BS ISO 13643-1:2017

BSI Standards Publication

Ships and marine technology — Manoeuvring of ships

Part 1: General concepts, quantities and test conditions

National foreword

This British Standard is the UK implementation of ISO 13643-1:2017. It supersedes BS ISO 13643-1:2013 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/80, Maritime navigation and radiocommunication equipment and systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Second edition
2017-02

Ships and marine technology — Manoeuvring of ships —

Part 1: General concepts, quantities and test conditions

Navires et technologie maritime — Manoeuvres des navires —

Partie 1: Notions générales, grandeurs et conditions d'essais

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 6, *Navigation and ship operations*.

This second edition cancels and replaces the first edition (ISO 13643-1:2013), of which it constitutes a minor revision with the following changes:

— Table 8, CC-Code VK symbol "N" to "v";

— Table 8, CC-Code RHOWA symbol "P" to "ρ";

— Table 8, CC-Code OMN symbol "Ω" was changed to "ω";

— 7.9.2, Equations (1) and (2) in the last term Symbol "φ" was changed to "ϕ";

— 7.9.3, third sentence of the subclause "where as $q = \dot{\theta}$ and $\dot{q} = \ddot{\theta}$ well as $w = \dot{z}$ and $\dot{w} = \ddot{z}$ " was changed to "where $q = \dot{\theta}$ and $\dot{q} = \ddot{\theta}$ as well as $w = \dot{z}$ and $\dot{w} = \ddot{z}$";

— 8.2 "a) stopping test" has been inserted.

A list of all parts in the ISO 13643 series can be found on the ISO website.

Ships and marine technology — Manoeuvring of ships —

Part 1:
General concepts, quantities and test conditions

1 Scope

This document applies to manoeuvring tests with surface ships, submarines and models.

This document defines concepts, symbols and test conditions constituting general fundamentals which are to be applied for the description and determination of certain ship manoeuvring characteristics together with the respective test-specific physical quantities contained in ISO 13643-2 to ISO 13643-6.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19019, *Sea-going vessels and marine technology — Instructions for planning, carrying out and reporting sea trials*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp/

3.1
manoeuvring
all *manoeuvres* (3.2), *manoeuvring tests* (3.3) and tests or other methods, such as computations, simulations, etc. to establish manoeuvring characteristics

Note 1 to entry: Manoeuvring includes measures to maintain cruising conditions under external disturbances.

3.2
manoeuvre
ship operation measures to change course and/or speed, and in case of submarines, depth

Note 1 to entry: Special actions taken, e.g. for casting-off, turning aside or rescuing (person over board), are included.

3.3
manoeuvring test
test conducted with a full-scale ship, submarine or a model to determine and evaluate the manoeuvring characteristics under standardized conditions

Note 1 to entry: Manoeuvring tests are often similar to manoeuvres, but organized in such a manner that, as far as possible, specific manoeuvring characteristics can be measured individually.

3.4
CC-Code
computer compatible symbols introduced by the 14th International Towing Tank Conference

3.5
manoeuvring device
rudder, azimuthing thruster, hydroplane, cycloidal propeller or equivalent system used to *manoeuvre* (3.2) a vessel

4 Axis systems

4.1 General

Axis systems are three-dimensional, orthogonal, right-handed systems. Earth-fixed and ship-fixed axis systems are defined in Tables 1 and 2.

4.2 Earth-fixed axis system

Table 1 — Symbols and their definitions for the earth-fixed axis system

Symbol	CC-Code	SI-Unit	Term	Position	Positive sense
O_0	ORIGO	—	Origin, earth-fixed	Arbitrary, but preferably in the water surface	—
O	ORIG	—	Origin, ship-fixed (moving with the ship)	Preferably according to Table 2	—
x_0	X0	m	—	In the horizontal plane[a]	Arbitrary
y_0	Y0	m	Transverse axis	In the horizontal plane[a]	Right-handed system with x_0, z_0
z_0	Z0	m	Vertical axis	In the direction of gravity	Down

[a] Assuming earth or water surfaces to be plane.

4.3 Ship-fixed axis system

Table 2 — Symbols and their definitions for the ship-fixed axis system

Symbol	CC-Code	SI-Unit	Term	Position	Positive sense
O	ORIG	—	Origin, ship fixed	For surface ships in CL at the height of DWL at MP For submarines on MA in the lateral plane of B_∇	—
x	X	m	Longitudinal axis	In CL or MA	Forward
y	Y	m	Lateral axis	Perpendicular to CL	Starboard
z	Z	m	Normal axis	In CL	Right-handed system with x and y (under normal cruising conditions down)

5 Position coordinates

Table 3 — Symbols and their definitions for position coordinates of points under consideration

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
x (..)[a]	X (..)[a]	m	Longitudinal position	Distance between point under consideration and origin O measured parallel to the ship's longitudinal axis (see Table 2), positive if point under consideration is forward of origin O.
y (..)[a]	Y (..)[a]	m	Lateral position	Distance between point under consideration and origin O measured parallel to the ship's lateral axis, positive if point under consideration is starboard of origin O.
z (..)[a]	Z (..)[a]	m	Normal position	Distance between point under consideration and origin O measured parallel to the ship's normal axis, positive if point under consideration is below origin O.

[a] (..) = Supplement to symbol/CC-Code by code letters for points under consideration.

Code letters for the following special points:

A antenna (reference point);

B centre of buoyancy (static);

BB bow plane (reference point);

F stabilising fin (reference point);

G centre of gravity;

L lateral area below waterline (centre of area);

LV lateral area above waterline (centre of area);

P propeller (reference point);

R manoeuvring device (reference point);

S stern plane (reference point);

T thruster (reference point).

EXAMPLE z_R resp. ZR: Normal position of manoeuvring device (reference point).

6 Angles

6.1 Angles of flow

6.1.1 Angle of attack

Table 4 — Symbol and definition for the angle of attack

Symbol	CC-Code	SI-Unit	Concept		Axis of rotation	Measurement plane
			Term	Definition or explanation		
α	ALFA	rad[a]	Angle of attack	Angle by which the projection of the direction of heading through the water upon CL has to be turned about lateral axis *y*, such that it coincides with the *x*-axis. $\arctan \frac{w}{u}$ $\arcsin \frac{w}{\sqrt{u^2+w^2}}$	*y*	*xz*

[a] For angles, the unit ° (degree) may be used.

6.1.2 Drift angle

Table 5 — Symbol and definition for the drift angle

Symbol	CC-Code	SI-Unit	Concept		Axis of rotation	Measurement plane
			Term	Definition or explanation		
β	BET	rad[a]	Drift angle	Angle to the principal plane of symmetry from the vector of the ship's speed[b] relative to the water, positive in the positive sense of rotation about the *z*-axis. $\arctan \frac{-v}{u}$ $\arcsin \frac{-v}{\sqrt{u^2+v^2}}$	*z*	*xy*

[a] For angles, the unit ° (degree) may be used.

[b] Reference point for the path through the water within the ship usually is the origin O of the ship-fixed axis system according to Table 2.

6.2 Angles of flow at parts of the ship

The definition of angles of flow at parts of the ship is to follow the definition of the ship's angles of flow as far as possible. Their symbols are to be derived from those in 6.1.1 and 6.1.2 by means of suitable subscripts (for a selection, see Table 3).

EXAMPLE

α_S angle of attack at stern plane (see Table 4).

β_R drift angle at manoeuvring device (see Table 5).

6.3 Eulerian angles

6.3.1 General

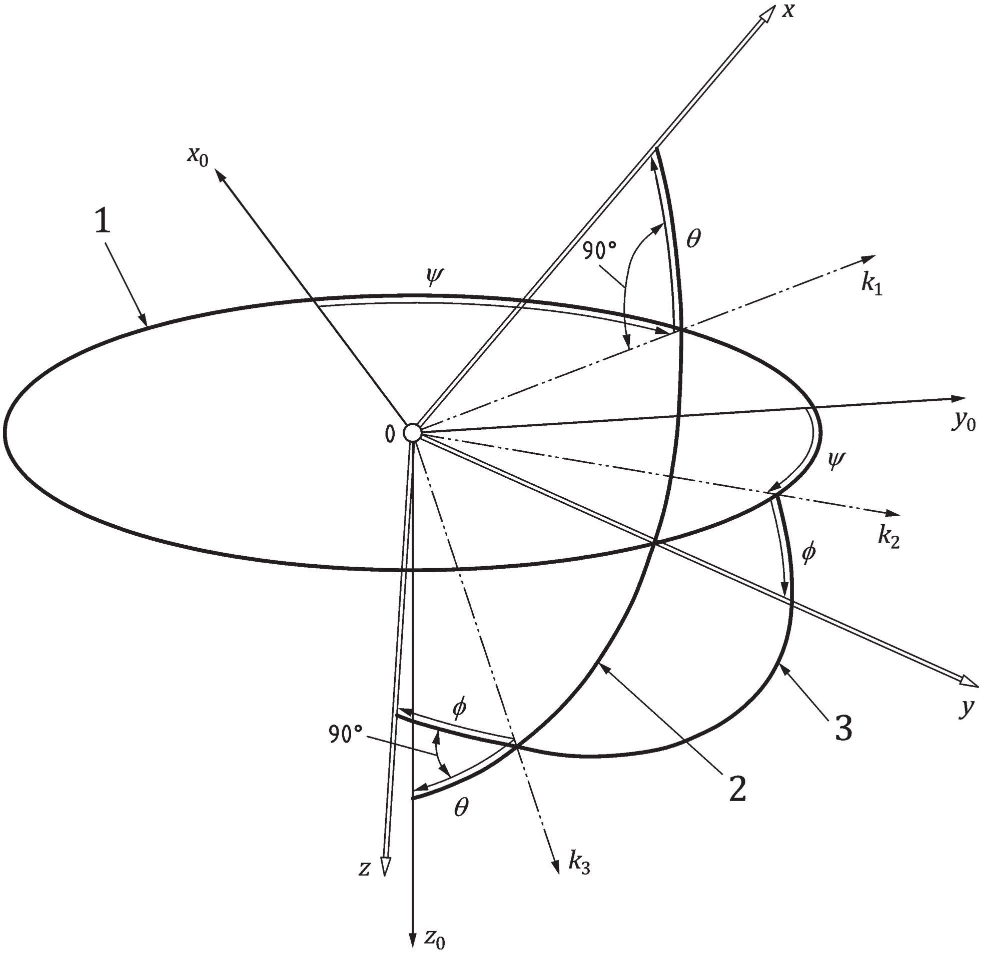
Eulerian angles are described in Figure 1 and Tables 6 and 7.

