-back procedures consequential to the failure and alert *conditions are stated in* 5.5.

5.1.3.5 Use of faulty signals

(See 6.4.5.6)

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

5.1.3.6 Cross-track alert

(See 6.4.5.7)

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

Category B and C systems shall monitor the actual position against the curved tracks. If this monitoring and alerting is not done, the system shall be a category A system and track control shall stop at the end of each leg.

5.1.3.7 Course difference alert

(See 6.4.5.8)

(A2/5.3.7) A warning 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 alerts (see Annex E).

5.1.3.8 Low speed alert

(See 6.4.5.9)

(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) *a* warning shall *be given.* This alert is not required to be an integral part of the track control system.

5.1.3.9 End of track alert

(See 6.4.5.10)

A warning shall be given between 3 min and 6 min before the last waypoint of the active track is passed. If the end of track warning is not confirmed/acknowledged by the officer of the watch (user) within 30 s the alert priority shall change from warning to alarm. The end of track alarm is defined to be associated with NA activation (see 5.1.3.11).

5.1.3.10 Track control stopped alert

(See 6.4.5.11)

A track control stopped warning shall be given if the system automatically switches over to heading control or is unable to continue operation. If the track control stopped warning is not confirmed/acknowledged by the officer of the watch (user) within 30 s the alert priority shall change from warning to alarm. The track control stopped alarm is defined to be associated with NA activation (see 5.1.3.11).

5.1.3.11 Handling of the Back-up Navigator Alarm (NA)

(See 6.4.5.13)

A graphical description of the sequences described here is given in Figure A.2.

The back-up navigator alarm shall call assistance to the bridge by transfer of the unacknowledged alarm within the track control system to the BNWAS (see IEC 62616).

For all those unacknowledged alarms, required by this standard to have the NA activation function, the track control system shall generate the back-up navigator alarm output to the BNWAS, i.e. activate the NA signal output (either by contact closure or equivalent circuit, or an IEC 61162 interface using the ALR sentence).

Power failure of track control system shall not activate the NA signal output.

The NA shall be activated in accordance with the following.

- If within 30 s of the alarm’s occurrence, the alarm has not been acknowledged, or has not been temporarily silenced, and the alarm condition has not been rectified, then the NA shall be activated.

- If within 30 s of the alarm's occurrence, the alarm has not been acknowledged, has not been rectified, but has been temporarily silenced by the operator, then the following will apply:

  When the silencing expires, the NA activation shall function as if the alarm condition just arose, but any further silencing shall not result in further delay of the NA. Note that the silencing specified here is the temporary silence function which expires, reactivating the audible announcement, after 30 s.

As soon as all of the alarms associated with NA activation are acknowledged or rectified, the NA shall be deactivated. Note that acknowledgement may occur locally, remotely, or as a result of turning off the alert generating function (e.g. disabling track control).

5.1.3.12 Remote acknowledgments of alerts

(See 6.4.5.14)

Remote temporary silencing and remote acknowledgement shall be possible via alert related communication described in IEC 61924-2 (see also Annex K).

Remote acknowledgement shall only be possible for category B alerts (alerts where no additional information for decision support is necessary as described in IEC 61924-2).

Remote silencing of the relevant audible alarms of the TCS shall be possible at any time.

5.2 Ergonomic criteria

5.2.1 Operational controls

5.2.1.1 Controls for track control

(See 6.4.8)

(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 alerts, *functions and other control parameters*.

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

NOTE There are restrictions described in 5.1.1.7.

5.2.1.2 Change over controls

(See 6.4.6.5, 6.4.8)

(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.*

5.2.2 Presentation of information

5.2.2.1 Continuously displayed information

(See 6.4.7.1)

(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;* for category B systems, an additional “assisted turn” indication shall be provided during course change manoeuvres*;*

.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;*

NOTE In this subclause the TO-waypoint means the related wheel-over.

.8 *next track course;*

.9 *selected track identification*.

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

All displayed information shall conform to the general requirements for displays contained in IEC 62288.

5.2.2.2 Information to be provided on demand

(See 6.4.7.2)

(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* of the curved track(s) (~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.

5.2.2.3 Presentation

(See 6.4.7.1)

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

5.3 Design and installation

The track control system shall be designed, manufactured and installed in accordance with recognized international quality standards, such as ISO 9000.

5.4 Interfacing

5.4.1 Sensors

(See 6.2.2.2)

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

NOTE Information flowing within the EUT can contain proprietary data.

5.4.2 Status information

(See 6.4.5.5)

(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.

If a sensor is capable of distributing both processed sensor data and unprocessed sensor data then the status of the processing shall be incorporated in the data communication protocol. For example, if the distributed heading is normally corrected for speed/latitude error then the protocol should inform if this being the case or not, see Annex K.

5.4.3 Standards

(See 6.2.2.2)

(A2/7.3) *The track control system* shall *be capable of digital, serial communication with the ships navigation system and comply with the* IEC 61162 series.

The track control system shall support the IEC 61162 series interfaces as given in Annex K as a minimum. In addition, suitable alternative input or output interfaces may be used for instance equivalent Parameter Group Numbers (PGNs) with a IEC 61162-3 interface.

The manufacturer shall specify which IEC 61162 part each physical interface supports.

5.5 Fall-back arrangements

5.5.1 Failure of track control

(See 6.4.6.1)

NOTE The associated alerts are stated in 5.1.3.

If track control fails, a 'track control stopped warning' 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 leg, *take the actual heading as the preset heading for the heading control,* or a calculated heading in such a way that the actual COG shall be approximately maintained,
– if sailing on a curved track, the turn shall be completed and the track course of the next 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.* The rudder angle shall be set to a fixed angle in such a way that:

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

– if sailing on a curved track, 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.

5.5.2 Failure of position sensor

(See 6.4.6.2)

Position can be based on single position sensor or optionally can be based on multiple position sensors.

If the Track Control System is connected to multiple sensors (not integrated into an INS) an automatic change of sensors shall generate a warning. In this case position information has failed, or is unavailable, when all connected position sensors fail or are unavailable at the same time.

If position is based on CCRS position available from the INS and if the INS has reported that the CCRS position has failed integrity check (state failed in NSR sentence from the INS) or has not been possible (state doubtful in NSR sentence from the INS), then this situation shall be treated as if the CCRS position has failed or is unavailable.

If position information 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 warning” shall be generated. The system shall
  - if sailing on a leg, take the actual heading as the preset heading;
  - if sailing on a curved track, complete the turn and take the track course of the next 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 warning shall be activated giving the advice to switch to a valid and available position sensor, heading control or manual steering;
- even if acknowledged, this warning shall be repeated every 2 min until steering mode has been changed manually or automatically.
- when a position sensor becomes available before steering mode has been changed manually or automatically, the system may switch automatically back to position sensor information and, in that case, shall generate a warning.

The manual or automatic switching of position information shall not generate excessive rudder activities.

5.5.3 Failure of the heading measuring system

(See 6.4.6.3)

Heading can be based on single heading sensor or optionally can be based on multiple heading sensors.

If the Track Control System is connected to multiple sensors (not integrated into an INS), an automatic change of sensors shall generate a warning. In this case heading information has failed or is unavailable, when all connected heading sensors fail or are unavailable at the same time.

If heading is based on CCRS heading available from the INS and if the INS has reported that the CCRS heading has failed integrity check (state failed in NSR sentence from the INS) or has not been possible (state doubtful in NSR sentence from the INS), then this situation shall be treated as if the CCRS heading has failed or is unavailable.

If heading information has failed or is unavailable, then:

- the heading sensor alarm shall be activated;
- the 'track control stopped' warning shall be activated, giving advice to the user to switch to manual control.
- (A2/8.2.1) *The 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 leg, the actual heading shall be approximately maintained;
  - if sailing on a curved track, the actual rate of turn shall be approximately maintained (~A).

5.5.4 Failure of the speed sensor

(See 6.4.6.4)

Speed can be based on single speed sensor/source or optionally can be based on multiple speed sensors/sources.

If the Track Control System is connected to multiple sensors (not integrated into an INS) an automatic change of sensors shall generate a warning. In this case speed information has failed or is unavailable, when all connected speed sensors fail or are unavailable at the same time.

If speed is based on CCRS speed available from the INS and if the INS has reported that the CCRS speed has failed integrity check (state failed in NSR sentence from the INS) or has not been possible (state doubtful in NSR sentence from the INS), then this situation shall be treated as if the CCRS speed has failed or is unavailable.

If speed information has failed or is unavailable, then:

– the speed sensor alarm shall be activated;

– the track control mode shall continue and use the last plausible speed of the ship, or a system derived speed as fallback information.

NOTE Examples of system derived speed information are an estimate deduced from continuous observation of shift of positions, or deduced from propeller RPM, etc.

In case of a reduction of the track control performance, the track control system shall additionally provide the following user guidance and alerts:

– after 1 min, or less, a warning shall be activated giving the advice to switch to a valid, alternative speed information or to change the steering mode.

– even if acknowledged, this warning shall be repeated every 2 min until a valid, alternative speed information (e.g. system derived speed) has been intentionally selected or steering mode has been changed.

When a suited speed sensor becomes available before the steering mode has been changed, the system may automatically switch back to speed sensor information and, in this case, shall generate a warning.

The manual or automatic switching of speed information shall not generate excessive rudder activities.

6 Test requirements and results

6.1 General

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

6.2 General requirements

6.2.1 Environmental tests

6.2.1.1 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 tests and checks shall be used for environmental tests:

– performance check: 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 a function.
– performance test: 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: visual check of the equipment or documentation.

6.2.1.2 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.

6.2.1.3 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 (see Annex D);

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.

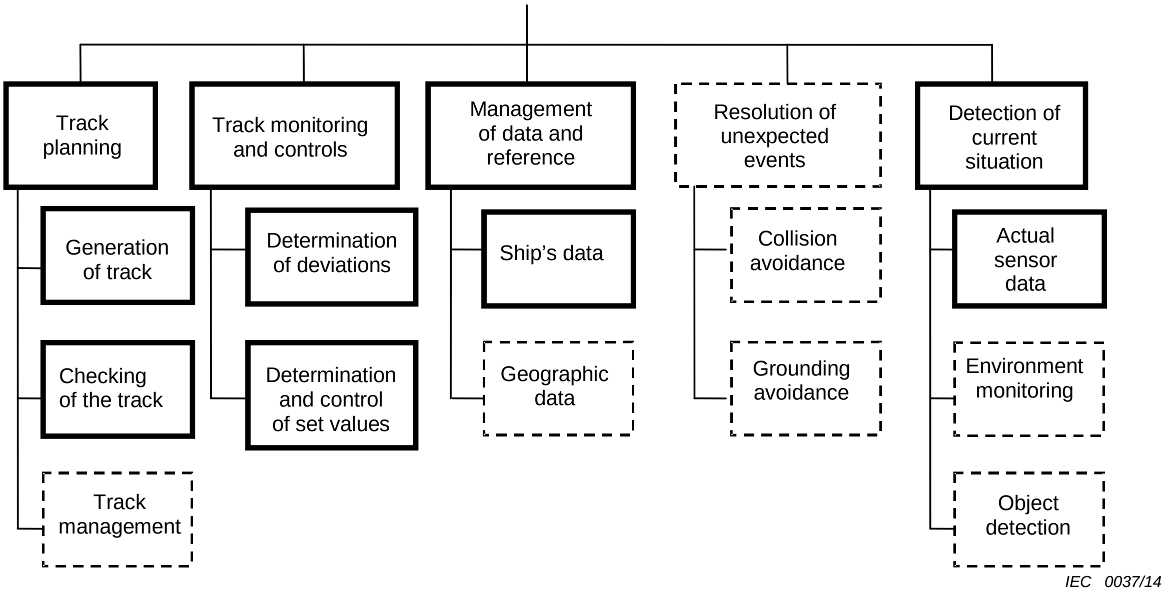


Figure 1 – Functional model of track control as part of an integrated navigation system

The information flow and the resulting dependencies between supported functions can be identified using the generic data flow diagram of the functional model (see 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.

6.2.1.4 Test of optional track control related modes

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

6.2.2 Documentation

6.2.2.1 Equipment manuals

(See 5.1.2)

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

6.2.2.2 Technical documentation for type approval

(See 5.1.1.3, 5.4.1, 5.4.2)

Manufacturer’s 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.

6.2.3 Declarations

Some requirements cannot be verified by objective measurements.

Verify that

- the declaration and relevant documentation comply with the requirements in Clause 5; and
- the general hardware and functional composition of the equipment and the relevant category of IEC 60945 for each unit is declared (see Clause 5).

6.3 Environment setup

6.3.1 General

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 (see 6.3.2) are available in the simulator. Prepare the scenarios by loading the test tracks into the planning system which is used by the EUT.

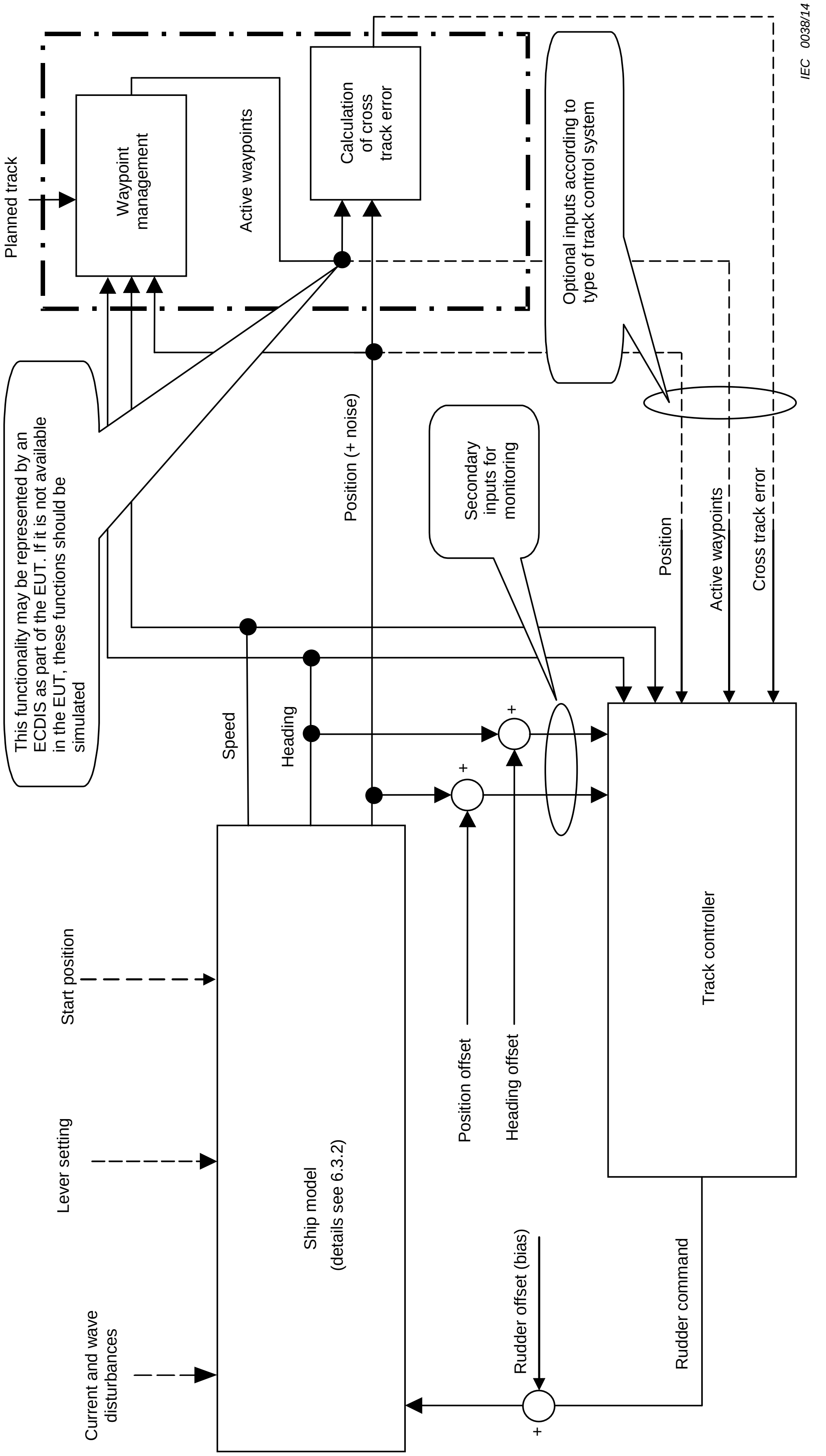


Figure 2 – Block diagram

6.3.2 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: ferry, 30 kn,
– ship class B: container ship, 25 kn,
– ship class C: tanker, 10 kn.

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.

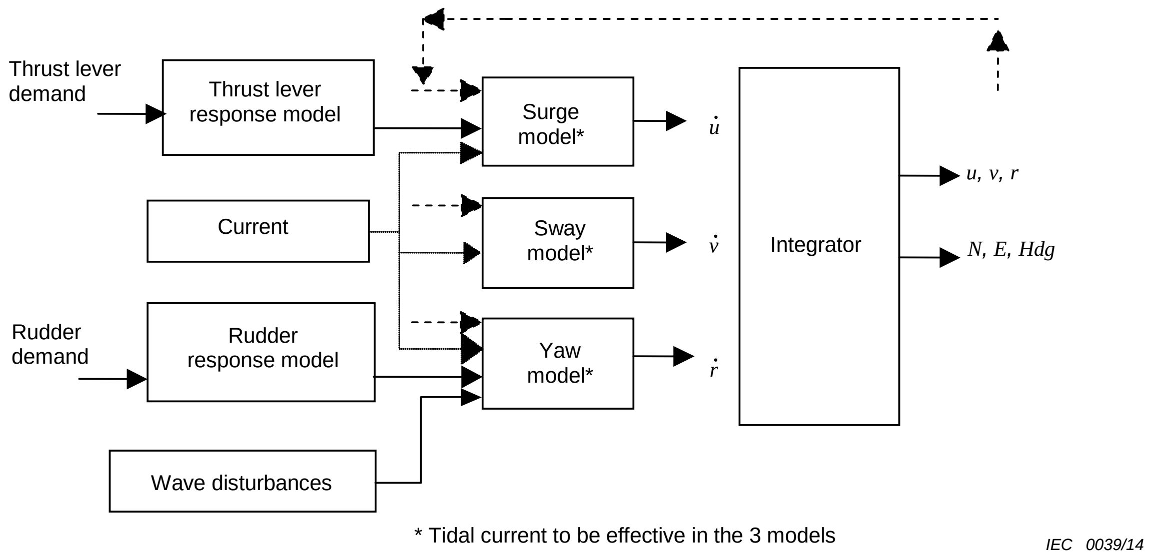


Figure 3 – High level block diagram

The mathematical model of the ship motion simulator is based on linear relationships between motions, propulsion and rudder control inputs, and the forces acting on the vessel (see Figure 3). 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 not 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, integrity, alert communication),
– heading (second heading source for monitoring, integrity, alert communication),
– speed (second speed source for monitoring, integrity, alert communication),
– steering mode selection, override tiller, alert panel.

