International Towing Tank Conference
ITTC Symbols and Terminology List

Final Version 1996

May 13, 1997

Supersedes all previous versions

Please go to next page for hypertext table of contents

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Preface

The 1996 Version of the 21st ITTC Symbols and Terminology List was prepared by the 21st ITTC Symbols and Terminology(SaT) Group whose membership is as follows:

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A first informal meeting of the SaT Group was held in San Francisco in September 1993, immediately after the closing of the 20th Conference. Four further Group meetings have been held on 24 October, 1994, at INSEAN at Rome, 30 October, 1994, at CSSRC at Wuxi, 5-8 June, 1995, at USNA at Annapolis and 4-6 January, 1996, at USNA at Annapolis.

The main activity of the SaT Group during this period was to restructure the 1993 Version of the SaT List to make it more user friendly and more consistent, avoiding unnecessary duplications and deleting cryptic notation. As shown on the title page a Hypertext Version of the SaT List has been installed on the World Wide Web.

The 1996 Version of the ITTC Symbols and Terminology List is recommended to the 21st ITTC Conference in September 1996 in Norway to be adopted as a reference document. The ITTC SaT List needs continuous updating, revision, and extensions and the Hypertext Version should be updated and re-issued at least on an annual basis.

Consequently Technical Committees, Specialist Groups, Member Organizations and other parties interested are encouraged to contact the SaT Group with suggestions for necessary additions to and improvements of the SaT List because its quality strongly depends upon user inputs. For that purpose the SaT Group needs to continue to implement methods for wide dissemination of the ITTC Symbols and Terminology List in various media to the Member Organizations and other interested parties such as naval and commercial shipbuilders, universities, and organizations e. g. ISO, ISSC.

A future task will be the proposed conversion of the ITTC Symbols and Terminology List to a terminological database. This task can be pursued once the Unicode character set becomes available in commercial databases in 1996/97.

A goal of the SaT Group is to produce a document that can replace the ISO Standard 7463 first edited on September 15, 1990 based on the obsolete 1975 Version of the SaT List.

The Symbols and Terminology Group will continue to monitor the international efforts in the field of neutral data formats, e. g. STEP developments, and to coordinate the development of neutral formats for the exchange of information between ITTC member organizations and their clients.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1	**Ships in General**			
1.1	**Basic Quantities**		see Remarks .1, .2, .3	
a, a^1	AC, A1	Linear or translatory acceleration	dv / dt	m/s^2
A	A, AR, AREA	Area in general		m^2
B	B, BR	Breadth		m
C, $F^F{}_2$	FF(2)	Cross force	Force normal to lift and drag (forces)	N
D, $F^F{}_1$	FF(1)	Drag (force)	Force opposing translatory velocity, generally for a completely immersed body	N
d, D	D, DI	Diameter		m
E	E, EN	Energy		J
f	FR	Frequency	1 / T	Hz
F, F^0	F, F0	Force		N
g	G, GR	Acceleration of gravity	Weight force / mass, strength of the earth gravity field	m/s^2
h	DE	Depth		m
H	H, HT	Height		m
I	I, IN	Moment of inertia	Second order moment of a mass distribution	kg m^2
L	L, LE	Length		m
L, $F^F{}_3$	FF(3)	Lift (force)	Force perpendicular to translatory velocity	N
m	M, MA, MASS	Mass		kg
M, F^1	M1, F1	Moment of forces	First order moment of a force distribution	Nm
M	MO	Momentum		Ns
n, N	FR, N	Frequency or rate of revolution	Alias RPS (RPM in some propulsor applications)	Hz
P	P, PO	Power		W

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
r, R	RD	Radius		m
R, F^F_1	R, RE, FF(1)	Resistance (force)	Force opposing translatory velocity	N
s	SP	Distance along path		m
t	TI	Time		s
t	TE	Temperature		K
T	TC	Period	Duration of a cycle of a repeating or periodic, not necessarily harmonic process	s
U	U, UN	Undisturbed velocity of a fluid		m/s
v, V^1	V, V1	Linear or translatory velocity of a body	ds / dt see Remark .2	m/s
V	VO	Volume		m^3
w	WD	Weight density, formerly specific weight	dW / dV = ρg	N/m^3
W	WT	Weight (force), gravity force acting on a body		N
γ	MR	Relative mass or weight, sometimes called specific gravity	Mass density of a substance divided by mass density of distilled water at 4 °C	1
η	EF, ETA	Efficiency	Ratio of powers, see Remark .3	
ρ	DN, RHO	Mass density	dm / dV	kg/m^3
τ	ST, TAU	Tangential stress		Pa
λ	SC	Scale ratio	Ship dimension divided by corresponding model dimension	1
σ	SN, SIGS	Normal stress		Pa
ω	FC, OMF	Circular frequency	2 π f	1/s
ω, V^0	V0, OMN	Angular velocity	2 π n	rad/s

1.1.1 Remarks

.1 Greek Symbols

For traditional reasons the computer symbols of the concepts denoted by Greek ITTC Symbols do in general not refer to the concepts, but rather to the Greek symbol. This state of affairs is more than unsatisfactory. The SaT Group feels that at the present stage it may be time for a radical change.

An example is the efficiency, the universally accepted symbol being the Greek η. The computer symbol should of course be EF, instead of ETA.

Another example is the traditional symbol ω for circular frequency and angular velocity. Clearly the computer symbols FC and V0, respectively, or similar would be much more reasonable than the traditional symbols listed.

.2 Velocities, Forces

In the following sections more general concepts are proposed, which permit an even more rational approach. Appropriate symbols for the linear and the angular velocity would be v^1 and v^0, respectively, in precisely that order! In terms of the generalized velocity v, the complete motion with six degrees of freedom, the components of the angular velocity are then uniquely denoted by $v^0_i = v_{3+i}$ with i = 1, 2, 3 and 'resulting' in the the computer symbols V0(I) = V(3+I), again with I = 1, 2, 3; see the section on 3.1.1 **Coordinates and Space Related Quantities** and the section on 3.2.3 **Rigid Body Motions**.

Concerning the hydrodynamic forces acting on a body due to translatory motion only the rational computer symbols are given. As a matter of fact this type of notation is used more and more in various applications. The advantages need not to be elaborated upon.

.3 Efficiencies

The concept of efficiency or factor of merit is that of a ratio of powers, preferably powers proper, but sometimes virtual powers are considered as well. The most appropriate notation for efficiencies would therefore be the following with two indices, namely the identifiers of the two powers put into proportion, i. e.

$$\eta_{XY} = P_X / P_Y .$$

This notation together with the computer notation EF*XY* would of course greatly improve the data handling as it is truly operational.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.2 Geometry and Hydrostatics
1.2.1 Hull Geometry

1.2.1.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_{BL}	ABL	Area of bulbous bow in longitudinal plane	The area of the ram projected on the middle line plane forward of the fore perpendicular; s. Remark .1	m^2
A_{BT}	ABT	Area of transverse cross-section of a bulbous bow (full area port and starboard)	The cross sectional area at the fore perpendicular. Where the water lines are rounded so as to terminate on the forward perpendicular A_{BT} is measured by continuing the area curve forward to the perpendicular, ignoring the final rounding; s. Remark .1	m^2
A_M	AM	Area of midship section	Midway between fore and aft perpendiculars	m^2
A_T	ATR	Area of transom (full area port and starboard)	Cross-sectional area of transom stern below the load waterline	m^2
A_V	AV	Area exposed to wind	Area of portion of ship above waterline projected normally to the direction of relative wind	m^2
A_W	AW	Area of water-plane		m^2
A_{WA}	AWA	Area of water-plane aft of midship		m_2
A_{WF}	AWF	Area of water-plane forward of midship		m^2
A_X	AX	Area of maximum transverse section		m^2
B	B	Beam or breadth, moulded, of ships hull		m
B_M	BM	Breadth, moulded of midship section at design water line		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
B_T	BTR	Breadth, moulded of transom at design water line		m
B_{WL}	BWL	Maximum moulded breadth at design water line		m
B_X	BX	Breadth, moulded of maximum section area at design water line		m
d,T	T	Draft, moulded, of ship hull		m
d_{KL}	KDROP	Design drop of the keel line	T_{AD} - T_{FD} alias “keel drag”	m
D	DEP	Depth, moulded, of a ship hull		m
f	FREB	Freeboard	From the freeboard markings to the freeboard deck, according to official rules	m
i_E	ANEN	Angle of entrance, half	Angle of waterline at the bow with reference to centerplane, neglecting local shape at stem	rad
i_R	ANRU	Angle of run, half	Angle of waterline at the stern with reference to the center-plane, neglecting local shape of stern frame	rad
L	L	Length of ship	Reference length of ship (generally length between the perpendiculars)	m
L_E	LEN	Length of entrance	From the forward perpendicular to the forward end of parallel middle body, or maximum section	m
L_{OA}	LOA	Length, overall		m
L_{OS}	LOS	Length, overall submerged		m
L_P	LP	Length of parallel middle body	Length of constant transverse section	m
L_{PP}	LPP	Length between perpendiculars		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
L_R	LRU	Length of run	From section of maximum area or after end of parallel middle body to waterline termination or other designated point of the stern	m
L_{WL}	LWL	Length of waterline		m
L_{FS}	LFS	Frame spacing	used for structures	m
L_{SS}	LSS	Station spacing		m
S	S, AWS	Area of wetted surface		m^2
t	TT	Taylor tangent of the area curve	The intercept of the tangent to the sectional area curve at the bow on the midship ordinate	1
T, d	T	Draft, moulded, of ship hull		m
T_A, d_A	TA, TAP	Draft at aft perpendicular		m
T_{AD}	TAD, TAPD	Design draft at aft perpendicular		m
T_F, d_F	TF, TFP	Draft at forward perpendicular		m
T_{FD}	TFD, TFPD	Design draft at forward perpendicular		m
T_H	THUL	Draft of the hull	Maximum draft of the hull without keel or skeg	m
T_M, d_M	TM, TMS	Draft at midship	$(T_A + T_F) / 2$ for rigid bodies with straight keel	m
T_{MD}	TMD, TMSD	Design draft at midship	$(T_{AD} + T_{FD}) / 2$ for rigid bodies	m
T_T	TTR	Immersion of transom	Vertical depth of trailing edge of boat at keel below water surface level	m
∇, V	DISPVOL	Displacement volume	$\Delta / (\rho\ g) = \nabla_{BH} + \nabla_{AP}$	m^3
∇_{BH}	DISPVBH	Displacement volume of bare hull	$\Delta_{BH} / (\rho\ g)$	m^3
∇_{AP}	DISPVAP	Displacement volume of appendages	$\Delta_{AP} / (\rho\ g)$	m^3

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Δ	DISPF	Displacement force (buoyancy)	$g\ \rho\ \nabla$	N
Δ_{BH}	DISPFBH	Displacement force (buoyancy) of bare hull	$g\ \rho\ \nabla_{BH}$	N
Δ_{AP}	DISPFAP	Displacement force (buoyancy) of appendages	$g\ \rho\ \nabla_{AP}$	N
λ	SC	Linear scale of ship model	$\lambda = L_S / L_M = B_S / B_M = T_S / T_M$	1

1.2.1.2 Derived Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
B^C	CIRCB	R.E. Froude's breadth coefficient	$B / \nabla^{1/3}$	1
C_B	CB	Block coefficient	$\nabla / (L\ B\ T)$	1
C_{IL}	CWIL	Coefficient of inertia of waterplane, longitudinal	$12\ I_L / (\ B\ L^3)$	1
C_{IT}	CWIT	Coefficient of inertia of waterplane, transverse	$12\ I_T / (B^3\ L)$	1
C_M	CMS	Midship section coefficient (midway between forward and aft perpendiculars)	$A_M / (B\ T)$	1
C_P	CPL	Longitudinal prismatic coefficient	$\nabla / (A_X\ L)$ or $\nabla / (A_M\ L)$	1
C_{PA}	CPA	Prismatic coefficient, afterbody	$\nabla_A / (A_X\ L / 2)$ or $\nabla_A / (A_M\ L / 2)$	1
C_{PE}	CPE	Prismatic coefficient, entrance	$\nabla_E / (A_X\ L_E)$ or $\nabla_E / (A_M\ L_E)$	1
C_{PF}	CPF	Prismatic coefficient forebody	$\nabla_F / (A_X\ L / 2)$ or $\nabla_F / (A_M\ L / 2)$	1
C_{PR}	CPR	Prismatic coefficient, run s. Remark .2	$\nabla_R / (A_X\ L_R)$ or $\nabla_R / (A_M\ L_R)$	1
C_S	CS	Wetted surface coefficient	$S / (\nabla\ L)^{1/2}$	1
C_{VP}	CVP	Prismatic coefficient vertical	$\nabla / (A_W\ T)$	1
C_{WA}	CWA	Water plane area coefficient, aft	$A_{WA} / (B\ L / 2)$	1
C_{WF}	CWF	Water plane area coefficient, forward	$A_{WF} /(B\ L / 2)$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
C_{WP}	CW	Water-plane area coefficient	A_W /(L B)	1
C_X	CX	Maximum transverse section coefficient	A_X / (B T),where B and T are measured at the position of maximum area	1
C_∇	CVOL	Volumetric coefficient	∇ / L^3	1
f_{BL}	CABL	Area coefficient for bul-bous bow	A_{BL} / (L T)	1
f_{BT}	CABT	Taylor sectional area coefficient for bulbous bow	A_{BT} / A_X	1
f_T	CATR	Sectional area coefficient for transom stern	A_T / A_X	1
M^C	CIRCM	R.E. Froude's length coefficient, or length-displacement ratio	L / $\nabla^{1/3}$	1
S^C	CIRCS	R.E. Froude's wetted surface area coefficient	S / $\nabla^{2/3}$	1
T^C	CIRCT	R.E. Froude's draft coefficient	T / $\nabla^{1/3}$	1

1.1.1.3 Symbols for Attributes and Subscripts

A	AB	After body
	AP	After perpendicular
	APP	Appendages
B	BH	Bare hull
	DW	Design waterline
E	EN	Entry
F	FB	Fore body
	FP	Fore perpendicular
	FS	Frame spacing
H	HU	Hull
	LP	Based on L_{PP}
	LW	Based on L_{WL}
M	MS	Midships

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
	PB	Parallel body		
R	RU	Run		
	SS	Station spacing		
W	WP	Water plane		
S	WS	Wetted surface		

1.2.1.4 Remarks

.1 Bulbous Bows

Below the load water line the stem contour sometimes recedes aft of the fore perpendicular before projecting forward to define the outline of the ram or the fore end of the bulb. In such instances this area should be calculated using as datum the aftermost vertical tangent to the contour instead of the fore perpendicular.

.2 Reference Quantities

The prismatic coefficient should generally be based upon maximum section area rather than on midsection area, as in the 1960 Committee Report, but it should be clearly stated which area has been used. Whatever ship length considered appropriate may be used for this end and another coefficient, but this length should be clearly indicated and stated.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.2.2	**Propulsor Geometry**			
1.2.2.1	**Screw Propellers**			
A_D	AD	Developed blade area	Developed blade area of a screw propeller outside the boss or hub	m^2
A_E	AE	Expanded blade area	Expanded blade area of a screw propeller outside the boss or hub	m^2
A_O	AO	Disc Area	$\pi D^2 / 4$	m^2
A_p	AP	Projected blade area	Projected blade area of a screw propeller outside the boss or hub	m^2
a_D	ADR	Developed blade area ratio	A_D / A_0	1
a_E	ADE	Expanded blade area ratio	A_D / A_0	1
a_P	ADP	Projected blade area ratio	A_D / A_0	1
c	LCH	Chord length		m
c_m	CHME	Mean chord length	The expanded or developed area of a propeller blade divided by the span from the hub to the tip	m
c_S	CS	Skew displacement	The displacement between middle of chord and the blade reference line. Positive when middle chord is at the trailing side regarding the blade reference line	m
d_h	DH	Boss or hub diameter	$2 r_h$	m
D	DP	Propeller diameter		m
f	FBP	Camber of blade profile		m
G_Z	GAP	Gap between the propeller blades	$2 \pi r \sin(\phi) / z$	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
h_O	HO	Immersion	The depth of submergence of the propeller measured vertically from the propeller center to the free surface	m
H_{TC}	HTC	Hull tip clearance	Distance between the propeller sweep circle and the hull	m
i_G	RAKG	Rake	The displacement from the propeller plane to the generator line in the direction of the shaft axis. Aft displacement is positive rake.	m
i_S	RAKS	Axial displacement, skew-induced	The axial displacement of a blade section which occurs when the propeller is skewed. Aft displacement is positive rake	m
i_T	RAKT	Axial displacement, total	The axial displacement of the blade reference line from the propeller plane $i_G + i_S = c_S \sin\phi$ Positive direction is aft.	m
N_{PR}	NPR	Number of propellers		1
p	PDR	Pitch ratio	P / D	1
P	PITCH	Propeller pitch in general		m
r	RL	Blade section radius		m
r_h	RH	Hub radius		m
R	RDP	Propeller radius		m
t	TM	Blade section thickness		m
t_O	TO	Thickness on axis of propeller blade	Thickness of propeller blade as extended down to propeller axis	m
x_B	XBDR	Boss to diameter ratio	d_h / D	
x_p	XP	Longitudinal propeller position	Distance of propeller center forward of the after perpendicular	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
y_p	YP	Lateral propeller position	Transverse distance of wing propeller center from middle line	m
Z, z	NPB	Number of propeller blades		1
z_p	ZP	Vertical propeller position	Height of propeller center above base line	m
θ_s	TETS	Skew angle	The angular displacement about the shaft axis of the reference point of any blade section relative to the generator line measured in the plane of rotation. It is positive when opposite to the direction of ahead rotation	rad
θ	RAKA	Angle of rake		rad
θ_{EXT}	TEMX	Skew angle extent	The difference between maximum and minimum local skew angle	rad
ϕ	PHIP	Pitch angle of screw propeller	$\mathrm{arctg}(P / (2 \pi R))$	1
ϕ_F	PHIF	Pitch angle of screw propeller measured to the face line		1
ψ	PSI	Propeller axis angle	Angle between horizontal plane and propeller shaft axis	rad
τ_b		Blade thickness ratio	t_0 / D	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.2.2.2 Ducts				
A_{DEN}	ADEN	Duct entry area		m^2
A_{DEX}	ADEX	Duct exit area		m^2
d_D	CLEARD	Propeller tip clearance	Clearance between propeller tip and inner surface of duct	m
f_D	FD	Camber of duct profile		m
L_D	LD	Duct length		m
L_{DEN}	LDEN	Duct entry part length	Axial distance between leading edge of duct and propeller plane	m
L_{DEX}	LDEX	Duct exit length	Axial distance between leading edge of duct and propeller plane	m
t_D	TD	Thickness of duct profile		m
α_D	AD	Duct profile-shaft axis angle	Angle between nose-tail line of duct profile and propeller shaft	rad
β_D	BD	Diffuser angle of duct	Angle between inner duct tail line and propeller shaft	rad

1.2.2.3 Waterjets (Future location: see Section 5.1, pp 130-131 of Version 1996)

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.2.3 Appendage Geometry

Related information may be found in Section 3.3.3 on Lifting Surfaces.

1.2.3.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_C	AC	Area under cut-up		m^2
A_{FB}	AFB	Area of bow fin		m^2
A_{FR}	AFR	Frontal area	Projected frontal area of an appendage	m^2
A_{RF}	AF	Flap area		m^2
A_R	ARU	Rudder area	Area of the rudder, including flap	m^2
A_{RX}	ARX	Area of the fixed part of rudder		m^2
A_{RP}	ARP	Area of rudder in the propeller race		m^2
A_{RT}	ART	Total rudder area	$A_{RX} + A_{RF}$	m^2
A_{FS}	AFS	Area of stern fin		m^2
A_{SK}	ASK	Skeg area		m^2
A_{WBK}	AWBK	Wetted surface area of bilge keels		m^2
c	CH	Chord length of an aerofoil or a hydrofoil		m
c_m	CHME	Mean chord length	A_{RT} / S	m
c_r	CHRT	Chord length at the root		m
c_t	CHTP	Chord length at the tip		m
f	FM	Camber of an aerofoil or a hydrofoil	Maximum separation of median and nose-tail line	m
L_F	LF	Length of flap or wedge	Measured in direction parallel to keel	m
t	TMX	Maximum thickness of an aerofoil or a hydrofoil	Measured normal to mean line	m
δ_{FB}	ANFB	Bow fin angle	s. Remark .1	rad
δ_{FS}	ANFS	Stern fin angle	s. Remark .1	rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
δ_F	DELFS	Flap angle (general)	Angle between the planing surface of a flap and the bottom before the leading edge	rad
δ_W	DELWG	Wedge angle	Angle between the planing surface of a wedge and the bottom before the leading edge	rad
δ_{FR}	ANFR	Flanking rudder angle	s. Remark .1	rad
δ_{FRin}	ANFRIN	Assembly angle of flanking rudders	Initial angle set up during the assembly as zero angle of flanking rudders	rad
δ_R	ANRU	Rudder angle	s. Remark .1	rad
δ_{RF}	ANRF	Rudder-flap angle	s. Remark .1	rad
λ_R	TARU	Rudder taper	c_t / c_r	1
λ_{FR}	TAFR	Flanking rudder taper		1
Λ_R	ASRU	Rudder aspect ratio	S^2 / A_{RT}	1
Λ_{FR}	ASRF	Flanking rudder aspect ratio		1

1.2.3.2 Identifiers for Appendages

BK	Bilge keel
BS	Bossing
FB	Bow foil
FR	Flanking rudder
FS	Stern foil
KL	Keel
RU	Rudder
RF	Rudder flap
SA	Stabilizer
SH	Shafting
SK	Skeg
ST	Strut
TH	Thruster

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
	WG	Wedge		

1.2.3.3 Remarks

.1 Sign Convention

Positive angles are defined as clockwise when viewed from the center of axes along the appropriate body axis, i. e. nose-up fin angles and port rudder angles are positive. See also Section 3.1.1 **Coordinates and Space Related Quantities**.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.2.4 Hydrostatics