6.3.2 Nodal axes

In this subclause, the rotational position of two axis systems relative to one another is described by Eulerian angles which are defined with the aid of nodal axes (see Table 6).

Table 6 — Symbols and their definitions for nodal axes

Symbol	Definition or explanation
k_1	Projection of the longitudinal axis x onto the horizontal x_0y_0-plane.
k_2	Positioned with respect to y_0 as k_1 to x_0.
k_3	Projection of vertical axis z_0 onto yz-plane.



Key

1 x_0y_0 plane

2 xz_0 plane

3 xy plane

Figure 1 — Angles between earth-fixed and ship-fixed axis system

6.3.3 Eulerian angles between earth-fixed and ship-fixed axis systems

Table 7 — Symbols and their definitions for angles between earth-fixed and ship-fixed axis systems

Symbol	CC-Code	SI-Unit	Concept		Axis of rotation	Measurement plane
			Term	Definition or explanation		
θ_S	TRIMS	rad[a]	Trim angle	Angle of turn about nodal axis k_2, measured from nodal axis k_1 to x-axis (angle between x-axis and horizontal plane); positive if unit vector in the direction of x-axis has a negative component in the direction of z_0-axis.	k_2	xz_0
θ	TETP	rad[a]	Pitch angle	Definition as for θ_S above; used for oscillatory processes; usually measured relative to mean trim angle.	k_2	xz_0
ϕ_S	HEELANG	rad[a]	Heel (bank) angle	Angle of turn about the x-axis, measured from nodal axis k_2 to y-axis; positive in clockwise direction.	x	yz
ϕ	PHIR	rad[a]	Roll angle	Definition as for ϕ_S above; used for oscillatory processes; usually measured relative to mean heel angle.	x	yz
ψ	PSIH	rad[a]	Heading	Angle of turn about vertical axis z_0, measured from x_0-axis to nodal axis k_1; positive in clockwise direction; usually x_0-direction coincides with north or initial heading.	z_0	x_0y_0
	PSIY	rad[a]	Yaw angle	Definition as above; used for oscillatory processes; usually measured relative to mean heading.	z_0	x_0y_0

[a] For angles, the unit ° (degree) may be used.

7 General quantities

7.1 Physical quantities

Table 8 — Symbols and their definitions for physical quantities

Symbol[a]	CC-Code[a]	SI-Unit	Concept	
			Term	Definition or explanation
F_n	FN	1	Froude number	$\frac{V}{\sqrt{gL}}$
F_{nh}	FH	1	Froude depth number	$\frac{V}{\sqrt{gh}}$
$F_{n\nabla}$	FV	1	Froude displacement number	$\frac{V}{\sqrt{g\nabla^{1/3}}}$
g	G	m s^{-2}	Acceleration due to gravity	—
h	DE	m	Water depth	—
h_m	DEME	m	Mean water depth	During the test
m	MA	kg	Ship's mass	Mass which shall be accelerated for speed changes, but without added mass
n	N	s^{-1}	Rate of revolution, general	—
P	P	W	Power, general	—
R_n	RN	1	Reynolds number	$\frac{V\,L}{\nu}$
s	SP	m	Track length	Measured along ship's track
t	TI	s	Time, general	—
$t°_A$	TEAI	°C	Air temperature	—
$t°_W$	TEWA	°C	Water temperature	—
V	V	m s^{-1} [b]	Ship's speed	Speed through the water; usually given for origin O
W	WT	N	Ship's weight	—
Δ	DISPM	kg	Displacement mass	$\rho\nabla$
Δ_F	DISPF	N	Displacement force	$\rho g\nabla$
ν	VK	m^{2}s^{-1}	Kinematic viscosity	—
ρ	RHOWA	kg m^{-3}	Water density	—
ρ_A	RHOAI	kg m^{-3}	Air density	—
ω	OMN	rad s^{-1}	Angular velocity	—

a Symbol and CC-Code can have the additional subscripts S (for ship) or M (for model) if necessary for distinction.

b The unit kn, common in the navigation, may be used.

7.2 Geometrical quantities

7.2.1 Symbols for manoeuvring

Table 9 — Symbols and their definitions for geometrical quantities

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
A_C	AC	m^2	Canal cross section	Cross section area of the canal.
A_L	AL	m^2	Lateral area below waterline	Moulded lateral area up to DWL, not including manoeuvring devices, fixed and movable parts of propulsors.
A_{LV}	ALV	m^2	Lateral area above waterline	Lateral area of the ship above DWL, generally without rigging, railings etc.
A_M	AM	m^2	Midship section area	Sectional area of moulded hull parallel to *yz*-plane at MP between BL and DWL.
AP	AP	—	After perpendicular	For surface ships: straight line on CL perpendicular to DWL through its intersection with the moulded stern contour (common practice for naval ships) or through the centreline of manoeuvring device stock (common practice for merchant ships). For submarines with one shaft: straight line perpendicular to MA through the intersection of the aft edge of stern tube with the centreline of the shaft. For submarines with several shafts, AP has to be determined adequately.
A_R	ARU	m^2	Rudder area	For the movable part (including flap); in way of a fixed post, aft of the stock axis only.
A_{RF}	ARF	m^2	Flap area	For the flap movable relative to the rudder, aft of its hinge axis only.
A_{RP}	ARP	m^2	Rudder area in the propeller race	For rudder in neutral position.
A_{RT}	ART	m^2	Total rudder area	$A_R + A_{RX}$
A_{RX}	ARX	m^2	Fixed post area of a rudder	Forward of the stock axis.
A_{SK}	ASK	m^2	Skeg area	For skeg or fixed fin.
A_X	AX	m^2	Maximum transverse section area	Maximum sectional area of moulded hull parallel to the *yz*-plane up to the DWL.
B	B	m	Breadth	Reference breadth of a ship; usually B_{DWL}.
B_{DWL}	BDWL	m	Breadth of design waterline	Maximum moulded breadth of design waterline.
BL	BL	—	Baseline	Line on CL parallel to DWL through the moulded keel line at MP.
B_∇	—	—	Centre of buoyancy of form displacement	Relative to ∇ .

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
b	SP	m	Rudder span, general	Distance between planes perpendicular to the stock axis through the extremities of the rudder.
b_R	SPRU	m	Rudder span	Distance between planes perpendicular to the stock axis through the extremities of the movable part (including flap); in way of a fixed post, aft of the stock axis only.
b_{RF}	SPRUF	m	Flap span for a rudder	Distance between planes perpendicular to its hinge axis through the extremities of the flap, aft of its hinge axis only.
b_{RT}	SPRUT	m	Total rudder span	Distance between planes perpendicular to the stock axis through the extremities of the total rudder including flap and fixed post.
b_{RX}	SPRUX	m	Fixed post span for a rudder	Distance between planes perpendicular to the stock axis through the extremities of the fixed post, forward of the stock axis only.
b_{SK}	SPSK	m	Skeg span	For skeg or fixed fin: distance between planes perpendicular to the skeg axis through the extremities of the skeg
CL	CL	—	Centreline plane	Vertical longitudinal plane of symmetry of the hull; for asymmetrical ships CL is to be specified in a suitable manner.
c	CH	m	Chord length, general	Maximum profile length normal to the stock axis.
c_m	CHME	m	Mean chord length, general	$\frac{A_R}{b}$
c_{mR}	CHMERU	m	Mean rudder chord length	$\frac{A_R}{b_R}$
c_{mRF}	CHMERUF	m	Mean flap chord length for a rudder	$\frac{A_{RF}}{b_{RF}}$
c_{mRT}	CHMERUT	m	Mean total rudder chord length	$\frac{A_{RT}}{b_{RT}}$
c_{mRX}	CHMERUX	m	Mean fixed post chord length for a rudder	$\frac{A_{RX}}{b_{RX}}$
c_{mSK}	CHMESK	m	Mean skeg chord length	$\frac{A_{SK}}{b_{SK}}$

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
c_{R}	CHRU	m	Rudder chord length	Maximum profile length of the movable part (including flap) normal to the stock axis; in way of a fixed post, aft of the stock axis only.
c_{RF}	CHRUF	m	Flap chord length for a rudder	Maximum flap profile length normal to its hinge axis; aft of the hinge axis only.
c_{RT}	CHRUT	m	Total rudder chord length	Maximum profile length, including flap and fixed post normal to the stock axis.
c_{RX}	CHRUX	m	Fixed post chord length for a rudder	Maximum profile length of the fixed post normal to the rudder stock, forward of the stock axis only.
c_{r}	CHRT	m	Rudder root chord length, general	Profile length normal to the stock axis on the inboard side.
c_{rR}	CHRRU	m	Rudder root chord length	On the inboard side of the movable part (including flap), normal to the stock axis; in way of a fixed post, aft of the stock axis only.
c_{rRF}	CHRRUF	m	Flap root chord length for a rudder	On the inboard side normal to its hinge axis, aft of the hinge axis only.
c_{rRT}	CHRRUT	m	Total rudder root chord length	On the inboard side of the total rudder including flap and fixed post, measured normal to the stock axis.
c_{rRX}	CHRRUX	m	Fixed post root chord length for a rudder	On the inboard side normal to the stock axis, forward of the stock axis only.
c_{rSK}	CHRSK	m	Skeg root chord length	For skeg or fixed fin: on the inboard side normal to the skeg axis.
c_{SK}	CHSK	m	Skeg chord length	For skeg or fixed fin: maximum profile length normal to the skeg axis.
c_{t}	CHT	m	Tip chord length, general	Profile length on the outboard side, normal to the stock axis.
c_{tR}	CHTRU	m	Rudder tip chord length	On the outboard side of the movable part (including flap), normal to the stock axis; in way of a fixed post, aft of the stock axis only.
c_{tRF}	CHTRUF	m	Flap tip chord length for a rudder	On the outboard side normal to the hinge axis, aft of the hinge axis only.
c_{tRT}	CHTRUT	m	Total rudder tip chord length	On the outboard side of the total rudder including flap and fixed post, normal to the stock axis.
c_{tRX}	CHTRUX	m	Fixed post tip chord length for a rudder	On the outboard side normal to the stock axis, forward of the stock axis only.

