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Ships and marine technology — Manoeuvring of ships —

Part 6: Model test specials

Navires et technologie maritime — Manoeuvres des navires —

Partie 6: Spécificités des essais sur modéle

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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: Turning 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 6:
Model test specials

1 Scope

This part of ISO 13643 defines symbols and terms and provides guidelines for the conduct of tests to determine the hydrodynamic forces and moments due to prescribed motions under a planar-motion, a circular-motion, or an oblique towing or flow system for models of surface ships and submarines. It also defines symbols and terms and provides guidelines for the conduct of tests in a wind tunnel. It is intended to be read in conjunction with ISO 13643-1.

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 13643-1, *Ships and marine technology — Manoeuvring of ships — Part 1: General concepts, quantities and test conditions*

3 Terms and definitions

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

3.1
planar motion test
manoeuvring test to determine the hydrodynamic forces and moments as functions of lateral velocity and acceleration as well as of angular velocity and acceleration about the *z*-axis or the *y*-axis, respectively

3.2
circular motion test
manoeuvring test to determine the hydrodynamic forces and moments as a function of the angular velocity for surface ships primarily about the *z*-axis, for submarines primarily about the *z*-axis as well as the *y*-axis

3.3
oblique towing or flow test
manoeuvring test to determine the forces and moments as a function of the drift angle and of the manoeuvring device angle and, in the case of submarines, the angle of attack and hydroplane deflections, in a towing tank, a circulating water tunnel, or a wind tunnel

3.4
wind tunnel test
test to determine the aerodynamic forces and moments acting upon the above-water portion of the ship as a function of the relative wind

Note 1 to entry: A wind tunnel may also be used for the underwater hull.

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

4 Test-related physical quantities

Test-related physical quantities are according to Table 1. General quantities and concepts are according to ISO 13643-1.

Table 1 — Test-related physical quantities

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
A_{LV}	ALV	m^2	Lateral area above waterline	(See ISO 13643-1.)
A_{XV}	AXV	m^2	Transverse projected area of ship above waterline	Projected cross section area above DWL, generally without rigging, railings, etc.
AP	AP	—	After perpendicular	(See ISO 13643-1.)
a_0	A0PMM	m	Displacement amplitude of the model movement	—
C	CWI	N	Cross force	Force perpendicular to relative wind direction
C_C	CC	1	Cross force coefficient	$2C/(\varrho_A\ V_{WRA}^2\ A_{LV})$
C_D	CD	1	Drag coefficient	$2D/(\varrho_A\ V_{WRA}^2\ A_{LV})$
C_{DAX}	CDAX	1	Drag coefficient	$2D/(\varrho_A\ V_{WRA}^2\ A_{XV})$, relative to cross section
C_K	CK	1	Roll-moment coefficient	$2K/(\varrho_A\ V_{WRA}^2\ A_{LV} L_{OA})$
C_N	CN	1	Coefficient of moment about z-axis	$2N/(\varrho_A\ V_{WRA}^2 A_{LV}\ L_{OA})$
C_X	CX	1	Longitudinal-force coefficient	$2X/(\varrho_A\ V_{WRA}^2\ A_{LV})$
C_{XAX}	CXAX	1	Longitudinal-force coefficient	$2X/(\varrho_A\ V_{WRA}^2\ A_{XV})$, relative to cross section
C_Y	CY	1	Lateral-force coefficient	$2Y/(\varrho_A\ V_{WRA}^2\ A_{LV})$
D	DWI	N	Drag	Force in direction in which relative wind blows
DWL	DWL	—	Design waterline	(See ISO 13643-1.)
FP	FP	—	Fore perpendicular	(See ISO 13643-1.)
F_T	FTWI	N	Resultant force	$\sqrt{C^2+D^2}$ and $\sqrt{X^2+Y^2}$, respectively
F_n	FN	1	Froude number	(See ISO 13643-1.)
F_{n0}	FN0	1	(Reference) Froude number	$V_0 / \sqrt{gL}$
$\overline{GM}$	GM	m	Metacentric height	(See ISO 13643-1.)
H_{LM}	HLM	m	Mean height of lateral area above design waterline	A_{LV}/L_{OA}
I_{xx}	IXX	kg m^2	Moment of inertia of the model about x-axis	(See ISO 13643-1.)
I_{yy}	IYY	kg m^2	Moment of inertia of the model about y-axis	(See ISO 13643-1.)

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
I_{zx}	IZX	kg m^2	Product of inertia of the model	(See ISO 13643-1.)
I_{zz}	IZZ	kg m^2	Moment of inertia of the model about *z*-axis	(See ISO 13643-1.)
K	MX	N m	Roll moment	Moment about *x*-axis Relative to ship-fixed axis system
$K_{\phi\text{stat}}$	DKDPST	N m rad^{-1}[a]	—	$\left.\frac{\partial K}{\partial \phi}\right\|_{V=0}$ from static test or calculation
K'	MXS	1	Non-dimensional roll moment	Especially for submarines: $\frac{K}{\frac{\rho}{2}L^3V^2}$ where $K(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{K}{\frac{\rho}{2}L^3V_0^2}$ where $K(V_0, \Delta u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
K'_{in}	MXINS	1	In-phase part of non-dimensional roll moment	$\frac{2}{nT}\int_{t}^{t+nT} K'(t)\sin\omega t\,\mathrm{d}t$
K'_{out}	MXOUTS	1	Quadrature part of non-dimensional roll moment	$\frac{2}{nT}\int_{t}^{t+nT} K'(t)\cos\omega t\,\mathrm{d}t$
K'_{p}	DKDPS	1	—	$\left.\frac{\partial K'}{\partial p'}\right\|_{K'=\hat{K}'_0}$
$K'_{\dot{p}}$	DKDPTS	1	—	$\left.\frac{\partial K'}{\partial \dot{p}'}\right\|_{K'=\hat{K}'_0}$
$K'_{\dddot{p}}$	DKDP3TS	1	—	$\left.\frac{\partial K'}{\partial \dddot{p}'}\right\|_{K'=\hat{K}'_0}$
K'_{r}	DKDRS	1	Slope through zero of K' versus r'	$\left.\frac{\partial K'}{\partial r'}\right\|_{K'=\hat{K}'_0}$
$K'_{\dot{r}}$	DKDRTS	1	—	$\left.\frac{\partial K'}{\partial \dot{r}'}\right\|_{K'=\hat{K}'_0}$
K'_{v}	DKDVS	1	Slope through zero of K' versus v'	$\left.\frac{\partial K'}{\partial v'}\right\|_{K'=\hat{K}'_0}$
$K'_{\dot{v}}$	DKDVTS	1	—	$\left.\frac{\partial K'}{\partial \dot{v}'}\right\|_{K'=\hat{K}'_0}$
$\hat{K}'_{pq}$	MXPQS	1	Non-dimensional coefficient used in representing K' as a function of p' q'	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{K}'_r$	MXRS	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}\ r'$	(for surface ships only)
$\hat{K}'_{ur}$	MXURS	1	Non-dimensional coefficient used in representing K' as a function of $u'\ r'$	(especially for submarines)
$\hat{K}'_{uu}$	MXUUS	1	Non-dimensional coefficient used in representing K' as a function of u'^2	(especially for submarines)
$\hat{K}_{uu\delta\mathrm{R}}$	MXUUDRS	1	Non-dimensional coefficient used in representing K' as a function of $u'^2\ \delta_\mathrm{R}$	(especially for submarines)
$\hat{K}_{uu\delta\delta\delta\mathrm{R}}$	MXUUDR3S	1	Non-dimensional coefficient used in representing K' as a function of $u'^2\ \delta_\mathrm{R}^3$	(especially for submarines)
$\hat{K}'_{uv}$	MXUVS	1	Non-dimensional coefficient used in representing K' as a function of $u'\ v'$	(especially for submarines)
$\hat{K}_{uv\delta\mathrm{R}}$	MXUVDRS	1	Non-dimensional coefficient used in representing K' as a function of $u'\ v'\ \delta_\mathrm{R}$	(especially for submarines)
$\hat{K}'_v$	MXVS	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}\ v'$	(for surface ships only)
$\hat{K}'_{vvv}$	MXV3S	1	Non-dimensional coefficient used in representing K' as a function of $v'\lvert v'\rvert\sqrt{v'^2+w'^2}F_{n0}$	(for surface ships only)
$\hat{K}'_{v\lvert v\rvert}$	MXVVAS	1	Non-dimensional coefficient used in representing K' as a function of $v'\sqrt{v'^2+w'^2}$	—
$\hat{K}'_{v\delta\mathrm{R}}$	MXVDRS	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}\ v'\ \delta_\mathrm{R}$	(for surface ships only)
$\hat{K}'_{wp}$	MXWPS	1	Non-dimensional coefficient used in representing K' as a function of $w'\ p'$	—
$\hat{K}'_{wr}$	MXWRS	1	Non-dimensional coefficient used in representing K' as a function of $w'\ r'$	—
$\hat{K}'_{\Delta u}$	MXDUS	1	Non-dimensional coefficient used in representing K' as a function of $\Delta u'$	(for surface ships only)
$\hat{K}'_{\Delta uv}$	MXDUVS	1	Non-dimensional coefficient used in representing K' as a function of $\Delta u'\ v'$	(for surface ships only)
$\hat{K}'_{\Delta\Delta u}$	MXDU2S	1	Non-dimensional coefficient used in representing K' as a function of $(\Delta u')^2$	(for surface ships only)
$\hat{K}'_{\delta\mathrm{R}}$	MXDRS	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}{}^2\ \delta_\mathrm{R}$	(for surface ships only)
$\hat{K}'_{\delta\delta\delta\mathrm{R}}$	MXDR3S	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}{}^2\ \delta_\mathrm{R}^3$	(for surface ships only)
$\hat{K}'_0$	MX0S	1	Non-dimensional coefficient used in representing K' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\tilde{K}'_\phi$	MXOPHS	1	Non-dimensional oscillatory roll coefficient	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
L	L	m	Model length	Reference length (see ISO 13643-1)
L_{OA}	LOA	m	Length overall	Length between the most aft and most forward points of the ship, permanent outfit included, measured parallel to DWL
M	MY	N m	Moment about y-axis	Relative to ship-fixed axis system
MA	MAX	—	Main axis	(See ISO 13643-1.)
$M_{\theta stat}$	DMDTST	N m rad^{-1} [a]	—	$\left.\frac{\partial M}{\partial \theta}\right\vert_{V=0}$ from static test or calculation
M'	MYS	1	Non-dimensional moment about y-axis	Especially for submarines $\frac{M}{\frac{\rho}{2} L^3 V^2}$, where $M\ (u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{M}{\frac{\rho}{2} L^3 V_0^2}$, where $M\ (V_0, \Delta u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
M'_{in}	MYINS	1	In-phase part of non-dimensional moment about y-axis	$\frac{2}{nT}\int_t^{t+nT} M'(t)\sin\omega t\,dt$
M'_{out}	MYOUTS	1	Quadrature part of non-dimensional moment about y-axis	$\frac{2}{nT}\int_t^{t+nT} M'(t)\cos\omega t\,dt$
M'_q	DMDQS	1	Slope through zero of M' versus q'	$\left.\frac{\partial M'}{\partial q'}\right\vert_{M'=\hat{M}'_0}$
$M'_{\dot{q}}$	DMDQTS	1	—	$\left.\frac{\partial M'}{\partial \dot{q}'}\right\vert_{M'=\hat{M}'_0}$
$M'_{\ddot{q}}$	DMDQ3TS	1	—	$\left.\frac{\partial M'}{\partial \ddot{q}'}\right\vert_{M'=\hat{M}'_0}$
M'_w	DMDWS	1	Slope through zero of M' versus w'	$\left.\frac{\partial M'}{\partial w'}\right\vert_{M'=\hat{M}'_0}$
$M'_{\dot{w}}$	DMDWTS	1	—	$\left.\frac{\partial M'}{\partial \dot{w}'}\right\vert_{M'=\hat{M}'_0}$
M'_θ	DMDTHS	rad^{-1} [a]	—	$\left.\frac{\partial M'}{\partial \theta}\right\vert_{M'=\hat{M}'_0}$
$\hat{M}'_{pp}$	MYPPS	1	Non-dimensional coefficient used in representing M' as a function of p'^2	—
$\hat{M}'_{pr}$	MYPRS	1	Non-dimensional coefficient used in representing M' as a function of $p'\,r'$	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{M}'_q$	MYQS	1	Non-dimensional coefficient used in representing M' as a function of $u' q'$	—
$\hat{M}'_{q\|q\|}$	MYQQAS	1	Non-dimensional coefficient used in representing M' as a function of $q' \|q'\|$	—
$\hat{M}'_{\|q\|\delta S}$	MYQADSS	1	Non-dimensional coefficient used in representing M' as a function of $u' \|q'\| \delta_S$	—
$\hat{M}'_{rr}$	MYRRS	1	Non-dimensional coefficient used in representing M' as a function of r'^2	—
$\hat{M}'_{uu}$	MYUUS	1	Non-dimensional coefficient used in representing M' as a function of u'^2	—
$\hat{M}'_{vp}$	MYVPS	1	Non-dimensional coefficient used in representing M' as a function of $v' p'$	—
$\hat{M}'_{vr}$	MYVRS	1	Non-dimensional coefficient used in representing M' as a function of $v' r'$	—
$\hat{M}'_w$	MYWS	1	Non-dimensional coefficient used in representing M' as a function of $u' w'$	—
$\hat{M}'_{ww}$	MYWWS	1	Non-dimensional coefficient used in representing M' as a function of $\|w'\| \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{w\|w\|}$	MYWWAS	1	Non-dimensional coefficient used in representing M' as a function of $w' \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{\|w\|}$	MYWAS	1	Non-dimensional coefficient used in representing M' as a function of $u' \|w'\|$	—
$\hat{M}'_{\|w\|q}$	MYWAQS	1	Non-dimensional coefficient used in representing M' as a function of $q' \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{\delta B}$	MYDBS	1	Non-dimensional coefficient used in representing M' as a function of $u'^2 \delta_B$	—
$\hat{M}'_{\delta S}$	MYDSS	1	Non-dimensional coefficient used in representing M' as a function of $u'^2 \delta_S$	—
$\hat{M}'_0$	MY0S	1	Non-dimensional coefficient used in representing M' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\tilde{M}'_\theta$	MY0THS	1	Non-dimensional oscillatory coefficient about y-axis	—
m	MA	kg	Model mass	—
N	MZ	N m	Moment about z-axis	Relative to ship-fixed axis system
$N_{\phi dyn}$	DNDPDYS	rad^−1a	—	$\left.\frac{\partial N'}{\partial \phi}\right\|_{N'=\hat{N}'_0} - \frac{N_{\phi stat}}{\frac{\rho}{2} L^3 V^2}$
$N_{\phi stat}$	DNDPST	N m rad^−1a	—	$\left.\frac{\partial N}{\partial \phi}\right\|_{V=0}$ from static test or calculation

