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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 modèle

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

This second edition cancels and replaces the first edition (ISO 13643-6:2013), of which it constitutes a minor revision with the following changes:

— in 3.6 $xy\psi$-carriage was inserted;

— in Table 1 “DNDPDYS” row, the symbol was changed from “$N_{\phi\mathrm{dyn}}$” to “$N'_{\phi\mathrm{dyn}}$”;

— in Table 1 “DYDVTS” row, the SI-unit was changed from “—” to “1”;

— in Equation (20) “ρ_W” was changed to “ρ”;

— in 7.3 paragraph 3, “moments” was changed to “motions”.

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

Ships and marine technology — Manoeuvring of ships —

Part 6:
Model test specials

1 Scope

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

ISO 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.

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

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

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

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

3.6
***xyψ*-carriage**

sub carriage (secondary towing system) to the towing carriage that allows a differential longitudinal, a transverse and a rotational motion of the model in the horizontal plane

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	$2C/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}})$
C_{D}	CD	1	Drag coefficient	$2D/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}})$
$\mathrm{C}_{\mathrm{DAX}}$	CDAX	1	Drag coefficient	$2D/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{XV}})$, relative to cross section
C_{K}	CK	1	Roll-moment coefficient	$2K/(\rho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}} L_{\mathrm{OA}})$
C_{N}	CN	1	Coefficient of moment about *z*-axis	$2N/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}} L_{\mathrm{OA}})$
C_{X}	CX	1	Longitudinal-force coefficient	$2X/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}})$
C_{XAX}	CXAX	1	Longitudinal-force coefficient	$2X/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{XV}})$, relative to cross section
C_{Y}	CY	1	Lateral-force coefficient	$2Y/(\varrho_{\mathrm{A}} V_{\mathrm{WRA}}^2 A_{\mathrm{LV}})$

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
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	$V_0 / \sqrt{gL}$
$\overline{\mathrm{GM}}$	GM	m	Metacentric height	(see ISO 13643-1)
H_{LM}	HLM	m	Mean height of lateral area above design waterline	$A_{\mathrm{LV}}/L_{\mathrm{OA}}$
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)
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
$K_{\phi\mathrm{stat}}$	DKDPST	N m rad^{-1} [a]	—	$\frac{\partial K}{\partial \phi}\Big\vert_{V=0}$ 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	$\frac{2}{nT}\int_t^{t+nT} K'(t)\sin\omega t\,dt$
K'_{out}	MXOUTS	1	Quadrature part of non-dimensional roll moment	$\frac{2}{nT}\int_t^{t+nT} K'(t)\cos\omega t\,dt$

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$K_{p}^{'}$	DKDPS	1	—	$\frac{\partial K'}{\partial p'}\Big\vert_{K'=\hat{K}_0^{'}}$
$K_{\dot{p}}^{'}$	DKDPTS	1	—	$\frac{\partial K'}{\partial \dot{p}'}\Big\vert_{K'=\hat{K}_0^{'}}$
$K_{\dddot{p}}^{'}$	DKDP3TS	1	—	$\frac{\partial K^{'}}{\partial \dddot{p}'}\Big\vert_{K'=\hat{K}_0^{'}}$
$K_{r}^{'}$	DKDRS	1	Slope through zero of K' versus r'	$\frac{\partial K'}{\partial r'}\Big\vert_{K'=\hat{K}_0^{'}}$
$K_{\dot{r}}^{'}$	DKDRTS	1	—	$\frac{\partial K'}{\partial \dot{r}'}\Big\vert_{K'=\hat{K}'_0}$
$K_{v}^{'}$	DKDVS	1	Slope through zero of K' versus v'	$\frac{\partial K'}{\partial v'}\Big\vert_{K'=\hat{K}_0^{'}}$
$K_{\dot{v}}^{'}$	DKDVTS	1	—	$\frac{\partial K'}{\partial \dot{v}'}\Big\vert_{K'=\hat{K}_0^{'}}$
$\hat{K}_{pq}^{'}$	MXPQS	1	Non-dimensional coefficient used in representing K' as a function of $p'\ q'$	—
$\hat{K}_{r}^{'}$	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 $v'\vert\ v'\ \vert\sqrt{v'^2+w'^2}\,F_{\mathrm{n}0}$	(for surface ships only)

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{K}'_{v\|v\|}$	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 $F_{\mathrm{n}0}\, v'\, \delta_{\mathrm{R}}$	(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 $F_{\mathrm{n}0}{}^2\, \delta_{\mathrm{R}}$	(for surface ships only)
$\hat{K}'_{\delta\delta\delta\mathrm{R}}$	MXDR3S	1	Non-dimensional coefficient used in representing K' as a function of $F_{n0}^{2}\, \delta_{R}^{3}$	(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	—
$\hat{K}'_{\phi}$	MXOPHS	1	Non-dimensional oscillatory roll coefficient	—
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)
$M_{\theta\mathrm{stat}}$	DMDTST	N m rad^{-1} [a]	—	$\frac{\partial M}{\partial \theta}\Big\|_{V=0}$ from static test or calculation

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
M'	MYS	1	Non-dimensional moment about y-axis	Especially for submarines $\frac{M}{\frac{\rho}{2}L^3V^2}$ where $M\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{M}{\frac{\rho}{2}L^3V_0^2}$ 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'	$\frac{\partial M'}{\partial q'}\Big\vert_{M'=\hat{M}'_0}$
$M'_{\dot{q}}$	DMDQTS	1	—	$\frac{\partial M'}{\partial \dot{q}'}\Big\vert_{M'=\hat{M}'_0}$
$M'_{\dddot{q}}$	DMDQ3TS	1	—	$\frac{\partial M'}{\partial \dddot{q}'}\Big\vert_{M'=\hat{M}'_0}$
M'_{w}	DMDWS	1	Slope through zero of M' versus w'	$\frac{\partial M'}{\partial w'}\Big\vert_{M'=\hat{M}'_0}$
$M'_{\dot{w}}$	DMDWTS	1	—	$\frac{\partial M'}{\partial \dot{w}'}\Big\vert_{M'=\hat{M}'_0}$
M'_{θ}	DMDTHS	rad^{-1} [a]	—	$\frac{\partial M'}{\partial \theta}\Big\vert_{M'=\hat{M}'_0}$
$\hat{M}'_{pp}$	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 $p'\,r'$	—

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 $u'\, q'$	—
$\hat{M}'_{q\lvert q\rvert}$	MYQQAS	1	Non-dimensional coefficient used in representing M' as a function of $q'\lvert q'\rvert$	—
$\hat{M}'_{\lvert q\rvert \delta\mathrm{S}}$	MYQADSS	1	Non-dimensional coefficient used in representing M' as a function of $u'\lvert q'\rvert\delta_\mathrm{S}$	—
$\hat{M}'_{rr}$	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 $\lvert w'\rvert \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{w\lvert w\rvert}$	MYWWAS	1	Non-dimensional coefficient used in representing M' as a function of $w' \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{\lvert w\rvert}$	MYWAS	1	Non-dimensional coefficient used in representing M' as a function of $u'\lvert w'\rvert$	—
$\hat{M}'_{\lvert w\rvert q}$	MYWAQS	1	Non-dimensional coefficient used in representing M' as a function of $q' \sqrt{v'^2 + w'^2}$	—
$\hat{M}'_{\delta\mathrm{B}}$	MYDBS	1	Non-dimensional coefficient used in representing M' as a function of $u'^2\, \delta_\mathrm{B}$	—
$\hat{M}'_{\delta\mathrm{S}}$	MYDSS	1	Non-dimensional coefficient used in representing M' as a function of $u'^2\, \delta_\mathrm{S}$	—
$\hat{M}'_{0}$	MY0S	1	Non-dimensional coefficient used in representing M' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\tilde{M}'_{\theta}$	MYOTHS	1	Non-dimensional oscillatory coefficient about y-axis	—
m	MA	kg	Model mass	—