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
c_{tSK}	CHTSK	m	Skeg tip chord length	For skeg or fixed fin: on the outboard side normal to the skeg axis.
DWL	DWL	—	Design waterline	Intersection of a horizontal plane, which is specified in the design for loaded condition of the ship (e.g. summer load line), with the moulded surface of the ship.
FP	FP	—	Fore perpendicular	For surface ships: straight line on CL perpendicular to DWL through its intersection with the outer stem contour. For submarines: straight line perpendicular to MA through its intersection with the outer stem contour.
f	F	m	Camber of a foil	Maximum separation of median and nose-tail line.
G	—	—	Centre of gravity	Point at which the resultant of the gravitational forces on the ship acts.
$\overline{\mathrm{GM}}$	GM	m	Metacentric height	Distance M to G
K	—	—	Keel reference	on BL
$\overline{\mathrm{KG}}$	KG	m	Centre of gravity above keel reference	—
L	L	m	Length	Reference length of a ship; usually L_{PP} for merchant ships and submarines, L_{DWL} for naval surface ships.
L_{DWL}	LDWL	m	Length of design waterline	Moulded length of design waterline.
L_{PP}	LPP	m	Length between perpendiculars	Distance between AP and FP.
M	—	—	Metacentre (transverse)	Intersection of the vertical line through the centre of buoyancy with CL, for small angles of heel.
MA	MAX	—	Main axis	Centreline of cylindrical part of the pressure hull extended over the boat's length.
MP	MP	—	Mid between perpendiculars	Straight line perpendicular to DWL in CL at the mid between perpendiculars.
P	—	—	Port (side)	—
PH	PH	—	Pressure hull	Part of the submarine hull without pressure tight appendages, which resists the water pressure at depth.
S	—	—	Starboard (side)	—
T	T	m	Draught	Reference draught of the ship; usually T_{DWL}.
T_A	TA	m	Draught aft	Moulded draft at AP.
T_{DWL}	TDWL	m	Design draught	Distance between BL and DWL.
T_F	TF	m	Draught forward	Moulded draft at FP.

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
t	TMX	m	Profile thickness, general	Maximum profile thickness at 0,5 b, normal to the camber surface.
t_R	TMRU	m	Rudder thickness	Maximum thickness of the movable part (including flap) at 0,5 b_{RT}, normal to the camber surface; in way of a fixed post, aft of the stock axis only.
t_{RF}	TMRUF	m	Flap thickness of a rudder	Maximum thickness of the flap at 0,5 b_{RT}, normal to the camber surface; aft of its hinge axis only.
t_{RT}	TMRUT	m	Total rudder thickness	Maximum thickness of the total rudder including flap and fixed post at 0,5 b_{RT}, normal to the camber surface.
t_{RX}	TMRUX	m	Fixed post thickness for a rudder	Maximum thickness of the fixed post at 0,5 b_{RX}, normal to the camber surface; forward of the stock axis only.
t_{SK}	TMSK	m	Skeg thickness	For skeg or fixed fin: maximum thickness at 0,5 b_{SK}, normal to the camber surface.
WL	WL	—	Waterline	Intersection of any selected plane on which the ship may float with the moulded surface of the ship.
w_B	WCANB	m	Bottom width of canal	Effective width of the canal at its deepest point.
w_S	WCANS	m	Surface width of canal	Width of the canal from bank to bank at the water surface.
Λ_R	ASRU	1	Rudder aspect ratio	$\frac{b^2}{A_{RT}}$
λ	SCALE	1	Model scale	Ratio of linear ship to model dimensions.
λ_R	TARU	1	Rudder taper	$\frac{c_t}{c_r}$
∇	DISPV	m^3	Displacement volume or form displacement	$\nabla_{SP} + \nabla_{AP} - \nabla_{LB}$ for surface ships; complete enveloped displacement volume for submarines.

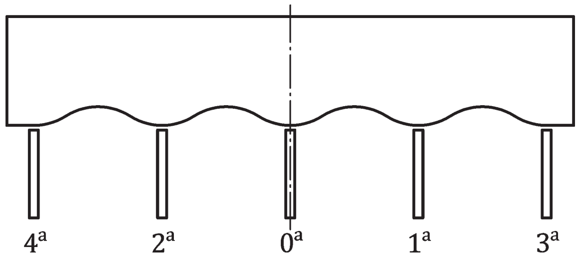
Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
∇_{AP}	DISPVAP	m^3	Displacement volume of appendages	Plating included; for surface ships: for all relevant appendages, e.g. shaft bossings, outer shaft lines, including struts and propellers, manoeuvring devices, stabiliser fins (fixed or foldable), structures guiding the stream lines (e.g. nozzles) and box keels; usually without bilge keels, unless these enclose a void space; for submarines: for all relevant pressure tight appendages, e.g. shell plating, stiffeners, and plating of free flooded spaces, pipe lines, cables, gas bottles, weapon tubes, fins, rods, rudders, planes, propeller shaft, stern tube, propeller, sensors, antennae, hoistable masts, solid ballast, etc. outside of PH.
∇_{LB}	DISPVLB	m^3	Lost buoyancy volume	Permanently flooded volumes, e.g. sea chests, thruster tunnels and fin boxes, but not seawater pipes; major lost volumes, e.g. moon pools of drilling ships are not usually taken into account here nor in ∇_{SP} .
∇_{SP}	DISPVSP	m^3	Displacement volume of hull	Shell plating included, without appendages; ∇_{LB} not deducted.

7.2.2 Additional and alternative indices

Table 10 — Definition and use of additional and alternative indices to symbols according to Table 9

Index resp. extension for CC-Code	Explanation	Example for the use with symbols and CC-Codes according to Table 9		
		Symbol	CC-Code	Term
(n)	Additional index to distinguish between multiple arrangements of manoeuvring devices, skegs and fixed fins, respectively. Numerals with the digit 0 designate manoeuvring devices, skegs and fixed fins located on the centreline. Counting begins with 0 from aft to forward (see Figure 4). Odd figures are used to identify installations to starboard of the centreline, even figures (except those with the digit 0) for those to port. Counting begins with 1 for the innermost fitting to starboard and 2 for the innermost fitting to port, thereafter increasing with successive fittings outwards. For X- or Y-plane arrangement, counting proceeds from upper to lower (see Figure 3). (n) is always the last index.	c_{R2}	CHRU2	Chord length of the 1st single rudder at the inner port side of an arrangement of parallel rudders (see Figure 2).
A	For the designation of stern planes which have no exclusively vertical or horizontal effect. In this case, A replaces the index R with respect to RU in the CC-Code and is to be combined with a number (n).	c_{A3}	CHA3	Chord length of 2nd single plane from above on starboard side of an X-plane arrangement (see Figure 3).
B	For the designation of a bow plane of a submarine or a bow rudder of a surface ship. In this case, B replaces the index R with respect to RU in the CC-Code.	c_B	CHB	Chord length of the bow plane and of the bow rudder of a surface ship, respectively.
S	For the designation of a stern plane of a submarine. In this case, S replaces the index R with respect to RU in the CC-Code.	c_S	CHS	Chord length of the stern plane.

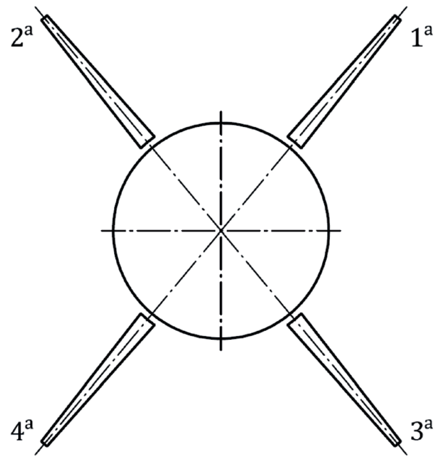


Key

a Rudder.

NOTE Stern of an inland navigation ship with five rudders.

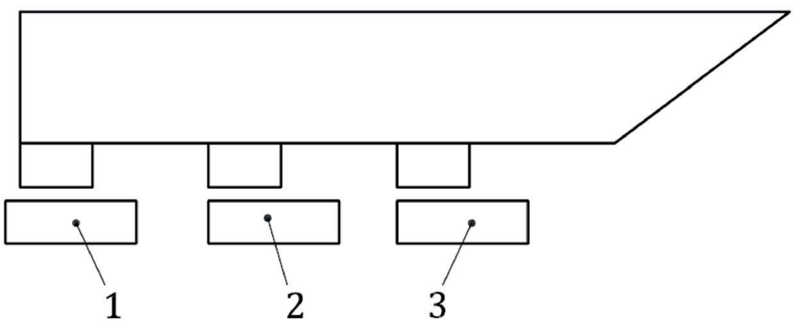
Figure 2 — Arrangement of parallel manoeuvring devices (view from aft)



Key

a Plane.