The noise model described in Annex H shall be used for the simulated 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 relevant part of IEC 61162. Any other types of interfaces (for example, stepper or synchro, pulse log) shall also be tested.

6.3.3 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.

6.3.4 Planning

6.3.4.1 General

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

6.3.4.2 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.

6.3.4.3 Enter additional data

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

6.3.4.4 Store

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

6.4 Test execution

6.4.1 General

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

All tests concerning curved tracks

- shall be executed with systems able to perform full track control on these track segments (category C).
- shall be executed with systems able to perform an approximation by means of an assisted turn on these track segments (category B).
- shall not be executed with systems without curved track control (category A). In these cases course changes to follow the scenarios specified within this standard shall be performed using means according to the manufacturer's documentation.

6.4.2 Check the track

6.4.2.1 Check the radius (~A)

(See 5.1.1.2)

6.4.2.1.1 Purpose

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).

6.4.2.1.2 Method of testing

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.

6.4.2.1.3 Required test results

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.

6.4.2.2 Check the waypoints

(See 5.1.1.2, 5.1.1.7)

6.4.2.2.1 Purpose

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

6.4.2.2.2 Method of testing

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.

6.4.2.2.3 Required test results

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.

6.4.2.3 Check against the ship dynamics (~A)

(See 5.1.1.2, 5.1.1.7)

6.4.2.3.1 Purpose

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).

6.4.2.3.2 Method of testing

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.

6.4.2.3.3 Required test results

Verify that track control cannot be activated and indications are produced that the track is not correct.

6.4.2.4 Invalidation of a modified track

(See 5.1.1.2, 5.1.1.7)

6.4.2.4.1 Application

If the planning system does not perform the check track function, this test applies.

6.4.2.4.2 Method of testing

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

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

6.4.2.4.3 Required test results

Verify that in all cases this modified track cannot become the active track.

6.4.2.5 Replace an active track without stopping track control

(See 5.1.1.7)

6.4.2.5.1 Application

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

6.4.2.5.2 Method of testing

Place the ship′s position between waypoints 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.

6.4.2.5.3 Required test results

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

6.4.3 Execution of the scenarios

6.4.3.1 Start track control on the pre-planned track

(See 5.1.1.2)

6.4.3.1.1 Application

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

6.4.3.1.2 Purpose

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.

6.4.3.1.3 Display of data

6.4.3.1.3.1 Method of testing

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.

Activate the pre-planned track.

6.4.3.1.3.2 Required test results

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.

6.4.3.1.4 “Start track control” not accepted

6.4.3.1.4.1 Method of testing

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.

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

6.4.3.1.4.2 Required test results

Verify with each of the methods that track control cannot be started and that the system gives an indication of the reason.

6.4.3.1.5 “Start track control” accepted

6.4.3.1.5.1 Method of testing

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.

6.4.3.1.5.2 Required test results

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.

6.4.3.1.6 Track modification

(See 5.1.1.7)

6.4.3.1.6.1 Method of testing

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

6.4.3.1.6.2 Required test results

Verify that this is not possible without creating a new track and passing the starting requirements (see 6.4.1).

6.4.3.1.7 Start track control using a temporary track (~A)

(See 5.1.1.2)

6.4.3.1.7.1 Application

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

6.4.3.1.7.2 Purpose

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.

6.4.3.1.7.3 Method of testing

Perform the following tests.

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.

6.4.3.1.7.4 Required test results

Verify that:

a) 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) the specified information to be displayed continuously or on demand is presented correctly;

c) if this was successful, track control cannot be started and the system gives an indication of the reason;

d) the following results are met:

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

   – the system turns the ship towards the track course of the temporary track and then follows it and joins the pre-planned track.

6.4.3.1.8 Temporary track modification

(See 5.1.1.7)

6.4.3.1.8.1 Method of testing

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

6.4.3.1.8.2 Required test results

Verify that this is not possible without creating a new temporary track and passing the starting requirements (see 6.4.1).

6.4.3.1.9 Pre-planned track modification

(See 5.1.1.7)

6.4.3.1.9.1 Method of testing

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.

6.4.3.1.9.2 Required test results

Verify that this is not possible without creating a new track and passing the starting requirements (see 6.4.1).

6.4.3.2 Execute track control under undisturbed conditions

(See 5.1.1.1, 5.1.1.8)

6.4.3.2.1 Application

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

6.4.3.2.2 Test using Scenario 1

6.4.3.2.2.1 Purpose

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.

6.4.3.2.2.2 Method of testing

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 alerts within the assigned time windows (~A).

For category A, at the end of each leg confirm/acknowledge the ‘end of track warning’ within the assigned time windows.

6.4.3.2.2.3 Required test results

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 alerts are given as specified in 5.1.1.5, 5.1.1.6 (~A);
– for category A, the ‘end of track warning’ is generated at the end of each leg as specified in 5.1.1.17.
– at the end of the track, the system proceeds as required under 5.1.1.17.

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;
– once the ROT (+/- 10 %) has been achieved and until the steady part of the turn completes, the RMS of applied rudder is less than 20 % of maximum rudder as defined by the model.

6.4.3.2.3 Test using scenario 2

6.4.3.2.3.1 Purpose

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.

6.4.3.2.3.2 Method of testing

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 alerts within the assigned time windows (see also 6.4.5.10) (~A).

6.4.3.2.3.3 Required test results

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 alerts are given as specified in 5.1.1.5, 5.1.1.6 (~A);
– at the end of the track the system proceeds as required under 5.1.1.17.

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.
– once the ROT (+/- 10 %) has been achieved and until the steady part of the turn completes, the RMS of applied rudder is less than 20 % of maximum rudder as defined by the model.

6.4.3.2.4 Test using scenario 3

6.4.3.2.4.1 Purpose

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.

6.4.3.2.4.2 Method of testing

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 alerts within the assigned time windows.

6.4.3.2.4.3 Required test results

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 5.1.1.5, 5.1.1.6 (~A);
– at the end of the track the system proceeds as required under 5.1.1.17.

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.
– once the ROT (+/- 10 %) has been achieved and until the steady part of the turn completes, the RMS of applied rudder is less than 20 % of maximum rudder as defined by the model.

6.4.3.2.5 Test using scenario 4 rhumb line (RL)

6.4.3.2.5.1 Purpose

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.

6.4.3.2.5.2 Method of testing

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 3 is passed. Confirm/acknowledge the course change alerts within the assigned time windows (~A).
b) Let the system follow the leg from waypoint 3 to waypoint 4 (this can be done unattended). Stop track control before or at waypoint 4.

6.4.3.2.5.3 Required test results

The following results are required.

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 alerts are given as specified in 5.1.1.5, 5.1.1.6 (~A).

b) Verify by recording or observation that the ship proceeds from waypoint 3 to waypoint 4 along a constant track course with a cross-track deviation not greater than 50 m.

6.4.3.2.6 Test using scenario 4 great circle (GC)

6.4.3.2.6.1 Application

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

6.4.3.2.6.2 Purpose

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.

6.4.3.2.6.3 Method of testing

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 07 to waypoint 08 to great circle mode.

a) Start track control at the end of the leg from waypoint 06 to waypoint 07 in rhumb line mode and let the system follow the track until waypoint 07. 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 07 and waypoint 08.
d) Restart track control after setting the position before and the heading along the end of the great circle leg between waypoint 07 and waypoint 08 and let the system pass waypoint 08. If the system does not switch automatically to rhumb line mode, select rhumb line mode manually.

6.4.3.2.6.4 Required test results

The following results are required.

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.

d) Verify that
   - the system is able to switch over from great circle to rhumb line mode automatically or manually after waypoint 08 has been passed;
   - the tested part of the leg between waypoint 08 and waypoint 09 is sailed on a rhumb line according to the calculated course and with a cross-track deviation not greater than 50 m.

6.4.4 Execution of additional tests

6.4.4.1 Adaptation

(See 5.1.1.9)

6.4.4.1.1 Purpose

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. Notice 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 ship 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 leg;
- influence of current during the turn;
- influence of sea state during the turn;
- influence of sea state change on a leg.

See Annex J for an explanation of the tests.

6.4.4.1.2 Method of testing

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

a) Adaptation to intended speed change
   1) 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 kn. Start track control. After the turn has been initiated, increase the commanded speed to 20 kn.
   2) 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 kn. After the turn has been initiated, decrease the commanded speed to 12 kn.

b) Adaptation to current change
   1) Restart track control on the second leg sailing a course of 140° at 20 kn. When the simulated ship is 4 NM to 5 NM from WP3, induce a simulated current of 5 kn perpendicular to the track.
   2) 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 kn. In the middle of the turn, induce a simulated current of 5 kn northwards.
   3) 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 kn. In the middle of the turn, induce a simulated current of 5 kn northwards.

c) Adaptation to sea state
   1) 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 kn. Set the simulated sea state to 2 and complete the turn.

2) Restart track control on the second leg at a distance of 2 NM to 3 NM after WP2 sailing a course of 140° at 20 kn at sea state 2. In the middle of the leg, induce a simulated sea state of 5.

d) Adaptation to loading conditions

Confirm by inspection of manufacturer’s documentation that the EUT includes a method for adaptation to different loading conditions.

6.4.4.1.3 Required test results

6.4.4.1.3.1 Category A and category C

For category A cases b) 1) and c) 2) and for category C cases a) 1) to c) 2).

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.

6.4.4.1.3.2 Category B

Cases a) 1), a) 2) and b) 2) to c) 1) 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 approximately,
– in case the actual position deviates from the curved track beyond the pre-set limit, a cross-track alarm is given (see 5.1.3.6),
– the manoeuvre back to the pre-planned track is performed in a predictable and safe manner without excessive rudder activity.
– it is possible to adjust the rate(radius) of turn during the execution of the turn automatically and/or manually.

Confirm by inspection of manufacturer’s documentation that:

– the manoeuvre back to track after exceeding the cross-track limit is exemplified including a graphical presentation,
– the conditions for reactivation of track control after the assisted turn is completed are described.

Cases b) 1) to c) 2):

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.

6.4.4.2 Rudder activity

(See 5.1.1.10)

6.4.4.2.1 Purpose

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.

6.4.4.2.2 Method of testing

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 kn.

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 kn,
  - position data 1/100 min (18 m).
– Induce statistically scattered position errors as per Annex H.

6.4.4.2.3 Required test results

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.

6.4.4.3 Ship steering bias

(See 5.1.1.9)

6.4.4.3.1 Purpose

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.

6.4.4.3.2 Method of testing

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 kn. Start track control. Stop track control after 20 min.

6.4.4.3.3 Required test results

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

6.4.5 Monitoring and alerts

6.4.5.1 General

All tests of operational alerts shall verify that these alerts, if acknowledged, remain as an indication while the alert condition exists and complies with 5.1.3.

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

6.4.5.2 Failure or reduction in power supply

(See 5.1.3.1)

6.4.5.2.1 Method of testing

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.

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

This test may be combined with environmental tests in 6.2.1.

6.4.5.2.2 Required test results

Verify that a warning is triggered (e.g. contact closure) by the track control system.

6.4.5.3 Position monitoring alert

(See 5.1.1.4, 5.1.3.2)

6.4.5.3.1 Method of testing

Supply a pair of position data to the position monitor function (see 5.1.1.4) 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 alert limit.

If multiple position sensors are offered, then repeat the test method as needed to verify all sensor configurations.

6.4.5.3.2 Required test results

Verify that a corresponding warning is given.

6.4.5.4 Heading monitoring alert

(See 5.1.1.16, 5.1.3.3)

6.4.5.4.1 Application

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

6.4.5.4.2 Method of testing

Supply a pair of heading data to the heading monitor function (see 5.1.1.16) 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 alert limit.

If multiple heading sensors are offered, then repeat the test method as needed to verify all sensor configurations.

6.4.5.4.3 Required test results

Verify that a corresponding warning is given.

6.4.5.5 Failure and alert status of sensors

(See 5.1.1.16, 5.1.3.4, 5.4.2)

6.4.5.5.1 Method of testing

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 alert 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.

6.4.5.5.2 Required test results

Verify that an alert sequence and corresponding indications are generated as specified in 5.1.3.4.

(See also test of fall-back procedures defined in 6.4.5.)

6.4.5.6 Use of faulty signals

(See 5.1.3.5)

6.4.5.6.1 Method of testing

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.

6.4.5.6.2 Required test results

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

6.4.5.7 Cross-track alert

(See 5.1.3.6)

6.4.5.7.1 Method of testing

Perform the following tests.

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

6.4.5.7.2 Required test results

Verify that

a) a corresponding alert of priority alarm is given.
b) the alert status and its indication are cleared.

6.4.5.8 Course difference alert

(See 5.1.3.7)

6.4.5.8.1 Method of testing

Perform the following tests.

a) Add a transversal current velocity so that the preset course difference alert limit is exceeded.
b) Acknowledge the alert and modify the current velocity so that the preset course difference alert limit is not exceeded.

6.4.5.8.2 Required test results

Verify that

a) a corresponding alert of priority warning is given,
b) the alert status and its indication are cleared.

6.4.5.9 Low speed alert

(See 5.1.3.8)

6.4.5.9.1 Application

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

6.4.5.9.2 Method of testing

Perform the following tests.

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

6.4.5.9.3 Required test results

Verify that

a) a corresponding alert of priority class warning is given,
b) the alert status and its indication are cleared.

6.4.5.10 End of track alert

(See 5.1.1.17, 5.1.3.9)

6.4.5.10.1 Method of testing

Follow a pre-planned track until the last waypoint is passed with and without acknowledging the “end of track” alert.

This test may be carried out simultaneously with other tests (see 6.4.2.3).

6.4.5.10.2 Required test results

Verify that corresponding alerts of priority class warning are given as described in 5.1.3.9.

6.4.5.11 Track control stopped alert

(See 5.1.3.10)

6.4.5.11.1 Method of testing

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

a) Use the manufacturer’s documentation (e.g. Failure mode & effect analysis (FMEA)) to identify all failure conditions within the track control system which cause the system to switch automatically to heading control or which render track control unusable. Create one of these conditions that do not represent a sensor failure.
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.
d) Disconnect the selected speed input from the track control system or define it as invalid.

6.4.5.11.2 Required test results

Verify that a track control stopped alert of priority class warning 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 5.1.3.10.

6.4.5.12 Course change alerts (~A)

(See 5.1.1.5, 5.1.1.6)

6.4.5.12.1 Purpose

The purpose of the following sequence of tests is to fully exercise the course change alert conditions (see 5.1.1.5, 5.1.1.6 and Annex A).

6.4.5.12.2 Method of testing

The tests may be carried out using any scenario of Annex G.

Start track control preceding any alerts becoming active and pass the wheel-over-time:

a) without acknowledgment of early course change warning (ECCW) and without acknowledgment of actual course change warning (ACCW);

b) with acknowledgment of ECCW and without acknowledgment of ACCW;

c) without acknowledgment of ECCW and with acknowledgment of ACCW;

d) with acknowledgment of both ECCW and ACCW.

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

6.4.5.12.3 Required test results

The following results are required.

a) With no acknowledgment of alerts verify that:
   - ECCW occurs between WOT – 6 min and WOT – 3 min;
   - ECCW changes priority to alarm status (ECCA) within 30 s;
   - NA is triggered within another 30 s time lapse;
   - the track controller follows automatically the planned track.

b) With acknowledgment of ECCW only verify that:
   - ECCW ceases and no ECCA occurs;
   - ACCW occurs at 30 s before the WOT;
   - ACCW changes priority to ACCA within 30 s;
   - NA is triggered within another 30 s time lapse;
   - the track controller follows automatically the planned track.

c) With acknowledgment of ECCW and ACCW verify that:
   - no alarm is activated;
   - no NA is activated;
   - the track controller follows automatically the planned track.

6.4.5.13 Handling of the Back-up Navigator Alarm (NA)

(See 5.1.3.11)

6.4.5.13.1 Method of testing

Confirm by inspection of documented evidence that the EUT provides at least one of the required interfaces to BNWAS. Perform subsequently tests a) to c) below each with no alerts present as the start condition. Create an alarm associated with NA activation.

a) After one minute acknowledge the alarm.

b) Wait 10 s and silence the alarm. Wait until the audible announcement of the alarm is activated again. Wait 10 s and silence the alarm again.

c) Rectify the cause of alarm after 40 s.

6.4.5.13.2 Required test results

Confirm by observation that:

a) 30 s after activation of the alarm

- If available ALR sentence defined at Annex K is generated,
- If available the contact is closed for NA transfer,
- If available other equivalent methods defined by the manufacturer are activated for NA transfer.

