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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'essai

Reference number
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Foreword

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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. www.iso.org/directives

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

ISO 13643 consists of the following parts, under the general title *Ships and marine technology — Manoeuvring of ships*:

— *Part 1: General concepts, quantities and test conditions*

— *Part 2: Tuning and yaw checking*

— *Part 3: Yaw stability and steering*

— *Part 4: Stopping, acceleration, traversing*

— *Part 5: Submarine specials*

— *Part 6: Model test specials*

Ships and marine technology — Manoeuvring of ships —

Part 1: General concepts, quantities and test conditions

1 Scope

This part of ISO 13643 applies to manoeuvring tests with surface ships, submarines, and models.

This part of ISO 13643 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, 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.

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

ISO 80000-1, *Quantities and units — Part 1: General*

ISO 80000-3, *Quantities and units — Part 3: Space and time*

3 Terms and definitions

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

3.1
manoeuvring
all manoeuvres, manoeuvring tests, 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 a vessel

3.6
quantities and units
quantities and their units shall be in accordance with ISO 80000-1 and ISO 80000-3

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 Table 1 and Table 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	ORIG0	—	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 $^{B}\nabla$	—
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

β_R Drift angle at manoeuvring device

6.3 Eulerian angles

6.3.1 General

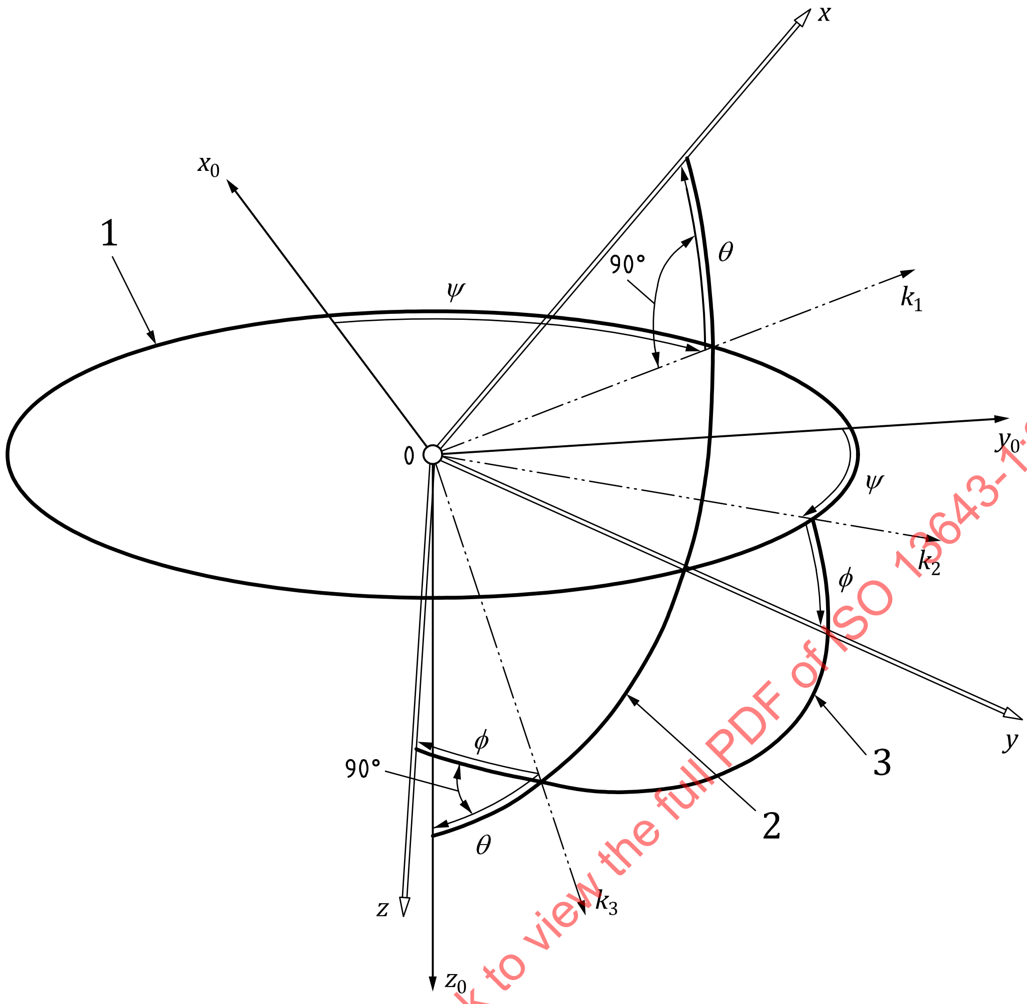
Eulerian angles are described in Figure 1 and in Table 6 and Table 7.