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
N	MZ	N m	Moment about z-axis	Relative to ship-fixed axis system
$N'_{\phi\text{dyn}}$	DNDPDYS	rad^{-1} [a]	—	$\frac{\partial N'}{\partial \phi}\Big\vert_{N'=\hat{N}'_0} - \frac{N_{\phi\,\text{stat}}}{\frac{\rho}{2}L^3V^2}$
$N_{\phi\text{stat}}$	DNDPST	N m rad^{-1} [a]	—	$\frac{\partial N}{\partial \phi}\Big\vert_{V=0}$ from static test or calculation
N'	MZS	1	Non-dimensional moment about z-axis	Especially for submarines: $\frac{N}{\frac{\rho}{2}L^3V^2}$ where $N\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$ For surface ships only: $\frac{N}{\frac{\rho}{2}L^3V_0^2}$ 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	$\frac{2}{nT}\int_{t}^{t+nT} N'(t)\,\sin\omega t\,dt$
N'_{out}	MZOUTS	1	Quadrature part of non-dimensional moment about z-axis	$\frac{2}{nT}\int_{t}^{t+nT} N'(t)\,\cos\omega t\,dt$
N'_{p}	DNDPS	1	—	$\frac{\partial N'}{\partial p'}\Big\vert_{N'=\hat{N}'_0}$
$N'_{\dot{p}}$	DNDPTS	1	—	$\frac{\partial N'}{\partial \dot{p}'}\Big\vert_{N'=\hat{N}'_0}$
$N'_{\dddot{p}}$	DNDP3TS	1	—	$\frac{\partial N'}{\partial \dddot{p}}\Big\vert_{N'=\hat{N}'_0}$
N'_{r}	DNDRS	1	Slope through zero of N' versus r'	$\frac{\partial N'}{\partial r'}\Big\vert_{N'=\hat{N}'_0}$

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$N'_{\dot{r}}$	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 $F_{\mathrm{n}0}$ 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 $F_{\mathrm{n}0} r' \delta_{\mathrm{R}}^2$	(for surface ships only)
$\hat{N}'_{\|r\|\delta\mathrm{R}}$	MZRADS	1	Non-dimensional coefficient used in representing N' as a function of $F_{\mathrm{n}0} \mid r' \mid \delta_{\mathrm{R}}$	(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)
$\hat{N}'_{ur\delta\delta\mathrm{R}}$	MZURDDS	1	Non-dimensional coefficient used in representing N' as a function of $u' r' \delta_{\mathrm{R}}^2$	(especially for submarines)
$\hat{N}'_{u\|r\|\delta\mathrm{R}}$	MZURADS	1	Non-dimensional coefficient used in representing N' as a function of $u' \mid r' \mid \delta_{\mathrm{R}}$	(especially for submarines)
$\hat{N}'_{uu}$	MZUUS	1	Non-dimensional coefficient used in representing N' as a function of u'^2	(especially for submarines)
$\hat{N}'_{uu\delta\mathrm{R}}$	MZUUDS	1	Non-dimensional coefficient used in representing N' as a function of u'^2 δ_{R}	(especially for submarines)
$\hat{N}'_{uu\delta\delta\delta\mathrm{R}}$	MZUUD3S	1	Non-dimensional coefficient used in representing N' as a function of $u'^2 \delta_{\mathrm{R}}^3$	(especially for submarines)
$\hat{N}'_{uv}$	MZUVS	1	Non-dimensional coefficient used in representing N' as a function of u' v'	(especially for submarines)

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{N}'_{v}$	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 $F_{\mathrm{n0}}\ v'\ r'^2$	(for surface ships only)
$\hat{N}'_{vvr}$	MZVVRS	1	Non-dimensional coefficient used in representing N' as a function of $F_{\mathrm{n0}}\ v'^2\ r'$	(for surface ships only)
$\hat{N}'_{vvv}$	MZV3S	1	Non-dimensional coefficient used in representing N' as a function of $v'^2 \sqrt{v'^2 + w'^2} F_{\mathrm{n0}}$	(for surface ships only)
$\hat{N}'_{v\lvert v\rvert}$	MZVVAS	1	Non-dimensional coefficient used in representing N' as a function of $v' \sqrt{v'^2 + w'^2}$	—
$\hat{N}'_{v\lvert r\rvert}$	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)
$\hat{N}'_{\delta\mathrm{R}}$	MZDRS	1	Non-dimensional coefficient used in representing N' as a function of $F_{\mathrm{n0}}{}^2\ \delta_{\mathrm{R}}$	(for surface ships only)
$\hat{N}'_{\delta\delta\delta\mathrm{R}}$	MZDR3S	1	Non-dimensional coefficient used in representing N' as a function of $F_{\mathrm{n0}}{}^2\ \delta_{\mathrm{R}}^3$	(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	—

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{N}'_{\phi}$	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
u_0	VX0	m s^{-1}	Longitudinal reference velocity	—
u'	VXS	1	Non-dimensional velocity in direction of *x*-axis	u/V_0

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
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 $z_{0\mathrm{A}}$	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 $z_{0\mathrm{A}}$	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	$V\,(\sin\phi_{\mathrm{S}}\cos\beta\sin\theta_{\mathrm{S}} - \sin\beta\cos\phi_{\mathrm{S}})$ 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	$V\,(\sin\phi_{\mathrm{S}}\sin\beta + \cos\phi_{\mathrm{S}}\cos\beta\sin\theta_{\mathrm{S}})$ 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	$\dfrac{X}{\frac{\rho}{2}L^2V_0^2}$
$\hat{X}'_{qq}$	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)

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{X}'_{uu\delta\delta\mathrm{R}}$	FXUUDDS	1	Non-dimensional coefficient used in representing X' as a function of $u'^2 \delta_\mathrm{R}^2$	(especially for submarines)
$\hat{X}'_{vr}$	FXVRS	1	Non-dimensional coefficient used in representing X' as a function of $v' r'$	—
$\hat{X}'_{vv}$	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 $F_{\mathrm{n0}}\,(\Delta u')^3$	(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 $F_{\mathrm{n0}}^2 \delta_\mathrm{R}^2$	(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]	—	$\frac{\partial Y}{\partial \phi}\Big\|_{V=0}$ from static test or calculation

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
Y'	FYS	1	Non-dimensional lateral force	Especially for submarines: $\frac{Y}{\frac{\rho}{2}L^2V^2}$ where $Y(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
				For surface ships only: $\frac{Y}{\frac{\rho}{2}L^2V_0^2}$ 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	$\frac{2}{nT}\int_{t}^{t+nT} Y'(t)\sin\omega t\,dt$
Y'_{out}	FYOUTS	1	Quadrature part of non-dimensional lateral force	$\frac{2}{nT}\int_{t}^{t+nT} Y'(t)\cos\omega t\,dt$
Y'_{p}	DYDPS	1	—	$\frac{\partial Y'}{\partial p'}\Big\vert_{Y'=\hat{Y}'_0}$
$Y'_{\dot{p}}$	DYDPTS	1	—	$\frac{\partial Y'}{\partial \dot{p}'}\Big\vert_{Y'=\hat{Y}'_0}$
$Y'_{\dddot{p}}$	DYDP3TS	1	—	$\frac{\partial Y'}{\partial \dddot{p}'}\Big\vert_{Y'=\hat{Y}'_0}$
Y'_{r}	DYDRS	1	Slope through zero of Y' versus r'	$\frac{\partial Y'}{\partial r'}\Big\vert_{Y'=\hat{Y}'_0}$
$Y'_{\dot{r}}$	DYDRTS	1	—	$\frac{\partial Y'}{\partial \dot{r}'}\Big\vert_{Y'=\hat{Y}'_0}$
Y'_{v}	DYDVS	1	Slope through zero of Y' versus v'	$\frac{\partial Y'}{\partial v'}\Big\vert_{Y'=\hat{Y}'_0}$
$Y'_{\dot{v}}$	DYDVTS	1	—	$\frac{\partial Y'}{\partial \dot{v}'}\Big\vert_{Y'=\hat{Y}'_0}$
Y'_{ϕ}	DYDPHIS	rad^{-1} [a]	—	$\frac{\partial Y'}{\partial \varphi}\Big\vert_{Y'=\hat{Y}'_0}$