1.2.4.1 Points and Centers (Under construction)

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A		Assumed center of gravity above keel used for cross curves of stability		
b		Mean center of flotation of added buoyant layer		
B		Center of buoyancy		
F		Center of flotation of the waterplane		
g		Center of gravity of an added or removed weight (mass)		
G		Center of gravity of a vessel		
K		Keel reference		
M		Metacenter of a vessel		
x_{cb}	XACB	Longitudinal mean center of floatation of added buoyant layer	Longitudinal distance from reference point to the center of the added buoyant layer, b	m
x_{CB} , L_{CB}	XCB	Longitudinal center of buoyancy (LCB)	Longitudinal distance from reference point to the center of buoyancy, B	m
x_{CF} , L_{CF}	XCF	Longitudinal center of flotation (LCF)	Longitudinal distance from reference point to the center of flotation, F	m
x_{cg}	XACG	Longitudinal center of gravity of added weight (mass)	Longitudinal distance from reference to the center of gravity,g, of an added or removed weight (mass)	m
x_{CG} , L_{CG}	XCG	Longitudinal center of gravity (LCG)	Longitudinal distance from a reference point to the center of gravity, G	m
y_{CG}	YCG	Lateral displacement of center of gravity (YCG)	Lateral distance from a reference point to the center of gravity, G	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Z	ZRA	Intersection of righting arm with line of action of the center of buoyancy		

1.2.4.2 Static Stability levers

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
$\overline{AB}$	XAB	Longitudinal center of buoyancy from aft perpendicular	Distance of center of buoyancy from aft perpendicular	m
$\overline{AF}$	XAF	Distance of center of flotation from after perpendicular		m
$\overline{AG}_L$	XAG	Longitudinal center of gravity from aft perpendicular	Distance of center of gravity from aft perpendicular	m
$\overline{AG}_T$	YAG	Transverse distance from assumed center of gravity A, to actual centre of gravity G		m
$\overline{AG}_V$	ZAG	Vertical distance from assumed center of gravity A, to actual center of gravity G		m
$\overline{AZ}$	YAZ	Righting arm based on horizontal distance from assumed center of gravity A, to Z	Generally tabulated in cross curves of stability	m
$\overline{BM}$	ZBM	Transverse metacenter above center of buoyancy	Distance from the center of buoyancy B to the transverse metacenter M. $\overline{BM} = I_T/\nabla = \overline{KM} - \overline{KB}$	m
$\overline{BM}_L$	ZBML	Longitudinal metacenter above center of buoyancy	$\overline{KM}_L - \overline{KB}$	
$\overline{FB}$	XFB	Longitudinal center of buoyancy, L_{CB}, from forward perpendicular	Distance of center of buoyancy from forward perpendicular	m
$\overline{FF}$	XFF	Longitudinal center of floatation, $L_{CF,}$ from forward perpendicular	Distance of center of flotation from forward perpendicular	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
$\overline{FG}$	XFG	Longitudinal center of gravity from forward perpendicular	Distance of center of gravity from forward perpendicular	m
$\overline{GG_H}$	GGH	Horizontal stability lever caused by a weight shift or weight addition		m
$\overline{GG_L}$	GGL	Longitudinal stability lever caused by a weight shift or weight addition		m
$\overline{GG_1}$, $\overline{GG_V}$	GG1, GGV	Vertical stability lever caused by a weight shift or weight addition	$\overline{KG_1} = \overline{KG_0} + \overline{GG_1}$	m
$\overline{GM}$	GM	Transverse metacentric height	Distance of center of gravity to the metacenter $\overline{KM} - \overline{KG}$	m
$\overline{GM}_{Eff}$	GMEFF	Effective transverse metacentric height	$\overline{GM}$ corrected for free surface and/or free communication effects	
$\overline{GM}_L$	GML	Longitudinal center of metacentric height	Distance from the center of gravity G to the longitudinal metacenter M_L $\overline{KM}_L - \overline{KG}$	m
$\overline{GZ}$	GZ	Righting arm or lever	$= \overline{AZ} - \overline{AG_V} \sin\phi - \overline{AG_T} \cos\phi$	m
$\overline{GZ}_{MAX}$	GZMAX	Maximum righting arm or lever		
$\overline{KA}$	ZKA	Assumed center of gravity above moulded base or keel	Distance from the assumed center of gravity A to the moulded base or keel K	m
$\overline{KB}$	ZKB	Center of buoyancy above moulded base or keel	Distance from the center of buoyancy B to the moulded base or keel K	m
$\overline{KG}$	ZKG	Center of gravity above moulded base or keel	Distance from center of gravity G to the moulded base or keel K	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
$\overline{Kg}$	ZKAG	Vertical center of gravity of added or removed weight above moulded base or keel	Distance from center of gravity, g, to the moulded base or keel K	m
$\overline{KM}$	ZKM	Transverse metacenter above moulded base or keel	Distance from the transverse metacenter M to the moulded base or keel K	m
$\overline{KM}_L$	ZKML	Longitudinal metacenter above moulded base or keel	Longitudinal M_L	m
l	XTA	Longitudinal trimming arm	$x_{cb} - x_{cg}$	m
t	YHA	Transverse heeling arm		m

1.2.4.3 Various Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
C_{MTL}	CMTL	Longitudinal trimming coefficient	trimming moment divided by change in trim which approximately equals $\overline{BM}_L / L$	1
f	FREB	Freeboard	From the freeboard markings to the freeboard deck, according to official rules	m
M_S	MS	Moment of ship stability in general	Other moments such as those of capsizing, heeling, etc. will be represented by M_S with additional subscripts as appropriate	NM
m	MA	Ship mass	W / g	kg
M_{TC}	MTC	Moment to change trim one centimeter		Nm/cm
M_{TM}	MTM	Moment to trim one meter	ΔC_{MTL}	Nm/m
t_s, t_{KL}	TRIM	Static trim	$T_A - T_F - d_{KL}$	m
W	WT	Ship weight	m g	N
z_{SF}	ZSF	Static sinkage at FP	Caused by loading	m
z_{SA}	ZSA	Static sinkage at AP	Caused by loading	m
z_S	ZS	Mean static sinkage	$(z_{SF} + z_{SA}) / 2$	m
δ	D	Finite increment in...	Prefix to other symbol	
δt_{KL}	DTR	Change in static trim		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Δ	DISPF	Displacement (buoyant) force	$g\ \rho\ \nabla$	N
∇	DISPVOL	Displacement volume	$\Delta / (\rho g)$	m^3
θ_S	TRIMS	Static trim angle	$\tan^{-1}((z_{SF} - z_{SA}) / L)$	rad
μ	PMVO	Volumetric permeability	The ratio of the volume of water entering a compartment to the volume of the compartment	1
ϕ	HEELANG	Heel angle		
ϕ_F	HEELANGF	Heel angle at flooding		

1.2.4.4 Remarks

.1 Other Notation

Alternatively, the position of the center of buoyancy B may be expressed in terms of the coordinate axes with the appropriate suffix e.g. X_B, Y_B, Z_B the position of other items such as the center of gravity, G, metacenter M and center of floatation F could also be treated in the same way.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3 Resistance and Propulsion
1.3.1 Hull Resistance (see also Section 3.4.1 on Waves)

1.3.1.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
m	BLCK	Blockage parameter	Maximum transverse area of model ship divided by tank cross section area	1
R_A	RA	Model-ship correlation allowance	Incremental resistance to be added to the smooth ship resistance to complete the model-ship prediction	N
R_{AA}	RAA	Air or wind resistance		N
R_{AP}	RAP	Appendage resistance		N
R_{AR}	RAR	Roughness resistance		N
R_C	RC	Resistance corrected for difference in temperature between resistance and self-propulsion tests	$R_{TM}((1 + k) (C_{FMC}) + C_R) / ((1 + k) (C_{FM}) + C_R))$ where C_{FMC} is the frictional coefficient at the temperature of the self-propulsion test	N
R_F	RF	Frictional resistance of a body	Due to fluid friction on the surface of the body	N
R_{FO}	RFO	Frictional resistance of a flat plate		N
R_P	RP	Pressure resistance	Due to the normal stresses over the surface of a body	N
R_{VP}	RVP	Viscous pressure resistance	Due to normal stress related to viscosity and turbulence	N
R_R	RR	Residuary resistance	$R_T - R_F$ or $R_T - R_{FO}$	N
R_{RH}	RRBH	Residuary resistance of the bare hull		N
R_S	RS	Spray resistance	Due to generation of spray	N
R_T	RT	Total resistance	Total towed resistance	N
R_{TBH}	RTBH	Total resistance of bare hull		N
R_V	RV	Total viscous resistance	$R_F + R_{VP}$	N
R_W	RW	Wavemaking resistance	Due to formation of surface waves	N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
R_{WB}	RWB	Wavebreaking resistance	Associated with the break down of the bow wave	N
R_{WP}	RWP	Wave pattern resistamce		N
S	S	Wetted surface area, underway	$S_{BH} + S_{AP}$	m^2
S_0	S0	Wetted surface area, at rest	$S_{BH0} + S_{AP0}$	m^2
S_{AP}	SAP	Appendage wetted surface area, underway		m^2
S_{AP0}	SAP0	Appendage wetted surface area, at rest		m^2
S_{BH}	SBH	Bare Hull wetted surface area, underway		m^2
S_{BH0}	SBH0	Bare Hull wetted surface area, at rest		m^2
ΔC_F	DELCF	Roughness allowance	(obsolete, see C_A)	1
V	V	Speed of the model or the ship		m/s
V_{KN}	VKN	Speed in knots		
V_R	VR	Wind velocity, relative		m/s
z_{VF}	ZVF	Running sinkage at FP		m
z_{VA}	ZVA	Running sinkage at AP		m
z_{VM}	ZVM	Mean running sinkage	$(z_{VF} + z_{VA}) / 2$	m
η	EW	Wave Elevation	see 3.4.1	m
θ_V , θ_D	TRIMV	Running (dynamic) trim angle	$\tan^{-1}((z_{VF} - z_{VA}) / L)$	1
τ_W	LSF, TAUW	Local skin friction	see 3.3.4	N/ m^2

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.3.1.2 Derived Quantities				
CA	CA	Incremental resistance coefficient for model ship correlation	$R_A / (S\ q)$	1
C_{AA}	CAA	Air or wind resistance coefficient	$R_{AA} / (A_V\ q_R)$	1
C_D	CD	Drag coefficient	$D / (S\ q)$	1
C_F	CF	Frictional resistance coefficient of a body	$R_F / (S\ q)$	1
C_{FO}	CFO	Frictional resistance coefficient of a corresponding plate	$R_{FO} / (S\ q)$	1
C_p	CP	Local pressure coefficient		1
C_{PR}	CPR	Pressure resistance coefficient, including wave effect	$R_P / (S\ q)$	1
C_{PV}	CPV	Viscous pressure resistance coefficient	$R_{PV} / (S\ q)$	1
C_R	CR	Residuary resistance coefficient	$R_R / (S\ q)$	1
C_S	CSR	Spray resistance coefficient	$R_S / (S\ q)$	1
C_T	CT	Total resistance coefficient	$R_T / (S\ q)$	1
C_{TL}	CTLT	Telfer's resistance coefficient	$g\ R\ L / (\Delta V^2)$	1
C_{TQ}	CTQ	Qualified resistance coefficient	$C_{T\nabla} / (\eta_H\ \eta_R)$	1
$C_{T\nabla}$	CTVOL	Resistance displacement	$R_T / (\nabla^{2/3}\ q)$	1
C_V	CV	Total viscous resistance coefficient	$R_V / (S\ q)$	1
C_W	CW	Wavemaking resistance coefficient	$R_W / (S\ q)$	1
C_{WP}	CWP	Wave pattern resistance coefficient, by wave analysis		1
C^C	CIRCC	R.E. Froude's resistance coefficient	$1000\ R / (\Delta (K^C)^2)$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
F^C	CIRCF	R.E. Froude's frictional resistance coefficient	$1000 R_F / (\Delta (K^C)^2)$	1
f	FC	Friction coefficient	Ratio of tangential force to normal force between two sliding bodies	1
k	K	Three dimensional form factor on flat plate friction	$(C_V - C_{FO}) / C_{FO}$	1
$k(\theta)$	WDC	Wind direction coefficient	C_{AA} / C_{AA0}	1
K^C	CIRCK	R.E. Froude's speed displacement coefficient	$(4\pi)^{1/2} F_{n\nabla}$ or $(4\pi/g)^{1/2} V_K / \nabla^{1/6}$	
K_R	KR	Resistance coefficient corresponding to K_Q, K_T	$R / (\rho D^4 n^2)$	1
q	PD, EK	Dynamic pressure, density of kinetic flow energy,	$\rho V^2 / 2$ see 3.3.2	Pa
q_R	PDWR, EKWR	Dynamic pressure based on apparent wind	$\rho V_{WR}^2 / 2$ see 3.4.2	Pa
S^C	CIRCS	R. E. Froude’ s wetted surface coefficient	$S / \nabla^{2/3}$	1
ϵ	EPSG	Resistance-displacement ratio in general	R / Δ	1
ϵ_R	EPSR	Residuary resistance-displacement ratio	R_R / Δ	1

1.3.1.3 Symbols for Attributes and Subscripts

FW	Fresh water
MF	Faired model data
MR	Raw model data
OW	Open water
SF	Faired full scale data
SR	Raw full scale data
SW	Salt water

1.3.2 Ship Performance

1.3.2.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
F_D	SFC	Skin friction correction in self propulsion test	Skin friction correction in a self propulsion test carried out at the ship self-propulsion point	N
F_P	FP	Force pulling or towing a ship		N
F_{PO}	FPO	Pull during bollard test		N
n	N	Frequency, commonly rate of revolution		Hz
P_B	PB	Brake power	Power delivered by prime mover	W
P_D , P_P	PD,PP	Delivered power, propeller power	$Q \omega$	W
P_E , P_R	PE,PR	Effective power, resistance power	$R V$	W
P_I	PI	Indicated power	Determined from pressure measured by indicator	W
P_S	PS	Shaft power	Power measured on the shaft	W
P_T	PTH	Thrust power	$T V_A$	W
Q	Q	Torque	P_D / ω	Nm
t_V	TV	Running trim		
V	V	Ship speed		m/s
V_A	VA	Propeller advance speed	Equivalent propeller open water speed based on thrust or torque identity	m/s
z_V	ZV	Running sinkage of model or ship		m
ω	V0,OMN	Angular shaft velocity	$2 \pi n$	rad/s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.2.2 Derived Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
a	RAUG	Resistance augment fraction	$(T + F_p) / R_T - 1$	1
C_{ADM}	CADM	Admiralty coefficient	$\Delta^{2/3} V^3 / P_S$	1
$C_{D\nabla}$	CDVOL	Power-displacement coefficient	$P_D / (\rho V^3 \nabla^{2/3} / 2)$	1
C_N	CN	Trial correction for propeller rate of revolution at speed identity	n_T / n_S	1
C_{NP}	CNP	Trial correction for propeller rate of revolution at power identity	P_{DT} / P_{DS}	1
C_P	CDP	Trial correction for delivered power		1
K_1	C1	Ship model correlation factor for propulsive efficiency	η_{DS} / η_{DM}	1
K_2	C2	Ship model correlation factor for propeller rate revolution	n_S / n_M	1
K_{AP}	KAP	Appendage correction factor	Scale effect correction factor for model appendage drag applied at the towing force in a self-propulsion test	1
s_V	SINKV	Sinkage, dynamic	Change of draft, fore and aft, divided by length	1
t_V	TRIMV	Trim, dynamic	Change of the trim due to dynamic condition, divided by length	1
t	THDF	Thrust deduction fraction	$1 - (R_T - F_P) / T$	1
w	WFT	Taylor wake fraction in general	$(V - V_A) / V$	1
w_F	WFF	Froude wake fraction	$(V - V_A) / V_A$	1
w_Q	WFTQ	Taylor torque wake fraction	Propeller speed V_A determined from torque identity	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
w_T	WFTT	Taylor thrust wake fraction	Propeller speed, V_A, determined from thrust identity	1
Δw	DELW	Ship-model correlation factor for wake fraction	$w_{T,M}$ - $w_{T,S}$	1
Δw_C	DELWC	Ship-model correlation factor with respect to $w_{T,s}$ method formula of ITTC 1978 method		1
x	XLO	Load fraction in power prediction	$\eta_D P_D / P_E - 1$	1
β	APSF	Appendage scale effect factor	Ship appendage resistance divided by model appendage resistance	1

1.3.2.3 Efficiencies etc

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
η_{AP}	ETAAP	Appendage efficiency	P_{EwoAP} / P_{EwAP}, R_{TBH} / R_T	1
η_B	ETAB, EFTP	Propeller efficiency behind ship	$P_T / P_D = T V_A / (Q \omega)$	1
η_D	ETAD, EFRP	Propulsive efficiency or quasi-propulsive coefficient	$P_E / P_D = P_R / P_P$	1
η_G	ETAG, EFGP	Gearing efficiency		1
η_H	ETAH, EFRT	Hull efficiency	$P_E / P_T = P_R / P_T$ $= (1 - t) / (1 - w)$	1
η_M	ETAM, EFSI	Mechanical efficiency	P_S / P_1 or P_B / P_1	1
η_O	ETAO	Propeller open water efficiency		1
η_R	ETAR, EFRO	Relative rotative efficiency	η_B / η_O	1
η_S	ETAS, EFPS	Shafting efficiency	$P_D / P_S = P_P / P_S$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.2.4 Remarks

.1 Basic Quantities

Traditionally the basic concepts resistance and propeller advance speed are implicitely understood to have certain traditional operational, i. e. experimental interpretations, namely in terms of hull towing and propeller open water tests, respectively. Very clearly these are not the only possible interpretations. In many cases, where the traditional interpretations are not possible, as in the case of full scale ships under service conditions, or where they are not meaningful, as e. g. in the case of wake adapted propellers, more adequate conventional interpretations have to be agreed upon.

The traditional set of basic concepts for the ship performance analysis is incomplete. It does e. g. not allow for the separation of displacement and energy wakes, fundamental for the analysis of hull-propeller interaction.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.3 Propulsor Performance

1.3.3.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_O	AO	Propeller disc area	$\pi D^2 / 4$	m^2
D	DP	Propeller diameter		m
n	FR	Propeller frequency of revolution		Hz
k_S	KS	Roughness height of propeller blade surface		m
q_A	QA	Dynamic pressure based on advance speed	$\rho V_A^2 / 2$ s. Remark .1	Pa
q_S	QS	Dynamic pressure based on section advance speed	$\rho V_S^2 / 2$	Pa
Q_S	QSP	Spindle torque	About spindle axis of controllable pitch propeller $Q_S = Q_{SC} + Q_{SH}$ positive if it increases pitch	Nm
Q_{SC}	QSPC	Centrifugal spindle torque		Nm
Q_{SH}	QSPH	Hydrodynamic spindle torque		Nm
T	TH	Propeller thrust		N
T_D	THDU	Duct thrust		N
T_P	THP	Ducted propeller thrust		N
T_T	THT	Total thrust of a ducted propeller unit		N
V_A	VA	Advance speed of propeller		m/s
V_P	VP	Mean axial velocity at propeller plane of ducted propeller		m/s
V_S	VS	Section advance speed at 0.7 R	$(V_A^2 + (0.7\ R\ \omega)^2)^{1/2}$ s. Remark .2	m/s
ρ_P	DNP	Propeller mass density		kg/m^3
ω	V0P	Propeller angular velocity	$2\ \pi\ n$	1/s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.3.2 Derived Quantities

B_P	BP	Taylor's propeller coefficient based on delivered horse power	$n P_D^{1/2} / V_A^{2.5}$ with n is revs/min, P_D in horsepower,and V_A in knots (obsolete)	1
B_U	BU	Taylor's propeller coefficient based on thrust horsepower	$n P_T^{1/2} / V_A^{2.5}$ with n is revs/min, P_T in horsepower,and V_A in knots (obsolete)	1
C_P	CPD	Power loading coefficient	$P_D / (A_P q_A V_A)$	1
C_{Q*}	CQS	Torque index	$Q / (A_P q_S)$	1
C_{Th}	CTH	Thrust loading coefficient, energy loading coefficient	$T / (A_P q_A)$ $= (T_P / A_P) / q_A$	1
C_{T*}	CTHS	Thrust index	$T / (A_P q_S)$	1
J	JEI,	Propeller advance ratio	$V_A / (D n)$	1
J_A , J_H	JA, JH	Apparent or hull advance ratio	$V / (D n) = V_H / (D n)$	1
J_P	JP	Propeller advance ratio for ducted propeller	$V_P / (D n)$	
J_T , J_{PT}	JT, JPT	Advance ratio of propeller determined from thrust identity		1
J_Q , J_{PQ}	JQ, JPQ	Advance ratio of propeller determined from torque identity		1
K_P	KP	Delivered power coefficient	$P_D / (\rho n^3 D^5) = 2 \pi K_Q$	1
K_Q	KQ	Torque coefficient	$Q / (\rho n^2 D^5)$	1
K_{SC}	KSC	Centrifugal spindle torque coefficient	$Q_{SC} / (\rho_P n^2 D^5)$	1
K_{SH}	KSH	Hydrodynamic spindle torque coefficient	$Q_{SH} / (\rho n^2 D^5)$	1
K_T	KT	Thrust coefficient	$T / (\rho n^2 D^4)$	1
K_{TD}	KTD	Duct thrust coefficient	$T_D / (\rho n^2 D^4)$	1
K_{TP}	KTP	Ducted propeller thrust coefficient	$T_P / (\rho n^2 D^4)$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
K_{TT}	KTT	Total thrust coefficient for a ducted propeller unit	$K_{TP} + K_{TD}$	1
K_{QO}	KQO	Torque coefficient of propeller converted from behind to open water condition	$K_Q \cdot \eta_R$	1
K_{QT}	KQ	Torque coefficient of propeller determined from thrust coefficient identity		1
P_J	PJ	Propeller jet power	η_{TJ} T V_A	
S_A	SRA	Apparent slip ratio	1 − V / (n P)	1
S_R	SRR	Real slip ratio	1 − V_A / (n P)	1
δ	ADCT	Taylor's advance coefficient	n D / V_A with n in revs/min, D in feet, V_A in knots (obsolete)	1
η_{JP}	EFJP	Propeller pump or hydraulic efficiency	$P_J / P_D = P_J / P_P$	1
η_{JP0}	ZETO, EFJPO	Propeller pump efficiency at zero advance speed, alias static thrust coefficient	$T / (\rho \pi / 2)^{1/3} / (P_D D)^{2/3}$	1
η_I	EFID	Ideal propeller efficiency	Efficiency in non-viscous fluid	1
η_{TJ}	EFTJ	Propeller jet efficiency	$2 / (1 + (1 + C_{Th})^{1/2})$	1
η_O , η_{TPO}	ETAO, EFTPO	Propeller efficiency in open water	$P_T / P_D = T V_A / (Q \omega)$ all quantities measured in open water tests	1
λ	ADR	Advance ratio of a propeller	$V_A / (n D) / \pi = J / \pi$	1
τ	TMR	Ratio between propeller thrust and total thrust of ducted propeller	T_P / T_T	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.3.3 Induced Velocities etc

U_A	UA	Axial velocity induced by propeller		m/s
U_{AD}	UADU	Axial velocity induced by duct of ducted propeller		m/s
U_{RP}	URP	Radial velocity induced by propeller of ducted propeller		m/s
U_{RD}	URDU	Radial velocity induced by duct of ducted propeller		m/s
U_{AP}	UAP	Axial velocity induced by propeller of ducted propeller		m/s
U_R	UR	Radial velocity induced by propeller		m/s
U_{TD}	UTDU	Tangential velocity induced by duct of ducted propeller		m/s
U_{TP}	UTP	Tangential velocity induced by propeller of ducted propeller		m/s
U_T	UT	Tangential velocity induced by propeller		m/s
β	BETB	Advance angle of a propeller blade section	$\mathrm{arctg}\,(V_A / (R\,\omega))$	rad
β_1	BET1	Hydrodynamic flow angle of a propeller blade section	Flow angle taking into account induced velocity	rad
β^*	BETS	Effective advance angle	$\mathrm{arctg}\,(V_A/ (0.7\,R\,\omega))$	rad

1.3.3.4 Waterjets (Future location: see Section 5.1, pp 130-131 of Version 1996)

1.3.3.4 Remarks

.1 Dynamic Pressure

It has become bad practice to write

$$q = \rho/2\ V^2 \text{ instead of } q = \rho\ V^2/2$$

for the dynamic pressure. This is confusing and should be avoided.