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

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

Table 7 *(continued)*

Symbol	CC-Code	SI-Unit	Concept		Axis of rotation	Measurement plane
			Term	Definition or explanation		
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 must be accelerated for speed changes, but without added mass
n	N	s^{-1}	Rate of revolution, general	—
P	P	W	Power, general	—

Table 8 *(continued)*

Symbol[a]	CC-Code[a]	SI-Unit	Concept	
			Term	Definition or explanation
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	$\rho\,g\,\nabla$
N	VK	m^2 s^{-1}	Kinematic viscosity	—
P	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

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
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 (incl. 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 ∇
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 (incl. 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 incl. flap and fixed post

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
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	$\frac{A_{SK}}{b_{SK}}$
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, incl. 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

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
c_{rR}	CHRRU	m	Rudder root chord length	On the inboard side of the movable part (incl. 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 incl. 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 (incl. 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 incl. 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
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

Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
G	—	—	Centre of gravity	Point at which the resultant of the gravitational forces on the ship acts
$\overline{\text{GM}}$	GM	m	Metacentric height	Distance M to G
K	—	—	Keel reference	on BL
$\overline{\text{KG}}$	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
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 (incl. 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 incl. 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

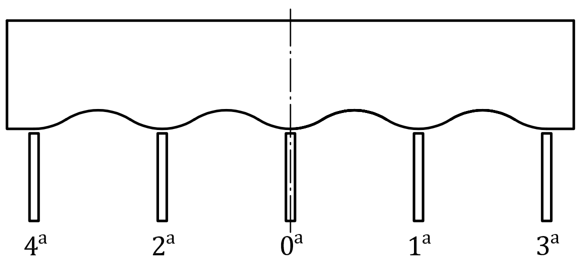
Table 9 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	**Definition or explanation**
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
∇_{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

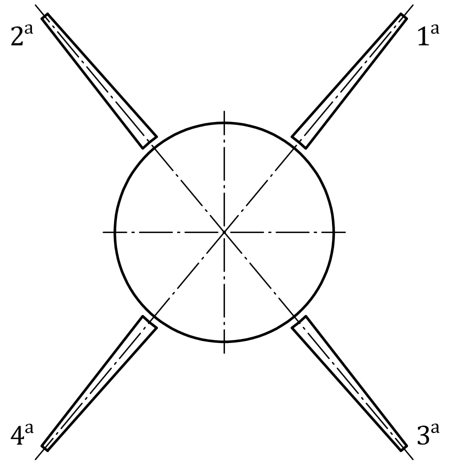
Index resp. extension for CC-Code	Explanation	Example for the use with symbols and CC-Codes according to Table 9		
		Symbol	CC-Code	Term
(n)	Additional index to distinguish between multiple arrangements of manoeuvring devices, skegs, and fixed fins, respectively. Numerals with the digit 0 designate manoeuvring 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 V- 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 not an 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