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$Y'_{\phi\text{dyn}}$	DNDPDYS	rad^{-1} [a]	—	$\frac{\partial Y'}{\partial \phi}\Big\vert_{Y'=\hat{Y}'_0} - \frac{Y_{\phi\text{stat}}}{\frac{\rho}{2}L^2V^2}$
$\hat{Y}'_{pq}$	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 $F_{\text{n0}}\,r'$	(for surface ships only)
$\hat{Y}'_{r\vert r\vert}$	FYRRAS	1	Non-dimensional coefficient used in representing Y' as a function of $r'\vert r'\vert$	—
$\hat{Y}'_{r\delta\delta\text{R}}$	FYRDDS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\text{n0}}r'\delta_{\text{R}}^2$	(for surface ships only)
$\hat{Y}'_{\vert r\vert\delta\text{R}}$	FYRADS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\text{n0}}\,\vert r'\vert\,\delta_{\text{R}}$	(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)
$\hat{Y}'_{ur\delta\delta\text{R}}$	FYURDDS	1	Non-dimensional coefficient used in representing Y' as a function of $u'r'\delta_{\text{R}}^2$	(especially for submarines)
$\hat{Y}'_{u\vert r\vert\delta\text{R}}$	FYURADS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\vert r'\vert\,\delta_{\text{R}}$	(especially for submarines)
$\hat{Y}'_{uu}$	FYUUS	1	Non-dimensional coefficient used in representing Y' as a function of u'^2	(especially for submarines)
$\hat{Y}'_{uu\delta\text{R}}$	FYUUDS	1	Non-dimensional coefficient used in representing Y' as a function of $u'^2\,\delta_{\text{R}}$	(especially for submarines)
$\hat{Y}'_{uu\delta\delta\delta\text{R}}$	FYUUD3S	1	Non-dimensional coefficient used in representing Y' as a function of $u'^2\delta_{\text{R}}^3$	(especially for submarines)
$\hat{Y}'_{uv}$	FYUVS	1	Non-dimensional coefficient used in representing Y' as a function of $u'\,v'$	(especially for submarines)
$\hat{Y}'_{u\vert v\vert\delta\text{R}}$	FYUVADS	1	Non-dimensional coefficient used in representing Y'as a function of $u'\vert v'\vert\,\delta_{\text{R}}$	(especially for submarines)

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	**Definition or explanation**
$\hat{Y}'_{v}$	FYVS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}\,v'$	(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 $F_{\mathrm{n}0}\,v'\,r'^2$	(for surface ships only)
$\hat{Y}'_{v\|r\|}$	FYVRAS	1	Non-dimensional coefficient used in representing Y' as a function of $\|\,r'\|\sqrt{v'^2+w'^2}\,\frac{\|\,v'\,\|}{v'}$	—
$\hat{Y}'_{vvr}$	FYVVRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}\,v'^2\,r'$	(for surface ships only)
$\hat{Y}'_{vvv}$	FYV3S	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}\,v'^2\sqrt{v'^2+w'^2}$	(for surface ships only)
$\hat{Y}'_{v\|v\|}$	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 $v'\,w'$	—
$\hat{Y}'_{\|v\|\delta\mathrm{R}}$	FYVADS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}\|v'\|\delta_{\mathrm{R}}$	(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)
$\hat{Y}'_{\Delta\Delta u}$	FYDU2S	1	Non-dimensional coefficient used in representing Y' as a function of $(\Delta u')^2$	(for surface ships only)
$\hat{Y}'_{\delta\mathrm{R}}$	FYDRS	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}{}^2\delta_{\mathrm{R}}$	(for surface ships only)
$\hat{Y}'_{\delta\delta\delta\mathrm{R}}$	FYDR3S	1	Non-dimensional coefficient used in representing Y' as a function of $F_{\mathrm{n}0}{}^2\,\delta_{\mathrm{R}}^3$	(for surface ships only)

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{Y}'_0$	FY0S	1	Non-dimensional coefficient used in representing Y' when angle of attack α, drift angle β, manoeuvring device, and plane angles are zero	—
$\hat{Y}'_\phi$	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: $\frac{Z}{\frac{\rho}{2}L^2V^2}$ where $Z\,(u, v, w, p, q, r, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r}, \phi, \theta)$
				For surface ships only: $\frac{Z}{\frac{\rho}{2}L^2V_0^2}$ 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	$\frac{2}{nT}\int_t^{t+nT} Z'(t)\sin\omega t\,dt$
Z'_{out}	FZOUTS	1	Quadrature part of non-dimensional normal force	$\frac{2}{nT}\int_t^{t+nT} Z'(t)\cos\omega t\,dt$
Z'_q	DZDQS	1	Slope through zero of Z' versus q'	$\frac{\partial Z'}{\partial q'}\Big\vert_{Z'=\hat{Z}'_0}$
$Z'_{\dot{q}}$	DZDQTS	1	—	$\frac{\partial Z'}{\partial \dot{q}'}\Big\vert_{Z'=\hat{Z}'_0}$
Z'_w	DZDWS	1	Slope through zero of Z' versus w'	$\frac{\partial Z'}{\partial w'}\Big\vert_{Z'=\hat{Z}'_0}$
$Z'_{\dot{w}}$	DZDWTS	1	—	$\frac{\partial Z'}{\partial \dot{w}'}\Big\vert_{Z'=\hat{Z}'_0}$
$\hat{Z}'_{pp}$	FZPPS	1	Non-dimensional coefficient used in representing Z' as a function of p'^2	—

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
$\hat{Z}'_{pr}$	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 $u'\ q'$	—
$\hat{Z}'_{rr}$	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 $u'\ w'$	—
$\hat{Z}'_{w\lvert q\rvert}$	FZWQAS	1	Non-dimensional coefficient used in representing Z' as a function of $\frac{w'\lvert\ q'\ \rvert}{\lvert\ w'\ \rvert}\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{ww}$	FZWWS	1	Non-dimensional coefficient used in representing Z' as a function of $\lvert\ w'\ \rvert\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{w\lvert w\rvert}$	FZWWAS	1	Non-dimensional coefficient used in representing Z' as a function of $w'\sqrt{v'^2+w'^2}$	—
$\hat{Z}'_{\lvert w\rvert}$	FZWAS	1	Non-dimensional coefficient used in representing Z' as a function of $u'\lvert w'\rvert$	—
$\hat{Z}'_{\delta \mathrm{B}}$	FZDBS	1	Non-dimensional coefficient used in representing Z' as a function of $u'^2\delta_\mathrm{B}$	—
$\hat{Z}'_{\delta \mathrm{S}}$	FZDSS	1	Non-dimensional coefficient used in representing Z' as a function of $u'^2\ \delta_\mathrm{S}$	—
$\hat{Z}'_{0}$	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	$-K/Y$

Table 1 *(continued)*

Symbol	CC-code	SI-unit	Concept	
			Term	Definition or explanation
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	m^2 s^{-1}	Kinematic viscosity of air	—
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 shall 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 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, shall be identical for model and full-scale. Reynolds number, R_{n0}, which scales the effect of viscosity, cannot be matched; it shall 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 $Y_{\phi\mathrm{stat}}$, $K_{\phi\mathrm{stat}}$, and $N_{\phi\mathrm{stat}}$, and for submarines also $M_{\theta\mathrm{stat}}$, 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:

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

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

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

Moment about z-axis:

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

For submarines, the following additional equations are used.