.2 Section Advance Speed

In the earlier versions of this list the notation for the concept of section advance speed deteriorated to the completely meaningless form

$$V_S = (V_A{}^2 + (0.7\ \pi\ n\ D)^2)^{1/2}\ ,$$

hiding the very simple meaning of the concept.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.3.4 Unsteady Propeller Forces

1.3.4.1 Basic Quantities

C_{uv}	SI(U,V)	Generalized stiffness	s. Remark .1	
D_{uv}	DA(U,V)	Generalized damping	s. Remark .1	
F_u	FG(I)	Generalized vibratory force	u = 1,.., 6 u = 1, 2, 3: force u = 4, 5, 6: moment	N N Nm
F_i	F(I)	Vibratory force	i = 1, 2, 3	N
K_{Fu}	KF(U)	Generalized vibratory force coefficients	According to definitions of K_{Fi} and K_{Mi}	1
K_{Fi}	KF(I)	Vibratory force coefficients	$F_i / (\rho\, n^2 D^4)$	1
K_{Mi}	KM(I)	Vibratory moment coefficients	$M_i / (\rho\, n^2 D^5)$	1
K_p	KPR	Pressure coefficient	$p / (\rho\, n^2 D^2)$	1
M_i	M(I)	Vibratory moment	i = 1, 2, 3	Nm
M_{uv}	MA(U,V)	Generalized mass	s. Remark .1	
p	PR	Pressure		Pa
R_u	R(U)	Generalized vibratory bearing reaction	u = 1,.., 6 u = 1, 2, 3: force u = 4, 5, 6: moment	N N Nm
V_i	V(I)	Velocity field of the wake	i = 1, 2, 3	m/s
x y z	X Y Z	Cartesian coordinates	Origin O coinciding with the centre of the propeller. The longitudinal x-axis coincides with the shaft axis, positive forward; the transverse y-axis, positive to port; the third, z-axis, positive upward	m m m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
x a r	X ATT R	Cylindrical coordinates	Cylindrical system with origin O and longitudinal x-axis as defined before; angular a-(attitude)-coordinate , zero at 12 o'clock position, positive clockwise looking forward, r distance measured from the x-axis	m 1 m
δ_u	DP(U)	Generalized vibratory displacement	u = 1,.., 6 u = 1, 2, 3: linear u = 4, 5, 6: angular	m m rad
$\dot{\delta}_u$	DPVL(U)	Generalized vibratory velocity	u = 1,.., 6 u = 1, 2, 3: linear u = 4, 5, 6: angular	m/s m/s rad/s
$\ddot{\delta}_u$	DPAC(U)	Generalized vibratory acceleration	u = 1,.., 6 u = 1, 2, 3: linear u = 4, 5, 6: angular	m/s^2 m/s^2 rad/s^2

1.3.4.2 Remarks

.1 General Quantities

The generalized Quantities have been introduced in Section 3. **General Mechanics**.

.2 Equation of motion

In terms of the notation introduced the linear equation of motions may be rendered in the concise form

$$M_{uv}\,\ddot{\delta}_v + D_{uv}\,\dot{\delta}_v + C_{uv}\,\delta_v = F_u\ .$$

In spectral terms it is just as simple

$$(M_{uv}\,(i\omega)^2 + D_{uv}\,i\omega + C_{uv})\ \delta^S_v = F^S_u\ .$$

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.4	**Manoeuvring and Seakeeping**	s. Remark .1		
1.4.1	**Manoeuvring**			
1.4.1.1	**Geometrical Quantities**	see also Section 1.2.1 and Section 1.2.3		
A_{FB}	AFBO	Area of bow fins		m^2
A_{FS}	AFST	Area of stern fins		m^2
A_{HL}	AHLT	Lateral area of the hull	The area of the profile of the underwater hull of a ship when projected normally upon the longitudinal centre plane	m^2
A_{LV}	AHLV	Lateral area of hull above water		m^2
A_R	ARU	Total lateral area of rudder		m^2
A_{Rmov}	ARMV	Movable area of rudder		m^2
A_{RN}	ARNO	Nominal area of rudder	$(A_R + A_{Rmov}) / 2$	m^2
b_R	SPRU	Rudder span		m
b_{RM}	SPRUME	Mean span of rudder		m
C_{AL}	CAHL	Coefficient of lateral area of ship	$A_{HL} / (L\ T)$	1
h	DE	Water depth		m
h_M	DEME	Mean water depth		m
x_R	XRU	Longitudinal position of rudder axis		m
λ_R	ASRU	Aspect ratio of rudder	b_R^2 / A_R	1
1.4.1.2	**Motions and Attitudes**			
p	OX, P	Roll velocity, angular velocity about body x-axis		1/s
q	OY, Q	Pitch velocity, angular velocity about body y-axis		1/s
r	OZ, R	Yaw velocity, angular velocity about body z-axis		1/s
$\dot{p}$	OXRT, PR	Roll acceleration, angular acceleration about body x-axis	dp / dt	$1/s^2$

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
$\dot{q}$	OYRT, QR	Pitch acceleration, angular acceleration about body y-axis	dq / dt	$1/s^2$
$\dot{r}$	OZRT, RR	Yaw acceleration, angular acceleration about body z-axis	dr / dt	$1/s^2$
u	VX, U	Surge velocity, linear velocity along body x-axis		m/s
v	VY, V	Sway velocity, linear velocity along body y-axis		m/s
w	VZ, W	Heave velocity, linear velocity along body z-axis		m/s
$\dot{u}$	VXRT, UR	Surge acceleration, linear acceleration along body x-axis	du / dt	m/s^2
$\dot{v}$	VYRT, VR	Sway acceleration, linear acceleration along body y-axis	dv / dt	m/s^2
$\dot{w}$	VZRT, WR	Heave acceleration, linear acceleration along body z-axis	dw / dt	m/s^2
V	V	Linear velocity of origin in body axes		m/s
V_A,V_O	VA, VO	Approach speed		m/s
V_u	V(U)	Generalized velocity		m/s
$\dot{V}_u$	V(U)	Generalized acceleration		m/s^2
V_F	VF	Flow or current velocity		m/s
V_{WR}	VWREL	Relative wind velocity		m/s
V_{WT}	VWABS	True wind velocity		m/s
ψ	YA	Yaw or course angle		rad
$d_t\psi$	YART	Rate of change of course	$d\psi$ / dt	rad/s
ψ_0	YAOR	Original course		rad
θ	PI	Pitch angle		rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
ϕ	RO	Roll angle		rad

1.4.1.3 Flow Angles etc

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
α	AAPI	Pitch angle	Angle of attack in pitch on the hull	rad
β	AADR	Drift angle	Angle of attack in yaw on the hull	rad
β_{WR}	ANWIRL	Angle of attack of relative wind		1
δ_{eff}	ANRUEF	Effective rudder inflow angle		rad
δ_0	ANRU0	Neutral rudder angle		1
δ_B	ANFB	Bow fin angle		rad
δ_S	ANFS	Stern fin angle		rad
δ_R	ANRU	Rudder angle		1
δ_{R0}	ANRUOR	Rudder angle, ordered		1
ψ_C	COCU	Course of current velocity		1
ψ_{WA}	COWIAB	Absolute wind direction	see also section 3.4.2, Wind	rad
ψ_{WR}	COWIRL	Relative wind direction		rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.4.1.4 Forces and Derivatives		s. Remark .2		
K	MX	Roll moment on body, moment about body x-axis		Nm
M	MY	Pitch moment on body, moment about body y-axis		Nm
N	MZ	Yaw moment on body, moment about body z-axis		Nm
N_r	NR	Derivative of yaw moment with respect to yaw velocity	$\partial N / \partial r$	Nms
$N_{\dot{r}}$	NRRT	Derivative of yaw moment with respect to yaw acceleration	$\partial N / \partial \dot{r}$	Nms^2
N_v	NV	Derivative of yaw moment with respect to sway velocity	$\partial N / \partial v$	Ns
$N_{\dot{v}}$	NVRT	Derivative of yaw moment with respect to sway acceleration	$\partial N / \partial \dot{v}$	Nms^2
N_δ	ND	Derivative of yaw moment with respect to rudder angle	$\partial N / \partial \delta$	Nm
Q_{FB}	QFB	Torque of bow fin		Nm
Q_R	QRU	Torque about rudder stock		Nm
Q_{FS}	QFS	Torque of stern fin		Nm
X	FX	Surge force on body, force along body x-axis		N
X_R	XRU	Longitudinal rudder force		N
X_u	XU	Derivative of surge force with respect to surge velocity	$\partial X / \partial u$	Ns/m
$X_{\dot{u}}$	XURT	Derivative of surge force with respect to surge acceleration	$\partial X / \partial \dot{u}$	Ns^2/m
Y	FY	Sway force on body, force along body y-axis		N
Y_r	YR	Derivative of sway force with respect to yaw velocity	$\partial Y / \partial r$	Ns
Y_R	YRU	Transverse rudder force		N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
$Y_{\dot{r}}$	YRRT	Derivative of sway force with respect to yaw acceleration	$\partial Y / \partial \dot{r}$	Ns^2
Y_v	YV	Derivative of sway force with respect to sway velocity	$\partial Y / \partial v$	Ns/m
$Y_{\dot{v}}$	YVRT	Derivative of sway force with respect to sway acceleration	$\partial Y / \partial \dot{v}$	Ns^2/m
Y_δ	YD	Derivative of sway force with respect to rudder angle	$\partial Y / \partial \delta$	N
Z	FZ	Heave force on body, force along body z-axis		N

1.4.1.5 Linear Models

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
C_r	CRDS	Directional stability criterion	$Y_v (N_r - mux_G) - N_v (Y_r - mu)$	N^2s^2
L_b	LSB	Static stability lever	N_v / Y_v	m
L_d	LSR	Damping stability lever	$(N_r - mux_G) / (Y_r - mu)$	m
T	TIC	Time constant of the 1st order manoeuvring equation		s
T_1	TIC1	First time constant of manoeuvring equation		s
T_2	TIC2	Second time constant of manoeuvring equation		s
T_3	TIC3	Third time constant of manoeuvring equation		s
K	KS	Gain factor in linear manoeuvring equation		1/s
P_n	PN	P-number, heading change per unit rudder angle in one ship length		1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.4.1.6 Turning Circles				
D_C	DC	Steady turning diameter		m
D_C'	DCNO	Non-dimensional steady turning diameter	D_C / L_{PP}	1
D_0	DC0	Inherent steady turning diameter $\delta_R = \delta_0$		m
D_0'	DC0N	Non-dimensional inherent steady turning diameter	D_0 / L_{PP}	1
l_r	LHRD	Loop height of r-δ curve for unstable ship		1/s
l_δ	LWRD	Loop width of r-δ curve for unstable ship		1
r_C	OZCI	Steady turning rate		1/s
r_C'	OZCINO	Non-dimensional steady turning rate	$r_C L_{PP} / U_C$ or $2 L_{PP} / D_C$	m
R_C	RC	Steady turning radius		m
t_{90}	TI90	Time to reach 90 degree change of heading		s
t_{180}	TI180	Time to reach 180 degree change of heading		s
U_C	UC	Speed in steady turn		m/s
x_{090}	X090	Advance at 90° change of heading		m
x_{0180}	X0180	Advance at 180° change of heading		m
x_{0max}	XMX	Maximum advance		m
y_{090}	Y090	Transfer at 90° change of heading		m
y_{0180}	Y0180	Transfer at 180° change of heading, tactical diameter		m
y_{0max}	Y0MX	Maximum transfer		m
β_C	DRCI	Drift angle at steady turning		rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
1.4.1.7 Zig-Zag Manoeuvres				
t_a	TIA	Initial turning time		s
t_{c1}	TIC1	First time to check yaw (starboard)		s
t_{c2}	TIC2	Second time to check yaw (port)		s
t_{hc}	TCHC	Period of changes in heading		s
t_r	TIR	Reach time		s
y_{0max}	Y0MX	Maximum transverse deviation		m
δ_{max}	ANRUMX	Maximum value of rudder angle		rad
ψ_S	PSIS	Switching value of course angle		rad
ψ_{01}	PSI01	First overshoot angle		rad
ψ_{02}	PSI02	Second overshoot angle		rad
1.4.1.8 Stopping Manoeuvres				
s_F	SPF	Distance along track, track reach		m
x_{0F}	X0F	Head reach		m
y_{0F}	Y0F	Lateral deviation		m
t_F	TIF	Stopping time		s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.4.1.9 Remarks

.1 Solid Body Motions

The whole Chapter 1.4 on Manoeuvring and Seakeeping relies heavily on the Section 3 on **General Mechanics**, Chapter 3.2 on **Solid Body Mechanics** in particular. Members of the Manoeuvring Committee are strongly urged to suggest further improvements in this section.

.2 Derivatives

The traditional notation for the "stability" derivatives is not very efficient and not in accordance with the notation outlined in Section 3 on General Mechanics. Instead of completely denoting the concepts of generalized hydrodynamic damping and inertia, respectively, by adequate symbols, the traditional symbols indicate some measuring procedures for the components.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

1.4.2 Seakeeping

Related information is to be found in Chapter 3 on General Mechanics in Sections 3.1.2 on **Time and Frequency Domain Quantities**, 3.1.3 on **Stochastic Processes**, 3.2.1 on **Inertial Propertiess,**, 3.2.2 on **Loads,** 3.2.3 on **Rigid Body Motions**, and 3.4.1 on **Waves**.

1.4.2.1 Basic Quantities

a_i	AT(I)	Attitudes of the floating system	i = 1, 2, 3, e. g. Euler angles of roll, pitch, and yaw, respectively	rad
f	FR	Frequency	$1 / T$	Hz
f_e	FE	Frequency of wave encounter	$1 / T_e$	Hz
f_z		Natural frequency of heave	$1 / T_z$	Hz
f_θ		Natural frequency of pitch	$1 / T_\theta$	Hz
f_ϕ		Natural frequency of roll	$1 / T_\phi$	Hz
F_L	FS(2)	Wave excited lateral shear force	Alias horizontal! s. Remark .1	N
F_N	FS(3)	Wave excited normal shear force	Alias vertical! s. Remark .1	N
M_L	MB(3), FS(6)	Wave excited lateral bending moment	Alias horizontal! s. Remark .1	Nm
M_N	MB(2), FS(5)	Wave excited normal bending moment	Alias vertical! s. Remark .1	Nm
M_T	MT(1), FS(4)	Wave excited torsional moment		Nm
n_{AW}	NAW	Mean increase of rate of revolution in waves		1/s
P_{AW}	PAW	Mean power increase in waves		W
Q_{AW}	QAW	Mean torque increase in waves		Nm
R_{AW}	RAW	Mean resistance increase in waves		N
$S_\eta(f)$, $S_{\eta\eta}(f)$, $S_\eta(\omega)$, $S_{\eta\eta}(\omega)$	EWSF, EWSC	Wave elevation auto spectral density	see also section 3.4.1, Waves	m^2s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
x_i	X(I)	Absolute displacement of the ship at the reference point	i = 1, 2, 3 :surge, sway, and heave respectively	m
x_u	X(U)	Generalized displacement of a ship at the reference point	u = 1...6 surge, sway, heave, roll, pitch, yaw	m rad
T_{AW}	TAW	Mean thrust increase in waves		N
T	TC	Wave period		s
T_e	TE	Wave encounter period		s
T_z	TNHE	Natural period of heave		s
T_θ	TNPI	Natural period of pitch		s
T_ϕ	TNRO	Natural period of roll		s
$Y_z(\omega)$, $A_{z\zeta}(\omega)$		Amplitude of frequency response function for translatory motions	$z_a(\omega) / \zeta_a(\omega)$ or $z_a(\omega) / \eta_a(\omega)$	1
$Y_{\theta\zeta}(\omega)$, $A_{\theta\zeta}(\omega)$		Amplitude of frequency response function for rotary motions	$\Theta_a(\omega) / \zeta_a(\omega)$ or $\Theta_a(\omega) / (\omega^2/ (g\zeta_a(\omega)))$	1
μ		Wave encounter angle	Angle between ship positive x axis and positive direction of waves (long crested) or dominant wave direction (short crested)	rad

Remarks

.1 Sectional Loads

Sectional loads are meaningful only referred to body fixed coordinates. The traditional terminology speaking of horizontal and vertical forces and moments, referring to space fixed coordinates, is adequate only for very special conditions of little interest for the sectional loads and should consequently be avoided as obsolete.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2 Special Craft
2.1 Planing and Semi-Displacement Vessels

2.1.1 Geometry and Hydrostatics

See also Section 1.2.1, Hull Geometry

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_P	APB	Planing bottom area	Horizontally projected planing bottom area (at rest), excluding area of external spray strips	m^2
B_{LCG}	BLCG	Beam at longitudinal position of the centre of gravity	Breadth over spray strips measured at transverse section containing centre of gravity	m
B_{PC}	BPC	Beam over chines	Beam over chines, excluding external spray strips	m
B_{PA}	BPA	Mean breadth over chines	A_P / L_P	m
B_{PT}	BPT	Transom breadth	Breadth over chines at transom, excluding external spray strips	m
B_{PX}	BPX	Maximum breadth over chines	Maximum breadth over chines, excluding external spray strips	m
L_{SB}	LSB	Total length of shafts and bossings		m
L_{PR}	LPRC	Projected chine length	Length of chine projected in a plane parallel to keel	m
β	BETD	Deadrise angle of planing bottom	Angle between a straight line approximating body section and the intersection of the basis plane with the section plane	1
β_M	BETM	Deadrise angle at midship section		1
β_T	BETT	Deadrise angle at transom		1
ϵ_{SH}	EPSSH	Shaft Angle	Angle between shaft line and reference line (positive, shaft inclined downwards)	

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.1.2 Geometry and Levers, Underway

2.1.2.1 Geometry, Underway

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
d_{TR}	DTRA	Immersion of transom, underway	Vertical depth of trailing edge of boat at keel below water surface level	m
h_P	HSP	Wetted height of strut palms		m
h_R	HRU	Wetted height of rudders		m
L_C	LC	Wetted chine length, underway		m
l_{CP}	LCP	Lever of resultant of pressure forces, underway	Distance between center of pressure and aft end of planing surface	m
L_K	LK	Wetted keel length, underway		m
L_M	LM	Mean wetted length, underway	$(L_K + L_C) / 2$	m
S_{WHP}	SWHP	Wetted area underway of planing hull	Principal wetted area bounded by trailing edge, chines and spray root line	m^2
S_{WB}	SWB	Wetted bottom area, underway	Area bounded by stagnation line, chines or water surface underway and transom	m^2
S_{WHE}	SWHE	Wetted hull area, underway	Total wetted surface of hull underway, including spray area and wetted side area, w/o wetted transom area	m^2
S_{WHS}	SWSH	Area of wetted sides	Wetted area of the hull side above the chine or the design water line	m^2
S_{WS}, S_S	SWS	Area wetted by spray	Wetted area between design line or stagnation line and spray edge	m^2
α_B	ALFSL	Angle of stagnation line	Angle between projected keel and stagnation line a in plane normal to centerplane and parallel to reference line	rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
α_{BAR}	ALFBAR	Barrel flow angle	Angle between barrel axis and assumed flow lines	rad
ϵ_{WL}	EPSWL	Wetted length factor	L_M / L_{WL}	1
ϵ_{WS}	EPSWS	Wetted surface area factor	S / S_0	1
θ_{DWL}	TRIMDWL	Running trim angle based on design waterline	Angle between design waterline and running waterline (positive bow up)	rad
θ_S, θ_0	TRIMS	Static trim angle	Angle between ship design waterline and actual water line at rest (positive bow up) $\tan^{-1}((z_{SF} - z_{SA}) / L)$	rad
θ_V , θ_D	TRIMV	Running (dynamic) trim angle	Angle between actual water line at rest and running water line (positive bow up) $\tan^{-1}((z_{VF} - z_{VA}) / L)$	rad
λ_W	LAMS	Mean wetted length-beam ratio	L_M / (B_{LCG})	1
τ_{DWL}	TAUDWL	Reference line angle	Angle between the reference line and the design waterline	1
τ_R	TAUR	Angle of attack relative to the reference line	Angle between the reference line and the running waterline	1
ϕ_{SP}	PHISP	Spray angle	Angle between stagnation line and keel (measured in plane of bottom)	1
$\delta\lambda$	DLAM	Dimensionless increase in total friction area	Effective increase in friction area length-beam ratio due to spray contribution to drag	1

2.1.2.2 **Levers, Underway** (This section is under construction and needs further clarification)