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
N′	MZS	1	Non-dimensional moment about z-axis	Especially for submarines: $\frac{N}{\frac{\rho}{2} L^3 V^2}$, where $N\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{N}{\frac{\rho}{2} L^3 {V_0}^2}$, where $N\,(V_0, \Delta u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
N'_{in}	MZINS	1	In-phase part of non-dimensional moment about *z*-axis	$\frac{2}{nT}\int_{t}^{t+nT} N'(t)\sin\omega t\,\mathrm{d}t$
N'_{out}	MZOUTS	1	Quadrature part of non-dimensional moment about *z*-axis	$\frac{2}{nT}\int_{t}^{t+nT} N'(t)\cos\omega t\,\mathrm{d}t$
N'_p	DNDPS	1	—	$\left.\frac{\partial N'}{\partial p'}\right\|_{N'=\hat{N}'_0}$
$N'_{\dot{p}}$	DNDPTS	1	—	$\left.\frac{\partial N'}{\partial \dot{p}'}\right\|_{N'=\hat{N}'_0}$
$N'_{\ddot{p}}$	DNDP3TS	1	—	$\left.\frac{\partial N'}{\partial \ddot{p}'}\right\|_{N'=\hat{N}'_0}$
N'_r	DNDRS	1	Slope through zero of *N′* versus *r′*	$\left.\frac{\partial N'}{\partial r'}\right\|_{N'=\hat{N}'_0}$
$N'_{\dot{r}}$	DNDRTS	1	—	$\left.\frac{\partial N'}{\partial \dot{r}'}\right\|_{N'=\hat{N}'_0}$
N'_v	DNDVS	1	Slope through zero of *N′* versus *v′*	$\left.\frac{\partial N'}{\partial v'}\right\|_{N'=\hat{N}'_0}$
$N'_{\dot{v}}$	DNDVTS	1	—	$\left.\frac{\partial N'}{\partial \dot{v}'}\right\|_{N'=\hat{N}'_0}$
$\hat{N}'_{pq}$	MZPQS	1	Non-dimensional coefficient used in representing *N′* as a function of *p′ q′*	—
$\hat{N}'_{qr}$	MZQRS	1	Non-dimensional coefficient used in representing *N′* as a function of *q′ r′*	—
$\hat{N}'_r$	MZRS	1	Non-dimensional coefficient used in representing *N′* as a function of $F_{n0}\,r'$	(for surface ships only)
$\hat{N}'_{r\|r\|}$	MZRRAS	1	Non-dimensional coefficient used in representing *N′* as a function of $r'\,\|r'\|$	—
$\hat{N}'_{r\delta\delta\mathrm{R}}$	MZRDDS	1	Non-dimensional coefficient used in representing *N′* as a function of $F_{n0}\,r'\delta_{\mathrm{R}}^2$	(for surface ships only)

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{N}'_{\|r\|\delta R}$	MZRADS	1	Non-dimensional coefficient used in representing N' as a function of $F_{n0}\ \|r'\|\delta_R$	(for surface ships only)
$\hat{N}'_{ur}$	MZURS	1	Non-dimensional coefficient used in representing N' as a function of $u'\,r'$	(especially for submarines)
$\hat{N}'_{ur\delta\delta R}$	MZURDDS	1	Non-dimensional coefficient used in representing N' as a function of $u'r'\delta_R^2$	(especially for submarines)
$\hat{N}'_{u\|r\|\delta R}$	MZURADS	1	Non-dimensional coefficient used in representing N' as a function of $u'\|r'\|\delta_R$	(especially for submarines)
$\hat{N}'_{uu}$	MZUUS	1	Non-dimensional coefficient used in representing N' as a function of u'^2	(especially for submarines)
$\hat{N}'_{uu\delta R}$	MZUUDS	1	Non-dimensional coefficient used in representing N' as a function of $u'^2\ \delta_R$	(especially for submarines)
$\hat{N}'_{uu\delta\delta\delta R}$	MZUUD3S	1	Non-dimensional coefficient used in representing N' as a function of $u'^2\ \delta_R^3$	(especially for submarines)
$\hat{N}'_{uv}$	MZUVS	1	Non-dimensional coefficient used in representing N' as a function of $u'\,v'$	(especially for submarines)
$\hat{N}'_{v}$	MZVS	1	Non-dimensional coefficient used in representing N' as a function of v'	(for surface ships only)
$\hat{N}'_{vq}$	MZVQS	1	Non-dimensional coefficient used in representing N' as a function of $v'\,q'$	—
$\hat{N}'_{vrr}$	MZVRRS	1	Non-dimensional coefficient used in representing N' as a function of $F_{n0}\ v'\,r'^2$	(for surface ships only)
$\hat{N}'_{vvr}$	MZVVRS	1	Non-dimensional coefficient used in representing N' as a function of $F_{n0}\ v'^2\ r'$	(for surface ships only)
$\hat{N}'_{vvv}$	MZV3S	1	Non-dimensional coefficient used in representing N' as a function of $v'^2\sqrt{v'^2+w'^2}\,F_{n0}$	(for surface ships only)
$\hat{N}'_{v\|v\|}$	MZVVAS	1	Non-dimensional coefficient used in representing N' as a function of $v'\sqrt{v'^2+w'^2}$	—
$\hat{N}'_{\|v\|r}$	MZVARS	1	Non-dimensional coefficient used in representing N' as a function of $r'\sqrt{v'^2+w'^2}$	—
$\hat{N}'_{wp}$	MZWPS	1	Non-dimensional coefficient used in representing N' as a function of $w'\,p'$	—
$\hat{N}'_{wr}$	MZWRS	1	Non-dimensional coefficient used in representing N' as a function of $w'\,r'$	—
$\hat{N}'_{\Delta u}$	MZDUS	1	Non-dimensional coefficient used in representing N' as a function of $\Delta u'$	(for surface ships only)
$\hat{N}'_{\Delta uv}$	MZDUVS	1	Non-dimensional coefficient used in representing N' as a function of $\Delta u'\,v'$	(for surface ships only)
$\hat{N}'_{\Delta\Delta u}$	MZDU2S	1	Non-dimensional coefficient used in representing N' as a function of $(\Delta u')^2$	(for surface ships only)