Normal force:

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

Moment about y-axis:

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

Nonlinear dependencies or their respective derivatives shall 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

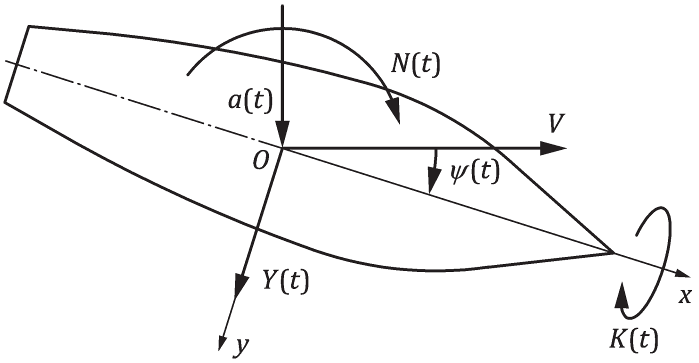


Figure 1 — Planar motion mechanism with the model in horizontal plane orientation

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

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

the following derivatives can be determined:

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

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

$$N'_{\dot{v}} = \frac{m\,x_G}{\frac{\rho}{2}L^4} + \left.\frac{\partial N'_{\mathrm{in}}}{\partial\left(\dfrac{\omega^2 a_0 L}{V_0{}^2}\right)}\right|_{\omega=0} \qquad (8)$$

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

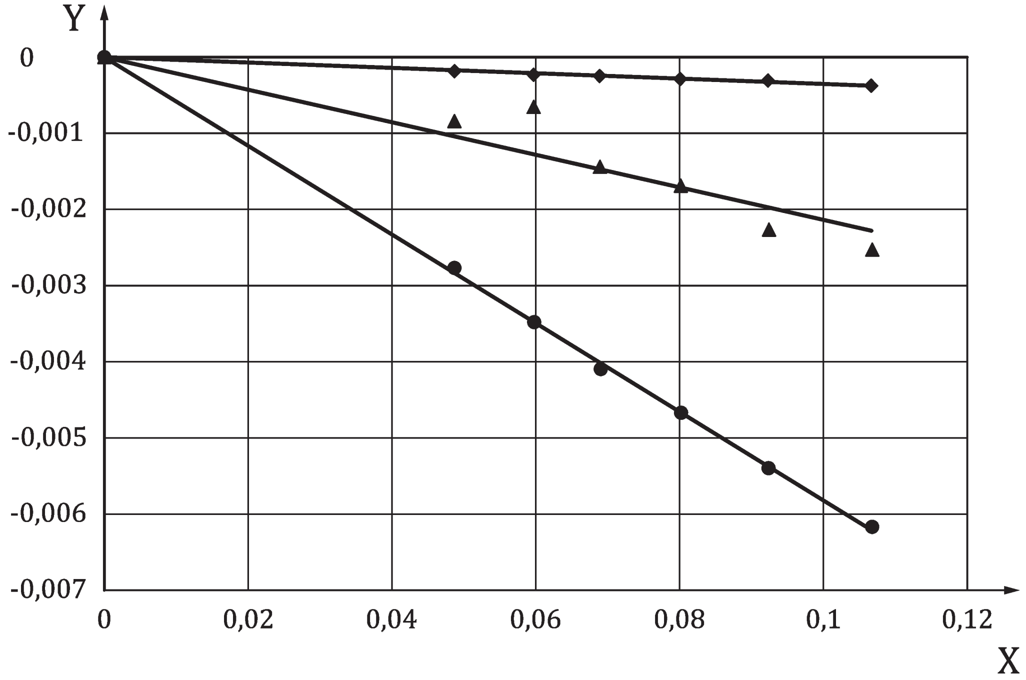
and if the roll moment were measured:

$$K'_{\dot{v}} = -\frac{m\,z_{\mathrm{G}}}{\frac{\rho}{2}L^4} + \left.\frac{\partial K'_{\mathrm{in}}}{\partial\left(\dfrac{\omega^2 a_0 L}{V_0{}^2}\right)}\right|_{\omega=0} \qquad (10)$$

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

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 Figures 2 and 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.



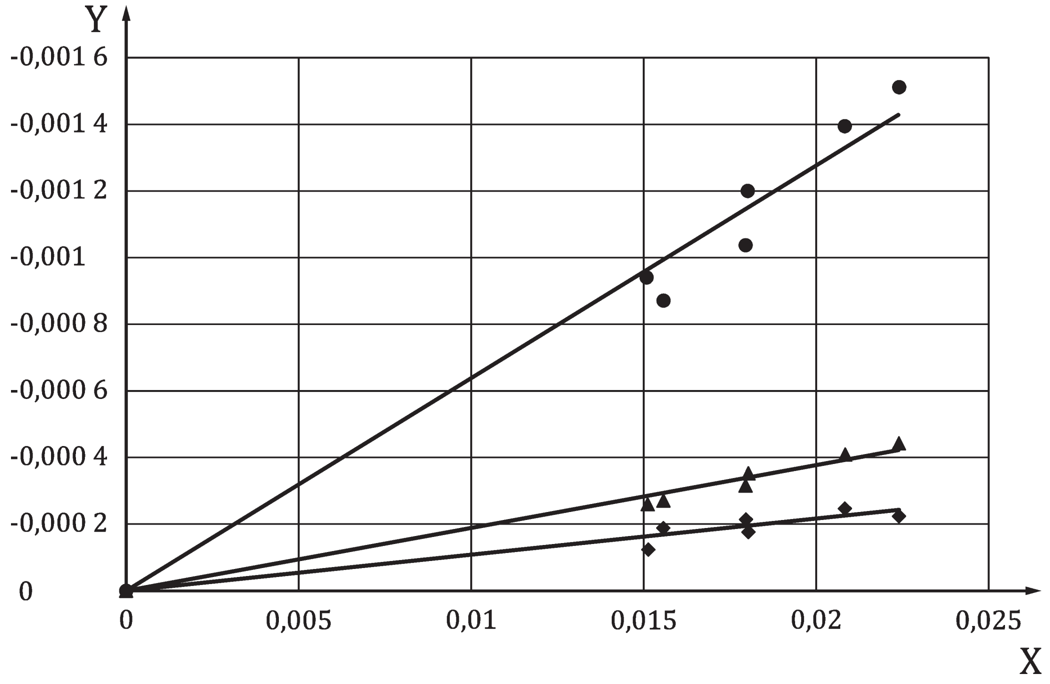
Key

- ● Y'_{in}
- ◆ $10^* K'_{\mathrm{in}}$
- ▲ $100^* N'_{\mathrm{in}}$

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}

◆ $100^* K'_{\mathrm{out}}$

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:

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

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

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

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

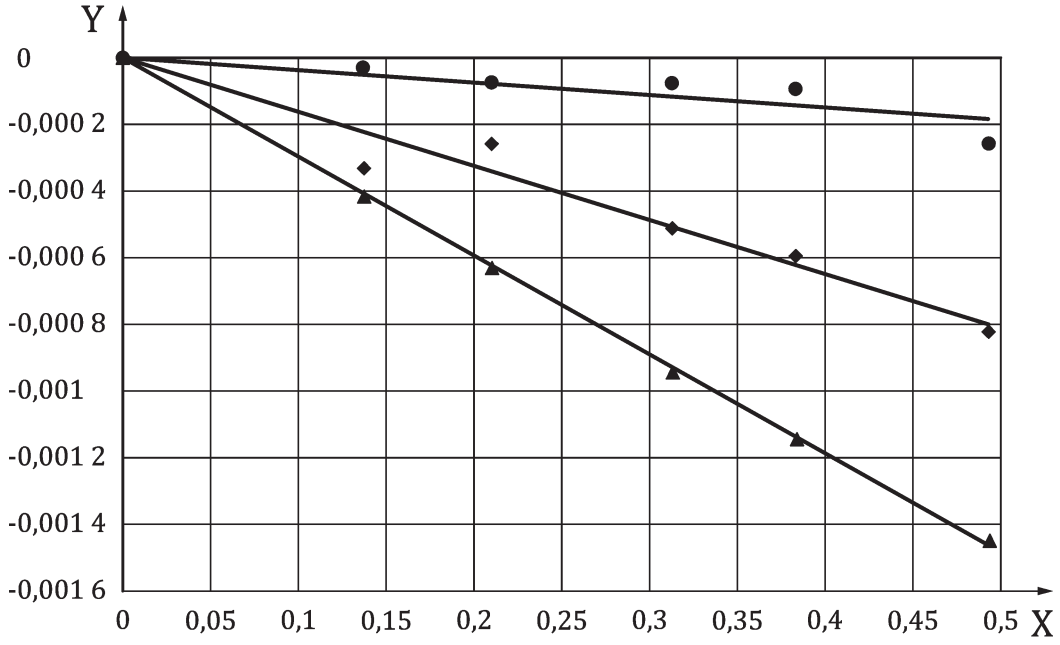
and if the roll moment were measured:

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

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

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 Figures 4 and 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}

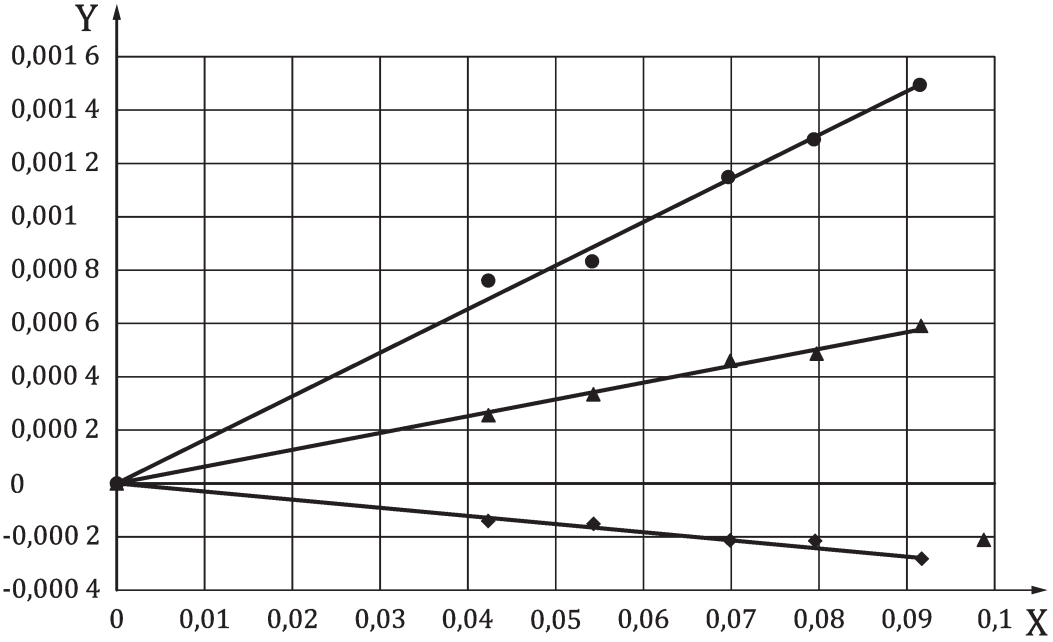
▲ N'_{in}

◆ 100*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}

◆ 100* 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)

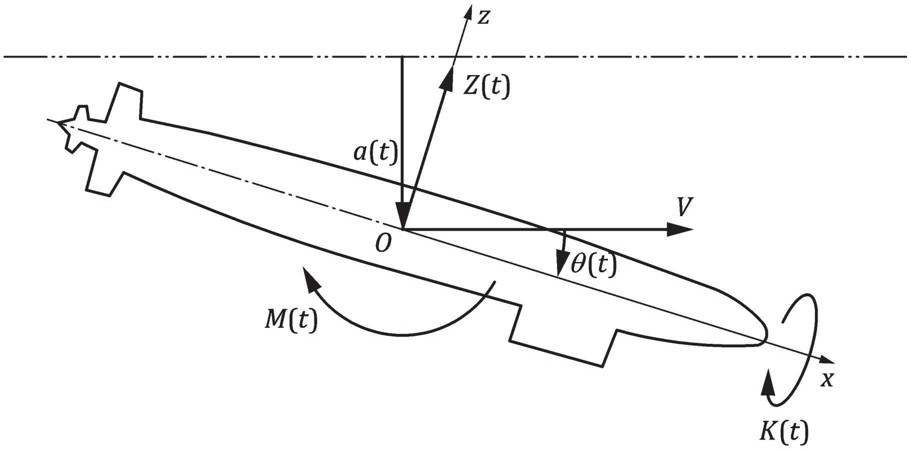


Figure 6 — Planar motion mechanism with the model in vertical plane orientation [model shown in inverted position chosen to avoid interference between sail and mounting strut(s)]

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

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

the following derivatives can be determined:

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

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

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

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

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 Figures 2 and 3). Linear curve fits yield the slopes of the curves used to determine the hydrodynamic derivatives.

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

$$a\left(t\right) = \theta_0 V_0 \cos\omega t$$

$$\theta\left(t\right) = \theta_0 \sin\omega t$$

the following derivatives can be determined:

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

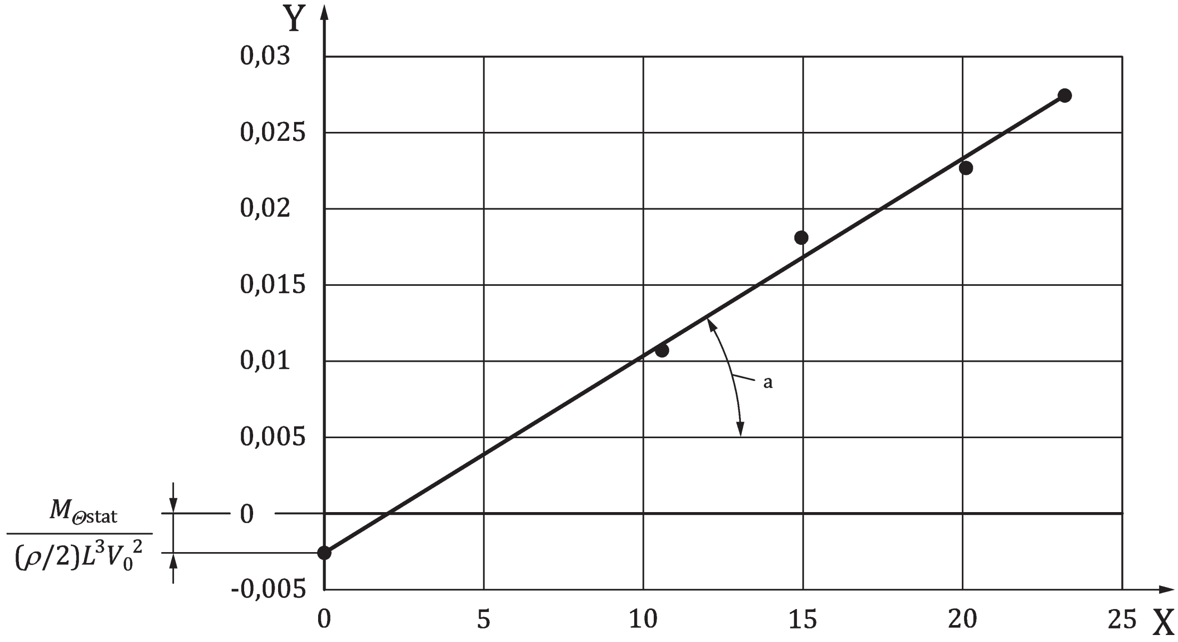
$$Z_q' = -\frac{m}{\frac{\rho}{2} L^3} - \left. \frac{\partial Z_{\text{out}}'}{\partial \left(\frac{\omega\, \theta_0 L}{V_0} \right)} \right|_{\omega=0} \tag{23}$$

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

$$M_q' = \frac{m\, x_{\text{G}}}{\frac{\rho}{2} L^4} - \left. \frac{\partial M_{\text{out}}'}{\partial \left(\frac{\omega\, \theta_0 L}{V_0} \right)} \right|_{\omega=0} \tag{25}$$

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 $\frac{M_{\theta\text{stat}}}{\frac{\rho}{2} L^3 V_0^{\ 2}}$ and $\tilde{M}_\theta'$ (see Figure 7).