Figure 3 — X-plane arrangement for submarines (view from aft)



Key

1 fin 01

2 fin 02

3 fin 03

Figure 4 — Numbering of centreline fitted fixed skegs or fins

7.3 Mass quantities

Table 11 — Symbols and their definitions for mass quantities

Symbol	CC-Code	SI-Unit	Concept: Term	Concept: Definition or explanation[a]
I_{xx}	IXX	kg m^2	Moment of inertia about *x*-axis	$\int\left\{\left(y-y_\mathrm{G}\right)^2+\left(z-z_\mathrm{G}\right)^2\right\}\mathrm{d}m$
I_{yy}	IYY	kg m^2	Moment of inertia about *y*-axis	$\int\left\{\left(x-x_\mathrm{G}\right)^2+\left(z-z_\mathrm{G}\right)^2\right\}\mathrm{d}m$
I_{zz}	IZZ	kg m^2	Moment of inertia about *z*-axis	$\int\left\{\left(x-x_\mathrm{G}\right)^2+\left(y-y_\mathrm{G}\right)^2\right\}\mathrm{d}m$
I_{xy}	IXY	kg m^2	Product of inertia	$\int\left(x-x_\mathrm{G}\right)\left(y-y_\mathrm{G}\right)\mathrm{d}m$
I_{yz}	IYZ	kg m^2		$\int\left(y-y_\mathrm{G}\right)\left(z-z_\mathrm{G}\right)\mathrm{d}m$
I_{zx}	IZX	kg m^2		$\int\left(z-z_\mathrm{G}\right)\left(x-x_\mathrm{G}\right)\mathrm{d}m$
k_{xx}	RDGX	m	Radius of inertia about *x*-axis	$\left\{\frac{\int\left[\left(y-y_\mathrm{G}\right)^2+\left(z-z_\mathrm{G}\right)^2\right]\mathrm{d}m}{\Delta}\right\}^{1/2}$
k_{yy}	RDGY	m	Radius of inertia about *y*-axis	$\left\{\frac{\int\left[\left(x-x_\mathrm{G}\right)^2+\left(z-z_\mathrm{G}\right)^2\right]\mathrm{d}m}{\Delta}\right\}^{1/2}$
k_{zz}	RDGZ	m	Radius of inertia about *z*-axis	$\left\{\frac{\int\left[\left(x-x_\mathrm{G}\right)^2+\left(y-y_\mathrm{G}\right)^2\right]\mathrm{d}m}{\Delta}\right\}^{1/2}$

[a] *x*, *y*, *z* stand for the coordinates of the mass element d*m* relative to the ship-fixed axis system (see Table 2).

7.4 Velocities and accelerations

Table 12 — Symbols and their definitions for velocities and accelerations

Symbol and vector	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
p	OMX	rad s^{-1}	Roll velocity	Angular velocity about x-axis. Relative to ship-fixed axis system.
q	OMY	rad s^{-1}	Angular velocity about y-axis	Relative to ship-fixed axis system.
r	OMZ	rad s^{-1}	Angular velocity about z-axis	Relative to ship-fixed axis system.
$\dot{p}$	OXRT	rad s^{-2}	Roll acceleration	Angular acceleration about x-axis. Relative to ship-fixed axis system.
$\dot{q}$	OYRT	rad s^{-2}	Angular acceleration about y-axis	Relative to ship-fixed axis system.
$\dot{r}$	OZRT	rad s^{-2}	Angular acceleration about z-axis	Relative to ship-fixed axis system.
u	VX	m s^{-1}	Longitudinal velocity	Velocity in direction of x-, y-, and z-axes, respectively. Relative to ship-fixed axis system; if otherwise, use subscripts according to Clause 5.
v	VY	m s^{-1}	Lateral velocity	
w	VZ	m s^{-1}	Normal velocity	
$\dot{u}$	VXRT	m s^{-2}	Longitudinal acceleration	Acceleration in direction of x-, y-, and z-axes, respectively. Relative to ship-fixed axis system; if otherwise, use subscripts according to Clause 5.
$\dot{v}$	VYRT	m s^{-2}	Lateral acceleration	
$\dot{w}$	VZRT	m s^{-2}	Normal acceleration	
V_K	VKA	m s^{-1} [a]	Speed over ground	Relative to earth-fixed origin (ground) directed along the tangent to ship's path[b].
V_U	VCU	m s^{-1} [a]	Current velocity	Relative to earth-fixed axis system.
V_{WR}	VWREL	m s^{-1} [a]	Relative wind velocity	Relative to ship-fixed axis system.
V_{WT}	VWABS	m s^{-1} [a]	True wind velocity	Relative to earth-fixed axis system. $\sqrt{V_K^2 + V_{WR}^2 - 2V_K V_{WR} \cos\left(\psi_{WR} + \beta\right)}$
V_0	V0	m s^{-1} [a]	Initial speed	Ship's speed through the water at start of the test (run)[b].
$\dot{\psi}$	YART	rad s^{-1}	Yaw velocity	Time derivative of ψ (see Clause 6).

[a] The unit kn, common in the navigation, may be used.

[b] The path of the ship is usually given for the origin O.

7.5 Forces, moments and their coefficients

Forces and moments are given in Table 13.

Their coefficients are obtained as follows.

Force coefficient: Force × (dynamic pressure × reference area)$^{-1}$

or

Force × (mass × acceleration due to gravity)$^{-1}$

Moment coefficient: Moment × (dynamic pressure × reference area × reference length)$^{-1}$

or

Moment × (mass × acceleration due to gravity × reference length)$^{-1}$

Table 13 — Symbols and their definitions for forces, moments and their coefficients

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
C	FNORM	N	Cross force	Force normal to lift and drag, on a body.
L	FL	N	Dynamic lift force	Force normal to direction of movement.
R	R	N	Resistance, general	Force opposite to direction of movement.
K	MX	N m	Roll moment	Moment about *x*-axis. Relative to ship-fixed axis system.
M	MY	N m	Moment about *y*-axis	Relative to ship-fixed axis system.
N	MZ	N m	Moment about *z*-axis	
K_R[a]	MXR	N m	Manoeuvring device moment about *x*-axis	Relative to ship-fixed axis system.
M_R[a]	MYR	N m	Manoeuvring device moment about *y*-axis	
N_R[a]	MZR	N m	Manoeuvring device moment about *z*-axis	
Q_R[a]	QRU	N m	Torque on manoeuvring device stock	—
Q_{RF}[a]	QRUF	N m	Torque on flap stock	—
X	FX	N	Longitudinal force	Force components in direction of ship-fixed *x*-, *y*-, and *z*-axes, respectively.
Y	FY	N	Lateral force	
Z	FZ	N	Normal force	
X_R[a]	FXR	N	Longitudinal manoeuvring device force	Components of manoeuvring device force in direction of ship-fixed *x*-, *y*-, *z*-axes, respectively.
Y_R[a]	FYR	N	Lateral manoeuvring device force	
Z_R[a]	FZR	N	Normal manoeuvring device force	

[a] For special arrangements of manoeuvring devices, the additional and alternative indices according to Table 10 shall be used.

7.6 Control quantities

Table 14 — Symbols and their definitions for control quantities

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
A_{LT}	ALT	m^2	Cross section of lateral thrust unit	Effective cross section.
e_F	EXF	1	Control point eccentricity for longitudinal thrust of cycloidal propeller	For ahead and astern action; measured in per cent design eccentricity and related to cylindrical axles of control point servomotors.
e_R	EXR	1	Control point eccentricity for lateral thrust of cycloidal propeller	For rudder action; measured in per cent design eccentricity and related to cylindrical axles of control point servomotors.
n_{LT}	NLT	s^{-1}	Rate of revolution of lateral thrust unit	—
P_{LT}	PITCHLT	m	Propeller pitch of lateral thrust unit	—
P_{SLT}	PSLT	W	(Shaft) power of lateral thrust unit	—
p_F	PPFR	1	Relative fore-and-aft pitch of cycloidal propeller	For ahead and astern action; measured at control stand and relative to maximum fore-and-aft pitch adjustment.
p_R	PPRR	1	Relative athwartship pitch of cycloidal propeller	For rudder action; measured at control stand and relative to maximum athwartship pitch adjustment.
δ_B	ANB	rad[b]	Bow plane angle	Relative to zero position of bow plane, positive downward tilt.
δ_R[a]	ANRU	rad[b]	Manoeuvring device angle	Actual value measured against zero position of manoeuvring device; positive to port.
δ_{RF}[a]	ANRUF	rad[b]	Rudder flap angle	Measured relative to main rudder, positive to port.
δ_{RO}[a]	ANRUOR	rad[b]	Manoeuvring device angle, ordered	Positive to port.
δ_S	ANS	rad[b]	Stern plane angle	Relative to zero position of stern plane, positive downward tilt; if necessary, an equivalent stern plane angle is to be given, e.g. for submarines with X-planes; $\frac{1}{4}(\delta_{A1} + \delta_{A2} + \delta_{A3} + \delta_{A4})$.
δ_0	ANRU0	rad[b]	Neutral manoeuvring device angle	Manoeuvring device angle for which the sums of hydrodynamic forces and moments are zero, if the ship is moving straight ahead, positive to port.

[a] For special arrangements of manoeuvring devices, the additional and alternative indices according to Table 10 shall be used. For planes which have both vertical and horizontal effect, the plane angle is positive if the trailing edge is moved downwards. This does not apply to slightly sloped rudders of surface ships.

[b] For angles, the unit ° (degree) may be used.