Confirm that after the acknowledgement of the alarm all BNWAS-interfaces reset the state to NA not activated.

b) 70 s after activation of the alarm

- If available ALR sentence defined at Annex K is generated,
- If available the contact is closed for NA transfer,
- If available other equivalent methods defined by the manufacturer are activated for NA transfer

Confirm that after the acknowledgement of the alarm all BNWAS interfaces reset the state to NA not activated.

c) 30 s after activation of the alarm

- If available ALR sentence defined at Annex K is generated,
- If available the contact is closed for NA transfer,
- If available other equivalent methods defined by the manufacturer are activated for NA transfer

Confirm that after the cause of the alarm is rectified (e.g. track control is switched off) all BNWAS interfaces reset the state to NA not activated.

6.4.5.14 Remote acknowledgments of alerts – Method of testing and required test result

(See 5.1.3.12)

Perform following test using a simulator for BAM:

a) Test of alert reporting and silencing

- Create 2 alerts, at least one of Cat B.
- Confirm by observation that ALF, ALC and HBT sentences are transmitted from the EUT to the BAM interface.
- Use simulator to send ACN sentence to the EUT to silence one of the alerts.
- Confirm by observation that ALF, ALC and HBT sentences report correctly the new state of the alerts.
- Use simulator to send ACN sentence to the EUT to acknowledge the Cat B alert.
- Confirm by observation that ALF, ALC and HBT sentences report correctly the new state of the alerts.

b) Test of attempt to acknowledge Cat A alert

- Create an alert of Cat A.
- Confirm by observation that ALF, ALC and HBT sentences are transmitted from the EUT to the BAM interface.
- Use simulator to send ACN sentence to the EUT to acknowledge the Cat A alert.
- Confirm by observation that the EUT refuses to acknowledge and that the ARC sentence reports correctly this refusal.

6.4.6 Fallback and manual change over

6.4.6.1 Failure of track control

(See 5.5.1)

6.4.6.1.1 Method of testing

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

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

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.

6.4.6.1.2 Required test results

Verify that the system reacts as specified in 5.5.1.

6.4.6.2 Failure of position sensor

(See 5.5.2)

6.4.6.2.1 Method of testing

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a leg and perform the following tests a, c, e, f, i, j.

Restart track control using scenario 3 and perform the following tests b, d, g, h, k, l, during a course change manoeuvre (~A).

a) Switch off the selected position.
b) If applicable, switch off all available positions.
c) Tag the selected position input as invalid.
d) If applicable, tag all available position inputs as invalid.

If applicable

e) tag the NSR-sentence for position input as integrity failed,
f) tag the NSR-sentence for position input as integrity doubtful,
g) switch off the selected speed sensor, wait 6 min and switch on the selected speed sensor,
h) switch off all available speed sensors, wait 6 min and switch on all available speed sensors,
i) tag the selected speed input as invalid, wait until 6 min and tag the selected speed input as valid,
j) tag all available speed inputs as invalid, wait 6 min and tag all available speed inputs as valid,
k) tag the NSR-sentence for speed input as integrity failed, wait 6 min and tag the selected speed input as passed,
l) tag the NSR-sentence for speed input as integrity doubtful, wait 6 min and tag the selected speed input as passed.

6.4.6.2.2 Required test results

For a, b, c, d, e, f, g, h, i, j, k and l), verify that the system reacts as specified in 5.5.2.

6.4.6.3 Failure of the heading measurement system

(See 5.5.3)

6.4.6.3.1 Method of testing

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

Restart track control using scenario 3 and perform the following tests b, d, f, during a course change manoeuvre (~A).

a) Switch off the selected heading sensor.

b) If applicable switch off all available heading sensors.

c) Tag the selected heading input as invalid.

d) If applicable, tag all available heading inputs as invalid.

e) If applicable, tag the NSR-sentence for heading input as integrity failed

f) If applicable, tag the NSR-sentence for heading input as integrity doubtful,

6.4.6.3.2 Required test results

For a, b, c, d, e and f), verify that the system reacts as specified in 5.5.3.

6.4.6.4 Failure of the speed sensor

(See 5.5.4)

6.4.6.4.1 Method of testing

Select scenario 3 and start track control. Wait until the ship is proceeding steadily on a leg and perform the following tests a, c, e, f, i, j.

Restart track control using scenario 3 and perform the following tests b, d, g, h, k, l, during a course change manoeuvre (~A).

a) Switch off the selected speed sensor.

b) If applicable, switch off all available speed sensors.

c) Tag the selected speed input as invalid.

d) If applicable, tag all available speed inputs as invalid.

If applicable

e) tag the NSR-sentence for speed input as integrity failed,

f) tag the NSR-sentence for speed input as integrity doubtful,

g) switch off the selected speed sensor, wait 6 min and switch on the selected speed sensor,

h) switch off all available speed sensors, wait 6 min and switch on all available speed sensors,

i) tag the selected speed input as invalid, wait until 6 min and tag the selected speed input as valid,

j) tag all available speed inputs as invalid, wait 6 min and tag all available speed inputs as valid,

k) tag the NSR-sentence for speed input as integrity failed, wait 6 min and tag the selected speed input as passed,

l) tag the NSR-sentence for speed input as integrity doubtful, wait 6 min and tag the selected speed input as passed.

6.4.6.4.2 Required test results

For a, b, c, d, e, f, g, h, I, j, k and l), verify that the system reacts as specified in 5.5.4.

6.4.6.5 Manual changeover from track control to manual steering (~A)

(See 5.1.1.11, 5.1.1.13, 5.2.1.2)

6.4.6.5.1 Method of testing

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

Switch over to manual steering.

Repeat this test using the override facility (input).

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.

6.4.6.5.2 Required test results

Verify that

– manual changeover can be done and, if part of EUT, by a single operator action,
– track control cannot be resumed without user intervention, and
– the system reacts as specified in 5.1.1.13.

6.4.6.6 Manual changeover from track control to heading control

(See 5.1.1.14)

6.4.6.6.1 Application

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

6.4.6.6.2 Method of testing

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

6.4.6.6.3 Required test results

Verify that

– manual changeover can be done and, if part of EUT, by a single operator action,
– track control cannot be resumed without user intervention,
  and
– the system reacts as specified in 5.1.1.14 including any options provided.

6.4.7 Display of information

6.4.7.1 Continuously displayed information

(See 5.1.1.15, 5.2.2.1, 5.2.2.3)

6.4.7.1.1 Method of testing

Locate the display of the information listed in 5.2.2.1. The test may be combined with and verified during execution of the normal mode and failure mode tests.

6.4.7.1.2 Required test results

The following results are required.

– 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 at the main conning position and conforms to the general requirements for displays contained in IEC 62288.
– Verify that the items listed in 5.2.2.1 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.

6.4.7.2 Information to be provided on demand

(See 5.2.2.2)

6.4.7.2.1 Method of testing

Locate the display of the information listed in 5.2.2.2 (which may be displayed on associated equipment). The test may be combined with and verified during execution of the normal mode and failure mode tests.

6.4.7.2.2 Required test results

Verify that that this information is available on demand.

6.4.8 Operational controls

(See 5.1.1.11, 5.2.1.1, 5.2.1.2)

6.4.8.1 Method of testing

NOTE The previous tests have verified that the requirements of 5.2.1.1 have been met.

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

6.4.8.2 Required test results

Verify that the location complies with 5.2.1.2.

Annex A
(normative)

Graphical description of sequences

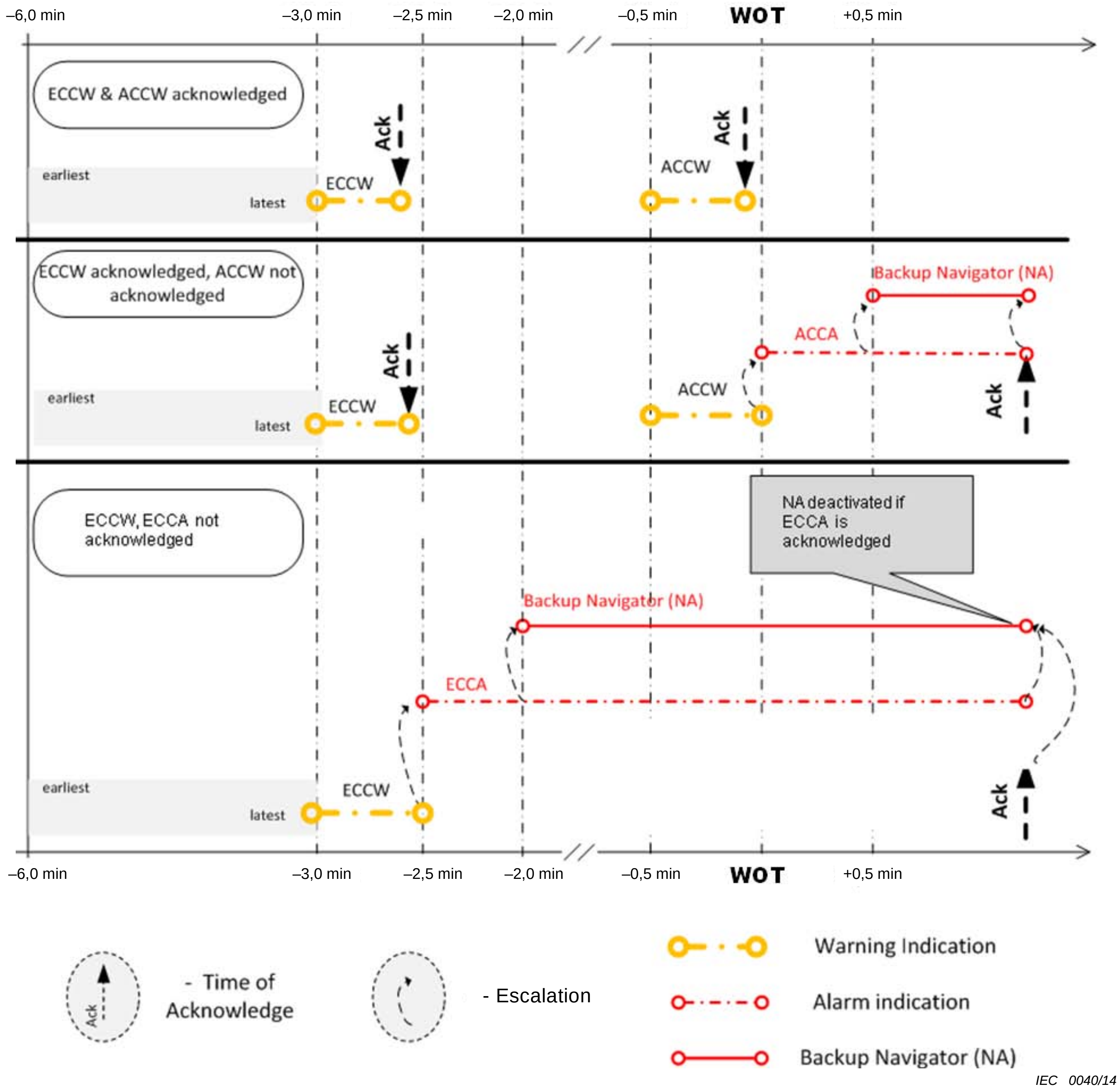


Figure A.1 – Sequence of course change alerts (~A)

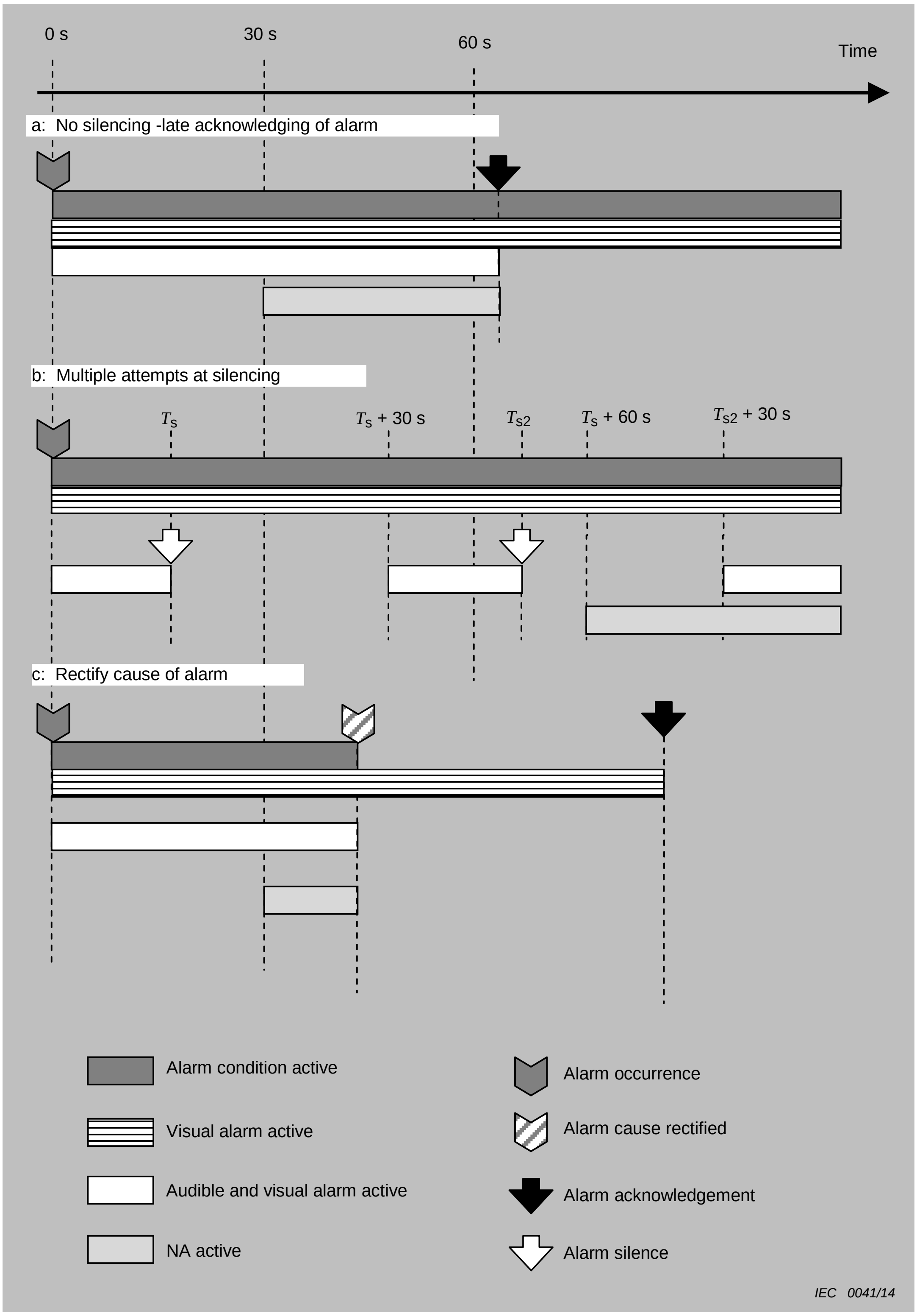


Figure A.2 – Handling of the Back-up Navigator Alarm (NA)

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 alerts

B.7.1 Loss of speed sensor

A valid speed sensor or source is crucial to closed-loop propulsion control. An alert of priority class alarm should be given upon loss of all speed sensors or sources 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 alert of priority class 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 alert of priority class warning 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 controllers

C.1 General

This annex includes specific advice for track control systems which include a primary controller and a back-up controller.

C.2 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.3 Change over from active to back-up track controller

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

The track control system should ensure that, or be installed so that, the switch-over does not result in excessive use of rudder.

C.4 Failure of track control

If the track controller fails, then a track control stopped alert of priority class warning 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 5.5.1.

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 5.5.1.

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 alert of priority class 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 alert of priority class warning 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

D.1 General

According to the functional model of track control (6.2.1.3 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.2 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.3 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.4 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.5 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 standards 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 gives recommended limits for certain parameters in Clause 5.

Table E.1 – Limits

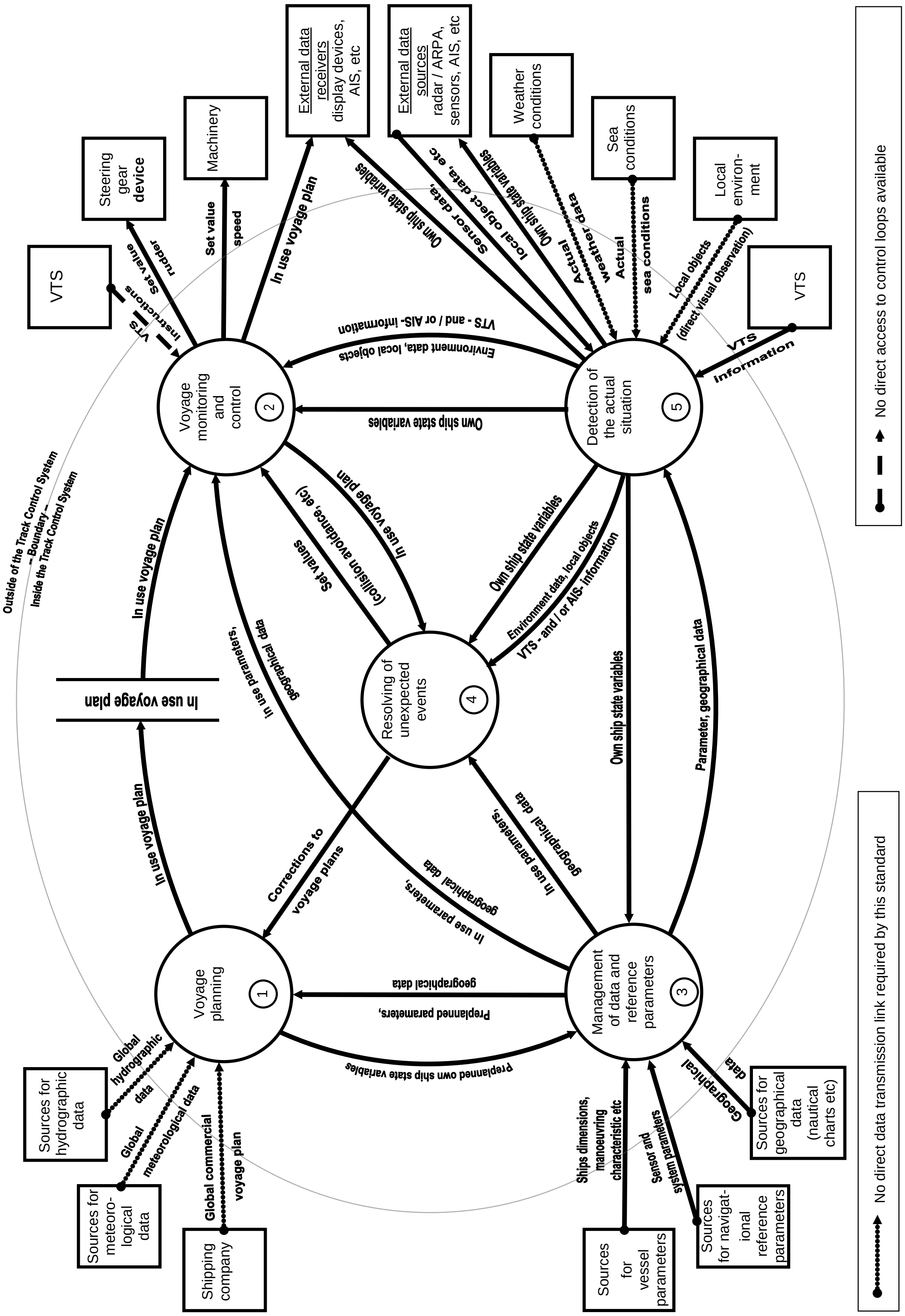
Clause/subclause	Item	Required	Recommended
5	Maximum manoeuvring speed	≤30 kn	
5	Maximum rate of turn	≤10°/s	
5.1.1.2	Ship's position relative to selected track for starting		≤1 NM
5.1.1.2	Course difference limit for starting		≤60°
5.1.3.2	Maximum position monitoring difference		≤1 NM
5.1.3.3	Maximum heading monitoring difference		≤25°
5.1.3.6	Maximum cross-track limit (for alert)		≤5 NM
5.1.3.7	Maximum course difference limit (for alert)		≤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

This Annex provides a generic data flow diagram identifying the information flow and the resulting dependencies between supported functions.