$M_{\phi\text{stat}}$ should correspond with the value found by the tare test and should equal $gm\overline{\text{GM}}$ of the model.



Key

X ω^2L^2/V_0^2

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

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

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

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

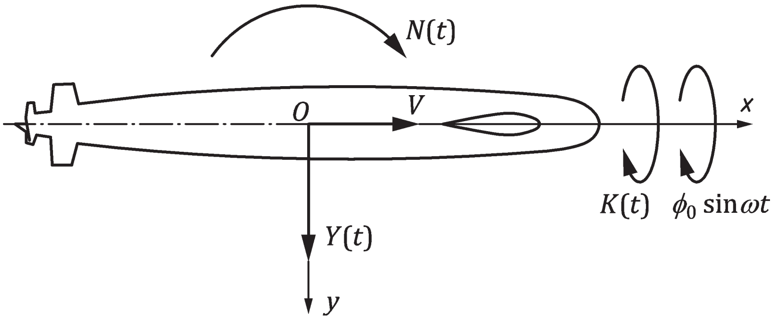


Figure 8 — Planar motion mechanism with a submarine model prepared for the determination of roll coefficients

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

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

and we get

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

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

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

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

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

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

Linear curve fits (see $\tilde{M}'_\theta$ in Figure 7) of $\tilde{Y}'_\phi-\dfrac{Y_{\phi\text{stat}}}{\frac{\rho}{2}L^2{V_0}^2}$, $\tilde{K}'_\phi-\dfrac{K_{\phi\text{stat}}}{\frac{\rho}{2}L^3{V_0}^2}$, and $\tilde{N}'_\phi-\dfrac{N_{\phi\text{stat}}}{\frac{\rho}{2}L^3{V_0}^2}$ plotted against $\omega^2\ L^2/V_0{}^2$ yield the slow motion derivatives $Y'_{\phi\text{dyn}}$, $Y'_{\dot{p}}$, $K'_{\phi\text{dyn}}$, $K'_{\dot{p}}$, $N'_{\phi\text{dyn}}$, and $N'_{\dot{p}}$. $Y_{\phi\text{stat}}$, $K_{\phi\text{stat}}$, and $N_{\phi\text{stat}}$ 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 ISO 13643-6 (6), Test 1 (1), conducted at a model towing speed V_0 = 3 m s^{-1} (03), an oscillation period T = 6 s (06), a model sway amplitude a_0 = 0 mm (00), and a yaw amplitude ψ_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 ISO 13643-6 (6), Test 1 (1), conducted at a model towing speed $V_0 = 3$ 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 ISO 13643-6 (6), Test 1 (1), conducted at a model towing speed $V_0 = 3$ 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, 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_{n0}, which scales the influence of surface waves, shall be maintained between model and full-scale surface vessels. As Reynolds number, R_{n0}, which scales the effect of viscosity, cannot be matched, it shall be ensured that the scale model attains fully turbulent flow (supercritical R_{n0}). 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 (see Figures 9 to 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 often used to describe these first-order coefficients is the same as that used for the corresponding stability and control derivatives. Here, this is taken into account by different symbols and terms.

The nonlinear derivatives shall 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 motions 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.

The type of nonlinear coefficients largely depends on the form of mathematical simulation algorithm to be used. The coefficients listed in Clause 4 shall 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 used for surface ships or submarines which has to be taken into account when choosing coefficients from Table 1.

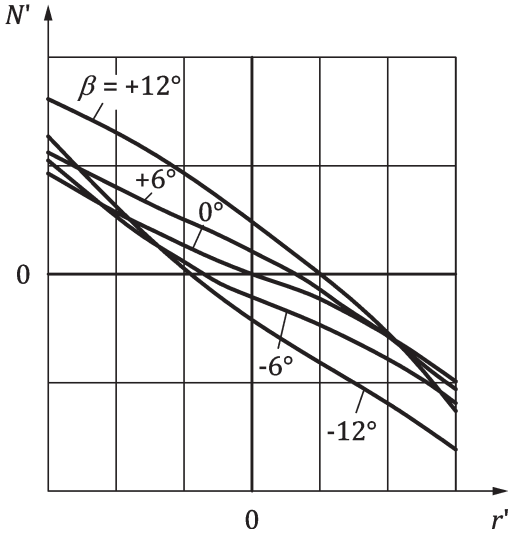
7.4 Designation of a circular motion test

Designation of a circular motion test according to ISO 13643-6 Test 2, conducted with the reference axis z (Z), a model reference speed $V_0 = 3\ \mathrm{m\ s^{-1}}$ (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 to ISO 13643-6 Test 2, 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 θ_S = 5° (05), a stern plane angle δ_S = 3°(03), and a bow plane angle δ_B = 0° (00):

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

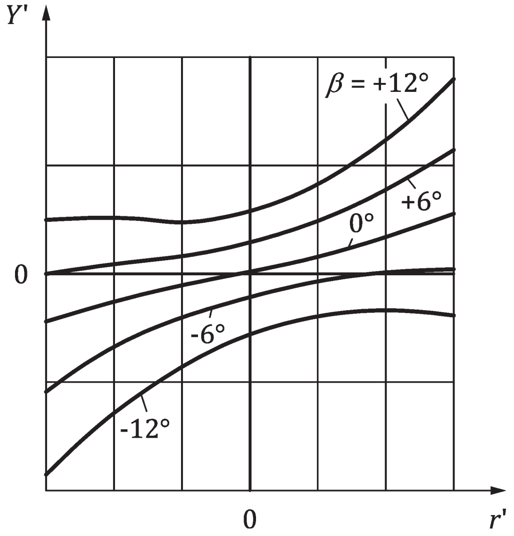


Key

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

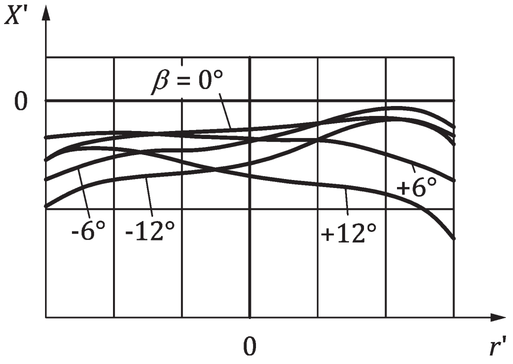


Key

Y' non-dimensional lateral force

r' non-dimensional angular velocity about z-axis

Figure 10 — Lateral force — Angular velocity about z-axis



Key

X'	non-dimensional longitudinal force
r'	non-dimensional angular velocity about *z*-axis

Figure 11 — Longitudinal force — Angular velocity about *z*-axis

8 Test 6.3 — Oblique towing or flow test

8.1 General

An oblique towing or flow test consists of a series with variations of drift angle, angle of attack and manoeuvring device angle within the specified ranges.

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

- The ship model is fixed to the towing carriage 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 pitch, heave, and possibly heel.
- In surface ship model tests, the Froude number, F_{n0}, which scales the influence of surface waves, shall be maintained between model and the full-scale vessel. As Reynolds number, R_{n0}, which scales the effect of viscosity, cannot be matched, turbulent flow at the scale model (supercritical R_{n0}) has to be ensured. Turbulence stimulators can be used near the bow as necessary.