7.7 Propulsion

Table 15 — Symbols and their definitions for quantities related to propulsion

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
A_E	AE	m^2	Expanded blade area of propeller	$Z \int_{0,5d_h}^{R} c\mathrm{d}r$
A_0	A0	m^2	Propeller disc area Propeller swept area	$\frac{\pi D^2}{4}$ for screw propellers $D\,L$ for cycloidal propellers
C_Q*[a]	CQS	1	Torque coefficient	$\frac{Q}{0{,}5\,\rho\left[V_A^2+u^2\right] A_0\,D}$
C_T	CT	1	Total resistance coefficient	$\frac{R_T}{0{,}5\,\rho\,V^2\,S}$
C_{TH}	CTH	1	Thrust loading coefficient	$\frac{T}{0{,}5\,\rho\,V_A^2\,A_0}$
C_T*[a]	CTHS	1	Thrust coefficient	$\frac{T}{0{,}5\,\rho\left[V_A^2+u^2\right] A_0}$
c	CHP	m	Chord length of propeller blade	—
D	DP	m	Propeller diameter	—
d_h	DH	m	Hub diameter	—
J	ADVC	1	Advance coefficient of propeller	$\frac{V_A}{n\,D}$
J_V	ADVCV	1	Apparent advance coefficient of propeller	$\frac{V}{n\,D}$
K_P	KP	1	Power coefficient	$\frac{P_D}{\rho\,n^3\,D^5}$ for screw propellers
K_{PC}	KPC	1	Power coefficient	$\frac{P_D}{\rho\,n^3\,LD^4}$ for cycloidal propellers
K_Q	KQ	1	Torque coefficient	$\frac{Q}{\rho\,n^2\,D^5}$ for screw propellers

[a] In this case, the asterisk is part of the symbol.

[b] For angles, the unit ° (degree) may be used.

Table 15 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
K_{QC}	KQC	1	Torque coefficient	$\frac{Q}{\rho n^2 LD^4}$ for cycloidal propellers
K_T	KT	1	Thrust coefficient	$\frac{T}{\rho n^2 D^4}$ for screw propellers
K_{TC}	KTC	1	Thrust coefficient	$\frac{T}{\rho n^2 LD^3}$ for cycloidal propellers
L	LF	m	Blade length	For cycloidal propellers
P	PITCH	m	Propeller pitch, general	—
P_B	PB	W	Brake power	Power at prime mover output
P_D	PD	W	Delivered power	At propeller $2 \pi Q n$
P_S	PS	W	Shaft power	P_D plus losses in shaft between propeller and the position of power measurement at the shaft
Q	Q	Nm	Torque	Torque at propeller according to P_D
R	RDP	m	Propeller radius	—
R_T	RT	N	Total resistance	Total towing resistance
S	S	m^2	Wetted surface	$S_{BH} + S_{AP}$
S_{AP}	SAP	m^2	Wetted surface of appendages	Plating included; for all relevant appendages, e.g. shaft bossings, outer shaft lines including struts and propellers, manoeuvring devices, stabiliser fins (fixed and foldable), structures guiding the stream lines (e.g. nozzles) and box keels; usually without bilge keels, unless these are very wide
S_{BH}	SBH	m^2	Wetted surface of bare hull	Moulded, without appendages
T	TH	N	Propeller thrust	—
t	THDF	1	Thrust deduction fraction	$\frac{T - R_T}{T}$
u	UP	$m\ s^{-1}$	Effective circumferential velocity of blades	$0{,}7 \pi n D$ for screw propellers $\pi n D$ for cycloidal propellers
V_A	VA	$m\ s^{-1}$	Speed of advance of propeller	$V (1 - w)$
w	WFT	1	Taylor wake fraction	$\frac{V - V_A}{V}$
Z	NPB	1	Number of propeller blades	—

[a] In this case, the asterisk is part of the symbol.

[b] For angles, the unit ° (degree) may be used.

Table 15 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
β^{*a}	BETS	rad[b]	Effective advance angle	$\arctan\left(\frac{V_A}{u}\right)$
η	ETA	1	Efficiency, general	—
η_B	ETAB	1	Efficiency of propeller behind the ship	$\frac{T V_A}{2 \pi Q n}$
η_D	ETAD	1	Propulsive efficiency or quasi propulsive coefficient	$\frac{R_T V}{2 \pi Q n}$
η_H	ETAH	1	Hull efficiency	$\frac{1-t}{1-w}$
η_R	ETAR	1	Relative rotative efficiency	$\frac{\eta_B}{\eta_0}$
η_S	ETAS	1	Shafting efficiency	$\frac{P_D}{P_S}$
η_0	ETA0	1	Efficiency of propeller in open water	—
Θ	TETAM	kg m^2	Polar moment of inertia of propulsion plant	Applies to engine including shafting, propeller and added hydrodynamic inertia reduced to propeller revolutions
λ	ADVR	1	Propeller advance ratio	$\frac{J}{\pi}$

[a] In this case, the asterisk is part of the symbol.

[b] For angles, the unit ° (degree) may be used.

7.8 Derivatives

A derivative is a partial derivative of the component of a force or moment or of their coefficients with respect to one of their variables. Quantities to be derived are forces and moments related to the ship-fixed axis system.

Variables with respect to which derivations are formed:

— components of velocity and acceleration (see Table 12);

— components of angular velocity and angular acceleration;

— heel and trim angle;

— manoeuvring device angle (see Table 14).

Within the scope of this document, the derivatives in Table 16 are relevant in connection with the stability criteria in 7.9.2 and 7.9.3.

Table 16 — Symbols and their definitions for derivatives

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
K_p	DKDP	N m s rad^{-1}	—	$\partial K / \partial p$
$K_{\dot{p}}$	DKDPT	N m s^2 rad^{-1}	—	$\partial K / \partial \dot{p}$
K_r	DKDR	N m s rad^{-1}	—	$\partial K / \partial r$
$K_{\dot{r}}$	DKDRT	N m s^2 rad^{-1}	—	$\partial K / \partial \dot{r}$
K_v	DKDV	N s	—	$\partial K / \partial v$
$K_{\dot{v}}$	DKDVT	N s^2	—	$\partial K / \partial \dot{v}$
$K_{\phi \mathrm{dyn}}$	DKDPHDY	N m rad^{-1}	—	$\partial K / \partial \phi + mg\overline{\mathrm{GM}}$
M_q	DMDQ	N m s rad^{-1}	—	$\partial M / \partial q$
$M_{\dot{q}}$	DMDQT	N m s^2 rad^{-1}	—	$\partial M / \partial \dot{q}$
M_w	DMDW	N s	—	$\partial M / \partial w$
$M_{\dot{w}}$	DMDWT	N s^2	—	$\partial M / \partial \dot{w}$
M_z	DMDZ	N	—	$\partial M / \partial z$
M_θ	DMDTP	N m rad^{-1}	—	$\partial M / \partial \theta$
N_p	DNDP	N m s rad^{-1}	—	$\partial N / \partial p$
$N_{\dot{p}}$	DNDPT	N m s^2 rad^{-1}	—	$\partial N / \partial \dot{p}$
N_r	DNDR	N m s rad^{-1}	—	$\partial N / \partial r$
$N_{\dot{r}}$	DNDRT	N m s^2 rad^{-1}	—	$\partial N / \partial \dot{r}$
N_v	DNDV	N s	—	$\partial N / \partial v$
$N_{\dot{v}}$	DNDVT	N s^2	—	$\partial N / \partial \dot{v}$
N_ϕ	DNDPHI	N m rad^{-1}	—	$\partial N / \partial \phi$
Y_p	DYDP	N s rad^{-1}	—	$\partial Y / \partial p$
$Y_{\dot{p}}$	DYDPT	N s^2 rad^{-1}	—	$\partial Y / \partial \dot{p}$
Y_r	DYDR	N s rad^{-1}	—	$\partial Y / \partial r$
$Y_{\dot{r}}$	DYDRT	N s^2 rad^{-1}	—	$\partial Y / \partial \dot{r}$
Y_v	DYDV	N m^{-1} s	—	$\partial Y / \partial v$

Table 16 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
$Y_{\dot{v}}$	DYDVT	N m^{-1} s^2	—	$\partial Y / \partial \dot{v}$
Y_ϕ	DYDPHI	N rad^{-1}	—	$\partial Y / \partial \phi$
Z_q	DZDQ	N s rad^{-1}	—	$\partial Z / \partial q$
$Z_{\dot{q}}$	DZDQT	N s^2 rad^{-1}	—	$\partial Z / \partial \dot{q}$
Z_w	DZDW	N m^{-1} s	—	$\partial Z / \partial w$
$Z_{\dot{w}}$	DZDWT	N m^{-1} s^2	—	$\partial Z / \partial \dot{w}$
Z_z	DZDZ	N m^{-1}	—	$\partial Z / \partial z$
Z_θ	DZDTP	N rad^{-1}	—	$\partial Z / \partial \theta$

7.9 Dynamic stability

7.9.1 General

A ship is described as dynamically stable if it returns to its original steady-state of motion after a temporary external disturbance.

Dynamic stability is particularly important with small angles of yaw and pitch.

In 7.9.2 and 7.9.3, the linearized equations for forces and moments acting on the ship are given. The simultaneous solution leads to differential equations from which the condition for a stable motion can be derived. This condition follows from the characteristic equations. The solutions of those equations are named stability indices. If these stability indices are negative real or complex conjugate with a negative real component, then stability results. In the equations, the symbol σ is used.

7.9.2 Dynamic stability of the coupled drift, yaw and roll motion (horizontal plane)

In the general case, drift, yaw and roll motions are coupled. In the limiting case of small deviations from a straight track, the following linearized equations are valid:

$$\left(m - Y_{\dot{v}}\right)\dot{v} - Y_v v + \left(m x_{\mathrm{G}} - Y_{\dot{r}}\right)\dot{r} + \left(m u - Y_r\right) r - \left(m z_{\mathrm{G}} + Y_{\dot{p}}\right)\dot{p} - Y_p p - Y_\phi \phi = 0 \quad (1)$$

$$\left(m x_{\mathrm{G}} - N_{\dot{v}}\right)\dot{v} - N_v v + \left(I_{zz} - N_{\dot{r}}\right)\dot{r} + \left(m x_{\mathrm{G}} u - N_r\right) r - \left(I_{zx} + N_{\dot{p}}\right)\dot{p} - N_p p - N_\phi \phi = 0 \quad (2)$$

$$-\left(m z_{\mathrm{G}} + K_{\dot{v}}\right)\dot{v} - K_v v - \left(I_{zx} + K_{\dot{r}}\right)\dot{r} + \left(m z_{\mathrm{G}} u + K_r\right) r + \left(I_{xx} - K_{\dot{p}}\right)\dot{p} - K_p p - \left(K_{\phi\mathrm{dyn}} - m g \overline{\mathrm{GM}}\right)\phi = 0 \quad (3)$$

The simultaneous solution of these three equations leads to a fourth-order differential equation from which the condition for stable translatory motion without yaw and roll can be derived.