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
e_A	ENAPP	Lever of appendage lift force N_A	Distance between N_A and center of gravity (measured normally to N_A)	m
e_B	ENBOT	Lever of bottom normal force N_B	Distance between N_B and center of gravity (measured normally to N_B)	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
e_{PN}	ENPN	Lever of propeller normal force N_{PN}	Distance between propeller centerline and center of gravity (measured along shaft line)	m
e_{PP}	ENPP	Lever of resultant of propeller pressure forces N_{PP}	Distance between N_{PP} and center of gravity (measured normally to N_{PP})	m
e_{PS}	ENPS	Lever of resultant propeller suction forces N_{PS}	Distance between N_{PS} and center of gravity (measured normal to N_{PS})	m
e_{RP}	ENRP	Lever of resultant of rudder pressure forces N_{RP}	Distance between N_{RP} and center of gravity (measured normal to N_{RP})	m
f_{AA}	FRAA	Lever of wind force R_{AA}	Distance between R_{AA} and center of gravity (measured normal to R_{AA})	m
f_{AP}	FRAP	Lever of appendage drag R_{AP}	Distance between R_{AP} and center of gravity (measured normal to R_{AP})	m
f_F	FRF	Lever of frictional resistance R_F	Distance between R_F and center of gravity (measured normal to R_F)	m
f_K	FRK	Lever of skeg or keel resistance R_K	Distance between R_K and center of gravity (measured normal to R_K)	m
f_R	FDRR	Lever of augmented rudder drag ΔR_{RP}	Distance between ΔR_{RP} and center of gravity (measured normal to ΔR_{RP})	m
f_S	FSL	Lever of axial propeller thrust	Distance between axial thrust and center of gravity (measured normal to shaft line)	m
f_T	FRT	Lever of total resistance R_T	Distance between R_T and center of gravity (measured normal to R_T)	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
2.1.3	**Resistance and Propulsion**		See also **Sections 1.3.1 on Hull Resistance**	
C_{Lo}	CL0D	Lift coefficient for zero deadrise	$\Delta / (B_{CG}^2\ q)$	1
$C_{L\beta}$	CLBET	Lift coefficient for deadrise surface	$\Delta / (B_{CG}^2\ q)$	1
C_V	CSP	Froude number based on breadth	$V / (B_{CG}\ g)^{1/2}$	1
C_Δ	CDL	Load coefficient	$\Delta / (B_{CG}^3\ \rho\ g)$	1
L_{VHD}	LVD	Vertical component of hydrodynamic lift		N
L_{VS}	LVS	Hydrostatic lift	Due to buoyancy	N
F_{TA}	FTAPP	Appendage drag force (parallel to reference line)	Drag forces arising from appendages inclined to flow, assumed to act parallel to the reference line	N
F_{TB}	FTBOT	Bottom frictional force (parallel to reference line)	Viscous component of bottom drag forces assumed acting parallel to the reference line	N
F_{TK}	FTKL	Keel or skeg drag force (parallel to reference line)	Drag forces arising from keel or skeg, assumed to act parallel to the reference line	N
F_{TRP}	FTRP	Additional rudder drag force (parallel to reference line)	Drag forces arising from influence of propeller wake on the rudder assumed to act parallel to the reference line	N
N_A	NAPP	Appendage lift force (normal to reference line)	Lift forces arising from appendages inclined to flow, assumed to act normally to reference line	N
N_B	NBOT	Bottom normal force (normal to reference line)	Resultant of pressure and buoyant forces assumed acting normally to the reference line	N
N_{PP}	NPP	Propeller pressure force (normal to reference line)	Resultant of propeller pressure forces acting normally to the reference line	N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
N_{PS}	NPS	Propeller suction force (normal to reference line)	Resultant of propeller suction forces acting normally to the reference line	N
N_{RP}	NRP	Rudder pressure force (normal to reference line)	Resultant of rudder pressure forces acting normally to the reference line	
R_K	RKEEL	Keel drag		N
R_π	RPI	Induced drag	$g \rho \nabla \mathrm{tg} \tau$	N
R_{PAR}	RPAR	Parasitic drag	Drag due to inlet and outlet openings	N
R_{PS}	RSP	Pressure component of spray drag		N
R_T	RT	Total resistance	Total towed resistance	N
R_{VS}	RSV	Viscous component of spray drag	$C_F S_{WS} q_S$	N
V_{BM}	VBM	Mean bottom velocity	Mean velocity over bottom of the hull	m/s
V_{SP}	VSP	Spray velocity	Relative velocity between hull and spray in direction of the spray	m/s

2.1.3. **Remarks**

.1 **Force orientations**
As a rule, the symbol R (resistance) is used when forces are directed horizontally, parallel and opposite to boat velocity and V when forces are directed vertically, normal to the boat velocity. Further, symbols N_F, F_N (normal) and F_T or D_F (tangential) are used for forces acting normally and tangentially to the reference line (keel or mean buttock line). The SaT Group prefers the use of F_T for the tangential forces, but the standard references (Savitsky and Hadler) use the second set of symbols.

.2 Reference line
The reference line line must be defined for each application. It is ususally the keel line or mean buttock line.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.2 Multi-Hull Vessels

2.2.1 Geometry and Hydrostatics

See also Section 1.2.1, Hull Geometry

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_I	AIA	Strut-hull intersection area		m^2
B_B	BB	Box beam	Beam of main deck	m
B_S	BS	Hull spacing	Distance between hull center lines	m
B_{TV}	BTUN	Tunnel width	Minimal distance of the demihulls at the waterline	m
D_H	DHUL	Hull diameter	Diameter of axis symmetric submerged hulls	m
D_X	DX	Hull diameter at the longitudinal position "X"		m
H_{DK}	HCLDK	Deck clearance	Minimum clearance of wet deck from water surface at rest	m
H_{SS}	HSS	Strut submerged depth	Depth of strut from still water line to strut-hull intersection	m
i_{EI}	ANENIN	Half angle of entrance at tunnel (inner) side	Angle of inner water line with reference to centre line of demihull	rad
i_{EO}	ANENOU	Half angle of entrance at outer side	Angle of outer water line with reference to centre line of demihull	rad
L_{CH}	LCH	Length of center section of hull	Length of prismatic part of hull	m
L_{CS}	LCS	Length of center section of strut	Length of prismatic part of strut	m
L_H	LH	Box length	Length of main deck	m
L_{NH}	LNH	Length of nose section of hull	Length of nose section of hull with variable diameter	m
L_{NS}	LNS	Length of nose section of strut	Length of nose section of strut with variable thickness	m
L_S	LS	Strut length	Length of strut from leading to trailing edge	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
L_{SH}	LSH	Length of submerged hull		m
t_s	TSTR	Maximum thickness of strut		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.2.2 Resistance and Propulsion

2.2.2.1 Resistance Components

See also **Section 1.3.1 on Hull Resistance**

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
R_{FMH}	RFMH	Frictional resistance of multi-hull vessel		N
R_{FINT}	RFINT	Frictional resistance interference correction	$R_{FMH} - 2\,R_F$	N
R_{RMH}	RRMH	Residuary resistance correction of multi-hull	$R_{TMH} - R_{FMH}$	N
R_{RI}	RRINT	Residuary resistance interference correction	$R_{RMH} - 2\,R_R$	N
R_{TMH}	RTMH	Total resistance of multi-hull vessel		N
R_{TI}	RTINT	Total resistance interference correction	$R_{TMH} - 2\,R_T$	N

2.2.2.2 Remarks

.1 Single hull quantities

In general, no specific symbols are introduced for quantities referred to single hulls because the use of symbols listed in Chapter 1 (Ships in General) is suggested without adding "ad hoc" subscripts or superscripts. For planing catamarans, several quantities can be found in section 2.1, Planing and Semi-displacement vessels.

.2 Resistance

Only the main resistance components are listed. If necessary, other symbols may be created for other resistance components, in particular for different interference effects.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.3 Hydrofoil Boats

2.3.1 Geometry and Hydostatics

See Sections 1.2.1 and Sections 1.2.4

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_F	AFO	Foil area (general)	Foil area in horizontal plane	m^2
A_{FT}	AFT	Total foil plan area		m^2
B_{FOA}	BFOA	Maximum vessel breadth including foils		m
b_S	BST	Span of struts		m
b_{ST}	BSTT	Transverse horizontal distance of struts		m
c_C	CHC	Chord length at center plane		m
c_F	CFL	Chord length of flap		m
c_M	CHM	Mean chord length		m
c_S	CSTR	Chord length of a strut		m
c_{SF}	CHSF	Chord length of strut at intersection with foil		m
c_T	CHTI	Chord length at foil tips		m
W_F	WTF	Weight of foil		N
α_c	ALFTW	Geometric angle of twist		1
θ_{DH}	DIHED	Dihedral angle		1
∇_F	DISVF	Foil displacement volume		m^3

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
2.3.1.1 **Geometry, Underway**				
A_{FE}	AFE	Emerged area of foil		m^2
A_{FF}	ASFF	Submerged area of front foil		m^2
A_{FR}	ASFR	Submerged area of rear foil		m^2
A_{FS}	AFS	Submerged foil area		m^2
A_{FST}	AFSTO	Submerged foil plan area at take-off speed		m^2
A_{SS}	ASS	Submerged strut area		m^2
b_w	BSPW	Foil span wetted		m
c_{PF}	CPFL	Distance of center of pressure on a foil or flap from leading edge		m
F_{nL}	FNFD	Froude number based on foil distance	$V / (g\ L_{FR})^{1/2}$	1
F_{nc}	FNC	Froude number based on chord length	$V / (g\ c_M)^{1/2}$	1
h_{CG}	HVCG	Height of center of gravity foilborne	Distance of center of gravity above mean water surface	m
h_F	HFL	Flight height	Height of foil chord at foilborne mode above position at rest	m
h_K	HKE	Keel clearance	Distance between keel and mean water surface foilborne	m
l_F	LEFF	Horizontal distance of center of pressure of front foil to center of gravity		m
l_{FR}	LEFR	Horizontal distance between centers of pressure of front and rear foils	$l_F + l_R$	m
l_R	LERF	Horizontal distance of center of pressure of rear foil to center of gravity		m
T_F	TFO	Foil immersion	Distance between foil chord and mean water surface	m
T_{FD}	TFD	Depth of submergence of apex of a dihedral foil	Distance between foil apex and mean water surface	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
T_{FM}	TFOM	Mean depth of foil submergence		m
α_{IND}	ALFIND	Downwash or induced angle		1
α_{M}	ALFM	Angle of attack of mean lift coefficient for foils with twist		1
α_{s}	AFS	Angle of attack for which flow separation (stall) occurs		1
α_{TO}	ATO	Incidence angle at take-off speed		1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
2.3.2	**Resistance and Propulsion**		See also **Section 1.3.1 Hull Resistance**	
2.3.2.1	**Basic Quantities**			
D_F	DRF	Foil drag	Force in the direction of motion of an immersed foil	N
D_{FR}	DFA	Drag force on rear foil	C_{DF} A_{FR} q	N
D_{FF}	DFF	Drag force on front foil	C_{DF} A_{FF} q	N
D_I	DRIND	Induced drag	For finite span foil, the component of lift in the direction of motion	N
D_{INT}	DRINT	Interference drag	Due to mutual interaction of the boundary layers of intersecting foil	N
D_{P0}	DRF0	Profile drag for angle of attack equal to zero lift	Streamline drag	N
D_S	DRSP	Spray drag	Due to spray generation	N
D_{ST}	DRST	Strut drag		N
D_W	DRWA	Wave drag	Due to propagation of surface waves	N
D_V	DRVNT	Ventilation drag	Due to reduced pressure at the rear side of the strut base	N
L_F	LF	Lift force on foil	C_L A_{FT} q	N
L_{FF}	LFF	Lift force on front foil	C_L A_{FF} q	N
L_{FR}	LFR	Lift force on rear foil	C_L A_{FR} q	N
L_0	LF0	Profile lift force for angle of attack of zero	C_{L0} A_{FT} q	N
L_{T0}	LT0	Lift force at take off	C_{LTO} A_{FT} q	N
M	MSP	Vessel pitching moment		Nm

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
2.3.2.2 **Derived Quantities**				
C_{DF}	CDF	Drag coefficient of foil	$D_F / (A_{FS}\ q)$	1
C_{DI}	CDI	Induced drag coefficient	$D_I / (A_{FS}\ q)$	1
C_{DINT}	CDINT	Interference drag coefficient	$D_{INT} / (A_{FS}\ q)$	1
C_{DO}	CDO	Section drag coefficient for angle of attack equal to zero	$D_P / (A_{FS}\ q)$	1
C_{DS}	CDSP	Spray drag coefficient	$D_S / (A_{FS}\ q)$	1
C_{DVENT}	CDVENT	Ventilation drag coefficient	$D_V / (A_{FS}\ q)$	1
C_{DW}	CDW	Wave drag coefficient	$D_W / (A_{FS}\ q)$	1
C_{LF}	CLF	Foil lift coefficient	$L_F / (A_{FS}\ q)$	1
C_{LO}	CLO	Profile lift coefficient for angle of attack equal to zero	$L_0 / (A_{FS}\ q)$	1
C_{LTO}	CLTO	Lift coefficient at take-off condition	$L_{TO} / (A_{FS}\ q)$	1
C_{LX}	CLA	Slope of lift curve	$dC_L / d\alpha$	1
C_M	CM	Pitching moment coefficient	$M / ((A_{FF} + A_{FR}) (l_F - l_R)\ q)$	1
M_F	MLF	Load factor of front foil	L_{FF} / Δ	1
M_R	MLR	Load factor of rear foil	L_{FR} / Δ	1
ϵ_F	EPSLDF	Lift/ Drag ratio of foil	L / D	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.4 ACV and SES

2.4.1 Geometry and Hydrostatics

See also Section 1.2.1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_C	CUA	Cushion area	Projected area of ACV or SES cushion on water surface	m^2
B_C	BCU	Cushion beam	SES cushion beam measured between the side walls	m
B_{WLT}	BWLT	Total waterline breadth of SES	At the water line	m
H_{CG}	HVCG	Height of center of gravity above mean water plane beneath craft		m
h_{BS}	HBS	Bow seal height	Distance from side wall keel to lower edge of bow seal	m
H_{SK}	HSK	Skirt depth		m
h_{SS}	HSS	Stern seal height	Distance from side wall keel to lower edge of stern seal	m
L_B	LB	Deformed bag contact length		m
L_C	LAC	Cushion length		m
L_E	LACE	Effective length of cushion	A_C / B_C	m
S_{H0}	SSH0	Wetted area of side hulls at rest off cushion	Total wetted area of side walls under way on cushion	m^2
S_{SHC}	SSHC	Wetted area of side hulls under way on cushion	Total wetted area of side walls under way on cushion	m^2
S_{SH}	SSH	Wetted area of side hulls under way off cushion	Total wetted area of side walls under way off cushion	m^2
X_H, L_H	XH, LH	Horizontal spacing between inner and outer side skirt hinges or attachment points to structure	needs clarification	m
X_S, L_S	XS, LS	Distance of leading skirt contact point out-board or outer hinge of attachment point to structure	needs clarification	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Z_H, H_H	ZH, HH	Vertical spacing between inner and outer side skirt hinges or attachment points to structure	needs clarification	m
δB_c	DBCV	Increase in cushion beam due to water contact		m
ϵ_{WS}	EPSWS	Wetted surface factor	S_{SHC} / S_{SH0}	1
θ_B	TETB	Bag contact deformation angle		1
θ_F	TETF	Finger outer face angle		1
θ_W	TETW	Slope of mean water plane for surface level beneath cushion periphery		1
ζ_C	ZETAC	Height of cushion generated wave above mean water plane at leading edge side of the skirt		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
2.4.2	**Resistance and Propulsion**		See also Section 1.3.1 on Hull Resistance	
C_Δ	CLOAD	Cushion loading coefficient	$\Delta / (g \rho_A A_C^{3/2})$	1
C_{PR}	CPR	Aerodynamic profile drag	$R_0 / (\rho_A V_R^2 A_C / 2)$	1
C_{WC}	CWC	Cushion wavemaking coefficient		1
p_B	PBM	Mean bag pressure		Pa
p_{BS}	PBS	Bow seal pressure	Pressure in the bow seal bag	Pa
p_{CE}	PCE	Mean effective skirt pressure		Pa
p_{CU}	PCU	Cushion pressure	Mean pressure in the cushion	Pa
p_{FT}	PFT	Fan total pressure		Pa
p_{LR}	PLR	Cushion pressure to length ratio	P_{CU} / L_C	Pa/m
p_{SK}	PSS	Skirt pressure in general		Pa
p_{SS}	PSS	Stern seal pressure	Pressure in the stern seal bag	Pa
P_{FCU}	PFCU	Power of lift fan		kW
P_{FSK}	PFSK	Power of skirt fan		kW
Q_{BS}	QBS	Bow seal air flow rate	Air flow rate to the bow seal	m^3/s
Q_{CU}	QCU	Cushion air flow rate	Air flow rate to cushion	m^3/s
Q_{SS}	QSS	Stern seal air flow rate	Air flow rate to the stern seal	m^3/s
Q_T	QT	Total air volume flow		m^3/s
R_{AT}	RAT	Total aerodynamic resistance	$R_M + R_0$	N
R_H	RH	Hydrodynamic resistance	$R_W + R_{WET}$	N
R_M	RM	Intake momentum resistance in general	$\rho_A Q_T V_A$	N
R_{MCU}	RMCU	Intake momentum resistance of cushion	$\rho_A Q_{TCU} V_A$	N
R_{MSK}	RMSK	Intake momentum resistance of skirt	$\rho_A Q_{TSK} V_A$	N
R_{WET}	RWET	Resistance due to wetting		N
T_C	TC0	Cushion thrust		N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.5 Ice Going Vessels

2.5.1 Resistance and Propulsion (See Figure 3.4, p 225 and Figure 3.8, p 231 of Volume 1 of the *Proceedings of the 21st ITTC*)

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
C_I	CI	Coefficient of net ice resistance	$R_I / (\rho_I\ g\ h^2\ B)$	1
C_{IW}	CIW	Coefficient of water resistance in the presence of ice	$R_{IW} / (S\ q_{IW})$	1
F_{IN}	FNIC	Normal ice force on a body	Projection of hull-ice interaction force on the external normal	N
F_{IT}	FTIC	Tangential ice force on a body	Projection of the hull ice interaction force on the direction of motion	N
F_{nI}	FNIC	Froude number based on ice thickness	$V / (g\ h_I)^{1/2}$	1
F_{XI} F_{YI} F_{ZI}	FXIC FYIC FZIC	Components of the local ice force		N N N
f_{ID}	CFRD	Coefficient of friction between surface of body and ice (dynamic)	Ratio of tangential force to normal force between two bodies (dynamic condition)	1
f_{IS}	CFRS	Coefficient of friction between surface of body and ice (static)	The same as above (static condition)	1
h_I	HTIC	Thickness of ice		m
h_{SN}	HTSN	Thickness of snow cover		m
K_{QIA}	KQICMS	Average coefficient of torque in ice	$Q_{IA} / (\rho_W\ n_{IA}^2\ D^5)$	1
K_{TIA}	KTICMS	Average coefficient of thrust in ice	$T_{IA} / (\rho_W\ n_{IA}^2\ D^4)$	1
n_{IA}	FRICMS	Average rate of propeller revolution in ice		Hz
P_{DI}	PDI	Delivered power at propeller in ice	$2\ \pi\ Q_{IA}\ n_{IA}$	W

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Q_{IA}	QIMS	Average torque in ice		Nm
R_I	RI	Net ice resistance	$R_{IT} - R_{IW}$	N
R_{IT}	RIT	Total resistance in ice	Ship towing resistance in ice	N
R_{IW}	RIW	Hydrodynamic resistance in presence of ice	Total water resistance of ship in ice	N
T_{IA}	TIMS	Average total thrust in ice		N
η_{ICE}	ERIC	Relative propulsive efficiency in ice	η_{ID} / η_D	1
η_{ID}	EFDIC	Propulsive efficiency in ice	$R_{IT} V / (2 \pi n_{IA} Q_{IA})$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

2.6 Sailing Vessels

2.6.1 Geometry and Hydrostatics

See also Section 1.2.1 on Hull Geometry

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_j	ASJ	Area of jib or genoa		m^2
A_{LK}	ALK	Lateral area of keel		m^2
A_{LT}	ALT	Total lateral area of yacht		m^2
A_m	ASM	Area of mainsail		m^2
A_N	ASN	Normalized sail area		m^2
A_{sp}	ASSP	Area of spinnaker		m^2
A_S, S_A	AS	Sail area in general	$(P\,E + I\,J) / 2$	m^2
B_{OA}	BOA	Beam, overall		m
E	EM	Mainsail base		m
I	I	Fore triangle height		m
J	J	Fore triangle base		m
P	P	Mainsail height		m
L_E	LEFF	Effective length for Reynolds Number		m
S_C	SC	Wetted surface area of canoe body		m^2
S_K	SK	Wetted surface area of keel		m^2
S_R	SR	Wetted surface area of rudder		
T_c	TCAN	Draft of canoe body		m
T_E	TEFF	Effective draft	$F_H / (\rho \pi V_B^2 R)^{.5}$	m
Z_{CE}	ZCE	Height of centre of effort of sails above waterline in vertical centerplane		m
∇_C	DVCAN	Displaced volume of canoe body		m^3
∇_K	DVK	Displaced volume of keel		m^3
∇_R	DVR	Displaced volume of rudder		m^3
Δ_C	DFCAN	Displacement force (weight) of canoe body		N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
Δ_K	DFK	Displacement force (weight) of keel		N
Δ_R	DFR	Displacement force (weight) of rudder		N

2.6.2 Resistance and Propulsion

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
C_{FU}	CFU	Frictional resistance coefficient (upright)	R_{FU} / (S q)	1
C_{RU}	CRU	Residuary resistance coefficient (upright)	R_{RU} / (S q)	1
C_{TU}	CTU	Total resistance coefficient (upright)	R_{TU} / (S q)	1
C_{WU}	CWU	Wave resistance coefficient (upright)		1
$C_{T\phi}$	CTPHI	Total resistance coefficient with heel and leeway	$R_{T\phi}$ / (S q)	1
C_I		Induced resistance coefficient		1
C_x, C_y, C_z		Force coefficients		1
F_H		Heeling force of sails		N
F_R		Driving force of sails		N
F_V		Vertical force of sails		N
H		Side force		N
L_{HY}		Hydrodynamic lift force		N
R_{aw}		Added Resistance in waves		N
R_{FU}		Friction resistance (upright)		N
R_{RU}		Residuary resistance (upright)		N
R_I		Resistance increase due to side (induced resistance)		N
R_{TU}	RTU	Total resistance (upright)		N
$R_{T\phi}$	RTUH	Total resistance when heeled	$R_{TU} + R_\phi$	N
R_ϕ , R_H	RTUHA	Resistance increase due to heel (with zero side force)		N

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
X,Y,Z		Components of resultant force along designated axis		N
U	V	Boat velocity		m/s
U_{aw}	VWREL	Apparent wind velocity		m/s
V_{tw}	VWABS	True wind velocity		m/s
V_{mc}	VMC	Velocity made good on course		m/s
V_{mg}	VMG	Velocity made good to windward (contrary to wind direction)		m/s
β_L	BETAL	leaway angle		rad
β_{aw}	BETWA	apparent wind angle (relative to boat course)		rad
β_{tw}	BETWT	true wind angle (relative to boat course)		rad

2.6.3 Remarks

This is only a partical list of symbols used in this specialized area. For a more complete list of sailing yacht symbols and how they are used, see Peter van Oossanen, "Predicting the Speed of Sailing Yachts" *Proceedings of Annual Meeting of SNAME*, 1993

3 Mechanics in General
3.1 Fundamental Concepts
3.1.1 Coordinates and Space Related Quantities

3.1.1.1 Coordinate systems

Orientation of coordinates

A problem of general interest, the orientation of the axes of coordinate systems, has been treated extensively in the Report of the 17th ITTC Information Committee. The present SaT Group recommends that the orientations of the coordinate systems chosen for convenience should be stated explicitly in any case. The coordinate system orientation should not be inferred from the symbols and/or names of the concepts or from national or professional traditions. All sign conventions of related Quantities should be consistent with the orientation chosen.