During the test, the following data shall be measured:

For tests with model rotated 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 model rotated about *y*-axis (for submarines only)

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

8.2 Description

After adjustment of the specific test parameters, such as drift angle, β, and manoeuvring device angle, δ_R, and in the case of submarines, angle of attack, α, and plane angle δ_B or δ_S as well, the ship model is force-towed on a straight path at a constant speed, V_0. 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.

In the stationary phase of the test, the measuring time should be at least 25 s.

8.3 Analysis and presentation of results of an oblique towing or flow test

The measured data are mostly plotted non-dimensionally as functions of the test parameters drift angle β and/or manoeuvring device angles (see Figures 12 to 14 show results of the drift-angle tests at different manoeuvring device angles as function of the velocity in direction of the *y*-axis v) and in the case of submarine trim-angle tests angle of attack α 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 dynamic stability 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 results are preferred compared to planar motion test data (see Clause 6) because these are the simplest, most direct experiments which can be carried out to obtain the derivatives concerned and are inherently more reliable. 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 equation of motion. This is taken into account by different symbols and terms.

The nonlinear coefficients shall be taken into account, in the case of numerical simulation of arbitrary manoeuvres employing suitable mathematical simulation algorithms. The linear derivatives Y'_v, K'_v, N'_v, Z'_w, and M'_w together with the respective results of the planar motion test (see Clause 6) and/or circular motion test (see Clause 7) serve to determine the vessel's dynamic stability for small circular motions about *z*- and *y*-axes. 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.

The type of nonlinear coefficients largely depends on the form of the mathematical simulation algorithm to be used. The coefficients listed in Table 1 shall 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 used for surface ships or submarines which has to be taken into account when choosing coefficients from Table 1.

8.4 Designation of an oblique towing or flow test

Designation of an oblique towing test series (T) for a model rotated about the *z*-axis (Z) according to ISO 13643-6 (6), Test 3 (3), conducted at a model speed $V_0 = 3\ \mathrm{m\ s^{-1}}$ (03), drift angles β ranging from 0°

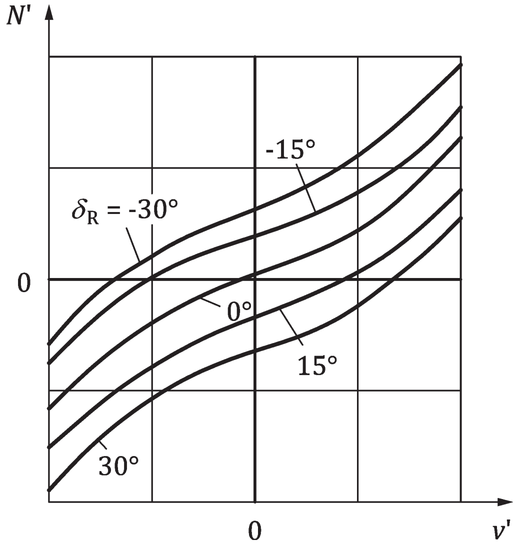
in steps of 3° to +15°(00:03:+15), angles of attack α ranging from 0° in steps of 0° to 0° (00:00:00) (i. e. no variation of angle of attack), and manoeuvring device angles δ_R ranging from −30° in steps of 10° to +30° (−30:10:+30):

Oblique towing test ISO 13643 – 6.3 × Z/03/00:03:+15/00:00:00/-30:10:+30/T

Designation of an oblique flow test series (F) for a model rotated about the *z*-axis (Z) according to ISO 13643-6 (6), Test 3 (3), conducted at a model speed V_0 = 3 m s^{-1} (03), drift angles β ranging from 0° in steps of 3° to +15°(00:03:+15), angles of attack α ranging from 0° in steps of 0° to 0° (00:00:00) (i. e. no variation of angle of attack), and manoeuvring device angles δ_R ranging from −30° in steps of 10° to +30° (−30:10:+30):

Oblique flow test ISO 13643 – 6.3 × Z/03/00:03:+15/00:00:00/-30:10:+30/F

NOTE For tests with the model rotated about the *y*-axis (for submarines only), the identifier would be Y instead of Z. The manoeuvring device angle would be replaced by the stern plane and the bow plane angle.



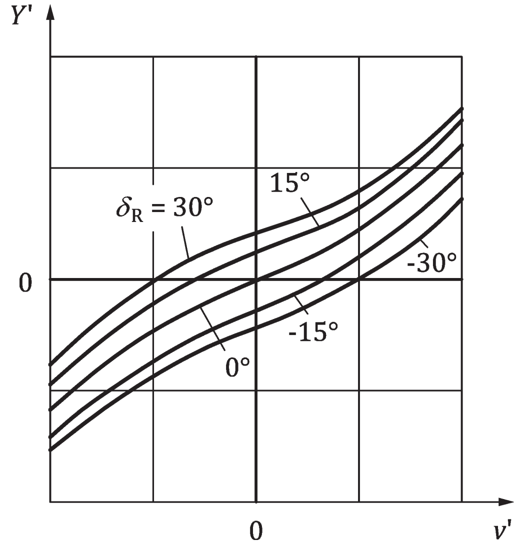
Key

N′ non-dimensional moment about *z*-axis

v′ non-dimensional lateral velocity

δ_R manoeuvring device angle

Figure 12 — Moment about *z*-axis – lateral velocity



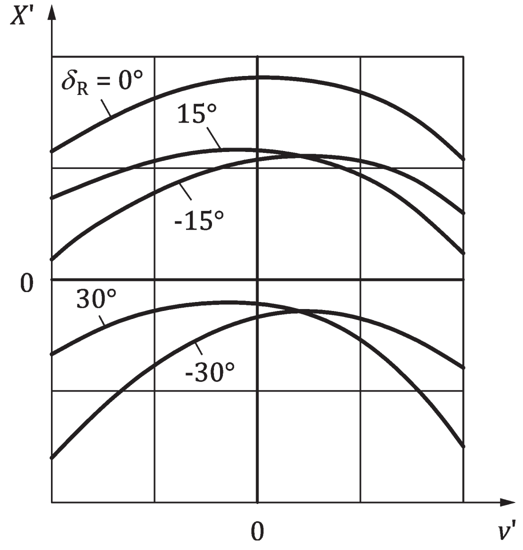
Key

Y' non-dimensional lateral force

v' non-dimensional lateral velocity

δ_R manoeuvring device angle

Figure 13 — Lateral force – lateral velocity



Key

X' non-dimensional longitudinal force

v' non-dimensional lateral velocity

δ_R manoeuvring device angle

Figure 14 — Longitudinal force – lateral velocity

9 Test 6.4 — Wind tunnel test

9.1 General

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

- The model of the above-water ship is attached over a model trough with an integrated dynamometer to a rotating disk representing the water surface and serving to vary the relative wind angle.
- The wind tunnel test comprises a series of individual runs. The relative wind angles to be tested range from 0° to 180° for ships symmetrical to the *xz*-plane and from 0° to 360° for non-symmetrical ships. For a symmetry check, few points between 180° and 360° may be considered.

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

roll moment	K (if required);
moment about z-axis	N;
drag	D;
cross force	C.

To ensure that the test results are independent of Reynolds number, the tests shall be repeated at least at two other Reynolds numbers.

9.2 Description

The ship model is tested in a homogeneous flow or in a flow having a velocity gradient. As the relative wind is a superposition of a homogeneous flow due to ship speed and the true wind with a gradient tests are typically performed in a homogeneous flow. For tests with a velocity gradient the power law:

$$\frac{V_{\mathrm{WT}}}{V_{\mathrm{WTA}}} = \left(\frac{z_0}{z_{0\mathrm{A}}}\right)^{\frac{1}{n}} \qquad (32)$$

where $n = 10$ may be used as a simple approximation to the logarithmic profile of the true wind over the sea surface. For full-scale ships, $z_{0\mathrm{A}} = -10$ m usually applies.