General solutions for v, r and ϕ are, where because of the linearization: $p = \dot{\phi}$ and $\dot{p} = \ddot{\phi}$:

$$v = v_1 e^{\sigma_1 t} + v_2 e^{\sigma_2 t} + v_3 e^{\sigma_3 t} + v_4 e^{\sigma_4 t} \quad (4)$$

$$r = r_1 e^{\sigma_1 t} + r_2 e^{\sigma_2 t} + r_3 e^{\sigma_3 t} + r_4 e^{\sigma_4 t} \tag{5}$$

$$\phi = \phi_1 e^{\sigma_1 t} + \phi_2 e^{\sigma_2 t} + \phi_3 e^{\sigma_3 t} + \phi_4 e^{\sigma_4 t} \tag{6}$$

v_1, v_2, v_3, v_4, r_1, r_2, r_3, r_4, ϕ_1, ϕ_2, ϕ_3 and ϕ_4 are integration constants, whereas σ_1, σ_2, σ_3, and σ_4 are called stability indices. After substitution of Equations (4), (5), and (6) into Equations (1), (2), and (3) and elimination of the integration constants, σ_1, σ_2, σ_3 and σ_4 can be determined from a fourth-order equation that may be written in the following form:

$$A_4\sigma^4 + A_3\sigma^3 + A_2\sigma^2 + A_1\sigma + A_0 = 0 \tag{7}$$

For rectilinear motion, dynamic stability of the coupled drift, yaw and roll motions is given if the stability indices are either negative real or complex conjugate with negative real part.

The stability condition can be reduced to:

$$\begin{aligned} A_0 = {} & N_v \left(mu - Y_r\right) - Y_v\left(mx_G u - N_r\right) + \\ & \begin{bmatrix} Y_v N_\phi \left(mz_G u + K_r\right) + Y_v K_{\phi\text{dyn}}\left(mx_G u - N_r\right) - N_v Y_\phi \left(mz_G u + K_r\right) - \\ N_v K_{\phi\text{dyn}}\left(mu - Y_r\right) - K_v Y_\phi \left(mx_G u - N_r\right) + K_v N_\phi \left(mu - Y_r\right) \end{bmatrix} \left(mg\overline{\text{GM}}\right)^{-1} > 0 \end{aligned} \tag{8}$$

For slow ship speeds and/or high static roll stability (i.e. large $\overline{\text{GM}}$), the term $mg\overline{\text{GM}}\phi$ dominates all other terms in Equation (3), such that the roll motion is small. This means that the drift and yaw motions can be considered independently of the roll motion. Therefore, the equations of motion can be reduced to:

$$\left(m - Y_{\dot v}\right)\dot v - Y_v v + \left(mx_G - Y_{\dot r}\right)\dot r + \left(mu - Y_r\right) r = 0 \tag{9}$$

$$\left(mx_G - N_{\dot v}\right)\dot v - N_v v + \left(I_{zz} - N_{\dot r}\right)\dot r + \left(mx_G u - N_r\right) r = 0 \tag{10}$$

Simultaneous solution of Equations (9) and (10) leads to a second-order differential equation from which the condition for stable rectilinear motion can be derived.

General solutions for v and r are:

$$v = v_1 e^{\sigma_1 t} + v_2 e^{\sigma_2 t} \tag{11}$$

$$r = r_1 e^{\sigma_1 t} + r_2 e^{\sigma_2 t} \tag{12}$$

As above v_1, v_2, r_1 and r_2 are integration constants, σ_1 and σ_2 stability indices. After substitution of Equations (11) and (12) into Equations (9) and (10), the following quadratic equation is obtained:

$$B_2\sigma^2 + B_1\sigma + B_0 = 0 \tag{13}$$

where

$$B_2 = \left(m - Y_{\dot v}\right)\left(I_{zz} - N_{\dot r}\right) - \left(mx_G - N_{\dot v}\right)\left(mx_G - Y_{\dot r}\right) \tag{14}$$

$$B_1 = \left(m - Y_{\dot v}\right)\left(mx_G u - N_r\right) - \left(mu - Y_r\right)\left(mx_G - N_{\dot v}\right) + N_v\left(mx_G - Y_{\dot r}\right) - Y_v\left(I_{zz} - N_{\dot v}\right) \tag{15}$$

$$B_0 = N_v \left(mu - Y_r \right) - Y_v \left(mx_G u - N_r \right) \tag{16}$$

For rectilinear motion, dynamic stability about the yaw axis is given if the stability indices σ_1 and σ_2 are either negative real or complex conjugate with a negative real component.

It can be shown that $B_2 > 0$ and $B_1 > 0$ independently of the choice of the origin. This means that the stability condition can be reduced to $B_0 > 0$.

7.9.3 Dynamic stability of the coupled heave and pitch motion (vertical plane)

For vessels with small waterplane area (e.g. SWATH) and for submerged vessels, the dynamic stability of the pitching motion shall be taken into account as well. In this case, the following, similarly linearized equations of motion apply:

$$\left(m - Z_{\dot{w}} \right) \dot{w} - Z_w\, w - Z_z\, z - \left(mx_G + Z_{\dot{q}} \right) \dot{q} - \left(mu + Z_q \right) q - Z_\theta\, \theta = 0 \tag{17}$$

$$-\left(mx_G + M_{\dot{w}} \right) \dot{w} - M_w\, w - M_z\, z + \left(I_{yy} - M_{\dot{q}} \right) \dot{q} + \left(mx_G u - M_q \right) q - M_\theta \theta = 0 \tag{18}$$

where $q = \dot{\theta}$ and $\dot{q} = \ddot{\theta}$ as well as $w = \dot{z}$ and $\dot{w} = \ddot{z}$

In this case, the general solutions are:

$$z = z_1 e^{\sigma_1 t} + z_2 e^{\sigma_2 t} + z_3 e^{\sigma_3 t} + z_4 e^{\sigma_4 t} \tag{19}$$

$$\theta = \theta_1 e^{\sigma_1 t} + \theta_2 e^{\sigma_2 t} + \theta_3 e^{\sigma_3 t} + \theta_4 e^{\sigma_4 t} \tag{20}$$

The stability indices σ_1, σ_2, σ_3 and σ_4 can be obtained from the following fourth-order equation:

$$A_4 \sigma^4 + A_3 \sigma^3 + A_2 \sigma^2 + A_1 \sigma + A_0 = 0 \tag{21}$$

where

$$A_4 = \left(m - Z_{\dot{w}} \right) \left(I_{yy} - M_{\dot{q}} \right) - \left(mx_G + M_{\dot{w}} \right) \left(mx_G + Z_{\dot{q}} \right) \tag{22}$$

$$A_3 = \left(m - Z_{\dot{w}} \right) \left(mx_G u - M_q \right) - \left(mu + Z_q \right) \left(mx_G + M_{\dot{w}} \right) - Z_w \left(I_{yy} - M_{\dot{q}} \right) - M_w \left(mx_G + Z_{\dot{q}} \right) \tag{23}$$

$$\begin{aligned} A_2 = {} & -M_\theta \left(m - Z_{\dot{w}} \right) - Z_w \left(mx_G u - M_q \right) - M_w \left(mu + Z_q \right) - Z_z \left(I_{yy} - M_{\dot{q}} \right) - \\ & M_z \left(mx_G + Z_{\dot{q}} \right) - \left(mx_G + M_{\dot{w}} \right) Z_\theta \end{aligned} \tag{24}$$

$$A_1 = Z_w\, M_\theta - M_w\, Z_\theta + Z_z \left(mx_G - M_q \right) - M_z \left(mu + Z_q \right) \tag{25}$$

$$A_0 = Z_z\, M_q \tag{26}$$

For rectilinear motion, dynamic stability regarding pitch is given if the stability indices σ_1, σ_2, σ_3 and σ_4 are negative real or complex conjugate with a negative real component.

For submerged vessels at large distances from the surface and the bottom (e.g. submarines):

$$Z_z = Z_\theta = M_z = 0 \tag{27}$$

The general solution for z and θ can then be reduced by one term each.

The stability indices σ_1, σ_2 and σ_3 can be obtained from the following third-order equation:

$$B_3\sigma^3 + B_2\sigma^2 + B_1\sigma + B_0 = 0 \tag{28}$$

In this case:

$$B_3 = \left(m - Z_{\dot{w}}\right)\left(I_{yy} - M_{\dot{q}}\right) - \left(mx_\mathrm{G} + M_{\dot{w}}\right)\left(mx_\mathrm{G} + Z_{\dot{q}}\right) \tag{29}$$

$$B_2 = \left(m - Z_w\right)\left(mux_\mathrm{G} - M_q\right) - \left(mu + Z_q\right)\left(mx_\mathrm{G} + M_{\dot{w}}\right) - Z_w\left(I_{yy} - M_{\dot{q}}\right) - M_w\left(mx_\mathrm{G} + Z_{\dot{q}}\right) \tag{30}$$

and B_1 and B_0 are:

$$B_1 = -M_\theta\left(m - Z_w\right) + Z_w\left(mux_\mathrm{G} - M_q\right) - M_w\left(mu + Z_q\right) \tag{31}$$

$$B_0 = Z_w M_\theta \tag{32}$$

The stability condition is unchanged for the stability indices σ_1, σ_2 and σ_3.