For ready reference the recommendation of the 17th ITTC Information Committee is quoted in the following.

> "In order to adapt ITTC nomenclature to common practice a proposal for a standard coordinate system was published in the newsletter No 7, March 1983, to generate discussion. The response was quite diverse. On the one hand it was suggested that instead of the two orthogonal right handed systems with the positive x-axis forward and the positive z-axis either up- or downward as proposed only one system should be selected, in particular the one with the positive z-axis upwards. On the other hand the attention of the Information Committee was drawn to the fact that in ship flow calculations neither of the two systems proposed is customary. Normally the x-axis is directed in the main flow direction, i.e. backwards, the y-axis is taken positive to starboard and the z-axis is positive upwards. The origin of the co-ordinates in this case is usually in the undisturbed free surface half way between fore and aft perpendicular.
>
> In view of this state of affairs the Information Committee (now SaT Group) may offer the following recommendation, if any:
>
> **Axes, coordinates**
>
> Preferably, orthogonal right handed systems of Cartesian co-ordinates should be used, orientation and origin in any particular case should be chosen for convenience.
>
> **Body axes (x,y,z)**
>
> Coordinate systems fixed in bodies or ships.
>
> For the definition of hull forms, for structural deflections, and exciting forces usually the x-axis positive forward and parallel to the reference or base line used to describe the body's shape, the y-axis positive to port, and the z-axis positive upwards.

For seakeeping and manoeuvring problems usually the x-axis as before the y-axis positive to starboard, and the z-axis positive downwards, the origin customarily at the centre of mass of the vehicle or at a geometrically defined position.

For ship flow calculations usually the x-axis positive in the main flow direction, i.e. backwards, the y-axis positive to starboard, and the z-axis positive upwards, the origin customarily at the intersection of the plane of the undisturbed free-surface, the centre plane, and the midship section.

Fixed or space axes (x_0,y_0,z_0)

Coordinate systems fixed in relation to the earth or the water. For further references see ISO Standard 1151/1 ...6: Terms and symbols for flight dynamics.

The Information Committee is aware that there may be other coordinate systems in use and sees no possibility for the adoption of a single system for all purposes. Any problem requires an adequate coordinate system and transformations between systems are simple, provided that orientations and origins are completely and correctly documented for any particular case."

.2 Origins of coordinates

In seakeeping and manoeuvring problems customarily the centre of mass of the vehicle is chosen as the origin of the coordinates. This is in most cases not necessarily advantageous, as all the hydrodynamic properties entering the problems are related rather to the geometries of the bodies under investigation. So any geometrically defined point may be more adequate for the purposes at hand.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.1.1.2 Basic Quantities			**see Remarks .1and .2**	
s	*S*	Any scalar quantity distributed, maybe singularly, in space	$\int \mathrm{d}s$	
S^0_{ij}	*S*M0(I,J)	Zeroth order moment of a scalar quantity	$\int \delta_{ij} \mathrm{d}s = \delta_{ij} S$	
S^1_{ij}	*S*M1(I,J)	First order moment of a scalar quantity, formerly static moments of a scalar distribution	$\int \epsilon_{ikj} x_k \mathrm{d}s$	
S^2_{ij}	*S*M2(I,J)	Second moment of a scalar quantity, formerly moments of inertia of a scalar distribution	$\int \epsilon_{kli} x_l \epsilon_{jkm}\, x_m \mathrm{d}s$	
S_{uv}	*S*(U,V)	Generalized moment of a scalar quantity distributed in space	s. Remark .3 $S_{ij} = S^0_{ij}$ $S_{i,\,3+j} = S^{1\ \mathrm{T}}_{ij}$ $S_{3+i,\,j} = S^1_{ij}$ $S_{3+i,\,3+j} = S^2_{ij}$	
T_{ij}	*T*(I,J)	Tensor in space referred to an orthogonal system of Cartesian coordinates fixed in the body	$T_{ij}^{\mathrm{s}} + T_{ij}^{\mathrm{a}}$	
T_{ij}^{A}	*T*AS(I,J)	Anti-symmetric part of a tensor	$(T_{ij} - T_{ji}) / 2$	
T_{ij}^{S}	*T*SY(I,J)	Symmetric part of a tensor	$(T_{ij} + T_{ji}) / 2$	
T_{ij}^{T}	*T*TR(I,J)	Transposed tensor	T_{ji}	
$T_{ij}\, v_j$		Tensor product	$\sum T_{ij}\, v_j$	
u_i, v_i	*U*(I), *V*(I)	Any vector quantities		
$u_i\, v_i$	*UV*PS	Scalar product	$u_i v_i$	
$u_i\, v_j$	*UV*PD(I,J)	Diadic product	$u_i v_j$	
$u \times v$	*UV*PV(I)	Vector product	$\epsilon_{ijk} u_j v_k$	

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
V^0_i, V_i	V0(I),V(I)	Zeroth order moments of a vector quantity distributed in space, referred to an orthogonal system of Cartesian coordinates fixed in the body	$\int dv_i$	
V^1_i	V1(I)	First order moments of a vector distribution	$\int \epsilon_{ijk} x_j d\nu_k$	
V_u	V(U)	Generalized vector	$V_i = V^0_i$ $V_{3+i} = V^1_i$	
x, x_1 y, x_2 z, x_3	X, X(1) Y, X(2) Z, X(3)	Body axes and corresponding Cartesian coordinates	Right-hand orthogonal system of coordinates fixed in the body, s. Remark .2	m
x_0, x_{01} y_0, x_{02} z_0, x_{03}	X0, X0(1) Y0, X0(2) Z0, X0(3)	Space axes and corresponding Cartesian coordinates	Right-hand orthogonal system of coordinates fixed in relation to the space, s. Remark .2	m
x_F, x_{F1} y_F, x_{F2} z_F, x_{F3}	XF, XF(1) YF, XF(2) ZF, XF(3)	Flow axes and corresponding Cartesian coordinates	Right-hand orthogonal system of coordinates fixed in relation to the flow, s. Remark .2	m
ϵ_{ijk}	EPS(I,J,K)	Epsilon operator	+1 : ijk = 123, 231, 312 − 1 : ijk = 321, 213, 132 0 : if otherwise	
δ_{ij}	DEL(I,J)	Delta operator	+1 : ij = 11, 22, 33 0 : if otherwise	

3.1.1.3 Remarks

.1 Notation

The symbols *s, S, T, u, v, V* denote variables to be replaced by the symbols of the specific quantities under consideration in any particular application.

The range of the operational indices i, j, k is from 1 to 3, while for the generalized concepts the operational indices u, v, w range from 1 to 6.

.2 Generalized vector or 6-D notation

Most mechanical problems related to bodies moving in three dimensional space are six dimensional due to the six degrees of freedom involved. Consequently it is extremely convenient to have an appropriate notation available. Historically a symbolic 'motor' notation has been proposed and successfully used by Richard von Mises (1924). Much later the operational notation ready for computer applications adopted here has been independently developed (Schmiechen, 1962) and used for the efficient solution of complex problems, including the motions of robots in flows (Schmiechen, 1989) .

The basic idea is to combine the two vectorial balances for the translational momentum and the rotational momentum, respectively, into only one 6-D balance of the generalized momentum, and consequently to deal with generalized forces, i. e. loads, generalized velocities, i. e. motions, generalized masses, i. e. inertia, etc. The generalized vectors, i. e. von Mises' motors, and the generalized tensors are simple matrices of vectors and tensors, respectively. As ordinary vectors and tensors their generalized counterparts obey certain transformation rules related to changes in the orientations and the origins of the coordinate systems.

The introduction of this notation at this very early stage is of course in line with the object oriented approach adopted and permitting an extremely efficient notation not only for the motions of bodies in general but the seakeeping and manouvring of ships, the notation for which was so far in a quite unacceptable state.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.1.2 Time and Frequency Domain Quantities

3.1.2.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
a	ADMP	Damping	s^r, in Laplace variable	1/s
f	FR	Frequency		Hz
f_C	FC	Basic frequency in repeating functions	$1 / T_C$	Hz
f_S	FS	Frequency of sampling	$1 / T_S$ period in repeating spectra	Hz
i	I	Imaginary unit	sqrt(−1)	1
I	IM	Imaginary variable		i
j	J	Integer values	$-\infty \ldots +\infty$	1
R	R	Complex variable	$\exp(s\, T_S)$ Laurent transform	
s	S	Complex variable	$a + 2\pi i f$ Laplace transform	1/s
t	TI	Time	$-\infty \ldots +\infty$	s
t_j	TI(J)	Sample time instances	$j\, T_S$	
T_C	TC	Period of cycle	$1 / f_C$ duration of cycles in periodic, repeating processes	s
T_S	TS	Period of sampling	Duration between samples	s
x	*x*	Values of real quantities	$x(t)$	
X		Real "valued" function		
x_j	*X*(J)	Variables for samples values of real quantities	$x(t_j) = \int x(t)\delta(t - t_j)dt$	
z	*Z*	Complex variable		

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.1.2.2 Complex Transforms				
x^A	*X*A	Analytic function	$X^A(t) = X(t) + iX^H(t)$	
x^{DF}	*X*DF	Fourier transform of sampled function	$X^{DF}(f) = \sum x_j \exp(-i2\pi fjT_S)$ i.e. periodically repeating $= X(0)/2 + f_S \sum X^F(f + jf_S)$ sample theorem: aliasing!	
x^{DL}	*X*DL	Laurent transform Sampled function	$X^{DL}(s) = \sum x_j \exp(-sjT_S)$	
x^F	*X*FT	Fourier transform	$X^F(f) = \int X(t)\exp(-i2\pi ft)dt$ inverse form: $= \int X^F(f)\exp(-i2\pi ft)dt$ if $X(t) = 0$ and $a = 0$ then $X^F(f)=X^L(f)$	
$x^F{}_j$	*X*FT(J)	Fourier transform of periodic function	$1/T_C \int X(t)\exp(-i2\pi jt/T_C)dt$ $t = 0\,..\,T_C$ $X^F = \sum x^F{}_j \delta(f - j/T_C)$ inverse form: $X(t) = \sum x^F{}_j \exp(-i2\pi fjT_C)$	
x^H	*X*HT	Hilbert transform	$X^H(t) = 1/\pi \int X(\tau)/(t - \tau)d\tau$	
x^{HF}	*X*HF	Fourier transform of Hilbert transform	$X^{HF}(f) = X^F(f)(-i \operatorname{sgn} f)$ $(1/t)^F = -i \operatorname{sgn} f$	
x^L	*X*LT	Laplace transform	$X^L(s) = \int X(t)\exp(-st)dt$ if $X(t<0) = 0$ then $= (X(t)\exp(-at))^F$	
x^R	*X*RT	Laurent transform	$X^R(r) = \sum x_j r^{-j} = X^{DL}$	
x^S	*X*S	Single-sided complex spectra	$X^S(f) = X^F(f)(1 + \operatorname{sgn} f)$ $= X^{AF}$ i.e. $= 0$ for $f < 0$	
$x^S{}_j$	*X*S(J)	Single-sided complex Fourier series	$X^F{}_j(1 + \operatorname{sgn} j)$ line spectra	

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.1.2.3 Complex Quantities

z^a	ZAM	Amplitude	$\mathrm{mod}(z) = \mathrm{sqrt}(z^{r2}+z^{i2})$	
z^c	ZRE	Real or cosine component	$z^c = \mathrm{real}(z) = z^a\cos(z^p)$	
z^i	ZIM	Imaginary or sine component	$\mathrm{imag}(z) = z^a\sin(z^p) = z^s$	
z^j	ZCJ	Conjugate	$z^r - \mathrm{i}z^i$	
z^l	ZLG	(Phase) Lag	$-z^p$	
z^p	ZPH	Phase	$\mathrm{arc}(z) = \mathrm{arctg}(z^i / z^r)$	
z^r	ZRE	Real or cosine component	$\mathrm{real}(z) = z^a\cos(z^p) = z^c$	
z^s	ZIM	Imaginary or sine component	$z^s = \mathrm{imag}(z) = z^a\sin(z^p)$	

3.1.2.4 Remarks

.1 Fourier transforms and spectra
The notation proposed has proved to be adequate for "real" problems at hand, these notes giving some useful background information in the most concise form.

The complex "values" may be quantities of any "complexity", e.g. tensors, matrices, and tensors of matrices as e.g. encountered in 6-D parameter identification.

The uniform use of the "natural" frequency instead of artifical circular frequency has the advantage that no factors are occuring in the Fourier transform pair.

.2 Group properties
The Fourier and Hilbert transforms are the unit elements of cyclic groups with the following properties:

$$X(\mathrm{t})^{\mathrm{F}} = X^{\mathrm{F}}(\mathrm{f}),\ \ X^{\mathrm{F}}(\mathrm{f})^{\mathrm{F}} = X(-\mathrm{t}),\quad X(-\mathrm{t})^{\mathrm{F}} = X^{\mathrm{F}}(-\mathrm{f}),\ \ X^{\mathrm{F}}(-\mathrm{f})^{\mathrm{F}} = X(\mathrm{t})$$

$$X(\mathrm{t})^{\mathrm{H}} = X^{\mathrm{H}}(\mathrm{t}),\ \ X^{\mathrm{H}}(\mathrm{t})^{\mathrm{H}} = -X(\mathrm{t}),\ \ -X(\mathrm{t})^{\mathrm{H}} = -X^{\mathrm{H}}(\mathrm{t}),\ -X^{\mathrm{H}}(\mathrm{t})^{\mathrm{H}} = X(\mathrm{t})\ .$$

Consequently among others the following fundamental relations hold:

$$\mathrm{F}^4 = \mathrm{H}^4 = 1.$$

.3 Fourier series
Due to the fact that in most cases only real functions and single-sided spectra are used the usual format of the Fourier series is

$$X(\mathrm{t}) = \mathrm{real}(\sum \mathrm{x}^{\mathrm{S}}_{\mathrm{j}} \exp(\mathrm{i}2\pi \mathrm{jt}/\mathrm{T_C}) = \sum \mathrm{x}^{\mathrm{Sc}}_{\mathrm{j}} \cos(2\pi \mathrm{jt}/\mathrm{T_C}) + \sum \mathrm{x}^{\mathrm{Ss}}_{\mathrm{j}} \sin(2\pi \mathrm{jt}/\mathrm{T_C})$$

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

The reason for this step is that the spectra are in fact Fourier transforms not of the real function being studied but of the corresponding analytic function.

For ready reference the following formulae are given

$$x^{S}{}_{j} = x^{F}{}_{j} (1 + \mathrm{sgn}\, j)$$

$$x^{Fc} = 1/T_C \int X(t) \cos(2\pi jt/T_C)dt$$

$$x^{Fs} = 1/T_C \int X(t) \sin(2\pi jt/T_C)dt$$

where the integration has to be extended over the cycle T_C .

.4 Causal functions

Causal functions, defined by

$$X(t<0) = 0,$$

are conveniently expressed as

$$X(t) = X^{e}(t)(1 + \mathrm{sgn}\, t)$$

with the even function

$$X^{e}(t) = (X(t) + X(-T))/2.$$

Noting the property

$$X^{eF} = X^{Fr}$$

the Fourier transform

$$X^{F} = X^{eF} - iX^{eFH}$$

leads to the relations

$$X^{Fi} = -X^{FrH}, \text{ i.e. } X^{FiF}(t) = -X^{FrF}(t)(-i\, \mathrm{sgn}\, t)$$

and, taking advantage of the group properties,

$$X^{Fr} = +X^{FiH}, \text{ i.e. } X^{FrF}(t) = +X^{FiF}(t)(-i\, \mathrm{sgn}\, t).$$

These relationships are known under various names and guises, the derivations sometimes obscured by irrelevant or misleading arguments., the worst being hydrodynamic.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

.5 Minimal phase functions

From the format

$X^{F} = X^{Fa}\exp(iX^{Fp})$

the logarithm

$\ln(X^{F}) = \ln(X^{Fa}) + iX^{Fp}$

is derived and it can be proved that the relations

$X^{Fp} = -(\ln(X^{Fa}))^{H}$, i.e. $X^{Fp}F(t) = -(\ln(X^{Fa}))F(t)(-i \operatorname{sgn} t)$

and

$\ln(X^{Fa}) = +X^{FpH}$, i.e. $(\ln(X^{Fa}))F(t) = +X^{FpF}(t)(-i \operatorname{sgn} t)$

hold for phase minimal functions; s.e.g. Papoulis, A.: The Fourier Integral and Its Applications. New York: McGraw-Hill, 1964.

.6 Spectral estimates

While for periodic functions the estimation of Fourier transforms, spectra, etc. can be efficiently performed by fast Fourier algorithms (FFA) the same is not true in general. Due to neccessary truncation FFT will in general produce results with systematic errors. These are a consequence of the implied periodic repetition, which in most cases is simply inadequate.

In these cases only autoregressive model techniques lead to unbiased estimates of the transforms. The reason is that these models provide proper harmonic descriptions of the truncated record; s.e.g. Childers, D.G.: Modern spectrum analysis. New York: IEEE Press, 1978.

In any case the algorithm used has to be clearly identified, possibly by reference to a full description or, ideally and unambiguously, a subroutine. At this stage it appears premature to try and introduce standard symbols for various standard procedures.

So far standard procedures not been agreed upon by the ITTC community, but in the near future it will be necessary to do so in order to arrive at comparable results. Agreement should not be reached by "vote", as has been tried by Ocean Engineeering Committee. The standard adopted by the hydrographic institutes for the estimation of power spectra is in general quite disputable as well.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.1.3	**Random Quantities and Stochastic Processes**		see Remark .1 and .2	
3.1.3.1	**Random Quantities**			
g^E, g^M, g^{MR}	*G*MR	Expected value of a function of a random quantity	$E(g) = \int g(x) f_x(x) dx$ $x = -\infty \dots \infty$	
x, y	*X*, *Y*	Random quantities	$x(\zeta)$, $y(\zeta)$	
x_i, y_i	*X*(I), *Y*(I)	Samples of random quantities	i = 1... n n : sample size	
x^{mE}	*X*mMR	m-th moment of a random quantity	x^{mE}	
x^D, x^{DR}, σ_x	*X*DR	Standard deviation of a random quantity	$x^{VR\ 1/2}$	
x^{DS}, s_x	*X*DS	Sample deviation of a random quantity	$x^{VS\ 1/2}$, unbiased random estimate of the standard deviation	
xx^R, xx^{MR}, R_{xx}	*XX*MR	Auto-correlation of a random quantity	$x\,x^E$	
xy^R, xy^{MR}, R_{xy}	*XY*MR	Cross-correlation of two random quantities	$x\,y^E$	
x^E, x^M, x^{MR}, μ_x	*X*MR	Expectation or population mean of a random quantity	$E(x)$	
x^A, x^{MS}, m_x	*X*MS	Average or sample mean of a random quantity	$1/n \sum x_i$, i = 1...n unbiased random estimate of the expectation with $x^{AE} = x^E$ $x^{VSE} = x^V / n$	
x^{PD}, f_x	*X*PD	Probability density of a random quantity	$d F_x / dx$	
xy^{PD}, f_{xy}	*XY*PD	Joint probability density of two random quantities	$\partial^2 F_{xy} / (\partial x\, \partial y)$	
x^{PF}, F_x	*X*PF	Probability function (distribution) of a random quantity		1
xy^{PF}, F_{xy}	*XY*PF	Joint probability function (distribution) function of two random quantities		1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
x^V, x^{VR}, xx^{VR}	*X*VR, *XX*VR	Variance of a random quantity	$x^{2\,E} - x^{E\,2}$	
x^{VS}, xx^{VS}	*X*VS, *XX*VS	Sample variance of a random quantity	$1/(n-1) \sum (x_i - x^A)^2$ i = 1...n unbiased random estimate of the variance $x^{VSE} = x^V$	
xy^V, xy^{VR}	*XY*VR	Variance of two random quantities	$x\,y^E - x^E\,y^E$	
ζ		Outcome of a random "experiment"		

3.1.3.2 Stochastic Processes

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
g^{MR}	*G*MR	Mean of a function of a random quantity	$M(g(t)) = \lim(1/T \int g(t)dt)$ $t = -T/2 \ldots +T/2$ $T = -\infty \ldots +\infty$	
g^{MS}	*G*MS	Average or sample mean of a function of a random quantity	$A(g(t)) = 1/T \int g(t)dt$ $t = 0 \ldots +T$	
x, y	*X*, *Y*	Stationary stochastic process	$x(\zeta,t)$, $y(\zeta,t)$	
xx^C, xx^{CR}, C_{xx}	*XX*CR	Auto-covariance of a stationary stochastic process	$(x(t) - x^E)(x(t+\tau) - x^E)^E$	
xy^C, xy^{CR}, C_{xy}	*XY*CR	Cross-covariance of two stationary stochastic processes	$(x(t) - x^E)(y(t+\tau) - y^E)^E$	
xx^R, xx^{RR}, R_{xx}	*XX*RR	Auto-correlation of a stationary stochastic process	$x(t)x(t+\tau)^E = R_{xx}(\tau)$ $R_{xx}(\tau) = R_{xx}(-\tau)$ if x is ergodic: $R_{xx}(\tau) = x(t)x(t+\tau)^{MR}$ $R_{xx}(\tau) = \int S_{xx}(\omega)\cos(\omega\tau)d\tau$ $\tau = 0 \ldots \infty$	
xy^R, R_{xy}	*XY*RR	Cross-correlation of two stationary stochastic processes	$x(t)y(t+\tau)^E = R_{xy}(\tau)$ $R_{yx}(\tau) = R_{xy}(-\tau)$ if x, y are ergodic: $R_{xy}(\tau) = x(t)y(t+\tau)^{MR}$	

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
xx^{S}, S_{xx}	*XX*SR	Power spectrum or autospectral power density of a stochastic process	xx^{RRSR}	
xy^{S}, S_{xy}	*XY*SR	Cross-power spectrum of two stationary stochastic processes	xy^{RRSR}	
τ	TICV	Covariance or correlation time		
ζ		Outcome of a random "experiment"		

3.1.3.3 Probability Operators

A, MS	MS	Average, sample mean		
C, CR	CR	Population covariance		
CS	CS	Sample covariance		
D, DR	DR	Population deviation		
DS	DS	Sample deviation		
E, M, MR	MR	Expectation, population mean		
PD	PD	Probability density		
PF	PF	Probability function		
S	SR	(Power) Spectrum		
SS	SS	Sample spectrum		
R, RR	RR	Population correlation		
RS	RS	Sample correlation		
V, VR	VR	Population variance		
VS	VS	Sample variance		

3.1.3.4 Remarks

.1 Quantities

An adequate introduction into the conceptual world of "Probability, Random Variables (Quantities!), and Stochastic Processes" is provided by A. Papoulis in his book with that same title.