Voyage planning 1
Voyage monitoring and control 2
Management of data and reference parameters 3
Resolving of unexpected events 4
Detection of the actual situation 5
In use voyage plan
Outside of the Track Control System
– Boundary –
Inside the Track Control System
Sources for hydrographic data
Sources for meteoro-logical data
Shipping company
Global hydrographic data
Global meteorological data
Global commercial voyage plan
Preplanned own ship state variables
Preplanned parameters,
geographical data
Sources for vessel parameters
Sources for navigat-ional reference parameters
Sources for geographical data (nautical charts etc)
Ships dimensions, manoeuvring characteristic etc
Sensor and system parameters
Geographical data
Corrections to voyage plans
In use parameters, geographical data
Own ship state variables
Parameter, geographical data
Environment data, local objects
VTS - and / or AIS- information
Set values
(collision avoidance, etc)
VTS
VTS instructions
Set value rudder
Steering gear device
Machinery
Set value speed
External data receivers display devices, AIS, etc
External data sources radar / ARPA, sensors, AIS, etc
Weather conditions
Sea conditions
Local environ-ment
Own ship state variables
Sensor data, local object data, etc
Actual weather data
Actual sea conditions
Local objects (direct visual observation)
VTS information
No direct data transmission link required by this standard
No direct access to control loops available
IEC 0042/14

Annex G
(normative)

Scenario definitions and plots

Tables G.1 to G.4 and Figures G.1 to G.4 give the details for the scenarios defined in 6.3.3. Distances are approximately from wheel-over point to wheel-over point along the curved track (accurate values are ship-dependent).

Table G.1 – Scenario 1

Scenario 1: Complex track at 0/0 with ship class A (20 kn)						
Waypoint No.	**Latitude**	**Longitude**	**Track** °	**Distance** NM	**Radius** NM	**Estimated ROT** °/min
001	00°01,000′ S	000°01,000′ W	000,0	1,40	-	-
002	00°01,000′ N	000°01,000′ W	090,0	1,86	0,60	32
003	00°01,000′ N	000°01,000′ E	315,0	1,21	0,20	95
004	00°02,000′ N	000°00,000′ E	225,0	0,92	0,20	95
005	00°01,000′ N	000°01,000′ W	135,0	2,69	0,60	32
006	00°01,000′ S	000°01,000′ E	270,0	1,51	0,20	95
007	00°01,000′ S	000°01,000′ W	045,0	1,86	0,20	95
008	00°01,000′ N	000°01,000′ E	180,0	1,98	0,40	48
009	00°01,000′ S	000°01,000′ E			-	-

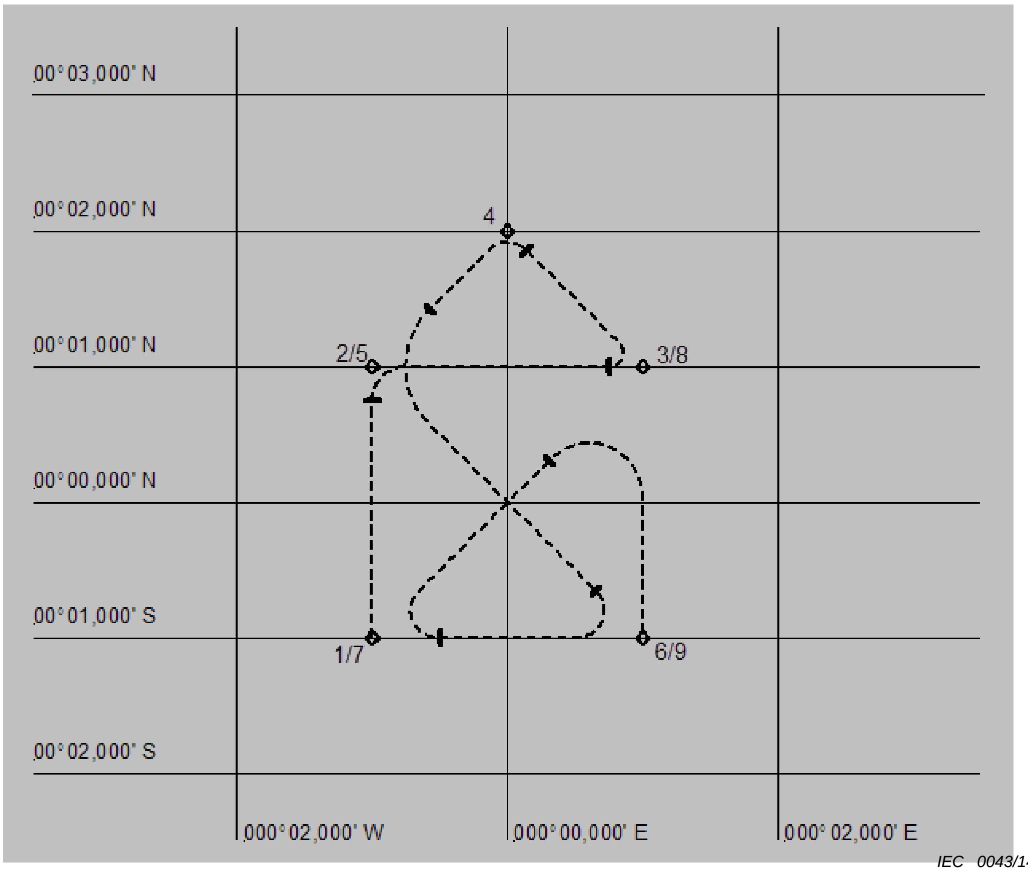


Figure G.1 – Scenario 1 plot

Table G.2 – Scenario 2

Scenario 2: Complex track at 0/180 with ship class C (10 kn)						
Waypoint No.	**Latitude**	**Longitude**	**Track** °	**Distance** NM	**Radius** NM	**Estimated ROT** °/min
001	00°03,000′ S	179°57,000′ W	000,0	5,00	-	-
002	00°03,000′ N	179°57,000′ W	270,0	4,64	1,00	10
003	00°03,000′ N	179°57,000′ E	045,0	3,19	0,80	12
004	00°06,000′ N	180°00,000′ W	135,0	3,31	1,00	10
005	00°03,000′ N	179°57,000′ W	225,0	6,92	1,50	7
006	00°03,000′ S	179°57,000′ E	090,0	4,02	1,00	10
007	00°03,000′ S	179°57,000′ W	315,0	5,33	0,80	12
008	00°03,000′ N	179°57,000′ E	180,0	5,93	1,25	8
009	00°03,000′ S	179°57,000′ E			-	-

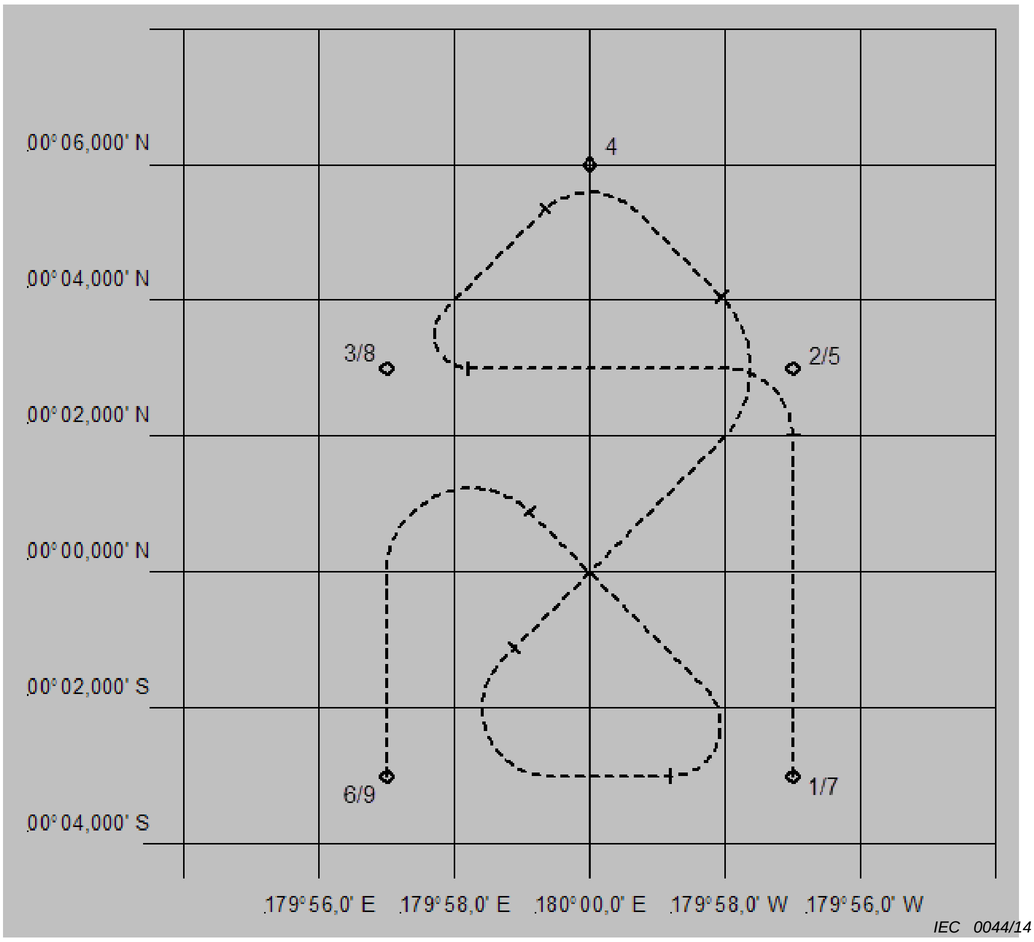
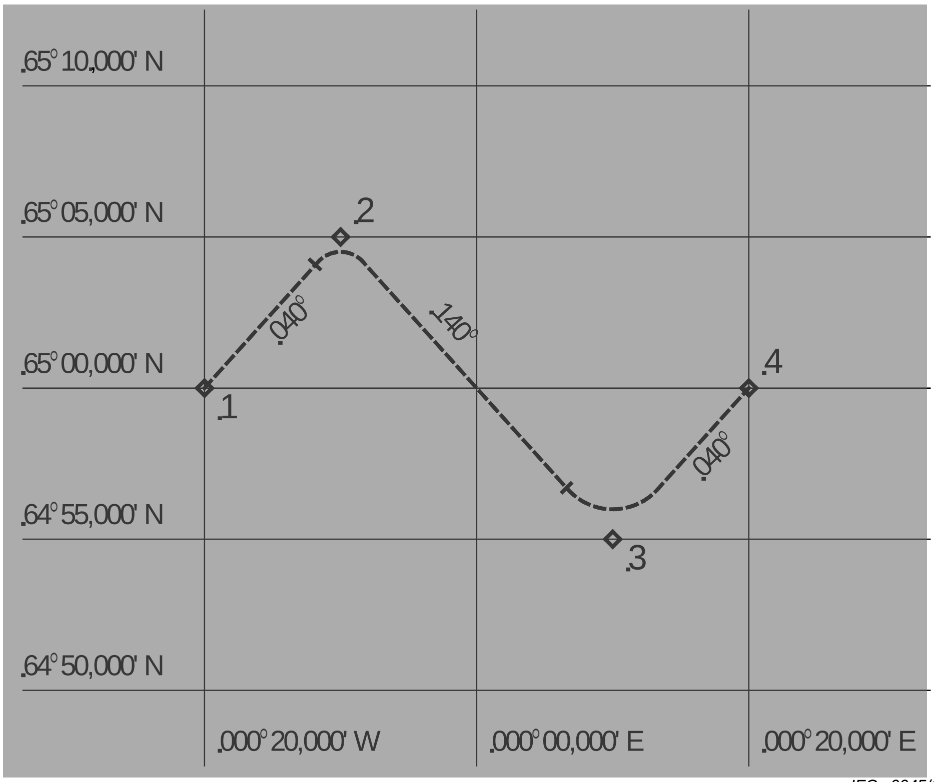


Figure G.2 – Scenario 2 plot

Table G.3 – Scenario 3

Scenario 3: Zigzag track at 65/0 with ship class B (20 kn)						
Waypoint No.	**Latitude**	**Longitude**	**Track** °	**Distance** NM	**Radius** NM	**Estimated ROT** °/min
001	65°00,000′ N	000°20,000′ W	040,2	5,35	-	-
002	65°05,000′ N	000°10,000′ W	139,8	11,26	1,0	20
003	64°55,000′ N	000°10,000′ E	040,2	7,65	2,0	10
004	65°00,000′ N	000°20,000′ E			-	-



IEC 0045/14

Figure G.3 – Scenario 3 plot

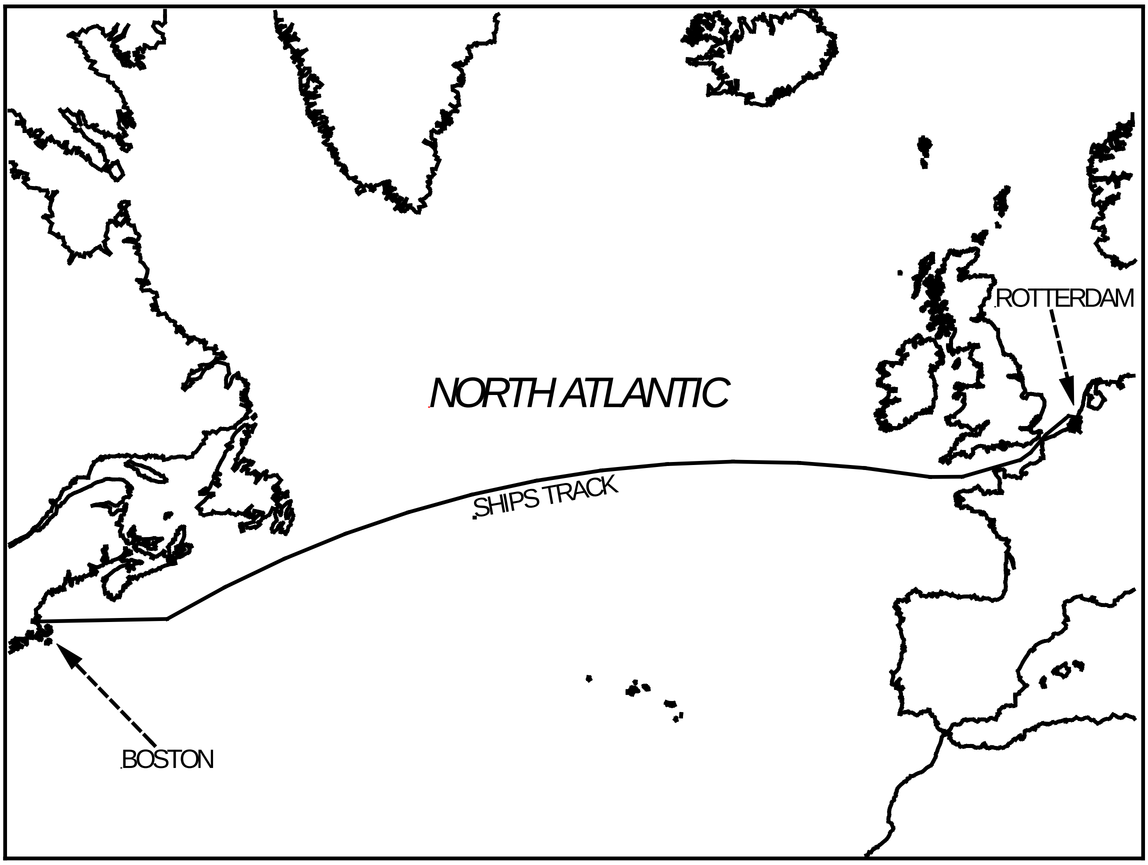
Table G.4 – Scenario 4

Scenario 4: Rhumb line/great circle Atlantic track (Boston to Rotterdam) with ship class B (20 kn)						
Waypoint No.	**Latitude**	**Longitude**	**Track** °	**Distance** NM	**Radius** NM	**Estimated ROT** °/min
001	42°22,380′ N	070°54,210′ W	079,5	4,9	-	-
002	42°23,275′ N	070°47,663′ W	065,1	9,5	1,0	19
003	42°27,287′ N	070°35,953′ W	088,2	126,4	1,0	19
004	42°31,223′ N	067°44,616′ W	085,4	272,9	1,0	19
005	42°53,045′ N	061°34,463′ W	065,2	202,7	1,0	19
006	44°17,923′ N	057°20,346′ W	067,1	307,8	1,0	19
007	46°17,898′ N	050°37,294′ W	067,1	1761,2	1,0	19
Great circle approximation	48°46,606′ N 50°04,547′ N 50°28,684′ N 50°00,935′ N	40°00′ W 30°00′ W 20°00′ W 10°00′ W	075,0 082,5 090,0 098,0			
008	49°38,074′ N	006°25,031′ W	084,5	147,4	1,0	19
009	49°52,252′ N	002°37,903′ W	074,5	144,2	1,0	19
010	50°30,788′ N	000°59,106′ E	049,7	18,33	1,0	19
011	50°42,637′ N	001°21,152′ E	016,3	13,03	1,0	19
012	50°55,140′ N	001°26,929′ E	038,1	19,59	1,0	19
013	51°10,551′ N	001°46,164′ E	041,5	15,62	1,0	19
014	51°22,252′ N	002°02,706′ E	041,6	46,69	1,0	19
015	51°57,145′ N	002°52,725′ E	084,9	13,15	1,0	19
016	51°58,304′ N	003°13,980′ E	082,4	24,71	1,0	19
017	52°01,567′ N	003°53,769′ E	112,1	7,20	1,0	19
018	51°58,858′ N	004°04,605′ E			-	-

NOTE

The position co-ordinates assume an ellipsoid which agrees with WGS 84.