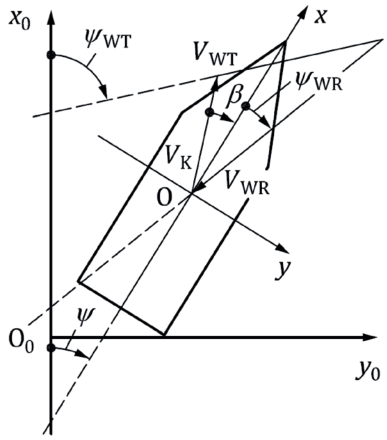
7.10 External disturbances

Table 17 — Symbols and their definitions for external disturbance

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
H_S	HS	m	Significant wave height	—
ψ_U	PSICU	rad[a]	Current direction	Direction to which the current flows, relative to an earth-fixed axis system.
ψ_WA	PSIWA	rad[a]	Wave direction	Mean direction to which the waves progress, relative to an earth-fixed axis system.

[a] For angles, the unit ° (degree) may be used.

Table 17 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
ψ_{WR}	PSIWREL	rad[a]	Relative wind direction	Direction from which the wind blows, relative to ship-fixed axis system.
ψ_{WT}	PSIWABS	rad[a]	True wind direction	Direction from which the wind blows, relative to an earth-fixed axis system. $\psi + \psi_{WR} + \arcsin^{-1}\left[\frac{V_K}{V_{WT}} \sin\left(\psi_{WR} + \beta\right)\right]$ 

[a] For angles, the unit ° (degree) may be used.

8 General test conditions, documentation

8.1 General

The conditions which generally apply to all manoeuvring tests according to the ISO 13643 series are compiled here because they form a recurrent part of the documentation. The requirements laid down in ISO 19019 shall also be taken into consideration.

8.2 Environment

For very calm conditions (wind force not exceeding Beaufort 2), tests may be started in any direction. With the wind force exceeding Beaufort 2, the approach is to be made into the wind for

a) stopping test,

b) coasting stop test,

c) acceleration test,

d) turning circle test,

e) accelerating turn test,

f) astern test,

g) zig-zag test, and

h) sine test.

In general, it is to be expected that tests at or near the surface are affected only marginally or to such an extent that correction by averaging can be applied successfully, provided the significant wave height is $H_S \leq 0{,}01L$ and the wind speed $V_{WT} \leq V_0$ (or the mean speed in tests where major speed changes are an inherent element of the individual run), respectively. If the sea condition is dominated by swell, the approach to the test runs should be into the wind. For the turning test with thrusters and for the traversing test, which are performed in both directions, i.e. into and with the wind, a higher wind speed may be acceptable (see Thruster turning test ISO 13643 – 2.3 and Traversing test 13643 – 4.4, respectively).

Specified limit conditions may be exceeded to a degree, provided a correction/interpretation method is agreed beforehand.

Water depth in the tests area should always exceed five times the mean draught of the ship, except that the tests serve specifically the determination of manoeuvrability at limited water depth.

It is preferable that manoeuvring tests are performed in sea areas with low current velocities.

Wave height and direction, wind speed and direction (see Table 17) and water depth prevailing during the individual test are to be recorded.

The description of each ship test according to the ISO 13643 series shall contain the following data or documents, as a minimum requirement:

— sea area, possibly a chart section;

— depth, temperature, and density of the water;

— direction and velocity of the current;

— wind direction and velocity;

— observed sea state.

8.3 Ship

For each ship under ship test conducted, in addition to the requirements of ISO 19019, the following data are to be recorded once for a related sequence of similar tests:

a) identification data;

b) principal dimensions;

c) number, type and direction of rotation of propellers;

d) number and type of manoeuvring devices/hydroplanes;

e) position of propellers and manoeuvring devices/hydroplanes;

f) typical rate of manoeuvring devices/hydroplane movements;

g) special manoeuvring systems;

h) appendages on subsurface hull, e.g.

  1) bilge keels;

  2) shaft bossings;

  3) shaft struts;

  4) sonar dome, including its operational conditions;

5) stabilizing fins, including their operational conditions;

i) floating condition (displacement mass, draughts, heel);

j) if manoeuvring performance as an exception has to be performed at a deviating displacement, i.e. ballast condition instead of full-load, a correction scheme has to be agreed, e.g. based on model tests or simulations;

k) dived depth of submarines;

l) position of antenna;

m) position of echo sounder transducer.

Parameters which vary during a test series, such as stability parameters, draughts and submarine's dived depth, are to be recorded separately for each test run.

8.4 Test reports

The results of ship tests should be reported using the formats of the annexes of ISO 19019.

8.5 Model tests

For model tests, the following test conditions apply:

a) Model scale

Model scale is to be selected in such a way that model size and model Reynolds numbers are as large as possible. It is to be observed that for Froude numbers (see Table 8) of more than 0,25, results are noticeably influenced by wave effects.

For wind tunnel tests, the blockage ratio shall be less than 15 % and the Reynolds number not less than 1×10^6.

b) Dimensional accuracy

For ship models, the deviations from the nominal offsets shall not exceed ±0,25 %. For dimensions of less than 200 mm, deviations shall be less than ±0,5 mm.

This refers also to appendages as shaft bossings, bilge keels, bow bulbs and sonar domes as well as for hull openings (e.g. for thrusters).

For profiled appendages such as shaft brackets, nozzles, fins, etc., the deviations from the nominal offsets are to be not more than ±0,2 mm. For rudders on which measurements are performed, attempts should be made to achieve deviations from the nominal of not more than ±0,1 mm.

c) Materials

Models for surface vessels for tank tests shall be made of wood or synthetic material; submarine models shall be made of wood, synthetic material or metal.

For appendages, wood (e.g. teak), synthetic materials or metal may be used.

d) Surface finish

Tank models and their appendages should be hydraulically smooth, i.e. $k < k_{\mathrm{perm}}$. Here, k is the roughness height of the surface and $k_{\mathrm{perm}} = 10\ \nu/V$, where ν is the kinematic viscosity and V is the speed representative for the test.

For wind tunnel tests, all edges shall be kept sharp.

e) Stability and inertia

For manoeuvring tests with free-running models, the transverse stability and the mass moments of inertia (see Table 11) are to be adjusted as close as possible to those of the vessel.

f) Propeller

If no models of the final propellers are available, stock propellers may be used for the manoeuvring tests. Geometry and performance data (see Table 15) should be as close as possible to those of the final propeller. The main parameters have to be given the following ranking:

1) diameter;

2) number of blades;

3) pitch ratio;

4) area ratio.

g) Test data

For each model under test, indications a) to i) according to 8.3 and additionally the following data shall be recorded once for a related series of similar tests:

1) model scale;

2) water temperature;

3) towing tank dimensions;

4) water depth.

Annex A
(informative)

Alphabetical list of symbols

Table A.1 — Alphabetical list of symbols

Symbol	CC-Code	Key word	Page
		A	
A		Reference point of antenna	3
A_C	AC	Canal cross section	9
A_E	AE	Blade area, propeller	21
A_L	AL	Lateral area below waterline	9
A_{LT}	ALT	Cross section of lateral thrust unit	20
A_{LV}	ALV	Lateral area above waterline	9
A_M	AM	Midship section area	
AP	AP	After perpendicular	
A_R	ARU	Rudder area	
A_{RF}	ARF	Flap area	
A_{RP}	ARP	Rudder area in the propeller race	
A_{RT}	ART	Total rudder area	
A_{RX}	ARX	Fixed post area of a rudder	
A_{SK}	ASK	Skeg area	
A_X	AX	Maximum transverse section area	
A_0	A0	Propeller disc area, propeller swept area	21
		B	
B	B	Breadth	9
B		Centre of buoyancy	3
BB		Reference point of bow plane	
B_{DWL}	BDWL	Breadth of design waterline	9
BL	BL	Baseline	
B_∇	—	Centre of buoyancy of form displacement	
b	SP	Rudder span	10
b_R	SPRU	Rudder span	
b_{RF}	SPRUF	Flap span for a rudder	
b_{RT}	SPRUT	Total rudder span	
b_{RX}	SPRUX	Fixed post span for a rudder	
b_{SK}	SPSX	Skeg span	
		C	
C	FNORM	Cross force	19
CL	CL	Centreline plane	10

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
C_Q*	CQS	Torque coefficient	21
C_T	CT	Total resistance coefficient	
C_{TH}	CTH	Thrust loading coefficient	
C_T*	CTHS	Thrust coefficient	
c	CH	Chord length, general	10
c	CHP	Chord length of propeller blade	21
c_m	CHME	Mean chord length, general	10
c_{mR}	CHMERU	Mean rudder chord length	
c_{mRF}	CHMERUF	Mean flap chord length for a rudder	
c_{mRT}	CHMERUT	Mean total rudder chord length	
c_{mRX}	CHMERUX	Mean fixed post chord length for a rudder	
c_{mSK}	CHMESK	Mean skeg chord length	
c_R	CHRU	Rudder chord length	11
c_{RF}	CHRUF	Flap chord length for a rudder	
c_{RT}	CHRUT	Total rudder chord length	
c_{RX}	CHRUX	Fixed post chord length for a rudder	
c_r	CHRT	Rudder root chord length, general	
c_{rR}	CHRRU	Rudder root chord length	
c_{rRF}	CHRRUF	Flap root chord length for a rudder	
c_{rRT}	CHRRUT	Total rudder root chord length	
c_{rRX}	CHRRUX	Fixed post root chord length for a rudder	
c_{rSK}	CHRSK	Skeg root chord length	
c_{SK}	CHSK	Skeg chord length	
c_t	CHT	Tip chord length, general	
c_{tR}	CHTRU	Rudder tip chord length	
c_{tRF}	CHTRUF	Flap tip chord length for a rudder	
c_{tRT}	CHTRUT	Total rudder tip chord length	
c_{tRX}	CHTRUX	Fixed post tip chord length for a rudder	
c_{tSK}	CHTSK	Skeg tip chord length	12
D			
D	DP	Propeller diameter	21
DWL	DWL	Design waterline	12
d_h	DH	Hub diameter	21
E			
e_F	EXF	Control point eccentricity of cycloidal propeller	20
e_R	EXR		
F			
F		Reference point of stabilising fin	3
F_n	FN	Froude number	8
F_{nh}	FH		
$F_{n\nabla}$	FV		