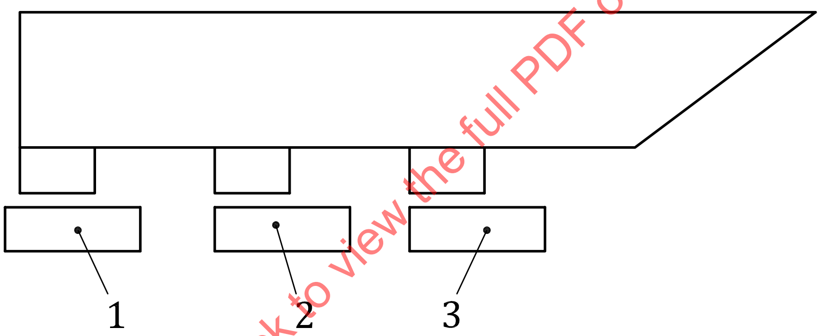
Figure 2 — Arrangement of parallel manoeuvring devices (view from aft); example: Stern of an inland navigation ship with five rudders



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	Definition or explanation
I_{xx}	IXX	kg m2	Moment of inertia about *x*-axis	$\int \left\{ (y-y_G)^2 + (z-z_G)^2 \right\} \mathrm{d}m$ [a]
I_{yy}	IYY	kg m2	Moment of inertia about *y*-axis	$\int \left\{ (x-x_G)^2 + (z-z_G)^2 \right\} \mathrm{d}m$ [a]

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

Table 11 *(continued)*

Symbol	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
I_{zz}	IZZ	kg m2	Moment of inertia about *z*-axis	$\int\left\{\left(x-x_G\right)^2+\left(y-y_G\right)^2\right\}\mathrm{d}m$ [a]
I_{xy}	IXY	kg m2	Product of inertia	$\int\left(x-x_G\right)\left(y-y_G\right)\mathrm{d}m$ [a]
I_{yz}	IYZ	kg m2		$\int\left(y-y_G\right)\left(z-z_G\right)\mathrm{d}m$ [a]
I_{zx}	IZX	kg m2		$\int\left(z-z_G\right)\left(x-x_G\right)\mathrm{d}m$ [a]
k_{xx}	RDGX	m	Radius of inertia about *x*-axis	$\left(\frac{\int\left(\left(y-y_G\right)^2+\left(z-z_G\right)^2\right)\mathrm{d}m}{\Delta}\right)^{1/2}$ [a]
k_{yy}	RDGY	m	Radius of inertia about *y*-axis	$\left(\frac{\int\left(\left(x-x_G\right)^2+\left(z-z_G\right)^2\right)\mathrm{d}m}{\Delta}\right)^{1/2}$ [a]
k_{zz}	RDGZ	m	Radius of inertia about *z*-axis	$\left(\frac{\int\left(\left(x-x_G\right)^2+\left(y-y_G\right)^2\right)\mathrm{d}m}{\Delta}\right)^{1/2}$ [a]

[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

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

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

Table 12 *(continued)*

Symbol and vector	CC-Code	SI-Unit	Concept	
			Term	Definition or explanation
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[b] (ground) directed along the tangent to ship's path
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; $¼(\delta_{A1} + \delta_{A2} + \delta_{A3} + \delta_{A4})$
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	$Z \int_{0,5 d_h}^{R} c\,dr$
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	$\frac{P_D}{\rho\,n^3\,L D^4}$ for cycloidal propellers
K_Q	KQ	1	Torque coefficient	$\frac{Q}{\rho\,n^2\,D^5}$ for screw propellers
K_{QC}	KQC	1	Torque coefficient	$\frac{Q}{\rho\,n^2\,L D^4}$ for cycloidal 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_T	KT	1	Thrust coefficient	$\frac{T}{\rho n^2 D^4}$ for screw propellers
K_{TC}	KTC	1	Thrust coefficient	$\frac{T}{\rho n^2 L D^3}$ 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	—
β^* [a]	BETS	rad[b]	Effective advance angle	$\arctan\left(\frac{V_A}{u}\right)$
η	ETA	1	Efficiency, general	—

[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
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,

— components of angular velocity and angular acceleration,

— heel and trim angle,

— manoeuvring device angle.