Distances are approximately from wheel-over point to wheel-over point along the curved track (since accurate values are ship-dependent).



IEC 0046/14

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 the GPS SPS Performance Standard:

Accuracy Standard	Conditions and Constraints
Worst Site Positioning Domain Accuracy • ≤ 36 meters 95% All-in-View Horizontal Error (SIS Only) • ≤ 77 meters 95% All-in-View Vertical Error (SIS Only)	• Defined for position solution meeting the representative user conditions • Standard based on a measurement interval of 24 hours for any point within the service volume

H.2 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 (7,5 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 × $\log_e$(Rand)

New frequency = F0 × Rand (independently for each sinusoid)
Phase step = 0,4π × Rand (independently for each sinusoid)

- At each step

For each sinusoid: Phase step = deltaTime × Frequency

Position error = 20 × Rand × cos(2π × Rand) + Amplitude × sum of {cos(Phase)} over all sinusoids

The standard deviation should be between

- 10 m and 15 m for GPS
- 2 m and 3 m for DGPS

The position error spectrum should conform to the distribution as shown in Figure H.1.

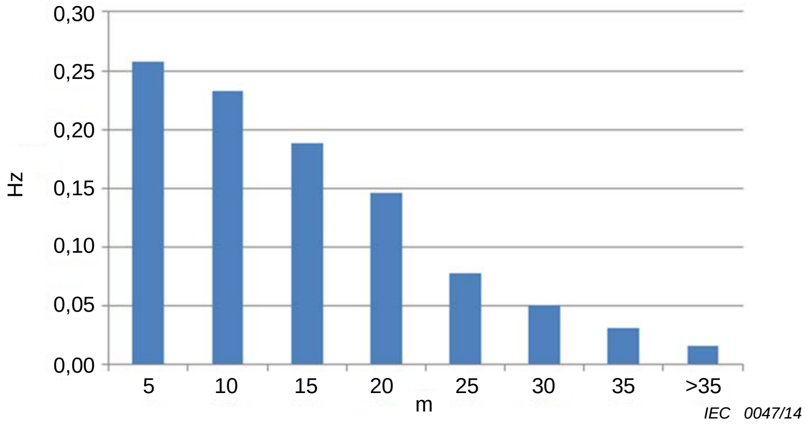


Figure H.1 – Spectral distribution of modelled GPS errors

H.3 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.4 Simulation of sea state

H.4.1 General

Clause H.4 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 shall 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.4.2 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:

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

$T_0(\text{SS})$ is a time constant characteristic of the sea state SS, listed in the Table H.1 below.

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

Height:

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

$H_0(\text{SS})$ is the SWH characteristic of the sea state SS, listed in the Table H.1 below.

Table H.1 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.1 – 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 Figures H.2 and H.3 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.

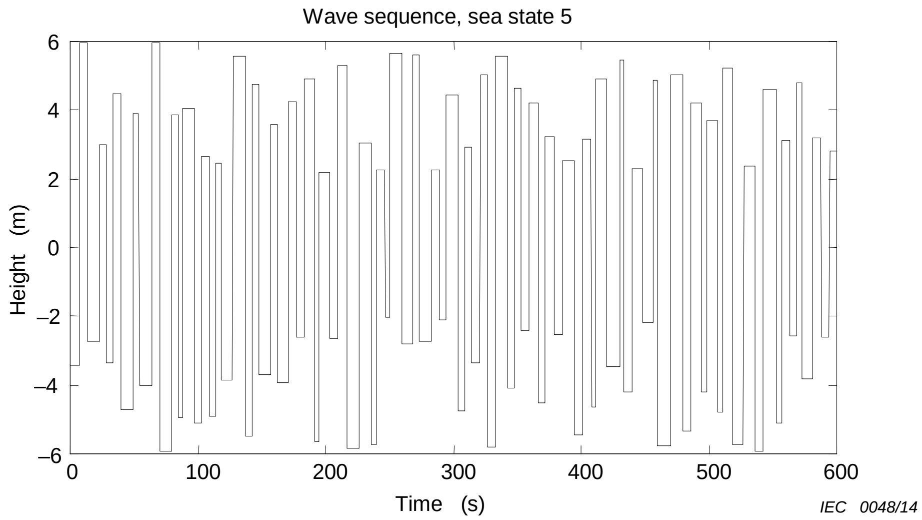


Figure H.2 – Wave sequence – sea state 5

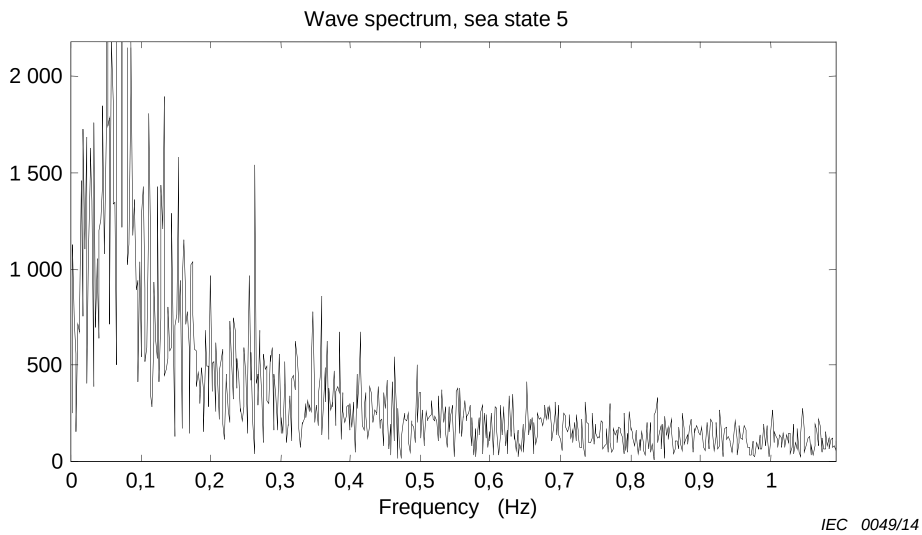


Figure H.3 – Wave spectrum – sea state 5

H.4.3 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 in Figures H.4, H.5 and H.6 for the tanker, container and ferry models.

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

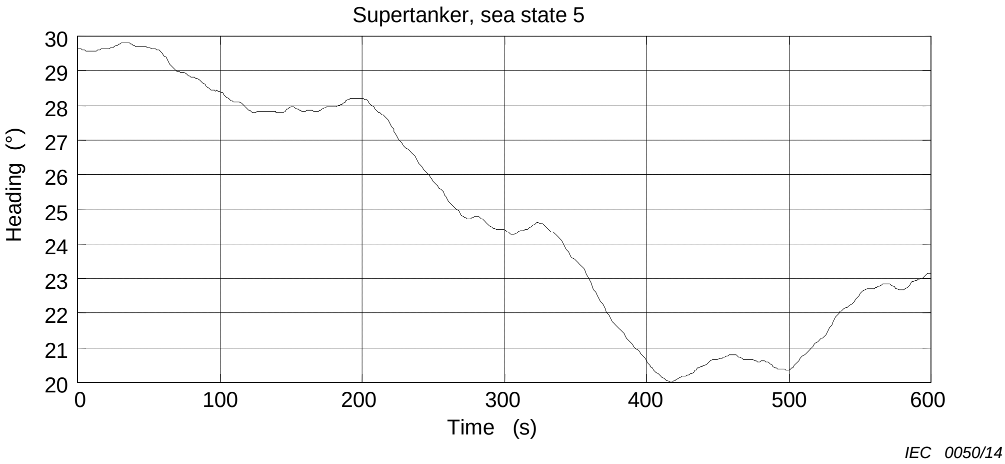


Figure H.4 – Supertanker – sea state 5

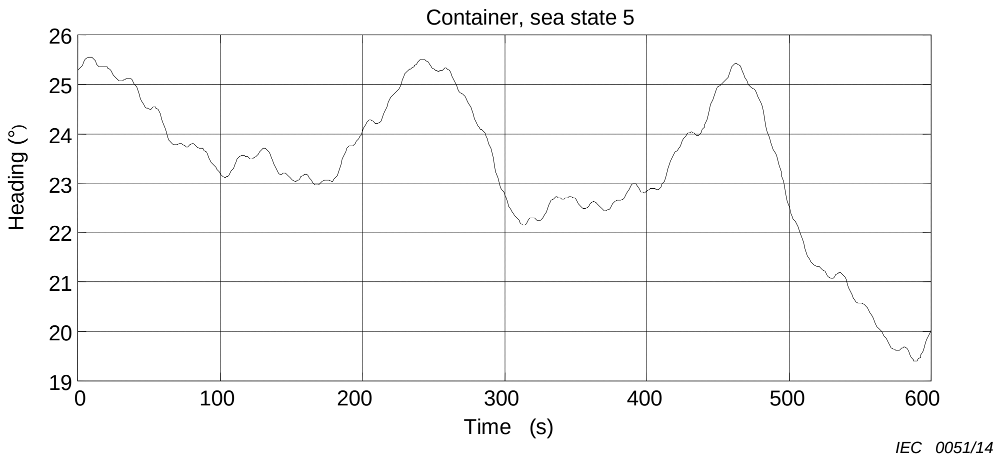


Figure H.5 – Container ship – sea state 5

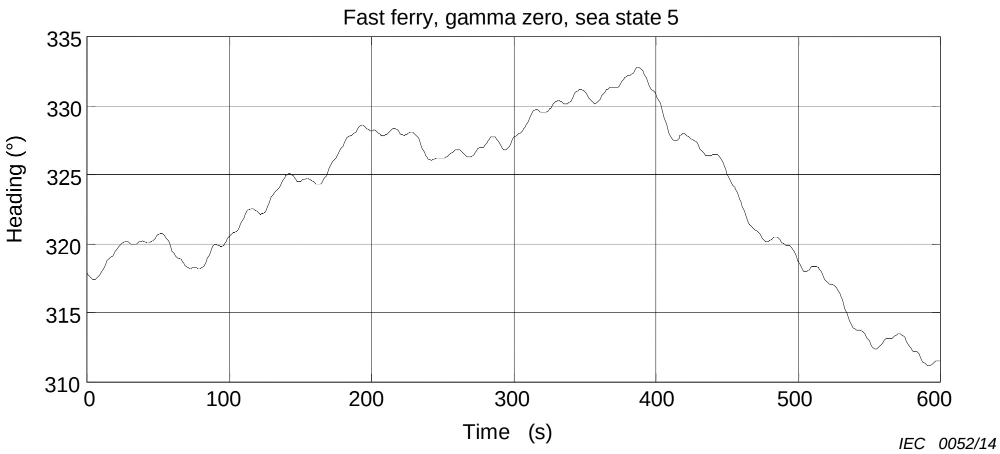


Figure H.6 – Fast ferry – sea state 5

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, Figure H.7 illustrates the behaviour of the container class in sea state 2:

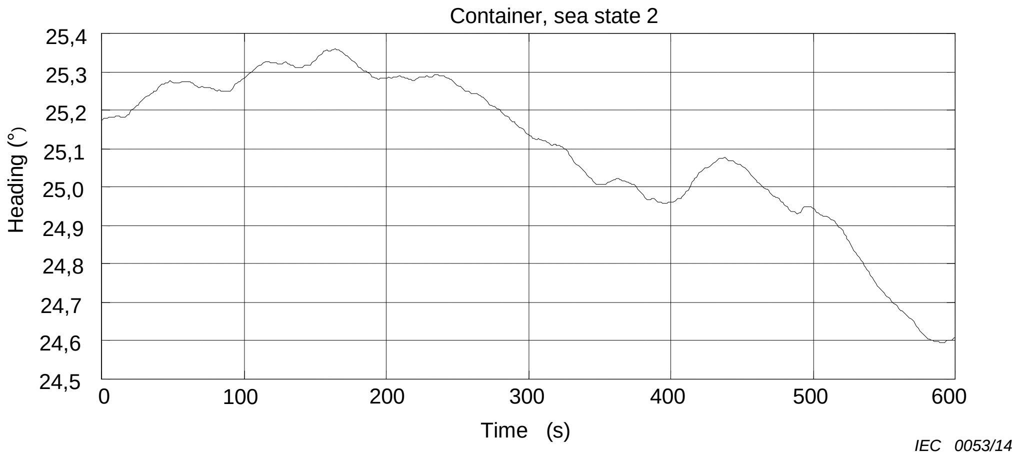


Figure H.7 – Container ship – sea state 2

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 ships and their manoeuvrability can be simulated by using parameter sets as listed in Clause I.5.

NOTE This model is a simplified model of ship behaviour having pertinent parameters which have been established for the objective of testing a track control system. For the reason of ease of use, it has been simplified beyond the normal parameters of a ship.

I.2 Overview – 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 propulsion 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.3 The model – Derivation

I.3.1 General

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.

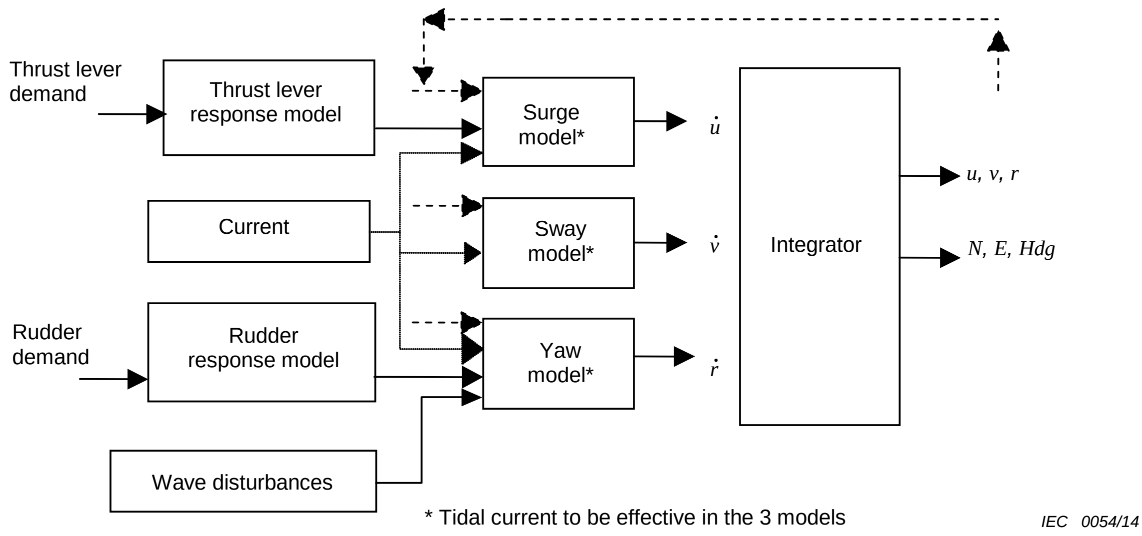


Figure I.1 – High level model block diagram

The individual components of the model are discussed individually in the remainder of this clause. In each subclause, 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.4, 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.3.2 Thrust lever response model

I.3.2.1 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:

$$\dot{P}_{\mathrm{a}} = \begin{cases} +R_{\mathrm{p}} & P_{\mathrm{a}} < P_{\mathrm{d}} \\ 0 & P_{\mathrm{a}} = P_{\mathrm{d}} \\ -R_{\mathrm{p}} & P_{\mathrm{a}} > P_{\mathrm{d}} \end{cases} \tag{I.1}$$

This is subject to minimum and maximum limits imposed on P_{a}.

$$X = const \times P_{\mathrm{a}} \tag{I.2}$$

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.3.2.2 Transformed equation

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

$$P' = P \,/\, P_{\mathrm{max}}, \quad \text{and} \quad R'_{\mathrm{p}} = R_{\mathrm{p}} \,/\, P_{\mathrm{max}}$$

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}:

$$T_{\mathrm{p}} = 2 \,/\, R'_{\mathrm{p}}$$

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

$$X' = X \,/\, X_{\mathrm{max}}$$

The equations used in computation are then:

$$\dot{P}'_{\mathrm{a}} = \begin{cases} +2 \,/\, T_{\mathrm{p}} & P'_{\mathrm{a}} < P'_{\mathrm{d}} \\ 0 & P'_{\mathrm{a}} = P'_{\mathrm{d}} \\ -2 \,/\, T_{\mathrm{p}} & P'_{\mathrm{a}} > P'_{\mathrm{d}} \end{cases} \tag{I.3}$$

where P_{a}' is constrained within the range –100 % to +100 %; and

$$X' = P'_{\mathrm{a}} \tag{I.4}$$

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 to its maximal value (–100 % to 100 %).