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{N}'_{\delta R}$	MZDRS	1	Non-dimensional coefficient used in representing N' as a function of $F_{n0}{}^2\,\delta_R$	(for surface ships only)
$\hat{N}'_{\delta\delta R}$	MZDR3S	1	Non-dimensional coefficient used in representing N' as a function of $F_{n0}{}^2\,\delta_R^3$	(for surface ships only)
$\hat{N}'_0$	MZ0S	1	Non-dimensional coefficient used in representing N' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\tilde{N}'_\phi$	MZOPHS	1	Non-dimensional oscillatory coefficient about z-axis	—
n	N	1	—	Number of periods used in Fourier integral
	NWI	1	Exponent	—
p	OMX	rad s^{-1} [a]	Roll velocity	$-V/R\sin\theta_S$ Angular velocity about x-axis
p'	OXS	1	Non-dimensional roll velocity	$p\,L/V_0$
$\dot{p}$	OXRT	rad s^{-2} [a]	Roll acceleration	Angular acceleration about x-axis
$\dot{p}'$	OXRTS	1	Non-dimensional roll acceleration	$\dot{p}L^2/V_0^2$
$\dddot{p}$	OXR3T	rad s^{-4} [a]	3rd derivative of roll velocity	—
$\dddot{p}'$	OXR3TS	1	Non-dimensional 3rd derivative of roll velocity	$\dddot{p}\,L^4/V_0^4$
q	OMY	rad s^{-1} [a]	Angular velocity about y-axis	$V/R\sin\phi_S\cos\theta_S$ Relative to ship-fixed axis system
q'	OYS	1	Non-dimensional angular velocity about y-axis	$q\,L/V_0$
$\dot{q}$	OYRT	rad s^{-2} [a]	Angular acceleration about y-axis	Relative to ship-fixed axis system
$\dot{q}'$	OYRTS	1	Non-dimensional angular acceleration about y-axis	$\dot{q}\,L^2/V_0^2$
$\dddot{q}$	OYR3T	rad s^{-4} [a]	3rd derivative of angular velocity about y-axis	—
$\dddot{q}'$	OYR3TS	1	Non-dimensional 3rd derivative of angular velocity about y-axis	$\dddot{q}\,L^4/V_0^4$
R	RCM	m	Circular motion radius	—
R_{nA}	RNA	1	Reynolds number	$V_{WRA}\,L_{OA}/\nu_A$
R_{n0}	RN0	1	(Reference) Reynolds number	$V_0\,L/\nu$
r	OMZ	rad s^{-1} [a]	Angular velocity about z-axis	$V/R\cos\phi_S\cos\theta_S$ Relative to ship-fixed axis system
r'	OZS	1	Non-dimensional angular velocity about z-axis	$r\,L/V_0$
$\dot{r}$	OZRT	rad s^{-2} [a]	Angular acceleration about z-axis	Relative to ship-fixed axis system
$\dot{r}'$	OZRTS	1	Non-dimensional angular acceleration about z-axis	$\dot{r}\,L^2/V_0^2$
T	TIP	s	Period of oscillation	—
u	VX	m s^{-1} [b]	Longitudinal velocity	$V\cos\theta_S\cos\beta$ Relative to ship-fixed axis system

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
u_0	VX0	m s−1	Longitudinal reference velocity	—
u'	VXS	1	Non-dimensional velocity in direction of *x*-axis	u/V_0
V	V	m s−1 b	Model speed	$\sqrt{u^2+v^2+w^2}$
V_{WR}	VWREL	m s−1 b	Relative wind velocity	(See ISO 13643-1.)
V_{WRA}	VWRELA	m s−1 b	Reference velocity: Relative wind velocity at reference height z_{0A}	Usually 10 m above water surface, for full scale
V_{WT}	VWABS	m s−1 b	True wind velocity	(See ISO 13643-1.)
V_{WTA}	VWABSA	m s−1 b	Reference velocity: True wind velocity at reference height z_{0A}	Usually 10 m above water surface, for full scale
V_0	V0	m s−1 b	Reference speed	$\sqrt{u_0^2+v^2+w^2}$
V'	VS	m s−1 b	Non-dimensional speed	V/V_0
v	VY	m s−1 b	Lateral velocity	$V(\sin\phi_S \cos\beta \sin\theta_S - \sin\beta \cos\phi_S)$ Velocity in direction of *y*-axis
v'	VYS	1	Non-dimensional lateral velocity	v/V_0
$\dot{v}$	VYRT	m s−2	Lateral acceleration	Relative to ship-fixed axis system
$\dot{v}'$	VYRTS	1	Non-dimensional lateral acceleration	$\dot{v}\, L/V_0^2$
WL	WL	—	Waterline	(See ISO 13643-1.)
w	VZ	m s−1 b	Normal velocity	$V(\sin\phi_S \sin\beta + \cos\phi_S \cos\beta \sin\theta_S)$ Velocity in direction of *z*-axis
w'	VZS	1	Non-dimensional normal velocity	w/V_0
$\dot{w}$	VZRT	m s−2	Normal acceleration	Acceleration in direction of *z*-axis
$\dot{w}'$	VZRTS	1	Non-dimensional normal acceleration	$\dot{w}\, L/V_0^2$
X	FX	N	Longitudinal force	(See ISO 13643-1.)
X'	FXS	1	Non-dimensional longitudinal force	$\dfrac{X}{\frac{\rho}{2} L^2\, V_0{}^2}$
$\hat{X}'_{qq}$	FXQQS	1	Non-dimensional coefficient used in representing X' as a function of q'^2	—
$\hat{X}'_{q\lvert q\rvert}$	FXQQAS	1	Non-dimensional coefficient used in representing X' as a function of $q'\,\lvert q'\rvert$	—
$\hat{X}'_{rr}$	FXRRS	1	Non-dimensional coefficient used in representing X' as a function of r'^2	—
$\hat{X}'_{uu}$	FXUUS	1	Non-dimensional coefficient used in representing X' as a function of u'^2	(especially for submarines)
$\hat{X}'_{uu\delta\delta R}$	FXUUDDS	1	Non-dimensional coefficient used in representing X' as a function of $u'^2\ \delta_R^2$	(especially for submarines)
$\hat{X}'_{vr}$	FXVRS	1	Non-dimensional coefficient used in representing X' as a function of $v'\,r'$	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{X}'_{vv}$	FXVVS	1	Non-dimensional coefficient used in representing X' as a function of v'^2	—
$\hat{X}'_{wq}$	FXWQS	1	Non-dimensional coefficient used in representing X' as a function of $w' q'$	—
$\hat{X}'_{ww}$	FXWWS	1	Non-dimensional coefficient used in representing X' as a function of w'^2	—
$\hat{X}'_{\Delta u}$	FXDUS	1	Non-dimensional coefficient used in representing X' as a function of $\Delta u'$	(for surface ships only)
$\hat{X}'_{\Delta\Delta u}$	FXDU2S	1	Non-dimensional coefficient used in representing X' as a function of $(\Delta u')^2$	(for surface ships only)
$\hat{X}'_{\Delta\Delta\Delta u}$	FXDU3S	1	Non-dimensional coefficient used in representing X' as a function of F_{n0} $(\Delta u')^3$	(for surface ships only)
$\hat{X}'_{\delta\delta \mathrm{B}}$	FXDB2S	1	Non-dimensional coefficient used in representing X' as a function of $u'^2\ \delta_\mathrm{B}^2$	(especially for submarines)
$\hat{X}'_{\delta\delta \mathrm{R}}$	FXDR2S	1	Non-dimensional coefficient used in representing X' as a function of $F_{n0}{}^2 \delta_\mathrm{R}^2$	(for surface ships only)
$\hat{X}'_{\delta\delta \mathrm{S}}$	FXDS2S	1	Non-dimensional coefficient used in representing X' as a function of $u'^2\ \delta_\mathrm{S}^2$	(especially for submarines)
$\hat{X}'_0$	FX0S	1	Non-dimensional coefficient used in representing X' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
x_F	XFO	m	Longitudinal position of centre of pressure	*N/Y*
x_G	XG	m	Longitudinal position of centre of gravity of the model	(See ISO 13643-1.)
Y	FY	N	Lateral force	(See ISO 13643-1.)
$Y_{\phi\mathrm{stat}}$	DYDPST	N rad⁻¹ ᵃ	—	$\left.\frac{\partial Y}{\partial \phi}\right\|_{V=0}$ from static test or calculation
Y'	FYS	1	Non-dimensional lateral force	Especially for submarines: $\frac{Y}{\frac{\rho}{2} L^2 V^2}$, where $Y\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{Y}{\frac{\rho}{2} L^2 V_0^2}$, where $Y\,(V_0, \Delta u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
Y'_in	FYINS	1	In-phase part of non-dimensional lateral force	$\frac{2}{nT}\int_t^{t+nT} Y'(t)\sin\omega t\,\mathrm{d}t$
Y'_out	FYOUTS	1	Quadrature part of non-dimensional lateral force	$\frac{2}{nT}\int_t^{t+nT} Y'(t)\cos\omega t\,\mathrm{d}t$

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
Y'_p	DYDPS	1	—	$\left.\frac{\partial Y'}{\partial p'}\right\|_{Y'=\hat{Y}'_0}$
$Y'_{\dot{p}}$	DYDPTS	1	—	$\left.\frac{\partial Y'}{\partial \dot{p}'}\right\|_{Y'=\hat{Y}'_0}$
$Y'_{\ddot{p}}$	DYDP3TS	1	—	$\left.\frac{\partial Y'}{\partial \ddot{p}'}\right\|_{Y'=\hat{Y}'_0}$
Y'_r	DYDRS	1	Slope through zero of Y' versus r'	$\left.\frac{\partial Y'}{\partial r'}\right\|_{Y'=\hat{Y}'_0}$
$Y'_{\dot{r}}$	DYDRTS	1	—	$\left.\frac{\partial Y'}{\partial \dot{r}'}\right\|_{Y'=\hat{Y}'_0}$
Y'_v	DYDVS	1	Slope through zero of Y' versus v'	$\left.\frac{\partial Y'}{\partial v'}\right\|_{Y'=\hat{Y}'_0}$
$Y'_{\dot{v}}$	DYDVTS	—	—	$\left.\frac{\partial Y'}{\partial \dot{v}'}\right\|_{Y'=\hat{Y}'_0}$
Y'_ϕ	DYDPHIS	rad^{-1} [a]	—	$\left.\frac{\partial Y'}{\partial \varphi}\right\|_{Y'=\hat{Y}'_0}$
$Y'_{\phi\mathrm{dyn}}$	DNDPDYS	rad^{-1} [a]	—	$\left.\frac{\partial Y'}{\partial \phi}\right\|_{Y'=\hat{Y}'_0} - \frac{Y_{\phi\mathrm{stat}}}{\frac{\rho}{2} L^2 V^2}$
$\hat{Y}'_{pq}$	FYPQS	1	Non-dimensional coefficient used in representing Y' as a function of $p'\,q'$	—
$\hat{Y}'_{qr}$	FYQRS	1	Non-dimensional coefficient used in representing Y' as a function of $q'\,r'$	—
$\hat{Y}'_r$	FYRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\,r'$	(for surface ships only)
$\hat{Y}'_{r\|r\|}$	FYRRAS	1	Non-dimensional coefficient used in representing Y' as a function of $r'\,\|r'\|$	—
$\hat{Y}'_{r\delta\delta\mathrm{R}}$	FYRDDS	1	Non-dimensional coefficient used in representing Y' as a function of F_{n0} $r'\,\delta_{\mathrm{R}}^2$	(for surface ships only)
$\hat{Y}'_{\|r\|\delta\mathrm{R}}$	FYRADS	1	Non-dimensional coefficient used in representing Y' as a function of F_{n0} $\|r'\|\delta_{\mathrm{R}}$	(for surface ships only)
$\hat{Y}'_{ur}$	FYURS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\,r'$	(especially for submarines)
$\hat{Y}'_{ur\delta\delta\mathrm{R}}$	FYURDDS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\,r'\,\delta_{\mathrm{R}}^2$	(especially for submarines)

