# International Towing Tank Conference
# ITTC Symbols and Terminology List

## Final Version 1996

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## Supersedes all previous versions

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**Prepared by the 21st ITTC Symbols and Terminology Group**
**Version 1996**
**Edited and Produced by Bruce Johnson**
**U.S. Naval Academy**
**Annapolis, MD 21402-5042, USA**
**Phone +1 410-293-6457, Fax +1-410-293-2219**
**johnson@nadn.navy.mil**

**Based on the SaT List Version 1993**
**Edited and Produced by Michael Schmiechen**
**Versuchsanstalt für Wasserbau und Schiffbau,**
**Berlin: VWS, Mitteilungen, Heft 57 (1993)**
**Mueller-Breslau-Strasse (Schleuseninsel)**
**D-10623 Berlin, Germany**

**Please send or fax comments, suggestions, needed additions and clarifications to Professor Johnson**

# ITTC Symbols and Terminology List, Final Version 1996

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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:

Prof. Bruce Johnson (Chairman), U.S. Naval Academy, Annapolis (USA)
Prof. Michael Schmiechen (Secretary), VWS, Technical University Berlin (D)
Prof. Michio Nakato, Hiroshima University —Fukuyama Polytechnic College (J)
Prof. Carlo Podenzana-Bonvino, University of Genova (I)
Dr. David Clarke, University of Newcastle upon Tyne (GB)

So far, Consulting Members have been:

Prof. S. S. Yuan, Shanghai (C)
Dr. Kostadin Yossifov, B.S.H.C., Varna (BG)

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<br>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,<br>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 $\eta$. The computer symbol should of course be EF, instead of ETA.

Another example is the traditional symbol $\omega$ 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