.2 Estimates

Apart of the fundamental theory of probability with its concepts outlined here, in practice the theory of statistics is necessary, providing for the estimation of probabilities and or their parameters, e.g. expected values. In any case these estimates are at best free of bias, but they are random variables themselves and as such clearly distinct from the quantities for which they are estimates.

In the solution of real problems it is absolutely mandatory to account for this distinction. As the most important quantities of this type the sample mean and the sample variance have been introduced. It is important to note that as a matter of fact the terminology is still not standardized. The foregoing symbols and terminology are proposed in an attempt to provide tools for the tasks at hand in systems identification and in quality assurance.

.3 Sample Variance

It should be noted that in contrast to the practice elsewhere the sample variance is not defined as average of the squared sample deviations from the sample average. This provides for an unbiased estimate of the variance and the standard deviation right away. In some text books and some software packages the definition of the sample variance is different from the one proposed here. So care is necessary if unbiased estimates for small samples are being determined.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.1.4 Balances and System Related Concepts			**see Remark .1**	
q	*Q*Q	Quantity of the quality under consideration stored in a control volume		Q^{U}
Q		Quality under consideration		Q^{U}/s
Q^{C}	*Q*CF	Convective flux		Q^{U}/s
Q^{D}	*Q*DF	Diffusive flux		Q^{U}/s
Q^{F}	*Q*FL	Total flux across the surface of the control volume	Inward positive!	Q^{U}/s
Q^{M}	*Q*DM	Molocular diffusion		Q^{U}/s
Q^{P}	*Q*PN	Production of sources in the control volume		Q^{U}/s
Q^{S}	*Q*RT	Storage in the control volume, rate of change of the quantity stored	dq / dt	Q^{U}/s
Q^{T}	*Q*DT	Turbulent diffusion		Q^{U}/s

3.1.4.1 Remarks

.1 Balances

Traditionally balances of various extensive or socalled "conservative" qualities or properties are described by ad hoc symbols, disguising the similarities and essentials. For any quality Q enclosed in a control volume the balance may be written in the format

$$Q^{S} = Q^{F} + Q^{P} ,$$

implying, that the net storage of the quality in a given boundary equals the net flux of the quality across the boundary into the control volume and the net production of sources within the boundary.

The symbol Q is the variable for the symbol of the particular extensive qualitiy under investigation, e. g. mass, momentum, and energy. Q^{S}, Q^{F}, and Q^{P} are variables for values of the storage, flux, and production, respectively.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

The net storage is nothing else but the net rate of change of the quantity q of the quality Q stored in the control volume:

$$Q^{\mathrm{S}} = \mathrm{dq} / \mathrm{dt}\ .$$

q is the variable for values of the quantity of the quality Q stored in the control volume.

Concerning the flux there are two types to be clearly distinguished according to their mechanisms, the convective and the diffusive fluxes, i. e.

$$Q^{\mathrm{F}} = Q^{\mathrm{C}} + Q^{\mathrm{D}}\ .$$

The diffusive flux itself may be due to two types of diffusion, the molecular diffusion and the turbulent diffusion, i. e.

$$Q^{\mathrm{D}} = Q^{\mathrm{T}} + Q^{\mathrm{M}}\ .$$

Traditionally the time rate of change is denoted by a dot, i. e.

$$\mathrm{dq} / \mathrm{dt} = \dot{q}$$

According to some standards, e. g. the German DIN, fluxes and the productions may be denoted by symbols with a dot as well, apparently due to the fact, that they have the same dimension as time rates of change. This usage is misleading and confusing and therefore totally unacceptable.

The concepts of flux and source are fundamental concepts and essentially different, due to the totally different nature of the mechanisms, from the concept of rate of change of the quantity they cause to change, although they may each, in the absence of the other, be equal in value and balancing the rate of change.

Much more reasonable is to denote rate of change by an operator symbol as well, e. g. by R, as will be done in this version of the symbols, and write any balance in the format

$$\mathrm{q}^{\mathrm{R}} = Q^{\mathrm{S}} = Q^{\mathrm{C}} + Q^{\mathrm{T}} + Q^{\mathrm{M}} + Q^{\mathrm{P}}\ ,$$

clearly indicating the four totally different physical mechanisms taking part in the change of any quantities of extensive qualities.

If instead of the object oriented notation the function oriented notation is being used the balance would e. g. look like

$$\mathrm{q}^{\mathrm{R}} = \mathrm{S}_{Q} = \mathrm{C}_{Q} + \mathrm{T}_{Q} + \mathrm{M}_{Q} + \mathrm{P}_{Q}\ .$$

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

This is not very practical if the quality under consideration is of tensorial character or of even more complex matrix nature.

Q^{U} is the variable for the SI unit of the quality Q under consideration.

It will become evident from this very elementary exposition that precisely the most fundamental concepts are mostly used extremely carelessly. The concepts "variable", "quantity", and "quality" are rarely clearly distinguished as they ought to be.

E. g.: momentum is a quality and a body may have stored a certain quantity of it at a given time. M and MO are variables for vectors of numerical values of the quantity measured in Ns. t and TI are variables for values of the quantity of the quality time measured in s .

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.2	**Solid Body Mechanics**			
3.2.1	**Inertial and Hydrodynamic Properties**			
3.2.1.1	**Basic Quantities**		see Remarks	
A_{ij}	AM(I,J)	Added mass coefficient in ith mode due to jth motion		
B_{ij}	DA(I,J)	Damping coefficient in ith mode due to jth motion		
C_{ij}	RF(I,J)	Restoring force coefficient in ith mode due to jth motion		
D^h_{uv}	DH(U,V)	Generalized hydrodynamic damping	$\partial F^h_u / \partial V_v$	
F^h_u	FH(U)	Generalized hydrodynamic force		
I^h_{uv}	IH(U,V)	Generalized hydrodynamic inertia	$\partial F^h_u / \partial \dot{V}_v$	
I_L	IL	Longitudinal second moment of water-plane area	About transverse axis through center of floatation	m^4
I_T	IT	Transverse second moment of water-plane area	About longitudinal axis through center of floatation	m^4
I_y , I_{yy} , m^2_{22} , m_{55}	IY, IYY, M2(2,2), MA(5,5)	Pitch moment of inertia around the principal axis y		kg m^2
I_z , I_{zz} , m^2_{33} , m_{66}	IZ, IZZ, M2(3,3), MA(6,6)	Yaw moment of inertia around the principal axis z		kg m^2
I_{xy} , I_{12} I_{yz} , I_{23} I_{zx} , I_{31}	IXY, I2(1,2) IYZ, I2(2,3) IZX, I2(3,1)	Real products of inertia in case of non-principal axes		kg m^2
k_x, k_{xx} k	RDGX	Roll radius of gyration around the principal axis x	$(I_{xx}/m)^{1/2}$	m
k_y, k_{yy}	RDGY	Pitch radius of gyration around the principal axis y	$(I_{yy}/m)^{1/2}$	m
k_z, k_{zz}	RDGZ	Yaw radius of gyration around the principal axis z	$(I_{zz}/m)^{1/2}$	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
m	MA	mass		kg
m^0_{ij} , m_{ij}	M0(I,J), MA(I,J)	Zeroth moments of mass, i.e. inertia distribution, mass tensor	$m_{ij} = m\ \delta_{ij}$	kg
m^1_{ij}	M1(I,J)	First moments of mass, i.e. inertia distribution	Alias static moments of mass	kg m
m^2_{ij} , I_{ij}	M2(I,J), IN(I,J)	Second moments of mass, i.e. inertia distribution	Alias mass moments of inertia	kg m^2
M_{uv}	MA(U,V)	Generalized mass, i. e. generalized inertia tensor of a (rigid) body referred to a body fixed coordinate system	$M_{ij} = M^0_{ij}$ $M_{i,\,3+j} = M^{1T}_{ij}$ $M_{3+i,\,j} = M^1_{ij}$ $M_{3+i\,,\,3+j} = M^2_{ij}$	

3.2.1.2 Remarks

.1 Notation

The operational indices i, j, k range from 1 to 3, the indices u, v ,w of the generalized tensors from 1 to 6.
Refer to 3.1.1 **Coordinates and Space Related Quantities** for definition of generalized concepts.

.2 Reference Points

In any particular case the orientation and the origin of the coordinate system have to be specified and indicated, if necessary. If the coordinate system coincides with the principal axes system the generalized tensor has only components in the main diagonal, the first order moments as well as the real moments of inertia are vanishing.

While this aspect may be of interest in cases, where the translational and rotational motions may be considered as uncoupled, as in the case of gravitational forces acting alone on a solid body, or for qualitative considerations, where this condition holds at least approximately, it is not at all important for computational purposes. Quite to the contrary it requires the extra, in general unnecessary operation of transformation to the principal axes of the inertia tensor. Due to the hydrodynamic forces the translational and the rotational motions can in general not be considered decoupled from each other in the ordinary way just by construction of a special reference point.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.2.2	**Loads**	s. Remark .1		
3.2.2.1	**External Loads**	s. Remark .2		
F_u	F(U)	Force, generalized, load, in body coordinates	$M^F_u = M^M_u$ $F_i = F^0_i$ $F_{3+i} = F^1_i$	n
g_u	G(U)	Gravity field strength, generalized, in body coordinates	$g_i = g^1_i$ $g_{3+i} = 0$	m/s^2
g_i	G1(I)	Gravity field strength, in body coordinates!		m/s^2
K, M_x , F^1_1 , F_4	K, M(1), F1(1), F(4)	Moment around body axis x		Nm
M, M_y , F^1_2 , F_5	M, M(2), F1(2), F(5)	Moment around body axis y		Nm
N, M_z , F^1_3 , F_6	N, M(3), F1(3), F(6)	Moment around body axis z		Nm
X, F_x , F^0_1 , F_1	X, FX, F0(1), F(1)	Force in direction of body axis x		Nm
Y, F_y , F^0_2 , F_2	Y, FY, F0(2), F(2)	Force in direction of body axis y		Nm
Z, F_z , F^0_3 , F_3	Z, FZ, F0(3), F(3)	Force in direction of body axis z		Nm
G_u	G(U)	Gravity or weight force, generalized, in body coor-dinates!	$G_u = m_{uv}\, g_v$	
G^0i , G_i	G0(I)	Gravity or weight force in body coordinates!	$G_i = G^0_i = m^0_{ij}\, g_j$ $= mg_i$	N
G^1_i	G1(I)	Gravity or weight moment in body coordinates!	$G_{3+i} = G^1_i = \epsilon_{ikj}\, x_k\, G^0_j$ $= m^1_{ij}\, g_j$	Nm
q	UNQ	Load per unit length		N/m
w	WPUL	Weight per unit length	dW / dx_1	N/m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.2.2.2 Sectional Loads		s. Remark .3		
F^S_u	FS(U)	Force or load acting at a given planar cross-section of the body, generalized, in section coordinates!	$F^S_i = F^{S0}_i$ $F^S_{3+i} = F^{S1}_i = M^B_i$	N Nm
F^S_i	FS(I)	Shearing force	F^{S0}_2 , F^{S0}_3	N
F^T	FT, FS(1)	Tensioning or normal force	F^{S0}_1	N
M^B_i	MB(I)	Bending moment	F^{S1}_2 , F^{S1}_3	Nm
M^T	MT, MB(1)	Twisting or torsional moment	F^{S1}_1	Nm

3.2.2.3 Remarks

.1 Operational Indices

The operational vector and tensor indices i, j, k range from 1 to 3, the corresponding indices u, v, w for their generalized counterparts range from 1 to 6.

.2 Momentum Balance

For the fundamental balance of quantities of extensive qualities see Section 3.1.4 on **Balances**. For definition of the generalized concepts see Section 3.1.1 on **Coordinates and Space Related Quantities**.
According to the fundamental balance of extensive quantities applied to momentum two different types of 'external' forces have to be distinguished, namely the momentum flux across the boundaries, in the case of solid bodies by molocular diffusion only, i. e. stresses, the socalled surface forces, and the momentum sources in the volumes of the bodies, the socalled volume forces. In the usual applications the weight is the only momentum source, while all other forces acting on a body, distributed over the surface or concentrated, may be considered as surface forces.

.3 Sectional Loads

Sectional loads are surface loads, i. e. moments of stresses due to molecular momentum fluxes across the section. Sectional loads are only meaningful relative to the coordinates of the section, on which they act. If the components are referred to body coordinates as usual, this implies sections normal to the longitudinal axis. The former terminology referring to horizontal and vertical shear forces and bending moments is to be considered obsolete even in this context. Lateral and normal are the appropriate names in the context of body coordinates.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.2.3 Rigid Body Motions

3.2.3.1 Motions

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
p , ω_x , $v^0{}_1$, v_4	P, OMX, V0(1), V(4)	Angular (rotary) velocity around body axis x		rad/s
q , ω_y , $v^0{}_2$, v_5	Q, OMY, V0(2), V(5)	Angular (rotary) velocity around body axis y		rad/s
r , ω_z , $v^0{}_3$, v_6	R, OMZ, V0(3), V(6)	Angular velocity around body axis z		rad/s
u , v_x , $v^1{}_1$, v_1	U, VX, V1(1), V(1)	Translatory velocity in the direction of body axis x		m/s
v , v_y , $v^1{}_2$, v_2	V, VY, V1(2), V(2)	Translatory velocity in the direction of body axis y		m/s
w , v_z , $v^1{}_3$, v_3	W, VZ, V1(3), V(3)	Translatory velocity in the direction of body axis z		m/s
v_u	V(U)	Components of generalized velocity or motion relative to body axes	$v_i = v^1{}_i$ $v_{3+i} = v^0{}_i$ s.Remark .2	m/s rad/s
$\dot{p}$ $\dot{q}$ $\dot{r}$	PR QR RR	Rates of change of components of angular velocity relative to body axes	s.Remark .3	rad/s^2
$\dot{u}$ $\dot{v}$ $\dot{w}$	UR VR WR	Rates of change of components of linear velocity relative to body axes	s. Remark .3	m/s^2
α	AA	Angular acceleration	$d\omega/dt$	rad/s^2

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.2.3.2 Attitudes s.Remark .4				
α	AT ALFA	Angle of attack	The angle of the longitudinal body axis from the projection into the principal plane of symmetry of the velocity of the origin of the body axes relative to the fluid, positive in the positive sense of rotation about the y-axis	rad
β	DR BET	Angle of drift or side-slip	The angle to the principal plane of symmetry from the velocity vector of the origin of the body axes relative to the fluid, positive in the positive sense of rotation about the z-axis	rad
γ	RO GAMR	Projected angle of roll or heel	The angular displacement about the x_o axis of the principal plane of symmetry from the vertical, positive in the positive sense of rotation about the x_o axis	rad
ϕ	X(4), RO, PHIR	Angle of roll, heel or list	Positive in the positive sense of rotation about the x-axis	rad
θ	X(5), TR, TETP	Angle of pitch or trim	Positive in the positive sense of rotation about the y-axis	rad
ψ	X(6), YA, PSIY	Angle of yaw, heading or course	Positive in the positive sense of rotation about the z-axis	rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.2.3.3 Remarks

.1 Operational Indices

The operational vector and tensor indices i, j, k range from 1 to 3, the corresponding indices u, v , w for their generalized counterparts range from 1 to 6.

.2 Angular Velocities

The operational ("exponential") notation for the linear and angular velocities reflects the fact that the angular velocity of a rigid body is independent of the reference point, while the linear velocity changes with the change of reference point.

.3 Time Rates of Change

The computer symbols for the time derivatives have been either DXDT or XDOT, both being very unsatisfactory. The notation proposed is *X*RT etc for "*x* rate", in full "*x* time rate of change". See 3.1.4 on **Balances**.

.4 Angles

The proposed computer symbols for the various angles are an attempt to get away from the old cryptic notation. The Euler angles roll, pitch, and yaw are evidently to be considered as the natural extension of the position vector to the generalized position vector. It has of course to noted that contrary to the translatory motion the rotational motion can not directly integrated to obtain the attitudes in question.

Further, if extreme motions are to be considered the Euler angles may be not adequate for computational purposes, e. g. in numerical simulations, as the corresponding matrix of the directions cosines can become singular. This problem can be avoided if Euler parameters (quater-nions) are employed.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3	**Fluid Mechanics**			
3.3.1	**Flow Parameters**			
3.3.1.1	**Fluid Properties**			
c	CS	Velocity of sound	$(E / \rho)^{1/2}$	m/s
E	EL	Modulus of elasticity		Pa
w	WD	Weight Density	ρg (See 1.1.1)	
κ	CK	Kinematic capillarity	σ / ρ	m^3/s^2
μ	VI	Viscosity		kg/ms
ν	VK	Kinematic viscosity	μ / ρ	m^2/s
ρ	DN, RHO	Density		kg/m^3
σ	CA	Capillarity	Surface tension per unit length	kg/s^2
3.3.1.2	**Flow parameters**	s. Remark .1		
B_n	BN	Boussinesq number	$V / (g R_H)^{1/2}$	1
C_n	CN	Cauchy number	$V / (E / \rho)^{1/2}$	1
F_n	FN	Froude number	$V / (g L)^{1/2}$	1
F_{nh}	FH	Froude depth number	$V / (g h)^{1/2}$	1
$F_{n\nabla}$	FV	Froude displacement number	$V / (g \nabla^{1/3})^{1/2}$	1
M_n	MN	Mach number	V / c	1
R_n	RN	Reynolds number	$V L / \nu$	1
S_n	SN	Strouhal number	$f L / V$	1
T_n	TN	Thoma number		1
W_n	WN	Weber number	$V^2 L / \kappa$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3.1.3 Boundary conditions				
k	HK	Roughness height or magnitude	Roughness height, usually in terms of some average	m
k_s	SK	Sand roughness	Mean diameter of the equivalent sand grains covering a surface, s. Remark .2	
R_H	RH	Hydraulic radius	Area of section divided by wetted perimeter	m

3.3.1.4 Remarks

.1 Flow parameters

The ITTC notation for the flow parameters is not in accordance with that of Physics in general and somewhat redundant, but the SaT Group feels that the usage is so established now that there is no chance for a change.

The flow parameters are the normalized fluid properties, although mostly not written in that way. E. g. the inverse of the Reynolds number is the normalized viscosity

$$\mu^n = \mu \ / (\rho \ U \ L\ ) = 1 \ / \ R_n \ ,$$

with the reference quantities ρ, U and L for steady motion problems. For other problems other reference quantities may be more appropriate.

The Cauchy number is not identical with the Mach number. The modulus of elasticity entering is not that of the fluid but that of an elastic structure in the flow.

The search for "characteristic" reference quantities is a matter of physical argument or the evaluation of experiments, i. e. is a matter either of previous knowledge or a cura posterior. Dimensional analysis does not provide any apriory arguments!

The usage of scale factor in model testing relates full scale and model scale. A scale factor in absolute physical terms would be the normalized length

$$L^n = (R_n / F_n)^{2/3} = L \ g^{1/3} / \ \nu^{2/3} \ .$$

.2 Sand roughness

Although still widely used to characterize the roughness of a surface it is now well understood that sand roughness and the resulting roughness resistance are not typical for technical surfaces, ships' surfaces in particular.

So far no sound correlation between the surface description and the additional resistance has been established.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.3.2 Flow Fields

3.3.2.1 Velocities etc. s. Remark .1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
e	ED	Density of total flow energy	$\rho V^2 / 2 + p + \rho g h$	Pa
f_i	FS(I)	Mass specific force	Strength of force fields, usually only gravity field g_i	m/s^2
h	HS	Static pressure head	Δz_0 , z_0-axis positive vertical up!	m
H	HT	Total head	$e / w = h + p/w + q/w$	m
p	PR, ES	Pressure, density of static flow energy		Pa
p_0	P0	Ambient pressure in undisturbed flow		Pa
q	PD, EK	Dynamic pressure, density of kinetic flow energy,	$\rho V^2 / 2$	Pa
Q	QF, QFLOW	Rate of flow	Volume passing across a control surface in time unit	m^3/s
S_H	THL	Total head loss		m
s^R_{ij}	SR(I,J)	Turbulent or Reynolds stress	$\rho v_i v_j^{CR}$	Pa
s_{ij}	ST(I,J)	Total stress tensor	Density of total diffusive momentum flux due to molecular and turbulent exchange	Pa
s^V_{ij}	SV(I,J)	Viscous stress		Pa
u, v_x, v_1 v, v_y, v_2 w, v_z, v_3	VX, V1 VY, V2 VZ, V3	Velocity component in direction of x, y, z axes		m/s
v_i	V(I)	Velocity		m/s
V	VA	Velocity	$V = v_i v_i^{1/2}$	m/s
V_0	V0	Velocity of undisturbed flow		m/s
τ_w	TAUW	Wall shear stress	$\mu\ (\partial U / \partial y)_{y=0}$	Pa

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3.2.2 Circulation etc				
Γ^n	CN	Nomalized circulation	$\Gamma / (\pi D V)$ π is frequently omitted	1
I	ID	Induction factor	Ratio between velocities induced by helicoidal and by straight line vortices	1
γ	VD	Vortex density	Strength per length or per area of vortex distribution	m/s
Γ	CC	Circulation	$\oint V\, ds$ along a closed line	m^2/s
ϕ	PO	Potential function		m^2/s
ψ	SF	Stream function	ψ = const is the equation of a stream surface	m^3/s

3.3.2.3 Remarks

.1 Equation of Motion

The universal equation of motion for any continuum in space is the balance of mass specific momentum v_i , the Cauchy equation, in Cartesian coordinates,

$$\rho\, d_t\, v_i = \rho\, (\partial_t + v_j\, \partial_j)\, v_i = \rho\, (\partial_t\, v_i + v_j\, \partial_j\, v_i) = \partial_j\, s_{ji} + \rho\, f_i \,,$$

which can be derived if the balance of mass density ρ , the equation of continuity is taken into account.

$$d_t\, \rho = (\partial_t + v_j\, \partial_j)\, \rho = \partial_t \rho + v_j\, \partial_j\, \rho = -\, \rho\, \partial_j\, v_j$$

The notation used for differentiation is evidently

$$d_t = d / dt \,,$$
$$\partial_t = \partial / \partial t \,,$$
$$\partial_i = \partial / \partial x_i \,.$$

Further Einstein's summing convention is conveniently implied:

$$x_i\, y_i = \Sigma_i\, x_i\, y_i \,, \quad i = 1, 2, 3 \,.$$

In hydrodynamics incompressibility is a further adequate idealization and consequently the universal equations reduce to the two equations

$$\rho\, d_t\, v_i = \rho\, (\partial_t\, v_i + v_j\, \partial_j\, v_i) = \partial_j\, s_{ji} + \rho\, f_i\, ,$$

$$\partial_j\, v_j = 0\, .$$

In addition the balance of moments requires that the stress tensor is symmetric

$$s_{ji} = s_{ij}\, ,$$

(Boltzmann's axiom). The stress consists of three constituents: the pressure term, the stress proper, and the Reynolds stress:

$$s_{ji} = -\, p\, \delta_{ji} + s^V{}_{ij} + \rho\, v_j v_i^{CR}\, .$$

The first two terms represent the molecular diffusion of momentum, the last term the turbulent diffusion.