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
FP	FP	Fore perpendicular	12
f	F	Camber of a foil	
G			
G	—	Centre of gravity	12
$\overline{\text{GM}}$	GM	Metacentric height	
g	G	Acceleration due to gravity	8
H			
H_S	HS	Wave height	28
h h_m	DE DEME	Water depth	8
I			
I_{xx} I_{yy} I_{zz}	IXX IYY IZZ	Moment of inertia about x-axis Moment of inertia about y-axis Moment of inertia about z-axis	17
I_{xy} I_{yz} I_{zx}	IXY IYZ IZX	Product of inertia	
J			
J J_V	ADVC ADVCV	Advance coefficient	21
K			
K	MX	Moment about x-axis	19
K	—	Keel reference	12
$\overline{\text{KG}}$	KG	Centre of gravity above keel reference	
K_P K_{PC}	KP KPC	Power coefficient	21
K_Q	KQ	Torque coefficient	
K_{QC}	KQC		22
K_R	MXR	Manoeuvring device moment about x-axis	19
K_T	KT	Thrust coefficient	22
K_{TC}	KTC		
K_p	DKDP	Derivative	24
$K_{\dot{p}}$	DKDPT		
K_r	DKDR		
$K_{\dot{r}}$	DKDRT		
K_v	DKDV		
$K_{\dot{v}}$	DKDVT		
$K_{\phi\text{dyn}}$	DKDPHDY		

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
k_{xx}	RDGX	Radius of inertia about *x*-axis	17
k_{yy}	RDGY	Radius of inertia about *y*-axis	
k_{zz}	RDGZ	Radius of inertia about *z*-axis	
k_1	—	Nodal axis	5
k_2	—		
k_3	—		
		L	
L	L	Length	12
L	LF	Blade length	22
L	FL	Dynamic lift force	19
L		Centre of lateral area below waterline	3
L_{DWL}	LDWL	Length of design waterline	12
L_{PP}	LPP	Length between perpendiculars	
LV		Centre of lateral area above waterline	3
		M	
M	MY	Moment about *y*-axis	19
M	—	Metacentre	12
MA	MAX	Main axis	
MP	—	Mid between perpendiculars	
M_R	MYR	Manoeuvring device moment about *y*-axis	19
M_q	DMDQ	Derivative	24
$M_{\dot{q}}$	DMDQT		
M_w	DMDW		
$M_{\dot{w}}$	DMDWT		
M_z	DMDWP		
M_θ	DMDZ		
m	MA	Ship's mass	8
		N	
N	MZ	Moment about *z*-axis	19
N_R	MZR	Manoeuvring device moment about *z*-axis	
N_p	DNDP	Derivative	24
$N_{\dot{p}}$	DNDPT		
N_r	DNDR		
$N_{\dot{r}}$	DNDRT		
N_v	DNDV		
$N_{\dot{v}}$	DNDVT		
N_ϕ	DNDPHI		
n	N	Rate of revolution, general	8
n_{LT}	NLT	Rate of revolution of lateral thrust unit	20
		O	

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
O	ORIG	Origin	2
O_0	ORIG0		
P			
P	P	Power	8
P	PITCH	Propeller pitch	22
P		Port (side)	12
P		Reference point of propeller	3
P_B	PB	Power	22
P_D	PD		
PH	PH	Pressure hull	12
P_{LT}	PITCHLT	Propeller pitch of lateral thrust unit	20
P_S	PS	Power	22
P_{SLT}	PSLT	Power of lateral thrust unit	20
p	OMX	Roll velocity	18
$\dot{p}$	OXRT	Roll acceleration	
p_F	PPFR	Relative propeller pitch of cycloidal propeller	20
p_R	PPRR		
Q			
Q	Q	Torque	22
Q_R	QRU	Torque on manoeuvring device stock	19
Q_{RF}	QRUF	Torque on flap stock	
q	OMY	Angular velocity about y-axis	18
$\dot{q}$	OYRT	Angular acceleration about y-axis	
R			
R	R	Resistance	19
R	RDP	Propeller radius	22
R		Reference point of manoeuvring device	3
R_n	RN	Reynolds number	8
R_T	RT	Resistance	22
r	OMZ	Angular velocity about z-axis	18
$\dot{r}$	OZRT	Angular acceleration about z-axis	
S			
S	S	Wetted surface	22
S		Reference point of stern plane	3
S		Starboard (side)	12
S_{AP}	SAP	Wetted surface of appendages	22
S_{BH}	SBH	Wetted surface of bare hull	
s	SP	Track length	8
T			
T	T	Draught	12
T		Reference point of thruster	3
T	TH	Propeller thrust	22

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
T_A	TA	Draught	12
T_{DWL}	TDWL	Design draught	
T_F	TF	Draught	
t	TI	Time	8
t	THDF	Thrust deduction fraction	22
t	TMX	Profile thickness	13
t_R t_{RF} t_{RT} t_{RX}	TMRU TMRUF TMRUT TMRUX	Rudder thickness Flap thickness Rudder thickness Rudder thickness	
t_{SK}	TMSK	Skeg thickness	
$t°_A$ $t°_W$	TEAI TEWA	Temperature	8
U			
u	UP	Circumferential velocity	22
u	VX	Longitudinal velocity	18
$\dot{u}$	VXRT	Longitudinal acceleration	
V			
V	V	Ship's speed	8
V_A	VA	Speed of advance	22
V_K	VKA	Speed over ground	18
V_U	VCU	Current velocity	
V_{WR}	VWREL	Relative wind velocity	
V_{WT}	VWABS	True wind velocity	
V_0	V0	Initial speed	
v	VY	Lateral velocity	
$\dot{v}$	VYRT	Lateral acceleration	
W			
W	WT	Ship's weight	8
WL	WL	Waterline	13
w	WFT	Taylor wake fraction	22
w	VZ	Normal velocity	18
$\dot{w}$	VZRT	Normal acceleration	
w_B	WCANB	Bottom width of canal	13
w_S	WCANS	Surface width of canal	
X			
X	FX	Longitudinal force	19
X_R	FXR	Longitudinal manoeuvring device force	
x	X	Axis	2
x_0	X0		
$x_{(..)}$	X(..)	Longitudinal position	3

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
		Y	
Y	FY	Lateral force	19
Y_{R}	FYR	Lateral manoeuvring device force	
Y_p	DYDP	Derivative	24
$Y_{\dot{p}}$	DYDPT		
Y_r	DYDR		
$Y_{\dot{r}}$	DYDRT		
Y_v	DYDV		
$Y_{\dot{v}}$	DYDVT		25
Y_ϕ	DYDPHI		
y	Y	Axis	2
y_0	Y0		
$y_{(..)}$	Y(..)	Lateral position	3
		Z	
Z	FZ	Normal force	19
Z_{R}	FZR	Normal manoeuvring device force	
Z	NBP	Number of propeller blades	22
Z_q	DZDQ	Derivative	25
$Z_{\dot{q}}$	DZDQT		
Z_w	DZDW		
$Z_{\dot{w}}$	DZDWT		
Z_z	DZDZ		
Z_θ	DZDTP		
z	Z	Axis	2
z_0	Z0		
$z_{(..)}$	Z(..)	Normal position	3
		α	
α	ALFA	Angle of attack	4
		β	
β	BET	Drift angle	4
β^*	BETS	Effective advance angle	23
		Δ	
Δ	DISPM	Displacement mass	8
Δ_{F}	DISPF	Displacement force	
δ_{B}	ANB	Bow plane angle	20
δ_{R}	ANRU	Manoeuvring device angle	
δ_{RF}	ANRUF	Rudder flap angle	
δ_{RO}	ANRUOR	Manoeuvring device angle, ordered	
δ_{S}	ANS	Stern plane angle	
δ_0	ANRU0	Neutral manoeuvring device angle	

Table A.1 *(continued)*

Symbol	CC-Code	Key word	Page
		η	
η	ETA	Efficiency	23
η_B	ETAB	Efficiency	
η_D	ETAD	Propulsive efficiency	
η_H	ETAH	Hull efficiency	
η_R	ETAR	Relative rotative efficiency	
η_S	ETAS	Efficiency	
η_0	ETA0	Efficiency	
		Θ	
Θ	TETAM	Polar moment of inertia	23
θ	TETP	Pitch angle	7
θ_S	TRIMS	Trim angle	
		Λ	
Λ_R	ASRU	Rudder aspect ratio	13
λ	ADVR	Propeller advance ratio	23
λ	SCALE	Scale	13
λ_R	TARU	Rudder taper	
		ν	
ν	VK	Kinematic viscosity	8
		ρ	
ρ	RHOWA	Density	8
ρ_A	RHOAI		
		Σ	
σ	—	Stability index	25 to 28
		Φ	
ϕ	PHIR	Roll angle	7
ϕ_S	HEELANG	Heel (blank) angle	
		Ψ	
ψ	PSIH PSIY	Heading Yaw angle	7
ψ_U	PSICU	Current direction	28
ψ_{WA}	PSIWA	Wave direction	
ψ_{WR}	PSIWREL	Relative wind direction	29
ψ_{WT}	PSIWABS	True wind direction	
$\dot{\psi}$	YART	Yaw velocity	18
		Ω	
ω	OMN	Angular velocity	8
		∇	
∇	DISPV	Displacement volume	13
∇_{AP}	DISPVAP	Displacement volume	14
∇_{LB}	DISPVLB	Lost buoyancy volume	
∇_{SP}	DISPVSP	Displacement volume	

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