Within the scope of this part of ISO 13643, 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 s2 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 s2 rad-1	—	$\partial K / \partial \dot{r}$
K_v	DKDV	N s	—	$\partial K / \partial v$
$K_{\dot{v}}$	DKDVT	N s2	—	$\partial K / \partial \dot{v}$
$K_{\phi \mathrm{dyn}}$	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 s2 rad-1	—	$\partial M / \partial \dot{q}$
M_w	DMDW	N s	—	$\partial M / \partial w$
$M_{\dot{w}}$	DMDWT	N s2	—	$\partial M / \partial \dot{w}$
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 s2 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 s2 rad-1	—	$\partial N / \partial \dot{r}$
N_v	DNDV	N s	—	$\partial N / \partial v$
$N_{\dot{v}}$	DNDVT	N s2	—	$\partial N / \partial \dot{v}$
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 s2 rad-1	—	$\partial Y / \partial \dot{p}$
Y_r	DYDR	N s rad-1	—	$\partial Y / \partial r$
$Y_{\dot{r}}$	DYDRT	N s2 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	$\mathrm{N\ m^{-1}\ s^{2}}$	—	$\partial Y / \partial \dot{v}$
Y_{ϕ}	DYDPHI	$\mathrm{N\ rad^{-1}}$	—	$\partial Y / \partial \phi$
Z_{q}	DZDQ	$\mathrm{N\ s\ rad^{-1}}$	—	$\partial Z / \partial q$
$Z_{\dot{q}}$	DZDQT	$\mathrm{N\ s^{2}\ rad^{-1}}$	—	$\partial Z / \partial \dot{q}$
Z_{w}	DZDW	$\mathrm{N\ m^{-1}\ s}$	—	$\partial Z / \partial w$
$Z_{\dot{w}}$	DZDWT	$\mathrm{N\ m^{-1}\ s^{2}}$	—	$\partial Z / \partial \dot{w}$
Z_{z}	DZDZ	$\mathrm{N\ m^{-1}}$	—	$\partial Z / \partial z$
Z_{θ}	DZDTP	$\mathrm{N\ rad^{-1}}$	—	$\partial Z / \partial \theta$

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 formulae, 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:

$$\left(m - Y_{\dot{v}}\right)\dot{v} - Y_{v}\,v + \left(m\,x_{\mathrm{G}} - Y_{\dot{r}}\right)\dot{r} + \left(m\,u - Y_{r}\right)r - \left(m\,z_{\mathrm{G}} + Y_{\dot{p}}\right)\dot{p} - Y_{p}\,p - Y_{\phi}\varphi = 0 \qquad (1)$$

$$\left(m\,x_{\mathrm{G}} - N_{\dot{v}}\right)\dot{v} - N_{v}\,v + \left(I_{zz} - N_{\dot{r}}\right)\dot{r} + \left(m\,x_{\mathrm{G}}\,u - N_{r}\right)r - \left(I_{zx} + N_{\dot{p}}\right)\dot{p} - N_{p}\,p - N_{\phi}\varphi = 0 \qquad (2)$$

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

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 $\dot{p}=\ddot{\phi}$:

$$v=v_1\,e^{\sigma_1 t}+v_2\,e^{\sigma_2 t}+v_3\,e^{\sigma_3 t}+v_4\,e^{\sigma_4 t} \tag{4}$$

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

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

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 (4), (5), and (6) into Formulae (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:

$$A_0=N_v\left(m\,u-Y_r\right)-Y_v\left(m\,x_G\,u-N_r\right)+\begin{bmatrix}Y_v\,N_\phi\left(m\,z_G\,u+K_r\right)+Y_v\,K_{\phi\mathrm{dyn}}\left(m\,x_G\,u-N_r\right)-N_v\,Y_\phi\left(m\,z_G\,u+K_r\right)\\-N_v\,K_{\phi\mathrm{dyn}}\left(m\,u-Y_r\right)-K_v\,Y_\phi\left(m\,x_G\,u-N_r\right)+K_v\,N_\phi\left(m\,u-Y_r\right)\end{bmatrix}\left(m\,g\,\overline{\mathrm{GM}}\right)^{-1}>0 \tag{8}$$

For slow ship speeds and/or high static roll stability (i.e. large $\overline{\mathrm{GM}}$), the term $m\,g\,\overline{\mathrm{GM}}\,\phi$ dominates all other terms in Formula (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:

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

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

Simultaneous solution of Formulae (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 (11) and (12) into Formulae (9) and (10), the following quadratic equation is obtained:

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

where

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

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

$$B_0 = N_v (m u - Y_r) - Y_v (m x_G u - N_r) \tag{16}$$

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 must be taken into account as well. In this case, the following, similarly linearized equations of motion apply:

$$(m - Z_{\dot{w}})\dot{w} - Z_w w - Z_z z - (m x_G + Z_{\dot{q}})\dot{q} - (m u + Z_q) q - Z_\theta \theta = 0 \tag{17}$$

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

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

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

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

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

$$A_1 = Z_w M_\theta - M_w Z_\theta + Z_z \left(m x_G - M_q\right) - M_z \left(m u + Z_q\right) \tag{25}$$

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

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:

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

$$B_2 = \left(m - Z_w\right) \left(m x_G - M_q\right) - \left(m u + Z_q\right) \left(m x_G + M_{\dot{w}}\right) - Z_w \left(I_{yy} - M_{\dot{q}}\right) - M_w \left(m x_G + Z_{\dot{q}}\right) \tag{30}$$

and B_1 and B_0 are:

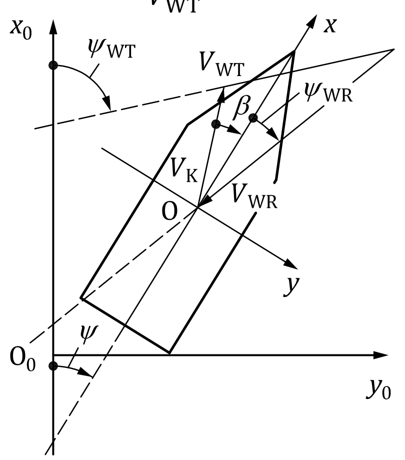
$$B_1 = -M_\theta \left(m - Z_w\right) + Z_w \left(m x_G - M_q\right) - M_w \left(m u + Z_q\right) \tag{31}$$

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

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[b]	Current direction	Direction to which the current flows, relative to an earth-fixed axis system
ψ_{WA}	PSIWA	rad[b]	Wave direction	Mean direction to which the waves progress, relative to an earth-fixed axis system
ψ_{WR}	PSIWREL	rad[b]	Relative wind direction	Direction from which the wind blows, relative to ship-fixed axis system
ψ_{WT}	PSIWABS	rad[b]	True wind direction	Direction from which the wind blows, relative to an earth-fixed axis system $\psi + \psi_{WR}$ $+\arcsin^{-1}(\frac{V_K}{V_{WT}} \sin(\psi_{WR} + \beta))$ 

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

b 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 of International Standards 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) coasting stop test,

b) acceleration test,

c) turning circle test,

d) accelerating turn test,

e) astern test,

f) zig-zag test,

g) 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 Tests 2.3 and 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, and water depth prevailing during the individual test are to be recorded.

The description of each ship test according to the ISO 13643 series of International Standards must 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.

8.4 Test reports

The results of ship tests should be reported using the formats at the annexes to 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 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. $k < k_{perm}$. Here, k is the roughness height of the surface and $k_{perm} = 10\ \nu/V$, 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 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 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, the following data shall be recorded once for a related series of similar tests:

Indications a) to i) according to 8.2, and additionally:

h) Model scale,

i) Water temperature,

j) Towing tank dimensions,

k) 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	8
A_E	AE	Blade area, propeller	20
A_L	AL	Lateral area below waterline	8
A_{LT}	ALT	Cross section of lateral thrust unit	19
A_{LV}	ALV	Lateral area above waterline	8
A_M	AM	Midship section area	
AP	AP	After perpendicular	9
A_R	ARU	Rudder area	9
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	9
A_X	AX	Maximum transverse section area	
A_0	A0	Propeller disc area, propeller swept area	20
		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	
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	10
b_{SK}	SPSX	Skeg span	
		C	
C	FNORM	Cross force	18
CL	CL	Centreline plane	10