.2 Constitutive Laws

Only at this stage the individual properties of fluids have to be introduced through constitutive laws, I. e. the laws for the stress tensor s. Newtonian fluids, I. e. incompressible linear viscous fluids, are defined by the law

$$s^V{}_{ij} = \mu\, \partial_I\, v_j^S = \mu\, (\partial_I\, v_j + \partial_j\, v_i) / 2\, .$$

Introducing the stress terms with the constitutive law into the universal Cauchy's equation results in the "Reynolds averaged" Navier-Stokes equation (RANSE) in its kinematic form

$$d_t\, v_i = \partial_t v_i + v_j\, \partial_j\, v_i = -\, \partial_I\, p/\rho + \nu\, \partial_j\, \partial_j\, v_i + \partial_j\, v_j v_i^{CR} + g_i\, .$$

Apart of the equation of continuity the closure of the problem requires further "constitutive" equations for the turbulent Reynolds stresses, the so-called turbulence models and, even worse, boundary conditions including details of the surface structure, I. e. roughness.

A very popular turbulence model is the k-ϵ model, with two balances for the density of the turbulent energy k and its dissipation ϵ , respectively. There are fundamental investigations under way to construct more advanced models in accordance with the rational theory of constitutive laws.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.3.3 Lifting Surfaces

3.3.3.1 Geometry

A	AP	Planform area	$b\ c_m$	m^2
b	SP	Wing or foil span		m
b_F	BSPF	Flap span		m
c_m	CHME	Mean chord length	A / b	m
c_t	CHTP	Tip chord length		m
c_r	CHRT	Root chord length		m
f_L	FML	Camber of lower side (general)		m
f_U	FMU	Camber of upper side		m
δ_f	ANFL	Flap deflection angle		rad
δ_s	ANSL	Slat deflection angle		rad
δ	DELTT	Thickness ratio of section (general)	t / C	1
δ_B	DELTB	Thickness ratio of trailing edge of struts	t_B / C_S	1
δ_F	DELTF	Camber ratio of mean line (general)	f / C	1
δ_{FL}	DLTFL	Angle of flap deflection		1
δ_L	DELTL	Camber ratio of lower side of foil	f_L / C	1
δ_S	DELTS	Thickness ratio of strut	t_S / C_S	1
δ_{STH}	DELTT	Theoretical thickness ratio of section	t_S / C_{STH}	1
δ_U	DELTU	Camber ratio of upper side	f_u / C	1
γ	ANSW	Sweep angle		rad
λ	TA	Taper ratio	c_t / c_r	1
Λ	AS	Aspect ratio	b^2 / A	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3.3.2 Flow angles etc				
V_I	VI	Induced velocity		m/s
V_T	VT	Resultant velocity of flow approaching a hydrofoil	Taking vortex induced velocities into account	m/s
α	AA, ALFA	Angle of attack or inci-dence	Angle between the direction of undisturbed relative flow and the chord line	rad
α_E	AAEF, ALFE	Effective angle of attack or incidence	The angle of attack relative to the chord line including the effect of induced velocities	rad
α_G	AAGE, ALFG	Geometric angle of attack or incidence	The angle of attack relative to the chord line neglecting the effect of induced velocities	rad
α_H	AAHY, ALFI	Hydrodynamic angle of attack	In relation to the position at zero lift	rad
α_I	AAID, ALFS	Ideal angle of attack	For thin airfoil or hydrofoil, angle of attack for which the streamlines are tangent to the mean line at the leading edge. This condition is usually referred to as "shock-free" entry or "smooth"	rad
α_0	AAZL ALF0	Angle of zero lift	Angle of attack or incidence at zero lift	rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3.3.3 Forces				
D_F	DRF	Foil drag	Force in the direction of motion of an immersed foil	N
D_I	DRIND	Induced drag	For finite span foil, the component of lift in the direction of motion	N
D_{INT}	DRINT	Interference drag	Due to mutual interaction of the boundary layers of intersecting foil	N
D_P	DRSE	Section or profile drag at zero lift	Streamline drag	N
L_F	LF	Lift force on foil	$C_L A_{FT} q$	N
L_0	LF0	Lift force for angle of attack of zero	$C_{L0} A_{FT} q$	N
3.3.3.4 Sectional coefficients				
C_D	CDSE	Section drag coefficient		1
C_{DI}	CDSI	Section induced drag coefficient		1
C_L	CLSE	Section lift coefficient		1
C_M	CMSE	Section moment coefficient		1
ϵ	EPSLD	Lift-Drag ratio	L/D	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.3.4	**Boundary Layers**	s. Remark .1		
3.3.4.1	**Two-dimensional Boundary Layers**			
C_f	CFL	Skin friction coefficient	$\tau / (\rho U_e^2 / 2)$	1
F	CQF	Entrainment factor	$1 / (U_e dQ / dx)$	1
H	HBL	Boundary layer shape parameter	δ^* / Θ	1
H_E	HQF	Entrainment shape parameter	$(\delta - \delta^*) / \Theta$	1
p	PR	Static pressure		Pa
P	PT	Total pressure		Pa
Q	QF	Entrainment	$\int_a^b U\, dy$	m^2/s
$R_{\delta*}$	RDELS	Reynolds number based on displacement thickness	$U_\infty \delta^* / \nu$ or $U_e \delta^* / \nu$	1
R_θ	RTHETA	Reynolds number based on momentum thickness	$U_\infty \Theta / \nu$ or $U_e \Theta / \nu$	1
u	UFL	Velocity fluctuations in boundary layer		m/s
u^s	UFLS	Root mean square value of velocity fluctuations		m/s
u^+	UPLUS		U / u_τ	1
u_τ	UTAU	Shear (friction) velocity	$(\tau / \rho)^{1/2}$	m/s
U_m	UMR	Time mean of velocity in boundary layer		m/s
U_i	UIN	Instantaneous velocity		m/s
U_∞	UFS	Free-stream velocity far from the model		m/s
U_e	UE	Velocity at the edge of the boundary layer at $y=\delta_{995}$		m/s
ΔU	UDEF	Velocity defect in boundary layer	$(U_e - U) / u_\tau$	1
y^+	YPLUS	Non-dimensional distance from the wall	$y u_\tau / \nu$	1
β	BETE	Equilibrium parameter	$\delta^* / (\tau_w dp / dx)$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
δ_{995}	DEL	Thickness of a boundary layer at $U=0.995U_e$		m
δ^*, δ_1	DELS	Displacement thickness of boundary layer	$\int(U_e - U) / U_e \, dy$	m
K	K	von Karman constant	0.41	1
Λ	PRGR	Pressure gradient parameter	$\delta_{995} / (\nu \, dU_e / dx)$	1
θ^*, δ^{**}	ENTH	Energy thickness	$\int(U / Ue) (1 - U^2 / U_e^2)dy$	m
Θ	THETA	Momentum thickness	$\int(U / U_e) (1 - U / U_e)dy$	m
τ_w	TAUW	Local skin friction	$\mu \, (\partial U / \partial y)_{y=0}$	Pa

3.3.4.2 Remarks

.1 Future work
In future the section should have an additional subsection on three dimensional boundary layers. And both subsections should be structured as follows:

Basic Quantities,
Differential Formulation,
Integral Formulation.

The Restistance and Flow Committee is strongly urged to provide a complete revision of the whole chapter along this line and accordance with the general concepts put forward.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.3.5 Cavitation

3.3.5.1 Flow parameters

a_s	GR	Gas content ratio	α / α_S	1
α	GC	Gas content	Actual amount of solved and undissolved gas in a liquid	ppm
α_S	GS	Gas content of saturated liquid	Maximum amount of gas solved in a liquid at a given temperature	ppm
σ	CNPC	Cavitation number	$(p_A - p_C) / q$	1
σ_V	CNPV	Vapor cavitation number	$(p_A - p_V) / q$	1

3.3.5.2 Flow fields

D_C	DC	Cavity drag		N
l_C	LC	Cavity length	Streamwise dimension of a fully-developed cavitating region	m
p_A	PA	Ambient pressure		Pa
p_{AC}	PACO	Collapse pressure	Absolute ambient pressure at which cavities collapse	Pa
p_{AI}	PAIC	Critical pressure	Absolute ambient pressure at which cavitation inception takes place	Pa
p_C	PC	Cavity pressure	Pressure within a steady or quasi-steady cavity	Pa
p_{CI}	PCIN	Initial cavity pressure	Pressure, maybe negative, i. e. tensile strength, necessary to create a cavity	Pa
p_V	PV	Vapor pressure of water	At a given temperature!	Pa
U_I	UNIN	Critical velocity	Free stream velocity at which cavitation inception takes place	m/s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
V_L	VOLS	Volume loss	W_L / w	m^3
W_L	WTLS	Weight loss	Weight of material eroded from a specimen during a specified time	N/s
δ_C	HC	Cavity height or thickness	Maximum height of a fully-developed cavity, normal to the surface and the stream-wise direction of the cavity	m

3.3.5.3 Pumps

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
H_N	HTNT	Net useful head of turbo-engines		m
H_U	HTUS	Total head upstream of turbo-engines		m
T_n	TN	Thoma number	$(H_U - p_V / w) / H_N$	1

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.4	**Environmental Mechanics**			
3.4.1	**Waves**		see Remark .1	

This section is related to Sections 3.1.2 **Time and Frequency Domain Quantities** and 3.1.3 **Random Quantities and Stochastic Processes**.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.4.1.1	**Periodic waves**		see Remark .2	
c_W	VP	Wave phase velocity or celerity	L_W / T_W	m/s
c_{Wi}	VP(I)	Wave phase velocity of harmonic components of a periodic wave	const = c_W for periodic waves	m/s
c_G	VG	Wave group velocity or celerity		m/s
f_W	FW	Basic wave frequency	$1 / T_W$	Hz
f_{Wi}	FW(I)	Frequencies of harmonic components of a periodic wave	$i\ f_W$	Hz
H_W	HW	Wave height	$\eta_C - \eta_T$	m
k, κ	WN	Wave number	$2 \pi / L_W$	1/m
L_W , λ_W	LW	Wave length	Measured in the direction of wave propagation	m
T_W	TW	Basic wave period	$1 / f_W$	s
α	WD	Wave direction		rad
η	EW	Instantaneous wave elevation at a given location	z-axis positive vertical up, zero at mean water level; s. Remark .3	m
η^a_i	EWAM(I)	Amplitudes of harmonic components of a periodic wave	η^{FSa}	m
η^p_i , ϵ_i	EWPH(I)	Phases of harmonic components of a periodic wave	η^{FSp}	rad
η_C	EC	Wave crest elevation		m
η_T	ET	Wave trough depression	Negative values!	m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
λ_W , L_W	LW	Wave length	Measured in the direction of wave propagation	m
ζ	DW	Instantaneous wave depression	z-axis positive vertical down, zero at mean water level	m
ω_W, σ	FC	Circular wave frequency	$2\ \pi\ f_W = 2\ \pi\ /\ T_W$	rad
3.4.1.2 Irregular waves			see Remark .3	
H_d	HD	Wave height by zero down-crossing		m
H_u	HU	Wave height by zero up-crossing		m
T_d	TD	Wave periods by zero downcrossing		s
T_u	TU	Wave periods by zero up-crossing		s
η_C	EC	Maximum of elevations of wave crests in a record		m
η_T	ET	Elevations of wave troughs in a record	Negative values!	m
λ_d	LD	Wave length by zero down-crossing		m
λ_u	LU	Wave length by zero up-crossing		m

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
3.4.1.3 Time Domain Analysis				
H_V	HV	Wave height estimated from visual observation		m
$H_{1/3d}$	H13D	Zero downcrossing significant wave height	Average of the highest one third zero downcrossing wave heights	m
$H_{1/3u}$	H13U	Zero upcrossing significant wave height	Average of the highest one third zero upcrossing wave heights	m
H_σ	HWDS	Estimate of significant wave height from sample deviation of wave elevation record		m
T_{rt}	TRT	Return period	The average interval in years between times that a given design wave is exceeded	
T_R	TR	Duration of record	$1 / f_R$	s
T_S	TS	Sample interval	$1 / f_S$, time between two successive samples	s
T_V	TV	Wave period estimated from visual observation		s
3.4.1.4 Frequency Domain Analysis				
b	B	Bandwidth of spectral resolution	Sampling frequency divided by the number of transform points	Hz
C_r	CRA	Average reflection coefficient		1
$C_r(f)$	CRF	Reflection coefficient amplitude function		1
f_P	FRPK	Spectral peak in frequency	Frequency at which the spectrum has its maximum	Hz
f_R	FRRC	Frequency resolution	$1 / T_R$	Hz
f_S	FRSA	Sample frequency	$1 / T_S$	Hz

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
H_{mo}	HMO	Significant wave height based on zeroth moment for narrow banded spectrum	$4\ (m_0)^{1/2}$	m
H_σ	HWDS	Estimate of significant wave height from sample deviation of wave elevation record		m
m_n	MN	n-th moment of wave power spectral density	$\int f^n\ S(f)df$	$m^2/\ s^n$
$S_i(f)$, $S_i(\omega)$	EISF, EISC	Incident wave power spectral density		m^2/Hz
$S_r(f)$, $S_r(\omega)$	ERSF, ERSC	Reflected wave power spectral density		m^2/Hz
$S_\eta(f)$, $S_\eta(\omega)$	EWSF, EWSC	Wave power spectral density		m^2/Hz
T_P	TP	Period with maximum energy	$2\pi f_P$	
T_{01}	T1	Average period from zeroth and first moment	m_0/m_1	s
T_{02}	T2	Average period from zeroth and second moment	$(m_0/m_2)^{1/2}$	s

3.4.1.5 Directional Waves

$D(f,\theta)$, $D(\omega,\mu)$	DIRSF	Directional spreading function	$S(f,\theta)=S(f)D(f,\theta)$ $\int_0^{2\pi} D(f,\theta)d\theta=1$	rad
f	FR	Frequency		Hz
$S\zeta(\omega,\mu)$ $S\theta(\omega,\mu)$ etc.	S2ZET S2TET etc.	Two dimensional spectral density		1
$S_\rho(f,\theta)$ $S_\zeta(\omega,\mu)$	STHETA	Directional spectral density		$m^2/Hz/$ rad
α	CWD	Component wave direction		rad
μ	WD	Dominant wave direction		rad

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.4.1.6 Remarks

.1 General

This section is of course in many ways related to the Sections 3.1.2 **Time and Frequency Domain Quantities** and 3.1.3 **Random Quantities and Stochastic Processes**. In terms of the object oriented paradigms only the time function, the wave elevation at a given location, denoted by η and EW, respectively, has to be introduced and the operations defined earlier along with the corresponding notation may be applied without modification and repetition.

.2 Periodic waves

The basic concepts on waves are derived from the model of periodic, not necessarily harmonic waves, but which may be considered as composed of harmonic components. Even periodic waves may be considered as samples of stochastic processes. In this case the wave parameters are random quantities with given joint probability functions. In practice only samples of such processes will be available and consequently only random sample estimates of the parameters can be obtained.

.3 Irregular waves

In the section on non-periodic waves only random quantities have been introduced as e. g. the crest height, to which all the probability concepts and parameters can be applied as defined earlier in Section 3.1.3., e. g. the population mean and variance of the crest height.

If waves are not periodic any individual infinite record may be considered as a random sample of stationary stochastic process, which is usually assumed to be ergodic, thus permitting to replace population means by appropriate time means. In future ergodicity may be required to be checked at least for research and quality assurance purposes.

.4 Finite records

In practice only records of finite duration are available of the hypothetical stochastic processes for the estimation of the population parameters. This should be reflected in the symbols and terminology, e. g. in the case of the wave crest only the random sample mean $\eta_C{}^A$ (ECMS) may be determined. And as long as in most cases no agreement has been reached on the optimum estimators to be used the symbols and terminology should even indicate the special estimators used in order to avoid confusion.

.5 Sampled values

Usually not even finite records are available for the estimation of spectra etc, but only finite sets of sampled values, namely η_i or EW(I).

.6 Research Parameters

Currently discussed research parameters may be found in the IAHR/PIANC List of Sea State Parameters, Supplement to Bulletin No 52, January 1986.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.4.2 Wind

3.4.2.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
T_{rt}	TRT	Return period	The average interval in years between times that a given wind speed is exceeded	
V_{WR}	VWREL	Apparent wind velocity	see section 1.4.1	m/s
V_{WT}	VWABS	True wind velocity	see section 1.4.1	m/s
β_{aw}	BETWA	Apparent wind angle (relative to vessel course)	see section 2.6	
β_{tw}	BETWT	True wind angle (relative to vessel course)	see section 2.6	
θ_W	TETWI	Wind direction		

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

3.4.3 Ice Mechanics

3.4.3.1 Basic Quantities

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
E	MEI	Modulus of elasticity of ice		n/m^2
S_I	SAIC	Salinity of ice	Weight of salt per unit weight of ice	1
S_W	SAWA	Salinity of water	Weight of dissolved salt per unit weight of saline water	1
$t^\circ{}_A$	TEAI	Temperature of air		°C
$t^\circ{}_I$	TEIC	Local temperature of ice		°C
$t^\circ{}_W$	TEWA	Temperature of water		°C
δ_I	ELIC	Deflection of ice sheet	Vertical elevation of ice surface	m
ϵ_I	STIC	Ice strain	Elongation per unit length	1
$\dot{\epsilon}_I$	STRTIC	Ice strain rate	$\partial\epsilon / \partial\tau$	1/s
μ_I	POIIC	Poisson's ratio of ice		1
ν_A	POAI	Relative volume of air	Volume of gas pores per unit volume of ice	1
ν_B	POBR	Relative volume of brine	Volume of liquid phase per unit volume of ice	1
ν_O	POIC	Total porosity of ice	$\nu_O = \nu_A + \nu_B$	1
ρ_I	DNIC	Mass density of ice	Mass of ice per unit volume	kg/m^3
ρ_{SN}	DNSN	Mass density of snow	Mass of snow per unit volume	kg/m^3
ρ_W	DNWA	Mass density of water		kg/m^3
ρ_Δ	DNWI	Density difference	$\rho_\Delta = \rho_W - \rho_I$	kg/m^3
σ_{CI}	SCIC	Compressive strength of ice		Pa
σ_{FI}	SFIC	Flexural strength of ice		Pa
σ_{TI}	SNIC	Tensile strength of ice		Pa
τ_{SI}	STIC	Shear strength of ice		Pa

4 Background and References

4.1 Symbols and Terminology Group

4.1.1 Terms of Reference

In May 1985 the Executive Committee of the 18th International Towing Tank Conference (ITTC) reorganized the former Information Committee (earlier Presentation Committee) to form a Symbols and Terminology (SaT) Group in the newly established ITTC Secretariat.

The task of the SaT Group for the 18th ITTC was to carry out Recommendations 1 through 5, related to the ITTC Standard Symbols, of the Information Committee of the 17th ITTC, which were:

1. The Information Committee should continue to monitor and co-ordinate the development of new symbols by the Technical Committees.

2. The Conference should adopt the new symbols for hydrostatics included in Appendix 4 and the Information Committee should then include these in the ITTC Standard Symbols.

3. The Information Committee should restructure the ITTC Standard Symbols according to the outline Proposal in Appendix 6 and include new symbols agreed by the Technical Committees.

4. The Information Committee should continue to revise the Dictionary of Ship Hydrodynamics as required.

5. The Information Committee should continue cooperation with other organizations to achieve a common agreement on symbols and terminology.

The 18th ITTC at Kobe adopted the following Recommendations to the Conference and for the future work of the SaT Group, respectively, related to Symbols:

Recommendations to the Conference:

1. The Conference should adopt the structure of the ITTC standard Symbols and Terminology List outlined by the Symbols and Terminology Group and used as the basis for the 1987 Draft List distributed at the 18th ITTC in Kobe.

2. The Conference should urge the Technical Committees and individuals to contribute to the completion of the List of Standard Symbols and should encourage the use of the symbols and their further development in cooperation with the Symbols and Terminology Group.

3. The Conference should decide to delay the review and update of the ITTC Dictionary of Ship Hydrodynamics and the official translations of this into principal languages until the final Symbols and Terminology List is published in 1990.

Recommendations for the future work of the Group:

1. The Symbols and Terminology Group should continue cooperation with other organizations to achieve a common agreement on symbols and terminology.

2. The Symbols and Terminology Group should continue to monitor and coordinate the development of new symbols and terminology by the Technical Committees of the ITTC.

3. The Symbols and Terminology Group should complete the ITTC Standard Symbols and Terminology List based on the 1987 Draft distributed at the 18th ITTC and distribute the final version with Volume 1 at the Proceedings of the 19th ITTC.

The 19th ITTC at Madrid adopted the following recommendations related to symbols:

Recommendations to the Conferences:

The 1990 version of the List of Standard symbols should be used as a working document without the formal approval of the Conference.

Recommendations for the future work of the Group:

The SaT Group to put the computer compatible symbols on a more rational basis in order to make them useful for data exchange purposes.