I.3.3 Rudder response model – 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 translation in the algebraic notation in Table I.1:

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

Thrust lever		Rudder	
P_a, P_d, etc.	Lever settings	δ_a, δ_d, etc.	Rudder settings
R_p	Lever rate	R_δ	Rudder rate
T_p	Lever time	T_δ	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, Δ, 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

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

or

$$\dot{\delta}'_a = R'_\delta \text{ (input option B)} \qquad (I.6)$$

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

Constant parameters to be entered by the user:

T_δ Rudder ramp time (full port – full starboard), in seconds (option A);

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

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

Run-time inputs:

δ'_d rudder demand, normalized (–100 % to +100 %) (option A);

R'_δ 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.3.4 Surge response model

I.3.4.1 Derivation

The surge response model calculates the forward acceleration which is brought about by the thrust X (provided by the propulsor) and the hydrodynamic resistance to forward 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.

$$M_u \dot{u}_g = X + M_u v_g r - R_u u_w \tag{I.7}$$

where

M_u	is the mass associated with forward acceleration;
u_g	is the forward component of ship velocity over the ground
$\dot{u}_g$	is the time-derivative of the forward ship velocity over the ground;
u_w	is the forward component of ship velocity through the water;
X	is the forward thrust imparted by the propulsor;
v_g	is the sideways component of ship velocity over the ground (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.3.4.2 Transformed equation

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

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

τ_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. Notice that the value of K_u is derived from easily measured or defined quantities.

The equation used in computation then becomes

$$\dot{u}_g = K_u X' + v_g r - u_w / \tau_u \tag{I.11}$$

Constant parameters to be entered by the user:

u_{max} maximum speed, metres per second;

τ_u acceleration time constant, seconds;

also, the initial value of u_g 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_w,v_g components of velocity, metres per second;

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

Run-time output:

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

I.3.5 Sway response model

I.3.5.1 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.

$$M_v \dot{v}_g = -M_v u_g r - R_v v_w \tag{I.12}$$

where

M_v is the mass associated with sideways acceleration;

v_w is the sideways component of ship velocity through water;

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

u_g is the forward component of ship velocity over ground;

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.3.5.2 Transformed equation

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

$$\tau_v = M_v / R_v \tag{I.13}$$

τ_v is the time constant of the linear response model.

The equation used in computation then becomes:

$$\dot{v}_g = -u_g r - v_w / \tau_v \qquad (I.14)$$

Constant parameters to be entered by the user:

τ_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_g, v_w components of velocity, metres per second;

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

Run-time output:

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

I.3.6 Yaw response model

I.3.6.1 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, δ_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.

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

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 yaw rate about the vertical axis (positive to starboard);

$\dot{r}$ is the time-derivative of the yaw rate;

K_r is a constant of proportionality;

δ_a is the achieved rudder position;

$K_r \delta_a K_u X' \tau_u / L$ 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;

γ 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;

$(v_w - \gamma L r)$ 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).

I.3.6.2 Transformed equation

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

$$\tau_r = I_z / R_r \tag{I.16}$$

τ_r is the time constant of the linear response model.

$$K_r' = \frac{r(\delta_a', X')}{\delta_a' \tau_r} \frac{L}{K_u X' \tau_u} \tag{I.17}$$

K_r' is the normalized coefficient of rudder moment, relating the steady-state yaw rate to the propeller thrust and normalized rudder position in the absence of any stability effects, i.e. with $\gamma = 0$. A practical method of estimating K_r' is given in I.4.1.

Using Equation (I.13), the equation is re-written as:

$$\dot{r} = K_r' \left(\frac{K_u X' \tau_u}{L} \delta_a' + W' \right) + \frac{\gamma L M_v (v_w - \gamma L r)}{I_z \tau_v} - \frac{r}{\tau_r} \tag{I.18}$$

For this computation, the equation has further been simplified by relating the moment of inertia to the mass and length, using a simple equation which relates the moment of inertia of a uniformly dense rod to its mass and length, i.e.

$$I_z = M_v L^2 / 12$$

This is without loss of generality as the coefficient γ is a quantity which is set by the user. Using this relationship, the equation becomes

$$\dot{r} = K_r' \left(\frac{K_u X' \tau_u}{L} \delta_a' + W' \right) + \frac{12\gamma (v_w - \gamma L r)}{L \tau_v} - \frac{r}{\tau_r} \tag{I.19}$$

Constant parameters to be entered by the user:

K_r' yaw coefficient, in units of reciprocal seconds;

τ_r time constant, seconds;

γ stability coefficient, dimensionless;

L overall ship length, metres.

Also, the initial value of r should be specified or taken as zero by default.

Run-time inputs:

δ'_a rudder achieved position (normalized with respect to its maximum value, –100 % to +100 %);

W' wave disturbance turning moment, related to the wave height as follows:
W' = H x SF / 100; where SF is a Scaling Factor. A value of 20 for the Scaling Factor is recommended.

H wave height from Clause H.4.

$K_u X' \tau_u / L$ thrust, multiplied by the thrust coefficient and divided by the forward motion time constant and the ship length. This quantity is in units of reciprocal seconds;

v_w sideways component of ship velocity through water, metres per second;

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

Run-time output:

$\dot{r}$ time-derivative of r, radians per second per second.

I.3.7 Integration (deduced reckoning)

The process of integrating the accelerations, to yield velocity components, yaw rate, heading and position is well-known and is briefly outlined below. For the purpose of testing track control systems, it is necessary to include the effects of a tidal current.

The first stage in the process is to recalculate the components of speed through the water, u_w and v_w, from previous values of the speed over the ground, heading, and the tidal flow. This calculation might be omitted if the tidal current were to be constant; but if the tidal current is to be suddenly altered, the calculation should take place at this point. This ensures that the new tidal current, on first introduction, introduces movement of the water relative to the ship, and this produces hydrodynamic forces on the ship, which reacts by accelerating accordingly.

(If the calculation were omitted, the ship would immediately be carried by the new tidal current, implying that the tidal set and drift is imposed suddenly and immediately, with a step change in ship velocity relative to land, which would be contrary to Newtonian dynamics.)

$$\begin{pmatrix} u_w \\ v_w \end{pmatrix} = \begin{pmatrix} u_g \\ v_g \end{pmatrix} - \begin{pmatrix} T_X \\ T_Y \end{pmatrix}$$

where

$$\begin{pmatrix} T_X \\ T_Y \end{pmatrix} = \begin{pmatrix} C & S \\ -S & C \end{pmatrix} \begin{pmatrix} T_N \\ T_E \end{pmatrix}$$

where

u_w and v_w velocity components relative to the water and are calculated from the ground referenced velocity components u_g and v_g.

C and S cosine and sine of the heading

The simplest way to interpolate the tidal vector during the ramp-period is to scale the northerly and easterly tide components T_N and T_E for the ramp.

The second stage in the process is to integrate the rates of change to obtain velocity and rate of turn (yaw).

$$u_g = \int \dot{u}_g dt$$

$$v_g = \int \dot{v}_g dt$$

$$r = \int \dot{r} dt$$

The third stage is to integrate the yaw rate to obtain heading:

$$Hdg = \int r dt$$

The fourth stage is to transform the ship-related velocity components to an absolute coordinate system based on N and E:

$$\begin{pmatrix} V_{GN} \\ V_{GE} \end{pmatrix} = \begin{pmatrix} C & -S \\ S & C \end{pmatrix} \begin{pmatrix} u_g \\ v_g \end{pmatrix}$$

where C and S are defined as above.

Finally, V_{GN} and V_{GE} are integrated to obtain the position of the vessel:

$$N = \int V_{GN} dt$$

$$E = \int V_{GE} dt$$

Constant parameters to be entered by the user:

T_N, T_E tidal current northerly and easterly components; typically entered as speed and direction by user and converted into northerly and easterly components by the ship model. Changes of tidal current happen with a transition ramp based on change rate 1 knot per 1 minute. This transition ramp shall be coded into the ship model simulation.

Run-time inputs:

$\dot{u}_g, \dot{v}_g, \dot{r}$ components of acceleration and rate of change of yaw.

Run-time outputs:

u_g, v_g, r components of velocity and yaw;

V_{WN}, V_{WE} components of water-velocity, in (N,E) coordinates;

V_{GN}, V_{GE} components of ground-velocity, in (N,E) coordinates;

Hdg heading;

N,E ship position.

I.4 Summary and block diagram

I.4.1 Constant inputs

The constant parameters to be entered by the user are listed in Table I.2.

Table I.2 – Constant parameters of the model

Item	Comments
T_p	Time for the thrust to ramp from minimum to maximum (s)
T_δ	Time for the rudder to swing from stop to stop (s)
Δ	Rudder follow-up offset
U_{max}	Maximum speed
τ_u	Time constant, surge
τ_v	Time constant, sway
K_r'	(Normalized) Yaw coefficient, defined by Equation (I.17)
τ_r	Time constant, yaw
γ	Stability coefficient, physically corresponds to the position of the centre of lateral pressure, normalized with respect to length L; 0 is neutral; typical values lie in the range –0,1 (unstable) to +0,1 (stable).
L	Overall vessel length

In addition to these parameters, the model should also be provided with user-input or default values for the initial conditions, i.e. start position and heading; start velocity and yaw rate; start rudder and lever achieved values. In all cases, zero may be specified as a valid starting value.

I.4.2 Estimating parameters for a given vessel or class

Most of the ship parameters are directly measurable or may even be estimated with reasonable accuracy for a given class of ship. The model is a linearized approximation and is not intended as a comprehensive solution; consequently the parameters may be estimated with considerable latitude and the best choice of parameters may be different for different regimes (speeds) of operation. It should also be borne in mind that changes of some of the parameters may only have a small effect on test results.

The sway time constant τ_v may be obtained by observing the drift characteristics during a turn. In the steady state condition, all time derivatives are zero and Equation (I.14) yields

$$\tau_v = -\frac{v_g}{u_g r} \qquad \text{(I.20)}$$

where all the parameters on the right-hand side are directly measurable.

Similarly, the surge time constant τ_u may be obtained by observing the drop in forward speed during a turn. In the steady state condition, Equation I.11 leads to

$$\tau_u = \frac{\partial u_g}{\partial (v_g r)} \tag{I.21}$$

In practice, this means simply observing the drop in forward speed during a steady-state turn, compared to straight-ahead motion with the same lever setting.

The yaw time constant, τ_r, is measurable from a graph of the yaw rate as a turn is initiated. It is likely to be of the same order of magnitude as the sway time constant τ_v because it arises from a physically related phenomenon, i.e. the resistance to water flow sideways under the hull: if this is uniformly distributed along the length of the vessel, τ_r and τ_v will be similar and for practical purposes, the same value may be used for both.

The yaw coefficient and the stability coefficient are measurable from a set of turning circle data. A first approximation may be made on the assumption that $\gamma = 0$, giving a value for K_r' from Equation I.17. For the purposes of setting up models for simulation testing, this is probably a good approach. A more accurate estimate may be made by performing turning circle trials with different values of u_g/L and rudder settings. Equation (I.19) may be re-arranged, for steady state conditions, to yield values of K_r' and γ from a set of graphs in which r is plotted against $K_r'\delta_a'u/L$.

The stability coefficient is generally likely to be in the region –0,1 to +0,1 and will, in practice, vary with speed. As explained in the derivation (I.3.6.1), this figure describes the position of the centre of lateral resistance, in terms of ships lengths. For example, a skeg fitted forward of the centre of gravity will tend to make the vessel unstable. For the purposes of autopilot testing, it might be recommended that the system be tested with neutral stability ($\gamma = 0$) and with some instability using a specified negative value, and a certain minimum speed, in a combination which is found to represent a suitably difficult but not impossible condition.

In setting up a model for tests, it is worth noting that the model will not exhibit a self-sustained turn unless the forward speed exceeds a threshold value. The threshold condition may be derived from Equation (I.19) to be

$$\frac{u_g}{L} > \frac{\gamma}{T_v} + \frac{1}{12\gamma T_r} \tag{I.22}$$

and, as stated earlier, $\gamma < 0$. With these conditions satisfied, the vessel will enter a turn (if an initial impetus is provided to port or starboard) and the turn will increase and settle on a value so that the forward speed is reduced to the threshold condition implied by Equation (I.22). Thus, given a self-sustained rate of turn and an initial forward speed, γ may be calculated from Equations (I.20) to (I.22).

I.4.3 Run-time inputs

Run-time inputs to the system are listed in Table I.3.

Table I.3 – Run-time inputs

Item	Comments
P_d'	Lever demand (normalized)
δ_d' or R_d'	Rudder (normalized) demand (option A) or rate (option B)
W'	Wave disturbance function (normalized with respect to rudder action)
Tidal current	Speed and direction, or N and E components

The wave disturbance function may take the form of a prescribed sequence of values and durations, for example as specified in ISO 16329.

I.4.4 Outputs

Model outputs are listed in Table I.4.

Table I.4 – Model outputs

Item	Comments
P_a'	Lever achieved (normalized)
X'	Thrust (normalized)
δ_a'	Rudder achieved (normalized)
$\dot{u}, \dot{v}, \dot{r}$	Accelerations in ship coordinates, and rate of change of yaw
u_w, v_w, u_g, v_g, r	Velocities in ship coordinates, and yaw
V_{WN},V_{WE}	Water velocity components with respect to fixed (N,E) axes
V_{GN},V_{GE}	Ground velocity components with respect to fixed (N,E) axes
Position	With respect to fixed (N,E) axes
Heading	With respect to north

I.4.5 Application of the model to system testing

In developing the model, care has been taken to ensure that the inputs and outputs correspond to those which are found on standard track control systems. It is worth noting that the connections provided on track control systems may vary according to manufacturers and types.

As far as lever settings are concerned, these are manual or follow-up (direct demand) rather than rate demands so the optional rate-input is not provided.

The machinery interface is provided with several options for connection, depending on whether the electronic decision-making system is being tested, or whether the test includes the mechanical means for driving the lever and rudder. It is arguable that these actuators, which are often provided as part of the system and can have a dramatic impact on performance, should be tested as part of the whole system.

The model block diagram is given in Figure I.2.

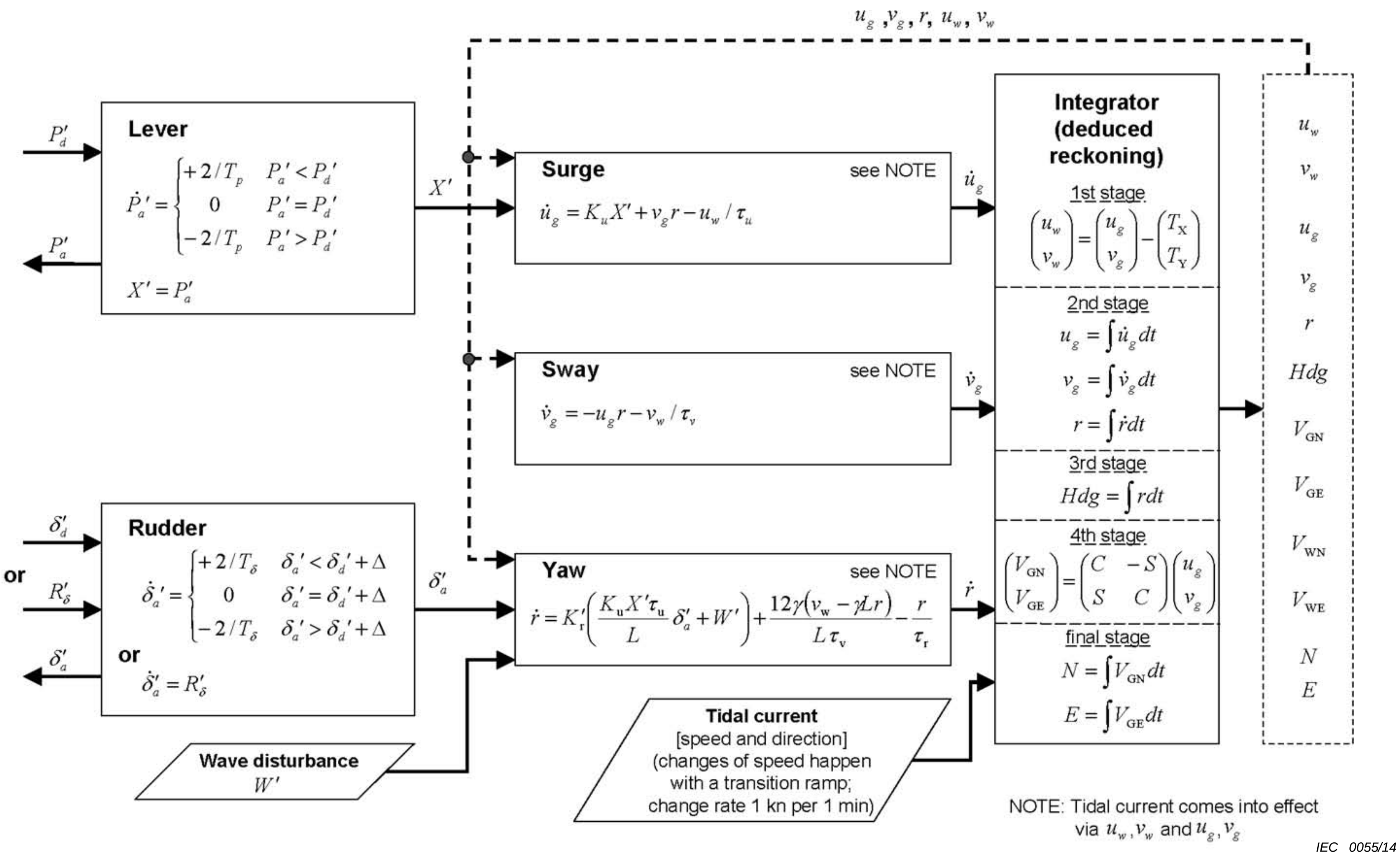


Figure I.2 – Model block diagram

I.4.6 Testing system only, without rudder actuators

I.4.6.1 Systems which output an absolute rudder demand (follow-up)

For follow-up systems which output absolute value demands, option A is selected in I.3.2. The demanded setting is converted from a voltage to a normalized numerical value, and applied directly to the P_δ run-time input as illustrated in Figure I.3.