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{Y}'_{u\lvert r\rvert\delta R}$	FYURADS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\lvert r'\rvert\delta_R$	(especially for submarines)
$\hat{Y}'_{uu}$	FYUUS	1	Non-dimensional coefficient used in representing Y' as a function of u'^2	(especially for submarines)
$\hat{Y}'_{uu\delta R}$	FYUUDS	1	Non-dimensional coefficient used in representing Y' as a function of $u'^2\ \delta_R$	(especially for submarines)
$\hat{Y}'_{uu\delta\delta\delta R}$	FYUUD3S	1	Non-dimensional coefficient used in representing Y' as a function of $u'^2\ \delta_R^3$	(especially for submarines)
$\hat{Y}'_{uv}$	FYUVS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\,v'$	(especially for submarines)
$\hat{Y}'_{u\lvert v\rvert\delta R}$	FYUVADS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\lvert v'\rvert\delta_R$	(especially for submarines)
$\hat{Y}'_{v}$	FYVS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\,v'$	(for surface ships only)
$\hat{Y}'_{vq}$	FYVQS	1	Non-dimensional coefficient used in representing Y' as a function of $v'\,q'$	—
$\hat{Y}'_{vrr}$	FYVRRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\ v'\,r'^2$	(for surface ships only)
$\hat{Y}'_{v\lvert r\rvert}$	FYVRAS	1	Non-dimensional coefficient used in representing Y' as a function of $\lvert r'\rvert\sqrt{v'^2+w'^2}\frac{\lvert v'\rvert}{v'}$	—
$\hat{Y}'_{vvr}$	FYVVRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\ v'^2\,r'$	(for surface ships only)
$\hat{Y}'_{vvv}$	FYV3S	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\,v'^2\sqrt{v'^2+w'^2}$	(for surface ships only)
$\hat{Y}'_{v\lvert v\rvert}$	FYVVAS	1	Non-dimensional coefficient used in representing Y' as a function of $v'\sqrt{v'^2+w'^2}$	—
$\hat{Y}'_{vw}$	FYVWS	1	Non-dimensional coefficient used in representing Y' as a function of $v'\,w'$	—
$\hat{Y}'_{\lvert v\rvert\delta R}$	FYVADS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}\lvert v'\rvert\delta_R$	(for surface ships only)
$\hat{Y}'_{wp}$	FYWPS	1	Non-dimensional coefficient used in representing Y' as a function of $w'\,p'$	—
$\hat{Y}'_{wr}$	FYWRS	1	Non-dimensional coefficient used in representing Y' as a function of $w'\,r'$	—
$\hat{Y}'_{\Delta u}$	FYDUS	1	Non-dimensional coefficient used in representing Y' as a function of $\Delta u'$	(for surface ships only)
$\hat{Y}'_{\Delta uv}$	FYDUVS	1	Non-dimensional coefficient used in representing Y' as a function of $\Delta u'\,v'$	(for surface ships only)

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{Y}'_{\Delta\Delta u}$	FYDU2S	1	Non-dimensional coefficient used in representing Y' as a function of $(\Delta u')^2$	(for surface ships only)
$\hat{Y}'_{\delta R}$	FYDRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}{}^2\delta_R$	(for surface ships only)
$\hat{Y}'_{\delta\delta\delta R}$	FYDR3S	1	Non-dimensional coefficient used in representing Y' as a function of $F_{n0}{}^2\ \delta_R^3$	(for surface ships only)
$\hat{Y}'_0$	FY0S	1	Non-dimensional coefficient used in representing Y' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\tilde{Y}'_\phi$	FYOPHS	1	Non-dimensional oscillatory lateral motion coefficient	—
Z	FZ	N	Normal force	(See ISO 13643-1.)
Z'	FZS	1	Non-dimensional normal force	Especially for submarines: $\dfrac{Z}{\frac{\rho}{2}L^2 V^2}$, where $Z\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\dfrac{Z}{\frac{\rho}{2}L^2 V_0{}^2}$, where $Z\,(V_0, \Delta u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
Z'_{in}	FZINS	1	In-phase part of non-dimensional normal force	$\dfrac{2}{nT}\displaystyle\int_t^{t+nT} Z'(t)\sin\omega t\,\mathrm{d}t$
Z'_{out}	FZOUTS	1	Quadrature part of non-dimensional normal force	$\dfrac{2}{nT}\displaystyle\int_t^{t+nT} Z'(t)\cos\omega t\,\mathrm{d}t$
Z'_q	DZDQS	1	Slope through zero of Z' versus q'	$\left.\dfrac{\partial Z'}{\partial q'}\right\vert_{Z'=\hat{Z}'_0}$
$Z'_{\dot{q}}$	DZDQTS	1	—	$\left.\dfrac{\partial Z'}{\partial \dot{q}'}\right\vert_{Z'=\hat{Z}'_0}$
Z'_w	DZDWS	1	Slope through zero of Z' versus w'	$\left.\dfrac{\partial Z'}{\partial w'}\right\vert_{Z'=\hat{Z}'_0}$
$Z'_{\dot{w}}$	DZDWTS	1	—	$\left.\dfrac{\partial Z'}{\partial \dot{w}'}\right\vert_{Z'=\hat{Z}'_0}$
$\hat{Z}'_{pp}$	FZPPS	1	Non-dimensional coefficient used in representing Z' as a function of $p'2$	—
$\hat{Z}'_{pr}$	FZPRS	1	Non-dimensional coefficient used in representing Z' as a function of $p'\,r'$	—
$\hat{Z}'_q$	FZQS	1	Non-dimensional coefficient used in representing Z' as a function of $u'\,q'$	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{Z}'_{rr}$	FZRRS	1	Non-dimensional coefficient used in representing Z' as a function of r'^2	—
$\hat{Z}'_{uu}$	FZUUS	1	Non-dimensional coefficient used in representing Z' as a function of u'^2	—
$\hat{Z}'_{vp}$	FZVPS	1	Non-dimensional coefficient used in representing Z' as a function of $v'\,p'$	—
$\hat{Z}'_{vr}$	FZVRS	1	Non-dimensional coefficient used in representing Z' as a function of $v'\,r'$	—
$\hat{Z}'_{w}$	FZWS	1	Non-dimensional coefficient used in representing Z' as a function of $u'\,w'$	—
$\hat{Z}'_{w\|q\|}$	FZWQAS	1	Non-dimensional coefficient used in representing Z' as a function of $\frac{w'\|q'\|}{\|w'\|}\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{ww}$	FZWWS	1	Non-dimensional coefficient used in representing Z' as a function of $\|w'\|\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{w\|w\|}$	FZWWAS	1	Non-dimensional coefficient used in representing Z' as a function of $w'\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{\|w\|}$	FZWAS	1	Non-dimensional coefficient used in representing Z' as a function of $u'\,\|w'\|$	—
$\hat{Z}'_{\delta B}$	FZDBS	1	Non-dimensional coefficient used in representing Z' as a function of $u'^2\,\delta_B$	—
$\hat{Z}'_{\delta S}$	FZDSS	1	Non-dimensional coefficient used in representing Z' as a function of $u'^2\,\delta_S$	—
$\hat{Z}'_0$	FZ0S	1	Non-dimensional coefficient used in representing Z' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
z	Z	m	Normal position	(See ISO 13643-1.)
z_F	ZFO	m	Normal position of centre of pressure	$-K/Y$
z_G	ZG	m	Normal position of centre of gravity of the model	(See ISO 13643-1.)
z_{0A}	Z0A	m	Reference height	—
α	ALFA	rad[a]	Angle of attack	(See ISO 13643-1.)
β	BET	rad[a]	Drift angle	(See ISO 13643-1.)
Δu	DVX	m s^{-1}	Surge velocity	$u - u_0$
$\Delta u'$	DVXS	1	Non-dimensional surge velocity	$\Delta u/V_0$
δ_B	ANB	rad[a]	Bow plane angle	(See ISO 13643-1.)
δ_R	ANRU	rad[a]	Manoeuvring device angle	(See ISO 13643-1.)
δ_S	ANS	rad[a]	Stern plane angle	(See ISO 13643-1.)
θ_S	TRIMS	rad[a]	Trim angle	(See ISO 13643-1.)
θ_0	TH0PMM	rad[a]	Amplitude of pitch oscillation	—
ν_A	VKAI	m2 s^{-1}	Kinematic viscosity of air	—

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

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

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
ρ_A	RHOAI	kg m^{-3}	Air density	—
ρ	RHOWA	kg m^{-3}	Water density	—
ϕ_S	HEELANG	rad[a]	Heel (bank) angle	(See ISO 13643-1.)
ϕ_0	PH0PMM	rad[a]	Amplitude of roll oscillation	—
Ψ	PSIH	rad[a]	Heading	(See ISO 13643-1.)
ψ_{WR}	PSIWREL	rad a	Relative wind direction	(See ISO 13643-1.)
ψ_0	PS0PMM	rad[a]	Amplitude of yaw oscillation	—
ω	OMN	s^{-1}	Angular velocity	$2\,\pi\,/T$

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

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

5 General test conditions

In addition to the general test conditions outlined in ISO 13643-1, the following specific test conditions must be complied with:

For submarine model tests, surface and bottom effects shall be excluded by the use of suitable measures.

6 Test 6.1 — Planar motion test

6.1 General

The general test conditions outlined in ISO 13643-1 and Clause 5 of this part of ISO 13643 shall be complied with.

Generally, the ship model is fixed to the planar motion mechanism by suitable force and torque gauges. For surface ship manoeuvring simulation in only three degrees of freedom (x, y, ψ), ensure that the ship model is free to trim, heave, and possibly heel.

In the case of submarines, usually two struts oscillating vertically are used to tow and oscillate the model. Two modes of attachment are used for the tests designated as vertical-plane orientation and horizontal-plane orientation. For the vertical-plane orientation, either one strut is attached to the upright model through the sail or two struts are attached to the inverted model to avoid interference between the struts and the sail. For the horizontal-plane orientation, the model is rotated 90° and the struts are usually attached through its side. Support by one strut from the aft is also possible.

During sway tests, and submarine roll tests, the following data shall be measured:

— moment about x-axis K (during sway tests, only if the model is restrained in heel);

— moment about z-axis N;

— longitudinal force X;

— lateral force Y;

and for submarines in tests about y-axis:

— moment about y-axis M;

— normal force Z.

In surface ship model tests, the Froude number, F_{n0}, which scales the influence of surface waves, must be identical for model and full-scale. Reynolds number, R_{n0}, which scales the effect of viscosity, cannot be matched; it must be ensured that the scale model attains fully turbulent flow (supercritical R_{n0}). Turbulence stimulators near the bow can be used as necessary.

Since the control surface(s) and propeller(s) affect the coefficients, both should be implemented in the model. For specific problems, tests may be run with bare hulls.

For surface ship models, the model mass, m, corresponds to the displacement volume, ∇ . For submarine models, the ballast should be adjusted both in quantity and location to establish a condition of neutral buoyancy and level trim. It is difficult to establish an exact condition of neutral buoyancy. Therefore, the exact model mass condition (negative or positive buoyancy) is determined by means of an inclining test, where the change of the axial force with the trim angle is equal to the excess of buoyancy.

The stability derivatives $Y_{\phi\text{stat}}$, $K_{\phi\text{stat}}$, and $N_{\phi\text{stat}}$, and for submarines also $M_{\theta\text{stat}}$, and the coordinates of the centre of gravity x_G and z_G are determined experimentally by performing inclining tests (standstills) or by calculation.