9.3 Analysis and presentation of results of a wind tunnel test

The measured data are usually plotted non-dimensionally as a function of the relative wind direction, ψ_{WR} (see Figures 15 to 20). The dynamic pressure of the relative wind velocity and the lateral area above waterline, A_{LV}, serve as reference quantities. The drag, D, and the longitudinal force, X, can also be relative to the transverse projected area of the ship above waterline, A_{XV}.

If the cross force, C, and the drag, D, are measured during the tests, the longitudinal force, X, and the lateral force, Y, can be obtained from the following relations:

$$X = C\sin\psi_{\mathrm{WR}} - D\cos\psi_{\mathrm{WR}} \qquad (33)$$

$$Y = C\cos\psi_{\mathrm{WR}} + D\sin\psi_{\mathrm{WR}} \qquad (34)$$

The coordinates x_{F} and z_{F} of the position of the pressure centre of wind force may be calculated from measured moments about x- and z-axes, respectively, according to the following formulae:

$$x_F = N / Y \tag{35}$$

$$z_F = -K / Y \tag{36}$$

9.4 Designation of a wind tunnel test

Designation of a wind tunnel test according to ISO 13643-6 Test 4, conducted at a wind velocity for the full-scale ship of V_{WR} = 20 m s^{-1} and relative wind directions ψ_{WR} ranging from 0° in steps of 15° to 180° (000/15/180):

Wind tunnel test ISO 13643 – 6.4 × 20/000:15:180

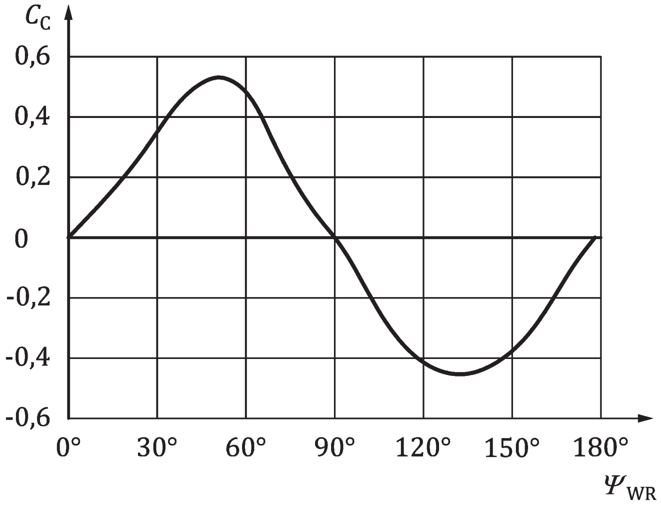


Figure 15 — Cross-force coefficient as function of relative wind direction

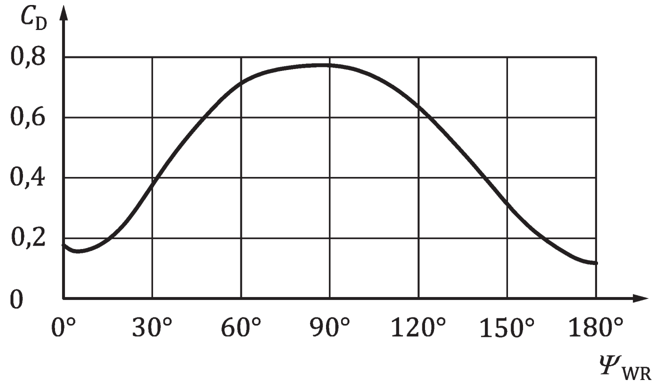


Figure 16 — Drag coefficient as function of relative wind direction

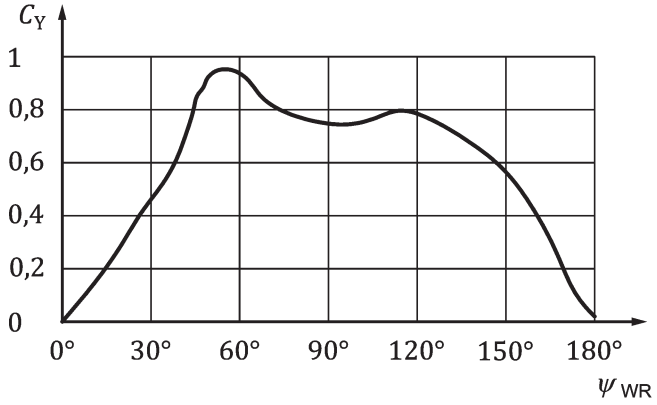


Figure 17 — Lateral-force coefficient as function of relative wind direction

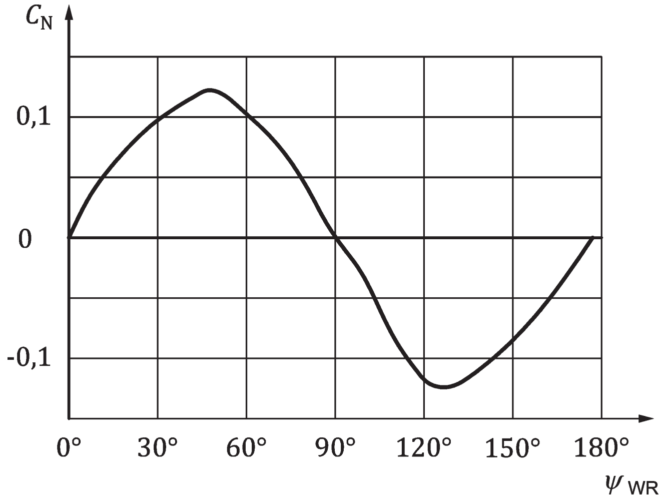


Figure 18 — Coefficient of moment about *z*-axis as function of relative wind direction

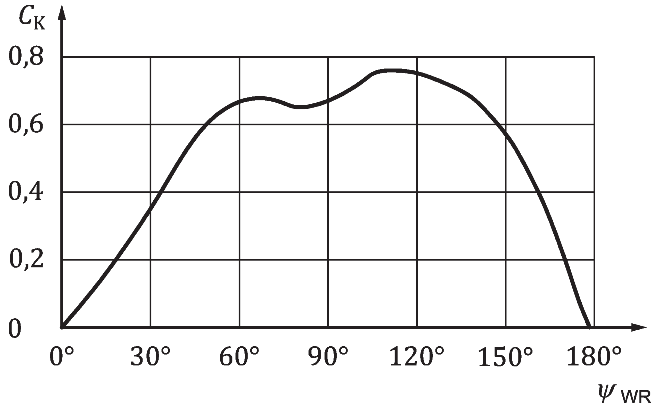


Figure 19 — Roll-moment coefficient as function of relative wind direction

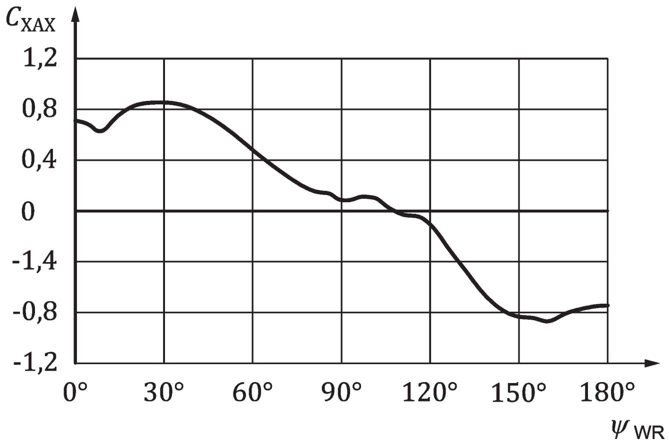


Figure 20 — Longitudinal-force coefficient relative to cross section of ship above waterline as function of relative wind direction

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