| | | | | |
|---|---|---|---|---|
| $A_{BL}$ | 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 |
| $\nabla$, V | DISPVOL | Displacement volume | $\Delta / (\rho g) = \nabla_{BH} + \nabla_{AP}$ | $m^3$ |
| $\nabla_{BH}$ | DISPVBH | Displacement volume of bare hull | $\Delta_{BH} / (\rho g)$ | $m^3$ |
| $\nabla_{AP}$ | DISPVAP | Displacement volume of appendages | $\Delta_{AP} / (\rho g)$ | $m^3$ |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\Delta$ | DISPF | Displacement force (buoyancy) | $g\ \rho\ \nabla$ | N |
| $\Delta_{BH}$ | DISPFBH | Displacement force (buoyancy) of bare hull | $g\ \rho\ \nabla_{BH}$ | N |
| $\Delta_{AP}$ | DISPFAP | Displacement force (buoyancy) of appendages | $g\ \rho\ \nabla_{AP}$ | N |
| $\lambda$ | SC | Linear scale of ship model | $\lambda = L_S / L_M = B_S / B_M$ <br> $= T_S / T_M$ | 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 <br> $\nabla_A / (A_M\ L / 2)$ | 1 |
| $C_{PE}$ | CPE | Prismatic coefficient, entrance | $\nabla_E / (A_X\ L_E)$ or <br> $\nabla_E / (A_M\ L_E)$ | 1 |
| $C_{PF}$ | CPF | Prismatic coefficient forebody | $\nabla_F / (A_X\ L / 2)$ or <br> $\nabla_F / (A_M\ L / 2)$ | 1 |
| $C_{PR}$ | CPR | Prismatic coefficient, run s. Remark .2 | $\nabla_R / (A_X\ L_R)$ or <br> $\nabla_R / (A_M\ L_R)$ | 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 |
| $C_\nabla$ | CVOL | Volumetric coefficient | $\nabla / L^3$ | 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 |
| $\theta_s$ | 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 |
| $\theta$ | RAKA | Angle of rake | | rad |
| $\theta_{EXT}$ | TEMX | Skew angle extent | The difference between maximum and minimum local skew angle | rad |
| $\phi$ | PHIP | Pitch angle of screw propeller | $\arctg(P / (2 \pi R))$ | 1 |
| $\phi_F$ | PHIF | Pitch angle of screw propeller measured to the face line | | 1 |
| $\psi$ | PSI | Propeller axis angle | Angle between horizontal plane and propeller shaft axis | rad |
| $\tau_b$ | | 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 |
| $\alpha_D$ | AD | Duct profile-shaft axis angle | Angle between nose-tail line of duct profile and propeller shaft | rad |
| $\beta_D$ | 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 |
| $\delta_{FB}$ | ANFB | Bow fin angle | s. Remark .1 | rad |
| $\delta_{FS}$ | ANFS | Stern fin angle | s. Remark .1 | rad |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\delta_F$ | DELFS | Flap angle (general) | Angle between the planing surface of a flap and the bottom before the leading edge | rad |
| $\delta_W$ | DELWG | Wedge angle | Angle between the planing surface of a wedge and the bottom before the leading edge | rad |
| $\delta_{FR}$ | ANFR | Flanking rudder angle | s. Remark .1 | rad |
| $\delta_{FRin}$ | ANFRIN | Assembly angle of flanking rudders | Initial angle set up during the assembly as zero angle of flanking rudders | rad |
| $\delta_R$ | ANRU | Rudder angle | s. Remark .1 | rad |
| $\delta_{RF}$ | ANRF | Rudder-flap angle | s. Remark .1 | rad |
| $\lambda_R$ | TARU | Rudder taper | $c_t / c_r$ | 1 |
| $\lambda_{FR}$ | TAFR | Flanking rudder taper | | 1 |
| $\Lambda_R$ | ASRU | Rudder aspect ratio | $S^2 / A_{RT}$ | 1 |
| $\Lambda_{FR}$ | 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 | $\Delta C_{MTL}$ | 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 |
| $\delta$ | D | Finite increment in... | Prefix to other symbol | |
| $\delta t_{KL}$ | DTR | Change in static trim | | m |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\Delta$ | DISPF | Displacement (buoyant) force | $g\ \rho\ \nabla$ | N |
| $\nabla$ | DISPVOL | Displacement volume | $\Delta / (\rho g)$ | $m^3$ |
| $\theta_S$ | TRIMS | Static trim angle | $\tan^{-1}((z_{SF} - z_{SA}) / L)$ | rad |
| $\mu$ | PMVO | Volumetric permeability | The ratio of the volume of water entering a compartment to the volume of the compartment | 1 |
| $\phi$ | HEELANG | Heel angle | | |
| $\phi_F$ | 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 | | $m^2$ |
| $\Delta C_F$ | 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 |
| $\eta$ | EW | Wave Elevation | see 3.4.1 | m |
| $\theta_V$ , $\theta_D$ | TRIMV | Running (dynamic) trim angle | $\tan^{-1}((z_{VF} - z_{VA}) / L)$ | 1 |
| $\tau_W$ | 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| 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 |
| $\epsilon$ | EPSG | Resistance-displacement ratio in general | $R / \Delta$ | 1 |
| $\epsilon_R$ | EPSR | Residuary resistance-displacement ratio | $R_R / \Delta$ | 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 |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