The model moments of inertia I_{xx}, I_{zx}, and I_{zz}, and for submarines also I_{yy}, are determined from oscillation tests performed in air. In the case of submarines, all apertures in the model are sealed and those spaces within the model which will subsequently be free flooding in towing tests are filled with water.

In the linear theory of small departures from steady reference motions of submarines and surface ships, it is standard practice to employ the idea of hydrodynamic derivatives. These derivatives permit the magnitudes of fluid forces and moments to be specified. The derivatives referred to in the maritime literature have invariably been ‘slow motion derivatives’ which serve to determine the vessel’s hydrodynamic stability for small motions about y- and z-axes.

The theory of the planar motion technique is recast in terms of oscillatory coefficients since they are more appropriate for use where the planar motion mechanism is concerned. Oscillatory coefficients are frequency dependent. If the frequency of the oscillatory motion is made very small, they approximate slow motion derivatives.

The planar motion mechanism (PMM) is essentially a device for oscillating a ship or submarine model while being towed in a tank. The mechanism allows separating the motions of a body moving through a fluid into the pure rotations about y- (or z-) axis and pure translatory motions in the direction of z- (or y-) axis. Combined motions can also be generated. The differential equations of motion referred to a moving body axis system are used to establish a direct and explicit relationship between the various rotary and acceleration derivatives and the measured in-phase and quadrature parts of the forces and moments. The linear force and moment equations describing the body motions with respect to the initial equilibrium conditions can be written as:

Lateral force:

$$Y=\left(\frac{\rho L^4}{2}Y'_{\dot{r}}-m x_G\right)\dot{r}+\left(\frac{\rho L^4}{2}Y'_{\dot{p}}+m z_G\right)\dot{p}+\frac{\rho L^3}{2}Y'_p V_0 p+\left(\frac{\rho L^3}{2}Y'_r-m\right)V_0 r+\left(\frac{\rho L^3}{2}Y'_{\dot{v}}-m\right)\dot{v}$$
$$+\frac{\rho L^2}{2}\left(Y'_v V_0 v+Y'_0 V_0{}^2+Y'_{\phi\,\mathrm{dyn}} V_0{}^2\phi\right)+Y_{\phi\,\mathrm{stat}}\phi \quad (1)$$

Moment about *x*-axis (if model is restrained in heel during sway tests or for roll tests):

$$K=\left(\frac{\rho L^5}{2}K'_{\dot{p}}-I_{xx}\right)\dot{p}+\left(\frac{\rho L^5}{2}K'_{\dot{r}}+I_{zx}\right)\dot{r}+\frac{\rho L^4}{2}K'_p V_0 p+\left(\frac{\rho L^4}{2}K'_r-m z_G\right)V_0 r$$
$$+\left(\frac{\rho L^4}{2}K'_{\dot{v}}+m z_G\right)\dot{v}+\frac{\rho L^3}{2}\left(K'_v V v+K'_0 V_0{}^2+K'_{\phi\,\mathrm{dyn}} V_0{}^2\phi\right)+K_{\phi\,\mathrm{stat}}\phi \quad (2)$$

Moment about *z*-axis:

$$N=\left(\frac{\rho L^5}{2}N'_{\dot{r}}-I_{zz}\right)\dot{r}+\left(\frac{\rho L^5}{2}N'_{\dot{p}}+I_{zx}\right)\dot{p}+\frac{\rho L^4}{2}N'_p V_0 p+\left(\frac{\rho L^4}{2}N'_r-m x_G\right)V_0 r$$
$$+\left(\frac{\rho L^4}{2}N'_{\dot{v}}-m x_G\right)\dot{v}+\frac{\rho L^3}{2}\left(N'_v V_0 v+N'_0 V_0{}^2+N'_{\phi\,\mathrm{dyn}} V_0{}^2\phi\right)+N_{\phi\,\mathrm{stat}}\phi \quad (3)$$

For submarines, the following additional formulae are used:

Normal force:

$$Z=\left(\frac{\rho L^4}{2}Z'_{\dot{q}}+m x_G\right)\dot{q}+\left(\frac{\rho L^3}{2}Z'_{\dot{w}}-m\right)\dot{w}+\left(\frac{\rho L^3}{2}Z'_q+m\right)V_0 q+\frac{\rho L^2}{2}\left(Z'_w V_0 w+Z'_0 V_0{}^2\right) \quad (4)$$

Moment about *y*-axis:

$$M=\left(\frac{\rho L^5}{2}M'_{\dot{q}}+I_{yy}\right)\dot{q}+\left(\frac{\rho L^4}{2}M'_{\dot{w}}+m x_G\right)\dot{w}+\left(\frac{\rho L^4}{2}M'_q-m x_G\right)V_0 q$$
$$+\frac{\rho L^3}{2}\left(M'_w V_0 w+M'_0 V_0{}^2\right)+M_{\theta\,\mathrm{stat}}\theta \quad (5)$$

Nonlinear dependencies or their respective derivatives must be taken into account, especially in the case of numerical simulation of arbitrary manoeuvres employing suitable mathematical simulation algorithms. Terms which do not involve accelerations or angular velocities (in the equations of motion quoted $\hat{Y}'_0$, $\hat{Y}'_{vw}$, and $\hat{Y}'_{v|v|}$) are obtained both in character and values directly and more reliably from an oblique towing or flow test (see Clause 8). Terms which involve angular velocities other than angular motion about *x*-axis (in this case $\hat{Y}'_{vq}$, $\hat{Y}'_{v|r|}$, $\hat{Y}'_{wr}$, $\hat{Y}'_{qr}$, and $\hat{Y}'_{r|r|}$) are obtained both in character and value directly from a circular motion test (see Clause 7).

NOTE The type of nonlinear derivatives or coefficients largely depends on the mathematical simulation algorithm to be used.

6.2 Description

After adjusting the specific test parameters such as

displacement amplitude, a_0, of the model movement and amplitude, ψ_0, of the oscillation about *z*-axis or the amplitude, ϕ_0, of the oscillation about *x*-axis, and

oscillation period, *T*, with corresponding angular velocity, ω, the towing carriage carrying the planar motion mechanism is moved at a given constant forward speed, V_0, with the planar motion mechanism superimposing the given periodic motion on this movement. The propeller revolutions are to be set according to the corresponding self-propulsion point of the full-scale ship or the model.

Constant carriage speed can be considered satisfactory for small amplitude oscillations. For larger amplitudes as possible with an $xy\psi$-subcarriage, an adequate oscillatory motion in the tank-longitudinal direction may need to be superimposed to make the model speed constant.

It is important that the oscillatory motions of the model are satisfactory approximations to simple harmonics and that the frequency is low enough for a proper approximation of oscillatory coefficients to slow motion derivatives.

Certain planar motion systems can be driven with more complex trajectories which aim at specific nonlinear terms.

6.3 Analysis and presentation of results of a planar motion test

6.3.1 Tests in the horizontal plane of motion

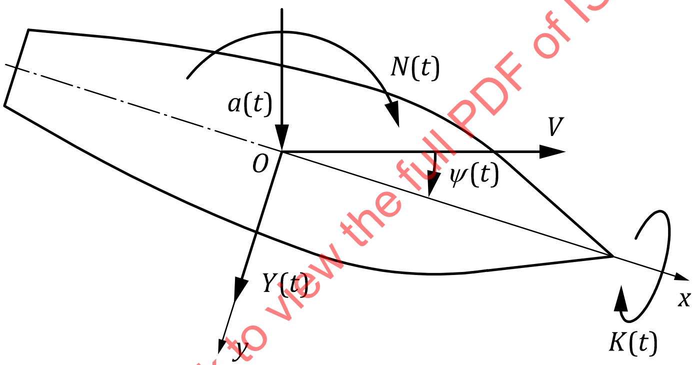


Figure 1 — Planar motion mechanism with the model in horizontal plane orientation

If a small sinusoidal lateral motion is superimposed to the forward moving model by setting

$$a(t) = a_0 \sin\omega t \quad \text{and} \quad \psi(t) = \psi_0 = 0$$

the following derivatives can be determined:

$$Y'_{\dot v} = \frac{m}{\frac{\rho}{2}L^3} + \left.\frac{\partial Y'_{\text{in}}}{\partial\left(\frac{\omega^2 a_0 L}{V_0^2}\right)}\right|_{\omega=0} \tag{6}$$

$$Y'_v = -\left.\frac{\partial Y'_{\text{out}}}{\partial\left(\frac{\omega a_0}{V_0}\right)}\right|_{\omega=0} \tag{7}$$

$$N'_{\dot v} = \frac{m x_{\text{G}}}{\frac{\rho}{2}L^4} + \left.\frac{\partial N'_{\text{in}}}{\partial\left(\frac{\omega^2 a_0 L}{V_0^2}\right)}\right|_{\omega=0} \tag{8}$$

$$N_v = -\left.\frac{\partial N'_{\text{out}}}{\partial\left(\frac{\omega\, a_0}{V_0}\right)}\right|_{\omega=0} \tag{9}$$

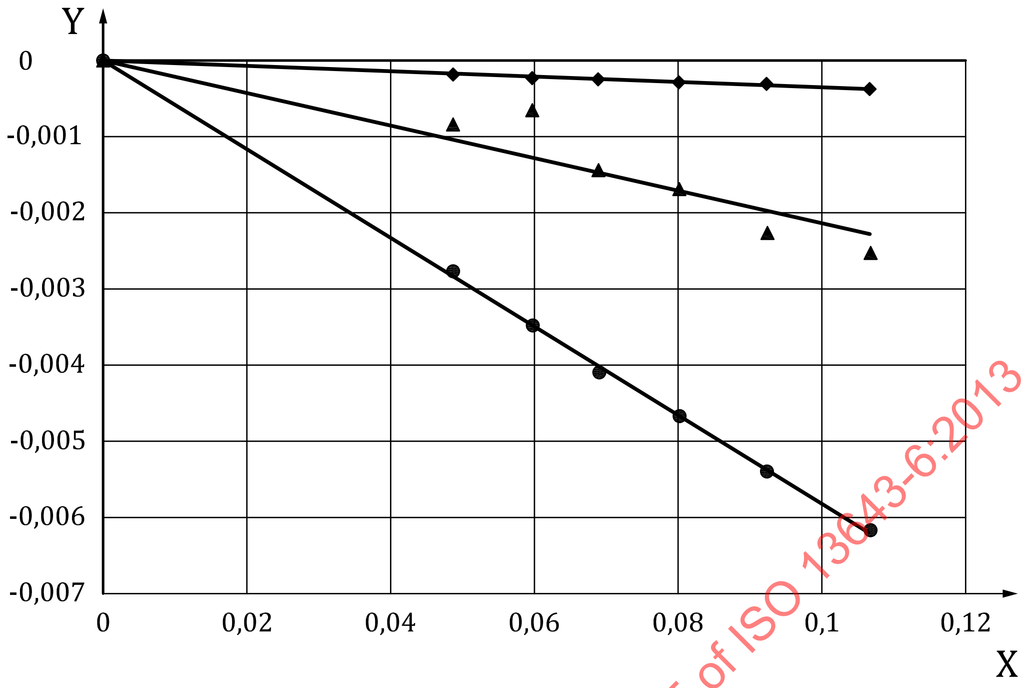
and if the roll moment were measured:

$$K'_v = -\frac{m\, z_G}{\frac{\rho}{2}L^4} + \left.\frac{\partial K'_{\text{in}}}{\partial\left(\frac{\omega^2\, a_0\, L}{V_0{}^2}\right)}\right|_{\omega=0} \tag{10}$$

$$K_v = -\left.\frac{\partial K'_{\text{out}}}{\partial\left(\frac{\omega\, a_0}{V_0}\right)}\right|_{\omega=0} \tag{11}$$

The in-phase and quadrature parts of force and moment are plotted against the corresponding non-dimensional amplitudes of motion parameters $\omega^2\, a_0\, L/V_0{}^2$ and $\omega\, a_0/V_0$, respectively, which vary due to changes of angular velocity, ω, speed, V_0, or amplitude, a_0 (see Figure 2 and Figure 3). Linear curve fits yield the slopes of the curves used to determine the hydrodynamic derivatives.