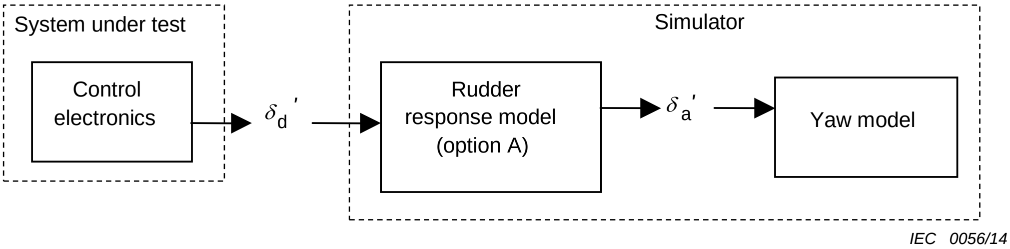


Figure I.3 – Application with simple follow-up

The model is capable of introducing an offset between the demand and the steady-state achieved settings, so as to simulate the effect of asymmetry in the ship behaviour, as may indeed arise from a miscalibration of the rudder follow-up mechanism.

I.4.6.2 Systems which output a rudder actuator command

Many autopilot devices have a feedback connection to the vessel, in which the demand is issued as a required rate of change, and the vessel feeds back a voltage which represents the achieved setting. It is worth noting that such systems do not have a calibrated zero position (for example a voltage which is guaranteed to represent rudder-amidships). The control system shall be capable of effectively calibrating itself to whatever the rudder-amidships voltage happens to be on a particular vessel, for example by accruing a corresponding offset in an integrator.

In this case, the model may be connected to the autopilot system by means of the demanded rate of change $R_\delta{}'$ and the achieved value δ_a is connected to the feedback input of the autopilot system. This arrangement, illustrated in Figure I.4, allows for a bipolar/zero rate input, or for a variable rate input for fine control of small rudder angles.

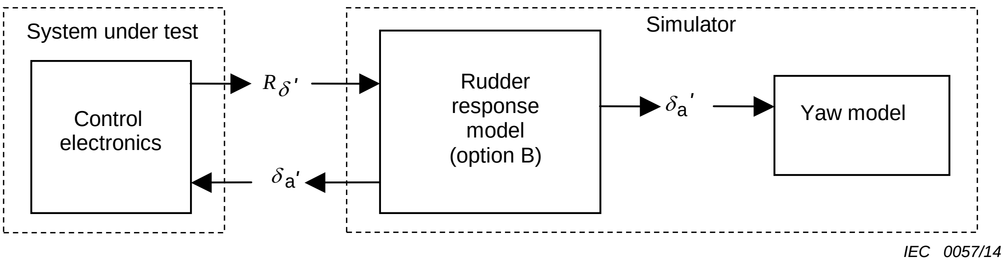


Figure I.4 – Control system using actuator outputs and feedback

I.4.7 Testing the whole system including actuation mechanism

If the actuator mechanism is included within the system under test, it is necessary to use its achieved setting in place of the rudder response model.

One way to achieve this is to bypass the rudder model completely, applying the controller output to the input of the yaw model, as illustrated in Figure I.5.

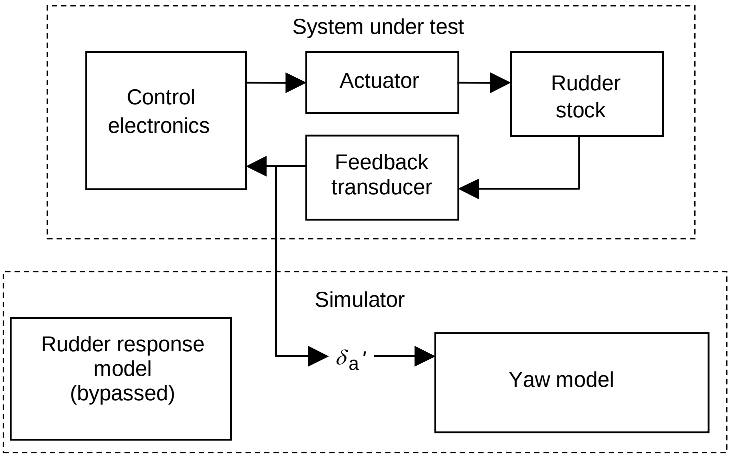


Figure I.5 – System with actuator mechanism, bypassing the rudder response model

Alternatively, the system may be configured using the follow-up arrangement (option A) with a ramp rate that is faster than that of the system under test, so that the model effectively keeps the rudder achieved position in step with the actuator output. This is illustrated in Figure I.6.

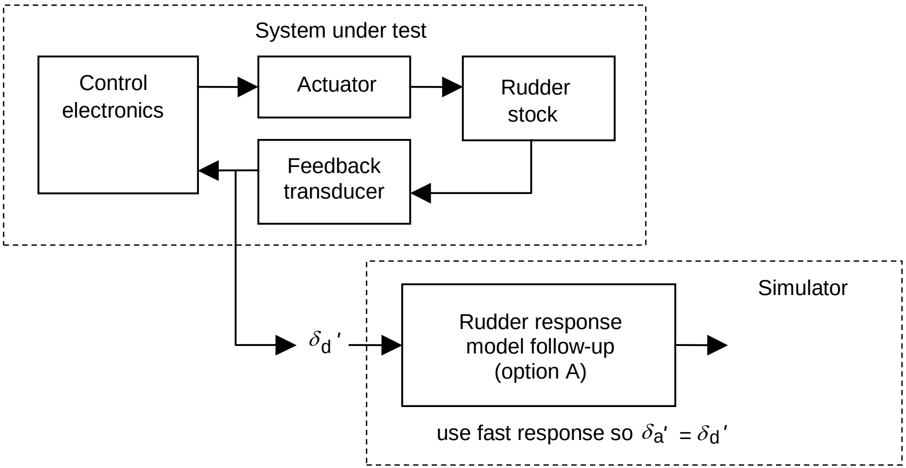


Figure I.6 – System with actuator mechanism using a fast rudder response time in the model

I.4.8 Model outputs: input to system under test

Other system outputs shall be converted to a format that is suitable for input to the system under test. A conveniently widespread format is IEC 61162-1 and IEC 61162-2, which provides for data transfer using serial data links. All the required data fields are provided by the model as outputs.

I.5 Ship parameter sets

Three sets of ship parameters have been created to represent, broadly, three classes of vessel to be used in the tests. These are presented in Table I.5.

Table I.5 – Parameter sets for three ships

Parameter	Ship A	Ship B	Ship C
Type	**Ferry**	**Container ship**	**Tanker**
L (m)	60	250	350
T_p (s)	20	30	30
T_δ (s)	12	30	30
Δ (%)	0	0	0
u_{max} (kn)	30	25	10
Kr' (deg/s/%)	0,025	0,01	0,005
τ_u (s)	150	600	800
τ_v (s)	2	4	36
τ_r (s)	4	23	46
γ	–0,05	0	0

I.6 Manoeuvring characteristics from turning circle manoeuvres (informative example)

Information about the turning ability of the three vessels can be obtained from turning circle manoeuvres as set out in the annex to the IMO circular MSC/Circ.1053 “Explanatory Notes to the Standards for ship manoeuvrability”.

The results from turning circle manoeuvres are presented in Table I.6 and Figures I.7 to I.9. The measured values in Table I.6 are rounded off to three relevant digits. If compared with results from different ship motion simulators, small differences may be observable due to different simulator properties.

Table I.6 – Results from turning circle manoeuvres

Parameter	Ship A	Ship B	Ship C	Comments
Type	**Ferry**	**Container ship**	**Tanker**	
Rudder order	100 **%**	100 **%**	100 **%**	Rudder order execute (TIME, conditions)
STW $_{\text{ahead}}$	30,0 **kn**	25,0 **kn**	10,0 **kn**	
TIME	0 **s**	0 **s**	0 **s**	
Advance	0,194 **NM**	0,551 **NM**	0,666 **NM**	
Transfer	0,089 **NM**	0,323 **NM**	0,349 **NM**	
STW $_{\text{ahead at 90°}}$	24,9 **kn**	22,6 **kn**	7,86 **kn**	
STW $_{\text{abeam at 90°}}$	**P** 4,17 **kn**	**P** 1,85 **kn**	**P** 1,72 **kn**	
TIME $_{\text{at 90°}}$	29,5 **s**	106 **s**	319 **s**	
Tactical Diameter	0,180 **NM**	0,640 **NM**	0,760 **NM**	
STW $_{\text{ahead at 180°}}$	20,2 **kn**	20,3 **kn**	6,42 **kn**	
STW $_{\text{abeam at 180°}}$	**P** 3,09 **kn**	**P** 1,68 **kn**	**P** 1,40 **kn**	
TIME $_{\text{at 180°}}$	49,3 **s**	183 **s**	585 **s**	
Final Turning Diameter	0,138 **NM ***	0,335 **NM ****	0,481 **NM ***	Results identified with different number of final complete turning circles: * 3rd circle ** 5th circle
STW $_{\text{ahead}}$	14,7 **kn ***	12,4 **kn ****	4,99 **kn ***	
STW $_{\text{abeam}}$	**P** 1,73 **kn ***	**P** 1,03 **kn ****	**P** 1,06 **kn ***	
ROT	203 **°/min ***	71 **°/min ****	20,3 **°/min ***	

NOTE The results are based upon observations and metered distances from turning circle trajectory (reference is made to a co-ordinate system starting with "rudder order execute").

Advance	metered at 90°of heading change
Transfer	metered at 90°of heading change (same time, same position as above)
Tactical Diameter	metered at 180°of heading change
Final Turning Diameter	metered after rate of turn and speed through the water have been stabilised to final values

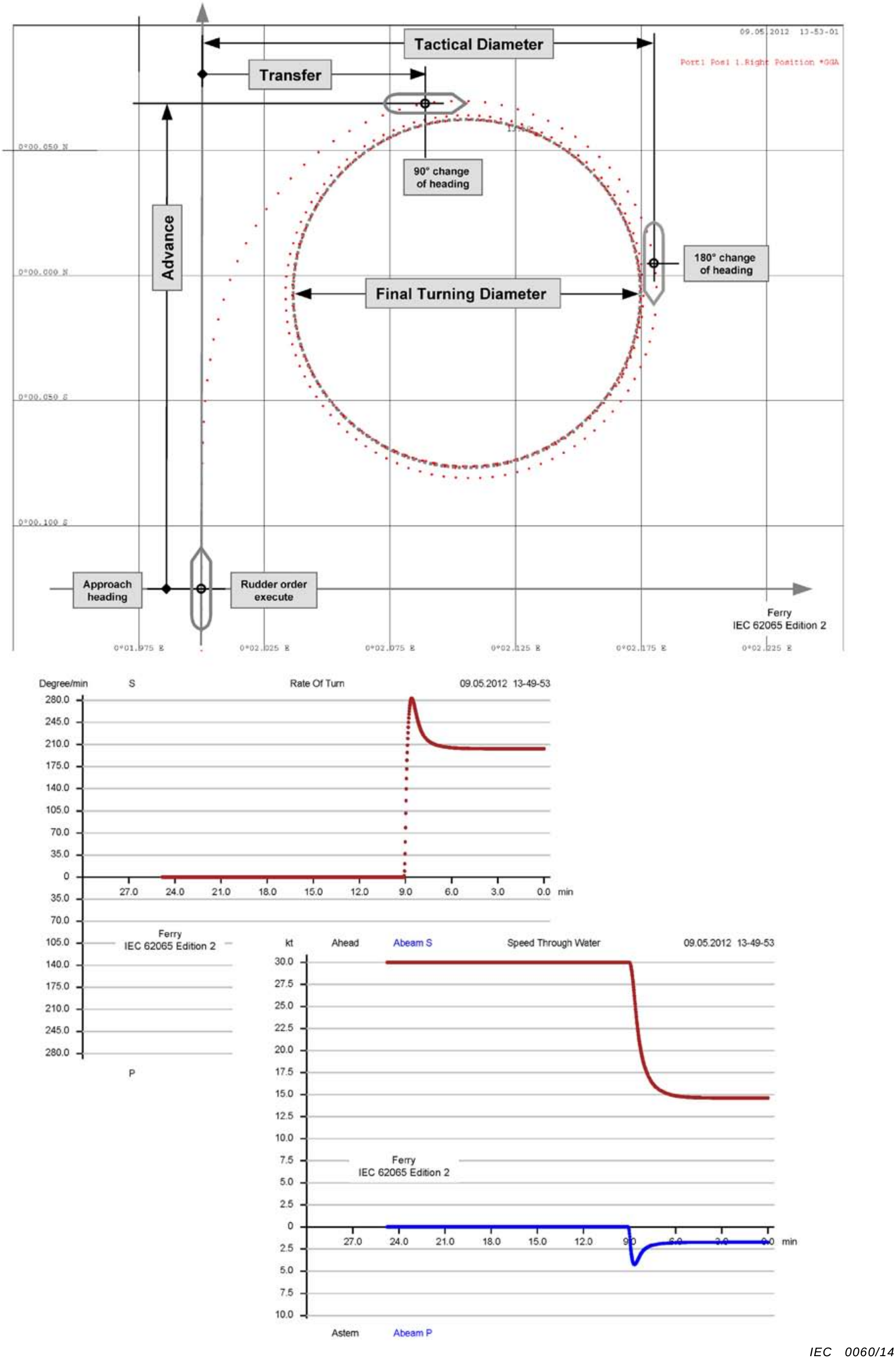
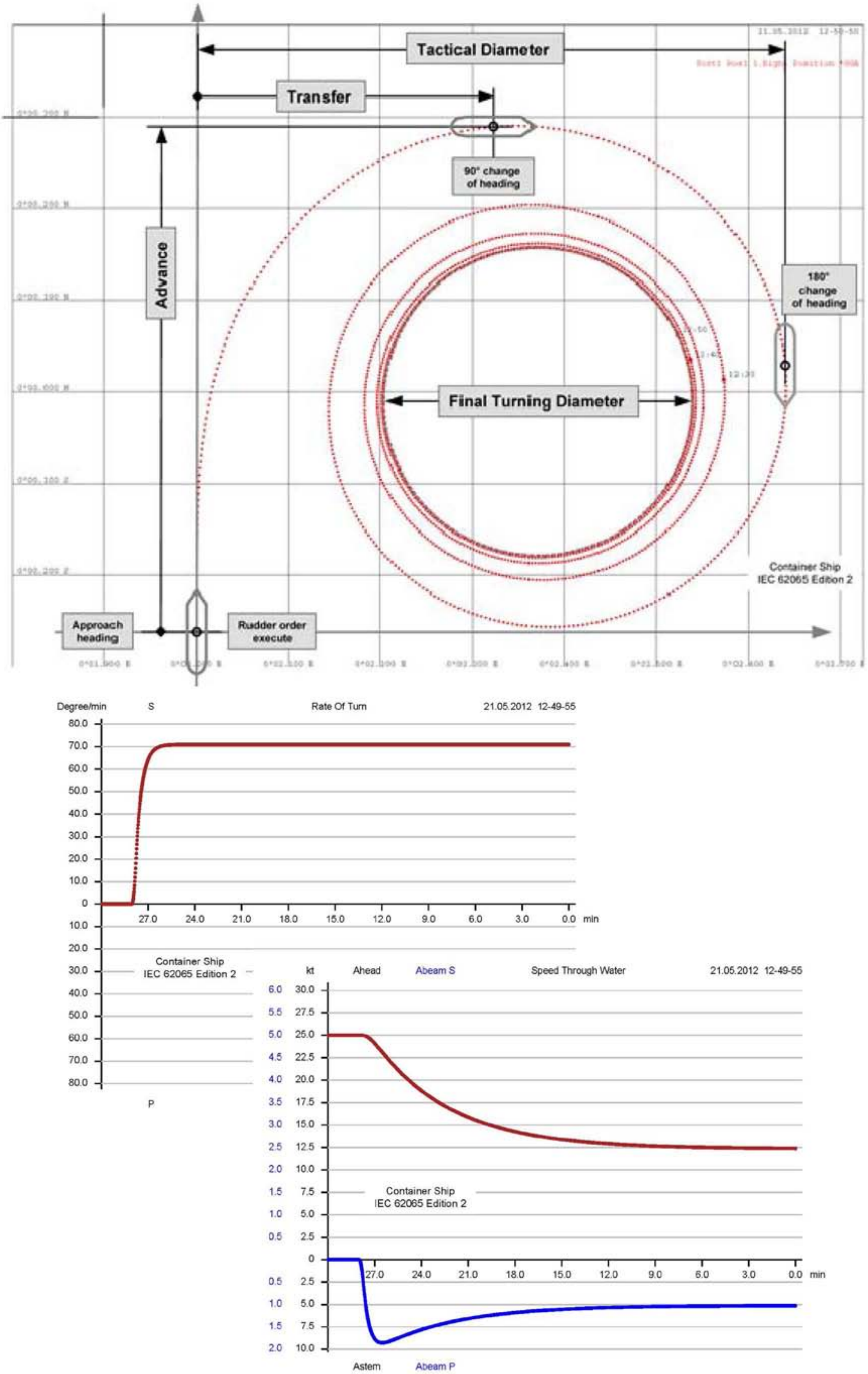
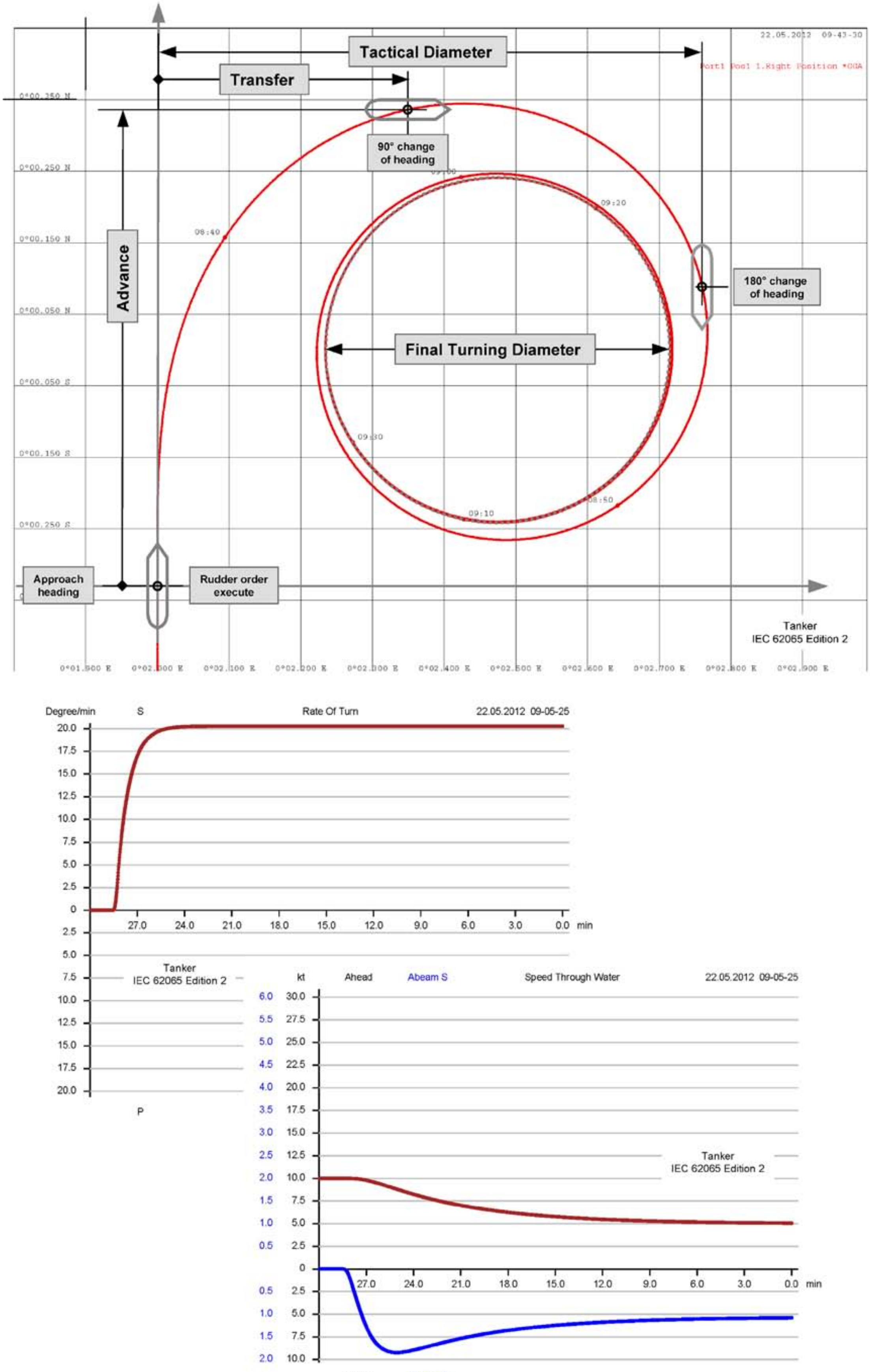