## 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 | $P_D / \omega$ | 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 |
| $\omega$ | 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 | $\eta_{DS} / \eta_{DM}$ | 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 |
| $\Delta w$ | DELW | Ship-model correlation factor for wake fraction | $w_{T,M}$ - $w_{T,S}$ | 1 |
| $\Delta w_C$ | 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 |
|---|---|---|---|---|
| $\eta_{AP}$ | ETAAP | Appendage efficiency | $P_{EwoAP} / P_{EwAP}$, $R_{TBH} / R_T$ | 1 |
| $\eta_B$ | ETAB, EFTP | Propeller efficiency behind ship | $P_T / P_D = T V_A / (Q \omega)$ | 1 |
| $\eta_D$ | ETAD, EFRP | Propulsive efficiency or quasi-propulsive coefficient | $P_E / P_D = P_R / P_P$ | 1 |
| $\eta_G$ | ETAG, EFGP | Gearing efficiency | | 1 |
| $\eta_H$ | ETAH, EFRT | Hull efficiency | $P_E / P_T = P_R / P_T$ $= (1 - t) / (1 - w)$ | 1 |
| $\eta_M$ | ETAM, EFSI | Mechanical efficiency | $P_S / P_1$ or $P_B / P_1$ | 1 |
| $\eta_O$ | ETAO | Propeller open water efficiency | | 1 |
| $\eta_R$ | ETAR, EFRO | Relative rotative efficiency | $\eta_B / \eta_O$ | 1 |
| $\eta_S$ | 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 | $\rho V_A^2 / 2$<br>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<br>$Q_S = Q_{SC} + Q_{SH}$<br>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 | $(V_A^2 + (0.7\ R\ \omega)^2)^{1/2}$<br>s. Remark .2 | m/s |
| $\rho_P$ | DNP | Propeller mass density | | $kg/m^3$ |
| $\omega$ | V0P | Propeller angular velocity | $2 \pi n$ | 1/s |

### 1.3.3.2 Derived Quantities

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $B_P$ | 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 | $\eta_{TJ}\ T\ V_A$ | |
| $S_A$ | SRA | Apparent slip ratio | $1 - V / (n P)$ | 1 |
| $S_R$ | SRR | Real slip ratio | $1 - V_A / (n P)$ | 1 |
| $\delta$ | ADCT | Taylor's advance coefficient | $n D / V_A$ with n in revs/min, D in feet, $V_A$ in knots (obsolete) | 1 |
| $\eta_{JP}$ | EFJP | Propeller pump or hydraulic efficiency | $P_J / P_D = P_J / P_P$ | 1 |
| $\eta_{JP0}$ | 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 |
| $\eta_I$ | EFID | Ideal propeller efficiency | Efficiency in non-viscous fluid | 1 |
| $\eta_{TJ}$ | EFTJ | Propeller jet efficiency | $2 / (1 + (1 + C_{Th})^{1/2})$ | 1 |
| $\eta_O$ , $\eta_{TPO}$ | ETAO, EFTPO | Propeller efficiency in open water | $P_T / P_D = T V_A / (Q\ \omega)$ all quantities measured in open water tests | 1 |
| $\lambda$ | ADR | Advance ratio of a propeller | $V_A / (n D) / \pi = J / \pi$ | 1 |
| $\tau$ | 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $U_A$ | 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 |
| $\beta$ | BETB | Advance angle of a propeller blade section | $\text{arctg}\ (V_A / (R\ \omega))$ | rad |
| $\beta_1$ | BET1 | Hydrodynamic flow angle of a propeller blade section | Flow angle taking into account induced velocity | rad |
| $\beta^*$ | BETS | Effective advance angle | $\text{arctg}\ (V_A / (0.7\ R\ \omega))$ | rad |

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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

### 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $C_{uv}$ | 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<br>u = 1, 2, 3: force<br>u = 4, 5, 6: moment | N<br>N<br>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<br>u = 1, 2, 3: force<br>u = 4, 5, 6: moment | N<br>N<br>Nm |
| $V_i$ | V(I) | Velocity field of the wake | i = 1, 2, 3 | m/s |
| x<br>y<br>z | X<br>Y<br>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<br>m<br>m |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $x$<br>$a$<br>$r$ | X<br>ATT<br>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<br>1<br>m |
| $\delta_u$ | DP(U) | Generalized vibratory displacement | u = 1,.., 6<br>u = 1, 2, 3: linear<br>u = 4, 5, 6: angular | m<br>m<br>rad |
| $\dot{\delta}_u$ | DPVL(U) | Generalized vibratory velocity | u = 1,.., 6<br>u = 1, 2, 3: linear<br>u = 4, 5, 6: angular | m/s<br>m/s<br>rad/s |
| $\ddot{\delta}_u$ | DPAC(U) | Generalized vibratory acceleration | u = 1,.., 6<br>u = 1, 2, 3: linear<br>u = 4, 5, 6: angular | $m/s^2$<br>$m/s^2$<br>$rad/s^2$ |