NOTE Where results are available from an oblique towing or flow test (see Clause 8), these values are to be preferred because these are the simplest, most direct experiments which can be carried out to obtain the derivatives concerned and are inherently more reliable.



Key

● Y'_{in}

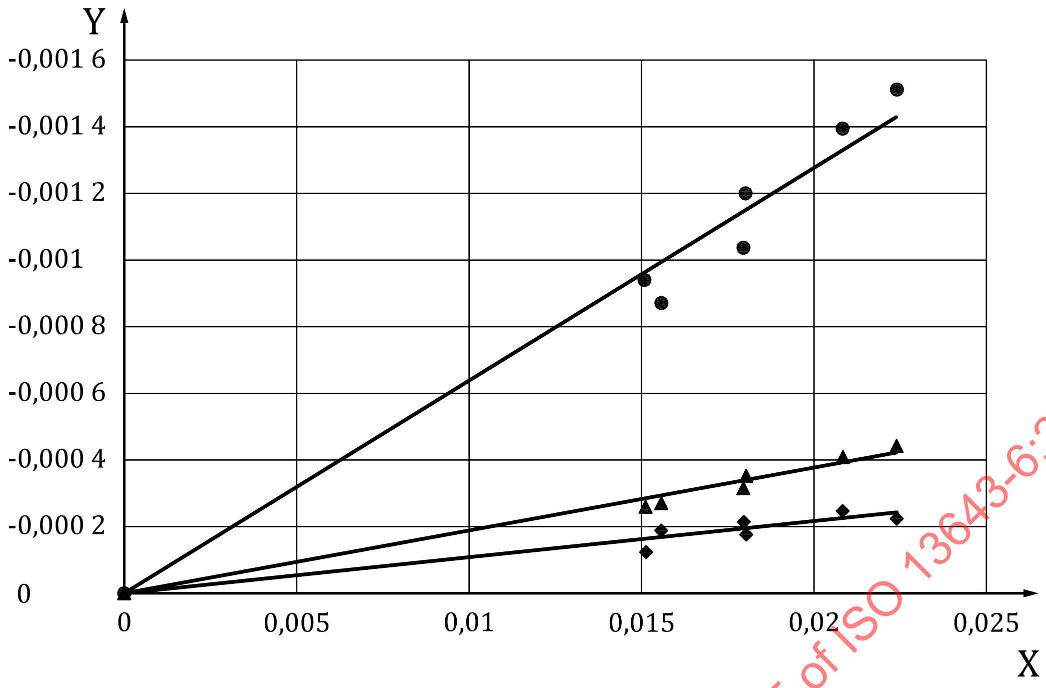
◆ 10* K'_{in}

▲ 100* N'_{in}

X non-dimensional linear acceleration parameter $\omega^2 \ a_0 \ L / V_0{}^2$

Y in-phase parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients

Figure 2 — Variation of in-phase parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients with non-dimensional linear acceleration amplitude



Key

● Y'_{out}

▲ N'_{out}

◆ $10^{*} K'_{out}$

X non-dimensional linear velocity parameter $\omega a_0 / V_0$

Y quadrature parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients 90° out of phase with respect to movement

Figure 3 — Variation of quadrature parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients (90° out of phase with respect to movement) with non-dimensional linear velocity amplitude

If a small sinusoidal rotation about *z*-axis is superimposed on the forward moving model by setting

$$a(t) = \psi_0 V_0 \cos \omega t$$
$$\psi(t) = \psi_0 \sin \omega t$$

the following derivatives can be determined:

$$Y'_{\dot{r}} = \frac{m x_G}{\frac{\rho}{2} L^4} + \left. \frac{\partial Y'_{in}}{\partial \left(\frac{\omega^2 \psi_0 L^2}{V_0^2} \right)} \right|_{\omega=0} \tag{12}$$

$$Y'_r = \frac{m}{\frac{\rho}{2} L^3} - \left. \frac{\partial Y'_{out}}{\partial \left(\frac{\omega \psi_0 L}{V_0} \right)} \right|_{\omega=0} \tag{13}$$

$$N'_{\dot{r}} = \frac{I_{zz}}{\frac{\rho}{2} L^5} + \left. \frac{\partial N'_{in}}{\partial \left(\frac{\omega^2 \psi_0 L^2}{V_0{}^2} \right)} \right|_{\omega=0} \tag{14}$$

$$N'_r = \frac{m x_G}{\frac{\rho}{2} L^4} - \left. \frac{\partial N'_{out}}{\partial \left(\frac{\omega \psi_0 L}{V_0} \right)} \right|_{\omega=0} \tag{15}$$

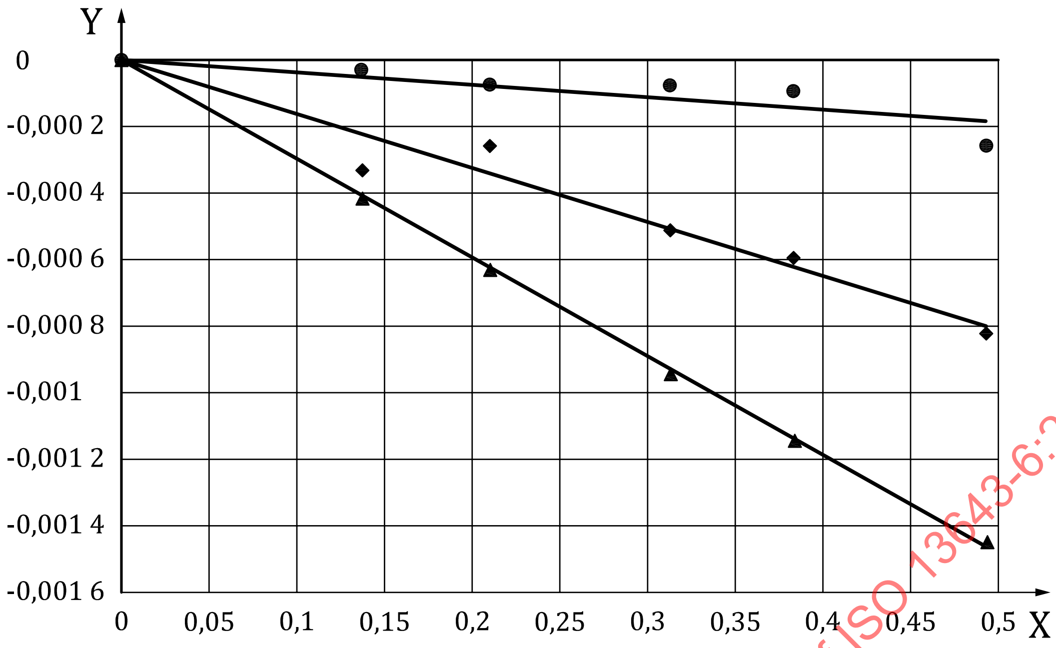
and if the roll moment were measured:

$$K'_{\dot{r}} = -\frac{I_{zx}}{\frac{\rho}{2} L^5} + \left. \frac{\partial K'_{in}}{\partial \left(\frac{\omega^2 \psi_0 L^2}{V_0{}^2} \right)} \right|_{\omega=0} \tag{16}$$

$$K'_r = -\frac{m z_G}{\frac{\rho}{2} L^4} - \left. \frac{\partial K'_{out}}{\partial \left(\frac{\omega \psi_0 L}{V_0} \right)} \right|_{\omega=0} \tag{17}$$

The in-phase and quadrature parts of force and moment are plotted against the corresponding non-dimensional amplitudes of motion parameters $\omega^2 \psi_0 L^2 / V_0{}^2$ and $\omega \psi_0 L / V_0$, respectively, which vary due to changes of angular velocity, ω, speed, V_0, or amplitude, ψ_0 (see Figure 4 and Figure 5). Linear curve fits yield the slopes of the curves used to determine the hydrodynamic derivatives.

NOTE Curvature derivatives may be expected to be more accurately obtained from the planar motion test than from the circular motion test (see Clause 7) owing to the limited radius of turn if a rotating arm or similar is used.



Key

● Y'_{in}

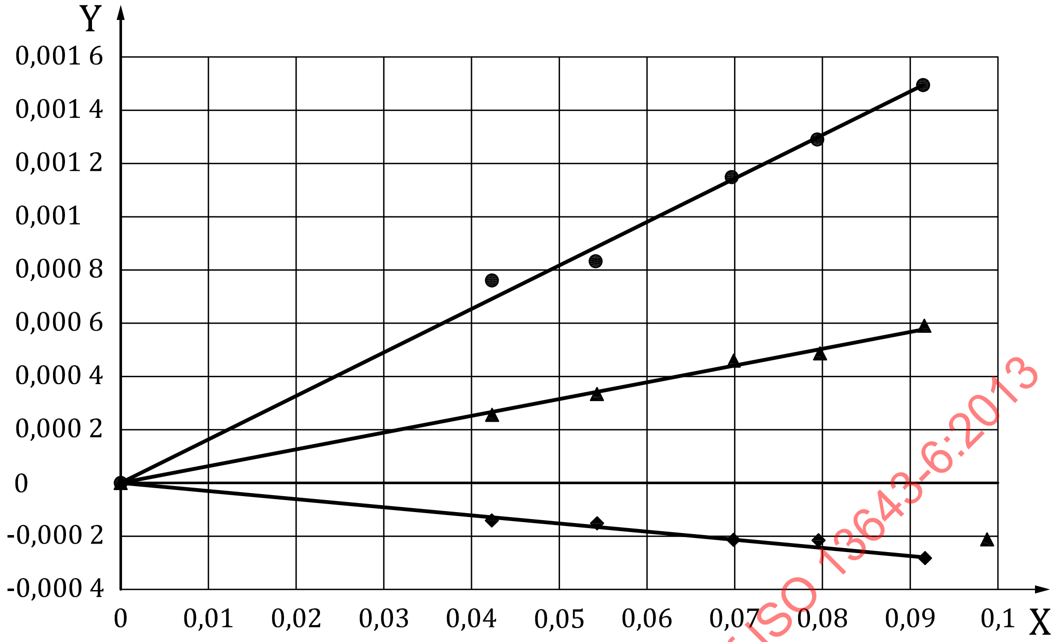
▲ N'_{in}

◆ $10^* K'_{in}$

X non-dimensional angular acceleration parameter $\omega^2 \ \psi_0 L^2 / V_0{}^2$