Figure I.7 – Turning circle manoeuvre – Ferry



IEC 0061/14

Figure I.8 – Turning circle manoeuvre – Container ship



IEC 0062/14

Figure I.9 – Turning circle manoeuvre – Tanker

Annex J
(informative)

Explanation of adaptation tests (6.4.4.1)

J.1 General

The Figures J.1 to J.5 in this annex indicate where events are to be introduced into scenario 3 for the testing of adaptation. The "End of test" as indicated depends on the performance of the EUT.

J.2 Adaptation to speed change

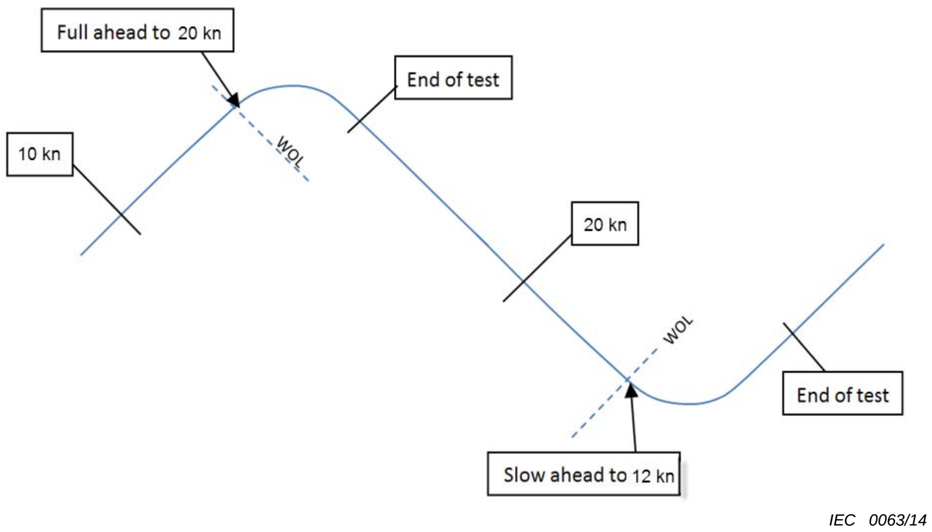


Figure J.1 – Adaptation to speed change

J.3 Adaptation to current changes along a leg

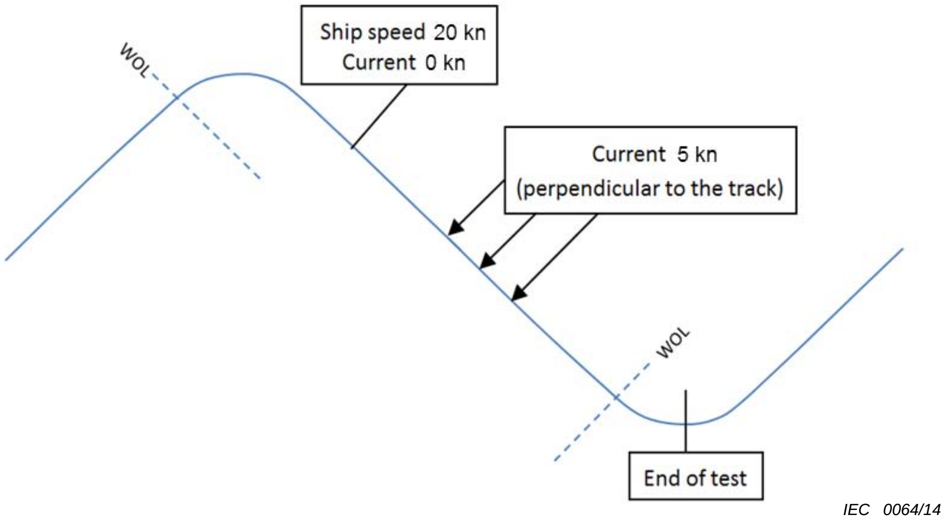


Figure J.2 – Adaptation to changes along a leg

J.4 Adaptation to current changes during turn

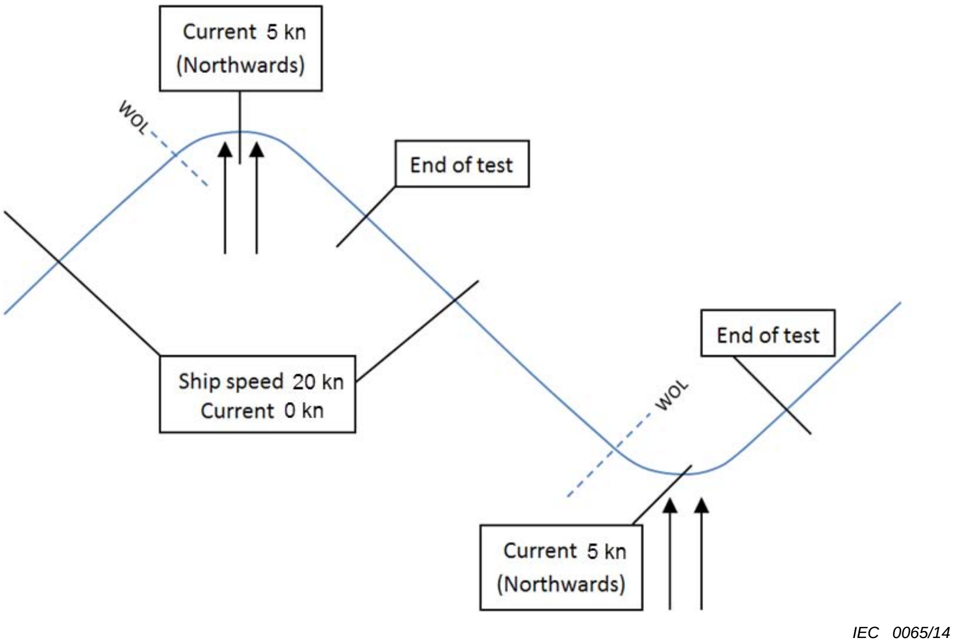


Figure J.3 – Adaptation to current changes during turn

J.5 Adaptation to sea state during turn

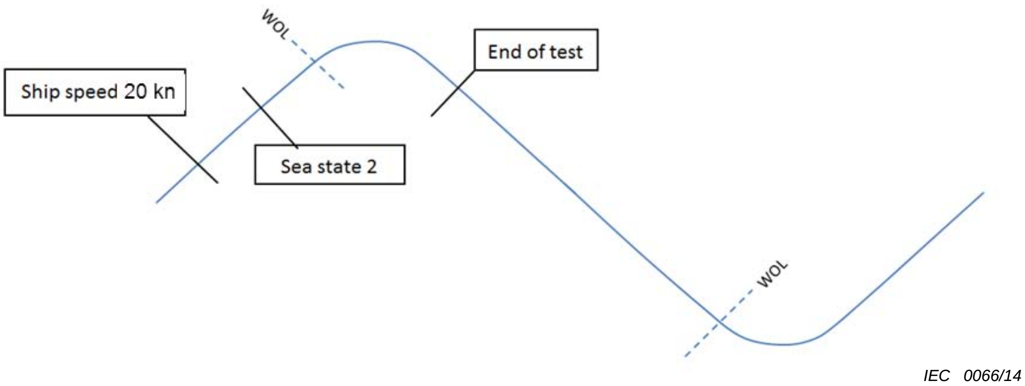


Figure J.4 – Adaptation to sea state during turn

J.6 Adaptation to sea state change on a leg

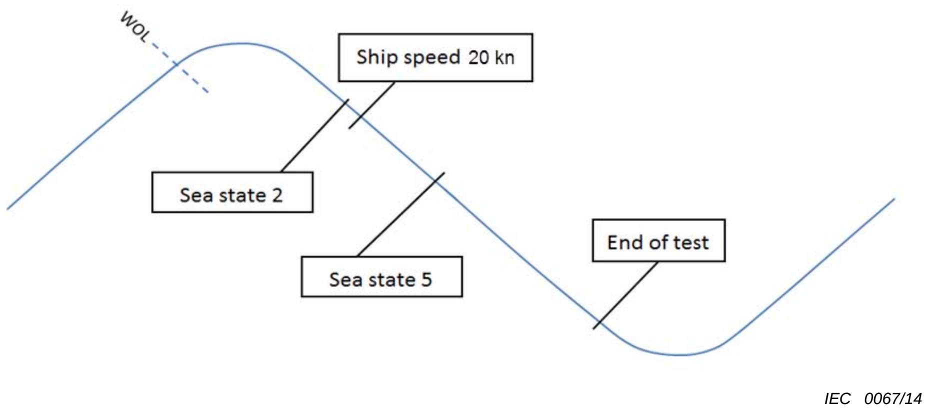


Figure J.5 – Adaptation to sea state change on a leg

Annex K
(normative)

IEC 61162 interfaces

K.1 Required interfaces

The IEC 61162 sentences for transmitting and receiving data for the track control system are specified in Tables K.1 and K.2. The manufacturer shall specify which IEC 61162 part each physical interfaces supports.

Figure K.1 shows the required logical interfaces. If more than one logical interface is implemented on a single physical interface, then all aspects of each logical interface, including alert communication, heartbeat, etc., shall be distinguishable from those of other logical interfaces implemented on the same physical interface.

If any equipment, sensor or source in Figure K.1 is included into the EUT, then there is no requirement to provide an external interface for it. In this case, the functionality needs to be verified.

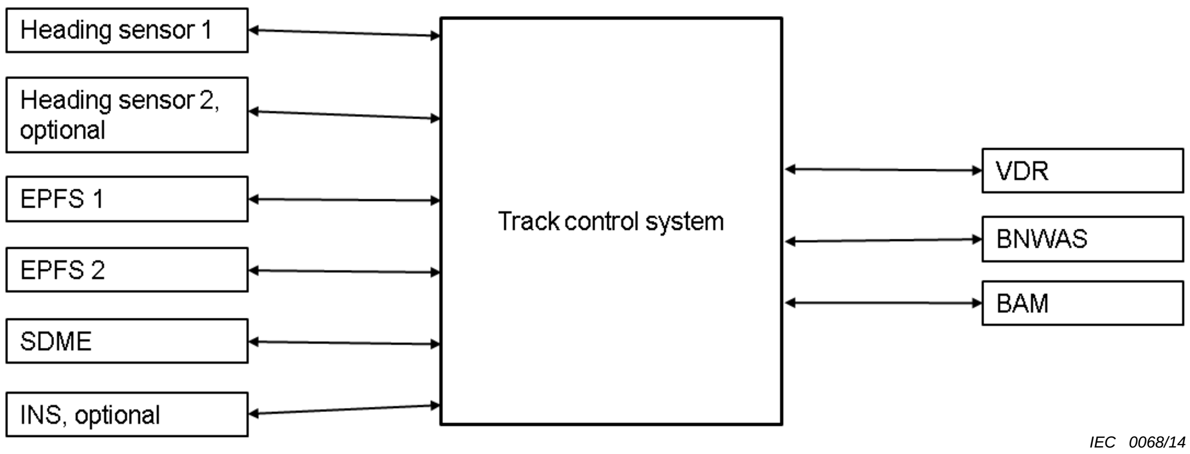


Figure K.1 – Track control system logical interfaces

Table K.1 – IEC 61162-1 sentences transmitted by the track control system

Mnemonic	Interface (see Figure K.1)	Name	Comment
ALC	VDR, BAM, INS	Cyclic alert list	List of current alert See IEC 61924-2
ALF	VDR, BAM, INS	Alert sentence	Details of a new alert See IEC 61924-2
ALR	BNWAS	Set alarm state	Alert transfer to BNWAS
ARC	BAM, INS	Alert command refused	Alert command not accepted See IEC 61924-2
EVE	BNWAS	Operator activity	Optional interface to reset dormant period of the BNWAS
HBT	BAM, INS	Heartbeat	Support reliable alert related communication

Table K.2 – IEC 61162-1 sentences received by the track control system

Mnemonic	Interface (see Figure K.1)	Name	Comment
ACN	BAM, INS	Alert command	Alert command e.g. acknowledge See IEC 61924-2
DTM	EPFS 1, EPFS 2, INS	Datum reference	
GLL GGA GNS RMC	EPFS 1, EPFS 2, INS	Geographic position – latitude/longitude	
HBT	BAM, INS	Heartbeat	Support reliable alert related communication
NSR	INS	Navigational status report	Integrity and plausibility of the CCRS data See IEC 61924-2
THS	Heading sensor 1, Heading sensor 2, INS	Heading source	
HCR	Heading sensor 1, Heading sensor 2, INS	Heading correction report	Defined in K.3
VBW VLW	SDME, INS	Speed log	
VTG	EPFS 1, EPFS 2, INS	Speed and course from EPFS	

K.2 Use of ALR for BNWAS

This standard requires that an unacknowledged alarm shall be transferred after a timeout to call a back-up navigator. The BNWAS standard IEC 62616 defines alternative methods to receive such information: either by using ALR-sentence, by contact closure or by other equivalent method. The EUT shall provide at least one alternative. If sending of ALR sentence method is used to actuate the “Emergency Call” system of the BNWAS, then the sentence below shall be used:

$TCALR,,260,A,V,Emergency Call*0C<CR><LF>

and to remove this “Emergency Call”

$TCALR,,260,A,A,Emergency Call*1B<CR><LF>

K.3 HCR – Heading correction report

Refer to IEC 61162-1 for a possible later version of this sentence.

This sentence is used to inform state and value of heading correction included in the heading reported by the THS sentence when the heading source can apply correction.

This sentence requires tight synchronization with THS sentence. This sentence should be sent immediately prior to every THS sentence for which the correction state field has changed compared to previous THS sentence. For all “correction states” the HCR sentence should be transmitted periodically at intervals of not greater than 1,0 s.

$--HCR, x.x, a, a, x.x *hh<CR><LF>

Correction value (see Note 4)

Correction state (see Note 3)

Mode indicator (see Note 2)

Heading, degrees true (see Note 1)

NOTE 1 Value of heading for which this HCR is referenced. This value is not replacing heading value from the THS sentence. This value is used for synchronization between high data rate of THS sentence and low data rate of HCR sentence.

NOTE 2 Mode indicator. This field should not be null.

A = Autonomous

E = Estimated (dead reckoning)

M = Manual input

S = Simulator mode

V = Data not valid (including standby)

NOTE 3 Correction state. This field should not be null.

A = Both Speed/latitude and dynamic correction included in heading

D = Dynamic correction included in heading

S = Speed/latitude correction included in heading

N = No correction included in heading

V = Not available, reporting device does not know about correction state

NOTE 4 Value of correction included in heading. Degrees +/- 180,0º with one decimal. Null field indicates correction state N (no correction included) or V (not available).

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