### 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $A_{FB}$ | 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 |
| $\lambda_R$ | ASRU | Aspect ratio of rudder | $b_R^2 / A_R$ | 1 |

### 1.4.1.2 Motions and Attitudes

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| 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 |
| $\psi$ | YA | Yaw or course angle | | rad |
| $d_t\psi$ | YART | Rate of change of course | $d\psi$ / dt | rad/s |
| $\psi_0$ | YAOR | Original course | | rad |
| $\theta$ | PI | Pitch angle | | rad |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\phi$ | RO | Roll angle | | rad |

**1.4.1.3 Flow Angles etc**

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\alpha$ | AAPI | Pitch angle | Angle of attack in pitch on the hull | rad |
| $\beta$ | AADR | Drift angle | Angle of attack in yaw on the hull | rad |
| $\beta_{WR}$ | ANWIRL | Angle of attack of relative wind | | 1 |
| $\delta_{eff}$ | ANRUEF | Effective rudder inflow angle | | rad |
| $\delta_0$ | ANRU0 | Neutral rudder angle | | 1 |
| $\delta_B$ | ANFB | Bow fin angle | | rad |
| $\delta_S$ | ANFS | Stern fin angle | | rad |
| $\delta_R$ | ANRU | Rudder angle | | 1 |
| $\delta_{R0}$ | ANRUOR | Rudder angle, ordered | | 1 |
| $\psi_C$ | COCU | Course of current velocity | | 1 |
| $\psi_{WA}$ | COWIAB | Absolute wind direction | see also section 3.4.2, Wind | rad |
| $\psi_{WR}$ | 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 | $\partial N / \partial \dot{v}$ | $Nms^2$ |
| $N_\delta$ | 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 | $\partial Y / \partial \dot{v}$ | $Ns^2/m$ |
| $Y_\delta$ | 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 |
| $l_\delta$ | 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 |
| $\beta_C$ | 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 |
| $\delta_{max}$ | ANRUMX | Maximum value of rudder angle | | rad |
| $\psi_S$ | PSIS | Switching value of course angle | | rad |
| $\psi_{01}$ | PSI01 | First overshoot angle | | rad |
| $\psi_{02}$ | 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 |