Y in-phase parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients

Figure 4 — Variation of in-phase parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients with non-dimensional angular acceleration amplitude



Key

● Y'_{out}

▲ N'_{out}

◆ $10^* K'_{out}$

X non-dimensional angular velocity parameter $\omega\ \psi_0\ L / V_0$

Y quadrature parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients

Figure 5 — Variation of quadrature parts of non-dimensional lateral force, roll moment, and moment about *z*-axis coefficients (90°out of phase with respect to movement) with non-dimensional angular velocity amplitude

6.3.2 Tests in the vertical plane of motion (for submarines only)

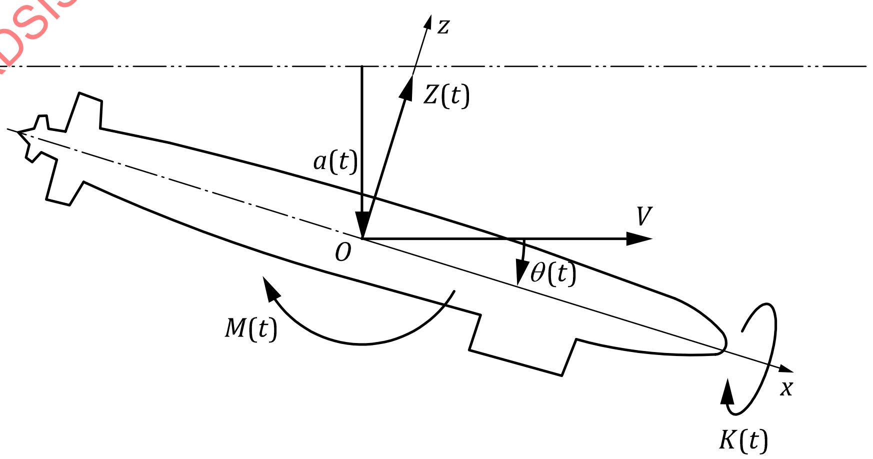


Figure 6 — Planar motion mechanism with the model in vertical plane orientation [model shown in inverted position chosen to avoid interference between sail and mounting strut(s)]

If a small sinusoidal motion in z-direction is superimposed to the forward moving model by setting

$$a(t)=a_0 \sin\omega t \quad \text{and} \quad \theta(t)=\theta_0=0$$

the following derivatives can be determined:

$$Z'_{\dot{w}}=\frac{m}{\frac{\rho}{2}L^3}+\left.\frac{\partial Z'_{\text{in}}}{\partial\left(\frac{\omega^2 a_0 L}{V_0^2}\right)}\right|_{\omega=0} \tag{18}$$

$$Z'_w=-\left.\frac{\partial Z'_{\text{out}}}{\partial\left(\frac{\omega a_0}{V_0}\right)}\right|_{\omega=0} \tag{19}$$

$$M'_{\dot{w}}=-\frac{m x_G}{\frac{\rho_w}{2}L^4}+\left.\frac{\partial M'_{\text{in}}}{\partial\left(\frac{\omega^2 a_0 L}{V_0^2}\right)}\right|_{\omega=0} \tag{20}$$

$$M'_w=-\left.\frac{\partial M'_{\text{out}}}{\partial\left(\frac{\omega a_0}{V_0}\right)}\right|_{\omega=0} \tag{21}$$

The in-phase and quadrature parts of force and moment are plotted against the corresponding non-dimensional amplitudes of motion parameters $\omega^2 a_0 L/V_0^2$ and $\omega a_0/V_0$, respectively, which vary due to changes of angular velocity, ω, speed, V_0, or amplitude, a_0 (see Figure 2 and Figure 3). Linear curve fits yield the slopes of the curves used to determine the hydrodynamic derivatives.

If a small sinusoidal rotation about y-axis motion is superimposed to the forward moving model by setting

$$a(t)=\theta_0 V_0 \cos\omega t$$
$$\theta(t)=\theta_0 \sin\omega t$$

the following derivatives can be determined:

$$Z'_{\dot{q}}=-\frac{m x_G}{\frac{\rho}{2}L^4}+\left.\frac{\partial Z'_{\text{in}}}{\partial\left(\frac{\omega^2 \theta_0 L^2}{V_0^2}\right)}\right|_{\omega=0} \tag{22}$$

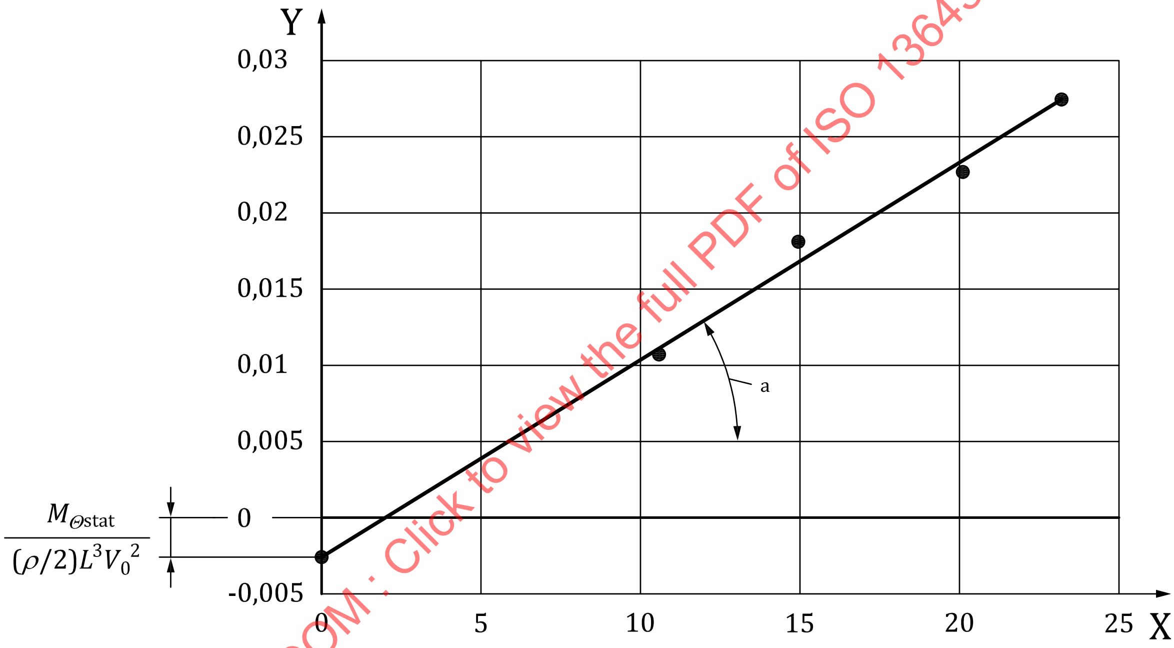
$$Z'_q=-\frac{m}{\frac{\rho}{2}L^3}-\left.\frac{\partial Z'_{\text{out}}}{\partial\left(\frac{\omega \theta_0 L}{V_0}\right)}\right|_{\omega=0} \tag{23}$$

$$\tilde{M}'_\theta=-\frac{I_{yy}}{\frac{\rho}{2}L^5}\frac{\omega^2 L^2}{V_0^2}-\frac{M'_{\text{in}}}{\theta_0}=\frac{M_{\theta\text{stat}}}{\frac{\rho}{2}L^3 V_0^2}-M'_{\dot{q}}\frac{\omega^2 L^2}{V_0^2}+M'_{\dddot{q}}\frac{\omega^4 L^4}{V_0^4}+\dots \tag{24}$$

$$M'_q = \frac{m\,x_G}{\frac{\rho}{2}L^4} - \left.\frac{\partial M'_{out}}{\partial\left(\frac{\omega\,\theta_0\,L}{V_0}\right)}\right|_{\omega=0} \tag{25}$$

The in-phase and quadrature parts of force and moment are plotted against the corresponding non-dimensional amplitudes of motion parameters $\omega^2\,\theta_0\,L^2/V_0{}^2$ and $\omega\,\theta_0\,L/V_0$, respectively, which vary due to changes of angular velocity, ω, speed, V_0, or amplitude, θ_0 (see Figure 7). Linear curve fits yield the slopes of the curves used to determine the hydrodynamic derivatives. A linear curve fit of $\tilde{M}'_\theta$ plotted against $\omega^2\,L^2/V_0{}^2$ yields both of the slow motion derivatives $\dfrac{M_{\theta\,\mathrm{stat}}}{\frac{\rho}{2}L^3\,V_0{}^2}$ and $\tilde{M}'_\theta$ (see Figure 7).

$M_{\phi\mathrm{stat}}$ should correspond with the value found by the tare test and should equal $g\,m\,\overline{\mathrm{GM}}$ of the model.



Key

X $\omega^2L^2/V_0{}^2$

Y non-dimensional oscillatory coefficient about y-axis $\tilde{M}'_\theta$

a $\arctan\left(-M'_{\dot{q}}\,\dfrac{\text{length scale of } \tilde{M}'_\theta \text{ axis}}{\text{length scale of } \omega^2\,L^2\,/V_0{}^2\text{axis}}\right)$

Figure 7 — Plot of non-dimensional oscillatory coefficient about y-axis $\tilde{M}'_\theta$ against $\omega^2L^2/V_0{}^2$

6.3.3 Tests for angular motion about *x*-axis (roll)

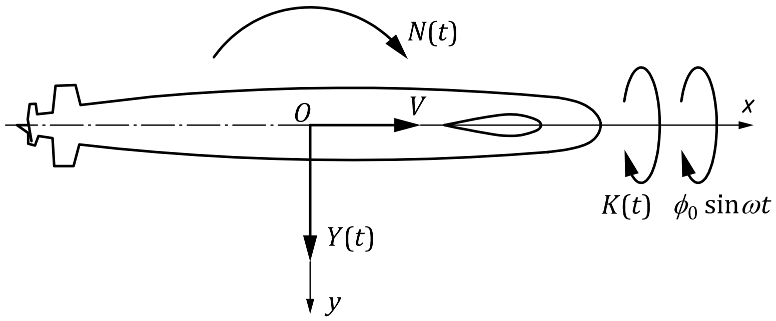


Figure 8 — Planar motion mechanism with a submarine model prepared for the determination of roll coefficients

For roll motion tests, submarine models have to be mounted in the horizontal mode position (see Figure 8). The displacements of the model mountings are held fixed while the model is towed down the tank.