The 20th ITTC at San Francisco adopted the following recommendations related to the SaT Group

Recommendation to the Conference

The Conference should approve, as a reference document, the 1993 Version of the ITTC Symbols and Terminology List.

Recommendations for Future Work of the SaT Group

Symbols.
The Symbols and Terminology Group will make appropriate corrections and additions to the 1993 Version of the ITTC Symbols and Terminology List and additions to the document which may include specialized topics and illustrative sketches as well as sections on measurement uncertainty, wave cut analysis and other suggestions from the Technical Committees. The Symbols and Terminology Group will pursue the conversion of the 1993 Version of the ITTC Symbols and Terminology List from a word-processor format to an object-oriented database format. This will enable users to prepare subsets of the ITTC Symbols and Terminology List more readily.

Formats.
The Symbols and Terminology Group to continue will monitor the international efforts in this field and to coordinate the development of neutral formats for the exchange of information between ITTC member organizations and their clients.

4.1.2 Activities of the SaT Group

The SaT Group took up its work immediately after it was established having its first meeting at Wageningen in October 1985, and coming up with the plan to produce the present draft of a restructured and enlarged list of the ITTC Standard Symbols 1987. The first raw draft was discussed at Berkeley in July 1986, the Draft 1987 published at the 18th ITTC in October 1987 at Kobe by the Society of Naval Architects of Japan, having been finalized at Trondheim in June 1987.

Work on various chapters has been continued by the 18th ITTC SaT Group and the results have been distributed to the Technical Committees at the Kobe Conference together with the printed Draft 1987.

The SaT Group of the 19th ITTC continued work on the Standard Symbols during meetings at Genova in March 1988, at the Hague and Berlin in September 1988 and in August 1989 at Trondheim, the 1990 version being completed at Genova in March 1990.

During this work, new and more rigorous requirements resulting from the proposed use of the symbols in validation work and in data bases caused a reconsideration of the fundamental aspects. Duplication of computer symbols had to be carefully traced and avoided, in order to permit automatic handling of symbols in data bases.

In order to facilitate the handling of the List of Symbols the earlier version was retyped as a series of WordPerfect files, which were available much too late for updating and were printed without even having been proof read! Consequently, the goal of finalizing the symbols list before the 19th ITTC at Madrid could not be reached. From the document itself it is evident that was less than a draft.

The SaT Group of the 20th ITTC met at Madrid in September 1990, at Berlin in June 1991, at Newcastle in May 1992 and at Genova in January 1993. The primary task after many years of frustrations with the computerized list of symbols was to finally establish a computer implementation permitting direct expert corrections on a PC.

After the previous transcription into the WordPerfect files using the tabulator function the solution was achieved by transformation to the table format. With the appropriate tools being available after all the next task tackled was to correct all the misprints and to implement all the improvements suggested by colleagues of member organizations and members of the SaT Group. The List of Symbols as printed is now available on floppy disks using the format of a WordPerfect 6.1

The main concern after this still rather traditional approach was to achieve the goal set out in the Recommendations for the future work of the SaT Group, to put the computer symbols on a more rational basis. And it soon became evident that the accomplishment of this task could only be achieved by rigorously following the object oriented paradigms applied earlier in restructuring the List of Symbols.

Two problems had to be solved: to maintain the traditional, in many ways inconsistent "Standard" Symbols as an accepted interim and suggest new consistent symbols as alternatives. Some of these are already used in computer work and SaT Group feels that due to their efficiency they will sooner or later completely replace the traditional symbols as has the system of SI-Units the traditional systems.

In view of the increasing demands concerning quality assurance systems the SaT Group felt that the ITTC Symbols should no longer be called Standard Symbols as this name implies legal obligations, which are not existent. The International Standard Organization and corresponding national organizations may at a later stage take measures to adopt the ITTC Symbols as a Standard as was already intended with the earlier version; s. 4.5.3.

During the work to rationalize the computer compatible symbols for use in databases etc the SaT Group became aware of a number of related efforts on an even more general level, which need to be taken into account in the further development of the ITTC Symbols. As documented in the Group Report to the 20th ITTC the development and application of terminological databases is dramatically increasing and has lead to a number of specialized workshops and symposia.

In the broadest sense terminological databases are basic for computer aided knowledge and science engineering, which are developing at a breath taking pace. In order to meet the forthcoming requirements the ITTC Symbols will have to be further rigorously rationalized. Compared to this formidable task, which has only been started with the new object oriented structure of the Symbols List, the transformation from the present table format into one of the rapidly developing terminological database formats awaits further software developments.

The software systems presently available do still not meet very basic requirements, as did the word processors up to now, absorbing too much of the energy of the SaT Group which should have been devoted to the symbols proper. While the problem of producing customized lists of symbols can be solved rather easily, the much more interesting problem of deriving consistent submodels from the general models of the complete list needs still much more development work.

At this stage, it is appropriate to acknowledge with thanks the tremendous work done by the former Presentation and Information Committees and the Technical Committees in their respective fields. It is only on the basis of their work that the task of the SaT Group could have been undertaken and can be carried on. Last but not least a word of thanks is due to the great number of typists who have at all stages contributed to the actual production of the document.

All the ITTC Community, the Technical Committees in particular are invited to contribute to the continuing task of updating and further improvement.

4.1.3 Membership

The membership of the SaT Group as appointed by the 18th ITTC Executive Committee in May 1985, re-appointed by the 19th ITTC Executive Committee in October 1987 and by the 20th ITTC Executive Committee in September 1993 is as follows:

Prof. Bruce Johnson (Chairman, 1985-1996)
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Prof. Carlo Podenzana-Bonvino (Secretary, 1985-1993)
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Most of the members were re-appointed again by the Executive Committee in September 1990, Dr. Matsumoto being followed by:

Prof. Michio Nakato (Member, 1990-1996)
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and as a new member was appointed:

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at the 21st ITTC in Norway, Professor Nakato was replaced by:

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4.2 List of Symbols

4.2.1 Classification

The prime concern in setting up a revised and enlarged list of ITTC Standard Symbols was to design an adequate system for the classification of concepts. As soon as the work started it became clear that the outline proposed by the Information Committee of the 17th ITTC (Proc. 17th ITTC (1984) Vol.1, p.56) had to be reconsidered in view of the problems encountered.

Subsequently the following design requirements and goals have been established:

1. produce a coherent document, meeting the present and possibly the future requirements of the ITTC community in general and particular user groups

2. establish an open ended matrix structure that can be easily expanded as requirements arise, without the need of restructuring and repetition or too many explicit cross-references

3. minimize departures from the well established and widely accepted previous list of symbols

After a series of attempts to meet these requirements the structure as listed in the table of contents evolved very much in line with the past development of the symbols, for instance by the High Speed Craft Committee and others. The essential features are the subject areas of rather limited scope, organized in an hierarchical order. Ideally each subject area represents a complete and coherent model of that area under consideration, for example rigid body motion, hull geometry, propulsion performance.

4.2.2 **Structure**

The concepts related to a given subject area or model are designated by the ITTC Symbol and called by their Name. Their meaning can in principle only be concluded from the context of the model, that is by coherent, so called 'implicit' definitions, to be derived from an explicit statement of the model, ideally an axiomatic system or any equivalent, for example a drawing.

The problem is that traditionally in lists of symbols as in dictionaries these explicit models are missing for various reasons. One reason is that many subject areas under discussion are far from being developed and understood to the extent necessary. A consequence of this situation is that the symbols proposed are not always as coherent as is necessary for advanced and systematic work, where the explicit models and adequate notations area are a prerequisite.

The problem under discussion is of course the same in national and international standards. In order to avoid the dilemma indicated, the ITTC Symbols should not only perpetuate past practice and jargon but try to take the lead and step forward. This is particularly important in view of the development trends in marine technology. In a rapidly changing world adequate tools are prerequisite for efficient problem solving.

As expert system and knowledge engineering technologies evolve the importance of adequate symbols and terminology is more widely acknowledged. The training of scientists working in the terminology field is being offered by the standards organizations. Some of these activities have been monitored but are felt to be lacking in clear-cut rules which may be readily understood and applied in practice.

The original idea to add indices of symbols and names to the document had to be delayed as long as adequate tools were missing. Now such an undertaking is felt to be still premature at the present stage, as it requires the resolution of a number of additional problems, such as standardization of names.

4.2.3 Organization

As has been emphasized the development of symbols is a continuing process and as the subject develops, further amendments and additions, as approved by the Conference, will be included in future editions of the list.

In order to avoid any extra problems the symbols are arranged in alphabetical order in each subject area as in previous lists. Continuous page numbering was discarded in earlier versions. The idea was to establish a loose leaf organization as the most appropriate, in view of new drafts to be incorporated.

In view of the extremely powerful modern word processing systems the whole idea was discarded and advantage was taken of the indexing capabilities etc. permitting efficient production of real updates including in future additional explanations and sketches or drawings related to particular sections where necessary, and as found in national and international standards.

But in view of the tremendous effort which explicit mathematical models, explanations, and sketches take for their preparation, the present SaT Group has only started to consider guidelines for these additions and has added only few examples of explanations to the present list. The Technical Committees and other interested parties are urged to provide further material for review by the SaT Group and future inclusion into the list.

It has been noted by the SaT Group that some users dislike the disruption of the list of symbols by lengthy explanations. But the Group feels that the complexity of the subject and the sensible use of the symbols require such explanations, the more so as the fundamentals of the theory of science and terminology are not taught to students of naval architecture and marine engineering.

4.3 Principles of Notation

4.3.1 Objects: Quantities

Standard notations have to be adequate for the problems to be dealt with and preferably have to be operational.

In general there is a body b, e. g. ship S or model M, in space s, referred to coordinates c with origin o, and time t of which the values q of quantities of certain physical qualities Q are of interest, i. e.

$$q = Q\ (b, s, c, o, t)\ ,$$

q is a variable for numerical values of quantities, while Q is a variable for functions constants, quantities of qualities, e. g. of inertia, momentum, or energy.

In many cases the quantities in question are components of vectorial or tensorial quantities; and should be denoted accordingly, s. 4.3.2.

Further, quite often various aspects of the same quantity are of interest, for example their spectra or aspects of those, in simpler cases just their expectation or estimates of these, e. g. time averages, all of them to be carefully distinguished; s. 4.3.3.

It should be evident, that the requirements concerning an adequate, operational notation are quite demanding. At the same time it should be understood that it is worthwhile to create such a notation, as waste of effort due to confusion of concepts may be reduced drastically.

The question is of course how far one wants to depart from current practice in order to cope with this situation. The example of the standard notation used in chemistry may serve as a guideline.

In the present context, the typical objects or "elements" referred to are the values of quantities in time or "signals". Consequently the symbols for the signals should be the primary symbol and components and transforms should be denoted by sub- and superscripts, respectively.

4.3.2 Components: Subscripts

In view of vector and tensor components, it is felt that it is appropriate to introduce a simple tensor notation at least for orthogonal coordinates. This helps to limit the number of symbols as it requires only one symbol for the particular set of components in question. For example the various, say at least two times thirty six "stability derivatives", i. e. generalized mass and damping, need not and cannot be introduced individually.

If vector or tensor components, in general matrix components are conveniently denoted by subscripts, the above situation thus becomes in more general terms

$$q_{ij} = Q_{ij}\ (b, s, c, o, t).$$

Numerical subscripts are truly operational in most algorithmic languages, which can handle matrices, usually called one-, two-, or three-dimensional arrays.

4.3.3 Operators: Superscripts

Superscripts are traditionally used for exponentiation but can be generally used to denote operators; the most satisfactory approach being the inverse Polish notation.

The advantage of this notation is that no brackets are required and operators are listed exactly in the sequence in which they are applied to the signal. As has been done with the matrix notation earlier this notation may in future be readily rendered operational in advanced software environments, object oriented languages in particular.

For convenience the computer symbols and symbols used in data bases should exactly reflect this notation in order to avoid any extra problems of translation. Consequently the earlier proposed prefixes in the computer symbols have been changed to suffixes. As an example the real part of the heave spectrum may be denoted as follows:

standard	computer data base
XSR3	XSR(3) or X_SR(3) or XxSpRe(3)
XSR3 or X_SR3 or XxSpRe3	

The main problem in any case is to define symbols for operations and not for the results of the operations. In order to have the most compact notation agreement should be reached concerning a one character notation, and a corresponding two character notation for the computer symbols, for well defined operations.

Due to the fact that it has not been possible to define symbols for concepts, qualifiers, operators etc uniformly in terms of two characters the above example show the presently used techniques to introduce separators. X and Xx denote symbol variables, to be replaced by symbols proper in any particular application.

If necessary the meaning of a operator symbol may depend on the context, i.e. its position with respect to others and the object it operates upon. This generic use of symbols is of course very efficient, but needs special care not to confuse concepts.

It is most important to note that in any case definitions of concepts or operations should not be confused with operational definitions, i.e. methods for determination or measurement of values. Separate identifiers have to be introduced in order to avoid confusion. A whole hierarchy of such operators and qualifiers is necessary.

Some 'operator' symbols are proposed in the following chapter on fundamental concepts. They concern:

1. identifiers of the object being tested, e. g. ship S or model M, or the various bodies in a multi-body problem,

2. identifiers of coordinate systems and of the reference points, not only forward and aft perpendicular,

3. the various aspects of complex quantities,

4. the various aspects of spectra and

5. the various aspects of random quantities and stochastic processes.

So far no particular identifiers have been introduced for various estimators. As an example the power spectra of stationary random processes may be estimated using Fourier techniques, as agreed upon by the oceanographic institutes world wide, or by autoregressive model techniques, avoiding systematic i. e. bias errors inherent in the first technique. Another example is the interpretation of the conceptual frame-work of hull-propeller interaction based on propulsion, hull resistance, and propeller open water tests or from the results of propulsion tests alone.

4.4 Details of Notation

4.4.1 Standard Symbols

The symbols in the first column of the tables are primarily intended for use in technical writing and mathematical expressions. The following notes are relevant:

1. All symbols, their subscripts, and superscripts should be written as shown.

2. In a number of instances alternative symbols are given.

3. In many cases the symbols, their sub- and superscripts denote variables to be replaced by symbols for any object, component and qualifier or operator, respectively.

4. Where for one reason or another departures from the standard symbols are made, these departures should be clearly indicated and stated.

4.4.2 Computer Symbols

Wherever possible the symbols in the second column of the tables have been chosen so that their meaning is readily apparent. They have been constructed from the CCITT International Telegraph Alphabet, restricted character set. They are therefore suitable for use in a wide range of situations e. g.: Telex messages, letters, computer printouts etc.

To ensure that the symbols can be used in a wide range of programming languages they currently have been kept to less than six characters long. The symbols should be used as defined, and, in accordance with modern programming practice, should have their type explicitly declared before use. The following rules were applied in the derivation of the symbols:

1. Only upper case letter A - Z and digits 0 - 9 have been used.

2. Formerly Greek letters have been spelled out, if necessary in abbreviated form or with changed spelling. This practice is considered obsolete.

3. The Froude 'circular' symbols are defined by the prefix CIRC.

4. All symbols start with a letter.

5. Qualifiers and operators, preferably two characters, are currently suffixed to the main symbol line, without spacing.

6. No one computer compatible symbol should be used for different concepts in a given context. This goal has not been completely achieved for the whole list. Ad hoc solutions have been attempted but discarded as unsatisfactory.

7. Since the computer compatible symbols have been proposed as the basis of attribute names for data exchanges, the above rules will probably be further developed in the near future.

A final remark on the Computer Symbols: in the computer, the letter O and figure 0 (zero) have fundamentally different meanings, but owing to their resemblance they can be easily confused. Thus it is necessary to distinguish rigorously between them. As a matter of fact there are contradictory conventions being widely used.

4.4.3 Names, Definitions, SI-Units

The third column in the tables contains the names of the concepts denoted by the symbols in the first and the second columns, while the fourth column usually contains a definition, or a short explanation where necessary. The last column gives the SI-Units for the concepts.

The dimensions of dimensionless quantities as well as their units are 1. They are measured in counts or "absolute units", which sometimes are given names, e.g. rad, rev, but this practice, usual in natural languages, is found to be not very useful in formal systems.

A number of concepts and their symbols are customarily defined and/or standardized differently in different fields of application. The SaT Group cannot resolve all of these discrepancies, but urges that in such cases the definitions and the units used are stated. Only a few examples having been discussed may be mentioned.

While the SI-Units of angle and velocity are rad and meter/second, respectively, the traditional units degree and knot are still widely used and clearly this situation will not change in the near future. In the spectral description of real deterministic or stochastic processes spectra and power spectra, respectively may be defined as double- or single-sided as functions of frequency or circular frequency. Any of these definitions has its particular advantages, but has to be clearly distinguished from the others.

A major step towards an unambiguous definition of the phase angle has been taken by explicitly distinguishing phase lead and lag of complex quantities. Despite the fact that both have opposite signs they are confused even in mathematically oriented standard textbooks!

4.5 References

4.5.1 ITTC Documents

1. International Towing Tank Conference, Standard Symbols 1971.
BSRA Technical Memorandum No.400, August 1971.

2. International Towing Tank Conference, Standard Symbols 1976.
BSRA T.M. No.500, 1976.

3. ITTC Dictionary of Ship Hydrodynamics.
RINA Maritime Technology Monograph No.6, 1978.

4. Translation of Overall Index of Titles of Dictionary of Ship Hydrodynamics.
Vol. 1: CETENA, Genova, 1984,
Vol. 2: University of Tokyo, 1984.

5. Bibliography and Proposed Symbols on Hydrodynamic Technology
as Related Model Tests of High Speed Marine Vehicles.
Prep. by 17th ITTC High-Speed Marine Vehicle Committee.
SPPA Maritime Research and Consulting. Rep. No.101, 1984.

4.5.2 Translations

A number of translations of the List of ITTC Standard Symbols into languages other than English has been made including French, German, Italian, Japanese, Russian, Spanish and Chinese. For obvious reasons these translations are no longer up-to-date as the present accepted list in English.

1. French Translation of ITTC Standard Symbols 1971.
Association Francaise de Normalisation (AFNOR).

2. International vereinbarte Buchstabensymbole und Bezeichnungen
auf dem Gebiet der Schiffshydrodynamik. Collatz, G.
Schiff und Hafen 27 (1975) No.10.

3. Italian Translation of ITTC Standard Symbols 1971. Luise E.
Appendix II, Report of Presentation Committee.
Proceedings 14th ITTC, Vol. 4, Ottawa 1975.

4. Japanese Translation of ITTC Standard Symbols.
Transactions of the Society of Naval Architects of Japan, No.538, April 1974.

5. Russian Translation of ITTC Standard Symbols 1971.
Brodarski Institute Publication No.28, Zagreb 1974.

6. Simbolos Internacionales en Arquitectura Naval.

Asociacion de Investigacion de la Construccion Naval,
Publication 7/75, Juli 1975, Madrid.

7. Report of Information Committee, Proc. 17th ITTC, Göteborg 1984.

8. Chinese Translation of ITTC Standard Symbols.
China Ship Scientific Research Centre, Wuxi.

4.5.3 Other References

Apart form the organizations represented on the ITTC these symbols have been recommended for use in technical writing on naval architecture by a number of organizations concerned with marine matters including The Royal Institution of Naval Architects, the American Society of Naval Architects and Marine Engineers and the American, British, Canadian, Australian, and Italian Navies. Where possible, the symbols for Section 3.4.1, Waves are consistent with the IAHR/PIANC *List of Sea State Parameters*, Supplement to Bulletin No 52, January 1986.

In 1985 the Draft International Standard ISO/DIS 7463 Shipbuilding - Symbols for Computer Applications - has been published. The symbols are based on the list approved by the ITTC in Ottawa 1975 and a related list produced by the ISSC in 1974, inconsistencies having been removed. The ISO/TC8/SC15 has been notified that major changes of the ITTC Symbols are under discussion. Subsequently processing of ISO/DIS 7463 has not been postponed, but the standard has been published as ISO 7463 in 1990.

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit

APPENDIX 5.1 PROPOSED LIST OF ITTC SYMBOLS FOR WATERJETS

(To be relocated to Section 1.3.3.4 in Version 1997)
See Figure A1. Definition of Station Numbers and Normalised Energy Flux, Volume 1 *Proceedings of 21st ITTC*

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
A_j	AJ	Cross sectional area at Station j		m²
b_1	B1	Maximum width of cross sectional area at Station 1		m
C_p	CP	Local pressure coefficient	$(p-p_0)/(\rho V^2 /2)$	1
E_j	EJ	Energy flux at Station j	$E_j = (\rho/2)\int_{Q_J} V_{Ej}^2 dQ_j$	W
h_1	H1	Maximum height of cross sectional area at Station 1		m
h_J	HJ	Height of jet centerline above undisturbed water surface		m
H_1	HT1	Local total head at Station 1		m
H_{35}	H35	Mean increase of total head across pump and stator or several pump stages		m
IVR	IVR	Intake velocity ratio	V_2/V	1
JVR	JVR	Jet velocity ratio	V_7/V	1
M_1	MF1	Momentum flux at Station 1	$M_1 = \rho\int_{Q_J} V_1 dQ_j$	N
M_7	MF7	Momentum flux at Station 7	$M_7 = \rho\int u_{7x} dQ_j + \int(p_7 - p_0)dA_7$	N
ΔM	DMF	Change of momentum flux		N
p_j	PRJ	Local static pressure at Station j		N/m²
p_0	PR0	Ambient pressure in undisturbed flow		N/m²
P_{JSE}	PJSE	Effective jet system power		W
P_{PE}	PPE	Effective pump power		W
Q_{bl}		Volume flow rate inside boundary layer		m³ /s
Q_J	QJ	Volume flow rate of jet		m³ /s
u_j	UJ	Local total velocity at Station j		m/s
u_{jx}	UJX	Local axial velocity at Station j		m/s
$u_{7\phi}$	UJFI	Local tangential velocity at Station 7		m/s

ITTC Symbol	Computer Symbol	Name	Definition or Explanation	SI-Unit
V_j	VJ	Mean velocity at Station j		m/s
V_{Ej}	VEJ	Local energy velocity at Station j	$\{u_j^2 + (2/\rho)(p_j - p_0)\}^{0.5}$	m/s
α	ALFA	Angle between centerline of jet and horizontal plane		1
η_{inst}	ETAIN	Pump installation efficiency		1
η_P	ETAP	Pump efficiency		1
η_{WJ}	ETAWJ	Effective jet system efficiency		
ζ_{13}	ZETA13	Inlet and diffusor loss coefficient Station 1-3, based on E0		1
ζ_{57}	ZETA57	Duct and nozzle loss coefficient Station 5-7, based on E7		1