### 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 |
| $f_\theta$ | | Natural frequency of pitch | $1 / T_\theta$ | Hz |
| $f_\phi$ | | 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<br>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 |
| $T_\theta$ | TNPI | Natural period of pitch | | s |
| $T_\phi$ | TNRO | Natural period of roll | | s |
| $Y_z(\omega)$,<br>$A_{z\zeta}(\omega)$ | | Amplitude of frequency response function for translatory motions | $z_a(\omega) / \zeta_a(\omega)$ or<br>$z_a(\omega) / \eta_a(\omega)$ | 1 |
| $Y_{\theta\zeta}(\omega)$,<br>$A_{\theta\zeta}(\omega)$ | | Amplitude of frequency response function for rotary motions | $\Theta_a(\omega) / \zeta_a(\omega)$ or<br>$\Theta_a(\omega) / (\omega^2 / (g\zeta_a(\omega)))$ | 1 |
| $\mu$ | | 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 |
| $\beta$ | 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 |
| $\beta_M$ | BETM | Deadrise angle at midship section | | 1 |
| $\beta_T$ | BETT | Deadrise angle at transom | | 1 |
| $\epsilon_{SH}$ | 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 | $m^2$ |
| $\alpha_B$ | 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 |
|---|---|---|---|---|
| $\alpha_{BAR}$ | ALFBAR | Barrel flow angle | Angle between barrel axis and assumed flow lines | rad |
| $\epsilon_{WL}$ | EPSWL | Wetted length factor | $L_M$ / $L_{WL}$ | 1 |
| $\epsilon_{WS}$ | EPSWS | Wetted surface area factor | S / $S_0$ | 1 |
| $\theta_{DWL}$ | TRIMDWL | Running trim angle based on design waterline | Angle between design waterline and running waterline (positive bow up) | rad |
| $\theta_S$, $\theta_0$ | 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 |
| $\theta_V$ , $\theta_D$ | 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 |
| $\lambda_W$ | LAMS | Mean wetted length-beam ratio | $L_M$ / ($B_{LCG}$) | 1 |
| $\tau_{DWL}$ | TAUDWL | Reference line angle | Angle between the reference line and the design waterline | 1 |
| $\tau_R$ | TAUR | Angle of attack relative to the reference line | Angle between the reference line and the running waterline | 1 |
| $\phi_{SP}$ | 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 $\Delta R_{RP}$ | Distance between $\Delta R_{RP}$ and center of gravity (measured normal to $\Delta R_{RP}$) | 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 |
| $C_\Delta$ | 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 |
| $R_\pi$ | 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 |
| $\alpha_c$ | ALFTW | Geometric angle of twist | | 1 |
| $\theta_{DH}$ | DIHED | Dihedral angle | | 1 |
| $\nabla_F$ | 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 |
| $\alpha_{IND}$ | ALFIND | Downwash or induced angle | | 1 |
| $\alpha_{M}$ | ALFM | Angle of attack of mean lift coefficient for foils with twist | | 1 |
| $\alpha_{s}$ | AFS | Angle of attack for which flow separation (stall) occurs | | 1 |
| $\alpha_{TO}$ | 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 | $L_{FF} / \Delta$ | 1 |
| $M_R$ | MLR | Load factor of rear foil | $L_{FR} / \Delta$ | 1 |
| $\epsilon_F$ | 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 |
| $\delta B_c$ | DBCV | Increase in cushion beam due to water contact | | m |
| $\epsilon_{WS}$ | EPSWS | Wetted surface factor | $S_{SHC} / S_{SH0}$ | 1 |
| $\theta_B$ | TETB | Bag contact deformation angle | | 1 |
| $\theta_F$ | TETF | Finger outer face angle | | 1 |
| $\theta_W$ | TETW | Slope of mean water plane for surface level beneath cushion periphery | | 1 |
| $\zeta_C$ | 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** | |
| $C_\Delta$ | 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 |
| $F_{XI}$<br>$F_{YI}$<br>$F_{ZI}$ | FXIC<br>FYIC<br>FZIC | Components of the local ice force | | N<br>N<br>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 |
| $\eta_{ICE}$ | ERIC | Relative propulsive efficiency in ice | $\eta_{ID} / \eta_D$ | 1 |
| $\eta_{ID}$ | 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 |
| $\nabla_C$ | DVCAN | Displaced volume of canoe body | | $m^3$ |
| $\nabla_K$ | DVK | Displaced volume of keel | | $m^3$ |
| $\nabla_R$ | DVR | Displaced volume of rudder | | $m^3$ |
| $\Delta_C$ | DFCAN | Displacement force (weight) of canoe body | | N |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\Delta_K$ | DFK | Displacement force (weight) of keel | | N |
| $\Delta_R$ | 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 |
| $R_\phi$ , $R_H$ | 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 |
| $\beta_L$ | BETAL | leaway angle | | rad |
| $\beta_{aw}$ | BETWA | apparent wind angle (relative to boat course) | | rad |
| $\beta_{tw}$ | 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