The imposed rotation is such that

$$\phi(t) = \phi_0 \sin \omega t$$

and we get

$$\tilde{Y}'_\phi - \frac{Y_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^2 V_0^2} = \frac{m z_G}{\frac{\rho}{2} L^4} \frac{\omega^2 L^2}{V_0^2} - \frac{Y'_{\mathrm{in}}}{\phi_0} - \frac{Y_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^2 V_0^2} = Y'_{\phi \mathrm{dyn}} - Y'_{\dot{p}} \frac{\omega^2 L^2}{V_0^2} + Y'_{\dddot{p}} \frac{\omega^4 L^4}{V_0^4} + \ldots \tag{26}$$

$$Y'_p = -\left. \frac{\partial Y'_{\mathrm{out}}}{\partial \left(\frac{\omega \phi_0 L}{V_0} \right)} \right|_{\omega=0} \tag{27}$$

$$\tilde{K}'_\phi - \frac{K_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^3 V_0^2} = -\frac{I_{xx}}{\frac{\rho}{2} L^5} \frac{\omega^2 L^2}{V_0^2} - \frac{K'_{\mathrm{in}}}{\phi_0} - \frac{K_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^3 V_0^2} = K'_{\phi \mathrm{dyn}} - K'_{\dot{p}} \frac{\omega^2 L^2}{V_0^2} + K'_{\dddot{p}} \frac{\omega^4 L^4}{V_0^4} + \ldots \tag{28}$$

$$K'_p = -\left. \frac{\partial K'_{\mathrm{out}}}{\partial \left(\frac{\omega \phi_0 L}{V_0} \right)} \right|_{\omega=0} \tag{29}$$

$$\tilde{N}'_\phi - \frac{N_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^3 V_0^2} = \frac{I_{xz}}{\frac{\rho}{2} L^5} \frac{\omega^2 L^2}{V_0^2} - \frac{N'_{\mathrm{in}}}{\phi_0} - \frac{N_{\phi \mathrm{stat}}}{\frac{\rho}{2} L^3 V_0^2} = N'_{\phi \mathrm{dyn}} - N'_{\dot{p}} \frac{\omega^2 L^2}{V_0^2} + N'_{\dddot{p}} \frac{\omega^4 L^4}{V_0^4} + \ldots \tag{30}$$

$$N'_{\mathrm{p}} = -\left.\frac{\partial N'_{\mathrm{out}}}{\partial\left(\dfrac{\omega\ \phi_0\ L}{V_0}\right)}\right|_{\omega=0} \tag{31}$$

Linear curve fits (see $\tilde{M}'_\theta$ in Figure 7) of $\tilde{Y}'_\phi - \dfrac{Y_{\phi\mathrm{stat}}}{\frac{\rho}{2}L^2\ V_0{}^2}$, $\tilde{K}'_\phi - \dfrac{K_{\phi\mathrm{stat}}}{\frac{\rho}{2}L^3\ V_0{}^2}$, and $\tilde{N}'_\phi - \dfrac{N_{\phi\mathrm{stat}}}{\frac{\rho}{2}L^3\ V_0{}^2}$ plotted against $\omega^2 L^2/V_0{}^2$ yield the slow motion derivatives $Y'_{\phi\mathrm{dyn}}$, $Y'_{\dot{p}}$, $K'_{\phi\mathrm{dyn}}$, $K'_{\dot{p}}$, $N'_{\phi\mathrm{dyn}}$, and $N'_{\dot{p}}$. $Y_{\phi\mathrm{stat}}$, $K_{\phi\mathrm{stat}}$, and $N_{\phi\mathrm{stat}}$ are to be determined by inclining tests at standstill or by calculation.

6.4 Designation of a planar motion test

6.4.1 Designation of a planar motion test in the horizontal plane (H)

Designation of a planar motion test in the horizontal plane (H) according to Part 6 (6), Test 1 (1) of the ISO 13643 series, conducted at a model towing speed $V_0 = 3\ \mathrm{m\ s^{-1}}$ (03), an oscillation period $T = 6$ s (06), a model sway amplitude $a_0 = 0$ mm (00), and a yaw amplitude $\psi_0 = 5°$ (05):

Planar motion test ISO 13643 – 6.1 × H/03/06/00/05

6.4.2 Designation of a planar motion test in the vertical plane (V)

Designation of a planar motion test in the vertical plane (V) according to Part 6 (6), Test 1 (1) of the ISO 13643 series, conducted at a model towing speed $V_0 = 3\ \mathrm{m\ s^{-1}}$ (03), an oscillation period $T = 6$ s (06), a model heave amplitude $a_0 = 10$ mm (10), and a pitch amplitude $\theta_0 = 3°$ (03):

Planar motion test ISO 13643 – 6.1 × V/03/06/10/03

6.4.3 Designation of a planar motion test for roll motion (R)

Designation of a planar motion test for roll motion (R) according to Part 6 (6), Test 1 (1) of the ISO 13643 series, conducted at a model towing speed $V_0 = 3\ \mathrm{m\ s^{-1}}$ (03), an oscillation period $T = 6$ s (06), and a roll amplitude $\psi_0 = 5°$ (05):

Planar motion test ISO 13643 – 6.1 × R/03/06/05

7 Test 6.2 — Circular motion test

7.1 General

Besides the general test conditions outlined in ISO 13643-1 and Clause 5 of this part of ISO 13643, the following specific test conditions shall be complied with:

— The ship model is fixed to the cantilever of the rotating arm or other circular motion device by a suitable force-sensing and towing device. For surface ship manoeuvring simulation in only three degrees of freedom (x, y, ψ), ensure that the ship model is free to trim, heave, and possibly heel.

— To a certain extent, circular motions may be generated by means of an $xy\psi$ carriage in a towing tank.

— In surface ship model tests, the Froude number, $F_{\mathrm{n}0}$, which scales the influence of surface waves, must be maintained between model and full-scale surface vessels. As Reynolds number, $R_{\mathrm{n}0}$, which scales the effect of viscosity, cannot be matched, it must be ensured that the scale model attains fully turbulent flow (supercritical $R_{\mathrm{n}0}$). Turbulence stimulators can be used near the bow as necessary.

— To avoid measuring errors, only one full rotation per test (including the acceleration phase) should be conducted with the rotating arm or other circular motion device.

During the test, the following data are to be measured:

For tests with circular motion about *z*-axis

roll moment	K (if heeling is restrained),
moment about *y*-axis	M (for submarines only),
moment about *z*-axis	N,
longitudinal force	X,
lateral force	Y,
normal force	Z (for submarines only).

For tests with circular motion about *y*-axis (for submarines only)

moment about *y*-axis	M,
longitudinal force	X,
normal force	Z.

7.2 Description

After adjustment of the specific test parameters, such as circular motion radius, R, heel angle, ϕ_S, trim angle, θ_S, drift angle, β and plane angles δ_R, δ_B, and δ_S, the ship model is force-towed on a circular path at a constant speed V_0 leading to the steady ship-fixed velocities p, q, r, u, v, w. Instead of u, the speed $u_0 + \Delta u$ also can be used in the equations of motion with a corresponding splitting into single coefficients, u_0 will be selected as appropriate. This is used only for surface ships for which, usually, the values of the coefficients vary with the Froude number.

The propeller revolutions are to be set according to the corresponding self-propulsion point of the full-scale ship or the model. In order to remove the component due to gauge zero, offset, and buoyancy, the tare value appropriate to the gauge and the attitude of the model is subtracted for the gauge readings, leaving only the component equal and opposite to the hydrodynamic force or moment on the model.

7.3 Analysis and presentation of results of a circular motion test

After deduction of the inertial effects, the measurement data are mostly plotted non-dimensionally as a function of the parameters angular velocity, drift angles, and/or manoeuvring device angles (example: Figure 9 to Figure 11, tests with circular motion about the *z*-axis at different drift angles) and in the case of submarine tests with circular motion about the *y*-axis as a function of angles of attack and/or hydroplane angles.

The non-dimensional coefficients used for general computer simulation studies are determined by curve-fitting the test data with appropriate equations in accordance with standardized methods. Non-dimensional curvature and control derivatives are determined from the slope through zero of the non-dimensional curves of force or moment versus the different non-dimensional test parameters. These curvature derivatives may be expected to be more accurately obtained from the planar motion test (see Clause 6) owing to the limited radius of turn available if a rotating arm or equivalent is used. It is found that unless the rotating arm values lie on a straight line when plotted non-dimensionally against the rate of turn, it is impossible to define the slope at zero turn precisely. Acceleration and roll derivatives are available experimentally from the planar motion test only. It should be emphasized that the values of the first order coefficients that are associated with curve fits to the force and moment curves are not necessarily equal to those customarily used for the corresponding stability and control derivatives in the linearized equations of motion. However, the standard notation used to describe these first-order coefficients is the same as that used for the corresponding stability and control derivatives.

The nonlinear derivatives must be taken into account in the case of numerical simulation of arbitrary manoeuvres employing suitable mathematical simulation algorithms. The linear derivatives Y'_r, K'_r, N'_r, Z'_q, and M'_q, together with the respective results of the planar motion test (see Clause 6) and/or oblique towing or flow test (see Clause 8) serve to determine the vessel's dynamic stability for small moments about z-axis and y-axis. However, the derivatives may also be used in specialized simulation studies such as design studies of automatic course keeping and/or depth keeping control systems, where a simplified mathematical model is entirely adequate.

NOTE The type of nonlinear coefficients largely depends on the form of mathematical simulation algorithm to be used. The coefficients listed in Clause 4 must therefore only be regarded as reference data for an appropriate test evaluation. For submarines in deeply submerged condition, the results are independent of the Froude number and forces and moments can be determined as a function of the longitudinal velocity, u. For surface ships, the hydrodynamic coefficients are determined for the Froude number belonging to the model speed, V_0, and instead of u, the surge velocity, Δu, is normally used in the force and moment equations. Therefore, there are differences in the coefficients sets use for surface ships or submarines which has to be taken into account when choosing coefficients from Table 1.

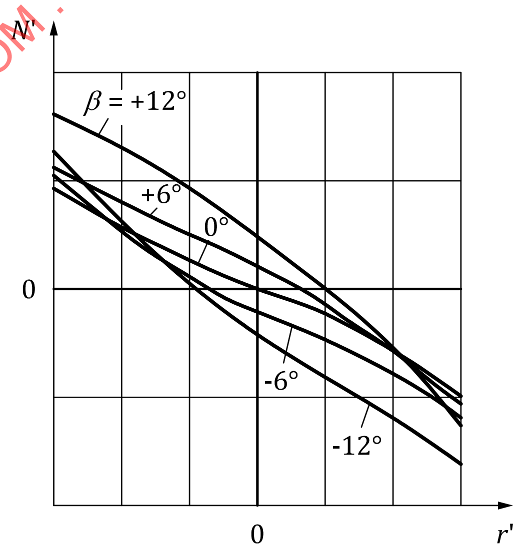
7.4 Designation of a circular motion test

Designation of a circular motion test according Part 6 (6), Test 2 (2) of the ISO 13643 series, conducted with the reference axis z (Z), a model reference speed $V_0 = 3$ m s^{-1} (03), a circular motion radius $R = 10$ m (10), a drift angle $\beta = 10°$ (10), and a manoeuvring device angle $\delta_R = 20°$(20):

Circular motion test ISO 13643 – 6.2 × Z/03/10/10/20

Designation of a circular motion test according Part 6 (6), Test 2 (2) of the ISO 13643 series, conducted with the reference axis y (Y), a model reference speed $V_0 = 3$ ms^{-1} (03), a circular motion radius $R = 10$ m (10), a trim angle $\theta_S = 5°$ (05), a stern plane angle $\delta_S = 3°$(03), and a bow plane angle $\delta_B = 0°$ (00):

Circular motion test ISO 13643 – 6.2 × Y/03/10/05/03/00



Key

N' non-dimensional moment about z-axis

r' non-dimensional angular velocity about z-axis

Figure 9 — Moment about *z*-axis – angular velocity about *z*-axis