## 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.

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

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<br>$S_{ij} = S^0_{ij}$<br>$S_{i,\,3+j} = S^{1\ \mathrm{T}}_{ij}$<br>$S_{3+i,\,j} = S^1_{ij}$<br>$S_{3+i,\,3+j} = S^2_{ij}$ | |
| $T_{ij}$ | *T*(I,J) | Tensor in space referred to an orthogonal system of Cartesian coordinates fixed in the body | $T_{ij}^{\mathrm{s}} + T_{ij}^{\mathrm{a}}$ | |
| $T_{ij}^{\mathrm{A}}$ | *T*AS(I,J) | Anti-symmetric part of a tensor | $( T_{ij} - T_{ji} ) / 2$ | |
| $T_{ij}^{\mathrm{S}}$ | *T*SY(I,J) | Symmetric part of a tensor | $( T_{ij} + T_{ji} ) / 2$ | |
| $T_{ij}^{\mathrm{T}}$ | *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 | $\int \epsilon_{ijk} x_j dv_k$ | |
| $V_u$ | V(U) | Generalized vector | $V_i = V^0_i$<br>$V_{3+i} = V^1_i$ | |
| $x, x_1$<br>$y, x_2$<br>$z, x_3$ | X, X(1)<br>Y, X(2)<br>Z, X(3) | Body axes and corresponding Cartesian coordinates | Right-hand orthogonal system of coordinates fixed in the body, s. Remark .2 | m |
| $x_0, x_{01}$<br>$y_0, x_{02}$<br>$z_0, x_{03}$ | X0, X0(1)<br>Y0, X0(2)<br>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 |
| $x_F, x_{F1}$<br>$y_F, x_{F2}$<br>$z_F, x_{F3}$ | XF, XF(1)<br>YF, XF(2)<br>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 |
| $\epsilon_{ijk}$ | EPS(I,J,K) | Epsilon operator | +1 : ijk = 123, 231, 312<br>− 1 : ijk = 321, 213, 132<br>0 : if otherwise | |
| $\delta_{ij}$ | DEL(I,J) | Delta operator | +1 : ij = 11, 22, 33<br>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** | | | | |
| 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 | $1 / T_S$<br>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 | $\exp(s\, T_S)$<br>Laurent transform | |
| s | S | Complex variable | $a + 2\pi i f$<br>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 | $1 / f_C$<br>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 | $X^{DF}(f) = \sum x_j \exp(-i2\pi fjT_S)$<br>i.e. periodically repeating<br><br>$= X(0)/2 + f_S \sum X^F(f + jf_S)$<br>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 | $X^F(f) = \int X(t)\exp(-i2\pi ft)dt$<br>inverse form:<br>$= \int X^F(f)\exp(-i2\pi ft)dt$<br>if $X(t) = 0$ and $a = 0$ then<br>$X^F(f)=X^L(f)$ | |
| $x^F_j$ | *X*FT(J) | Fourier transform of periodic function | $1/T_C \int X(t)\exp(-i2\pi jt/T_C)dt$<br>$t = 0 \,..\, T_C$<br>$X^F = \sum x^F_j \delta(f - j/T_C)$<br>inverse form:<br>$X(t) = \sum x^F_j \exp(-i2\pi fjT_C)$ | |
| $x^H$ | *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 | $X^{HF}(f) = X^F(f)(-i \operatorname{sgn} f)$<br>$(1/t)^F = -i \operatorname{sgn} f$ | |
| $x^L$ | *X*LT | Laplace transform | $X^L(s) = \int X(t)\exp(-st)dt$<br>if $X(t<0) = 0$ then<br>$= (X(t)\exp(-at))^F$ | |
| $x^R$ | *X*RT | Laurent transform | $X^R(r) = \sum x_j r^{-j} = X^{DL}$ | |
| $x^S$ | *X*S | Single-sided complex spectra | $X^S(f) = X^F(f)(1 + \operatorname{sgn} f)$<br>$= X^{AF}$<br>i.e. $= 0$ for $f < 0$ | |
| $x^S_j$ | *X*S(J) | Single-sided complex Fourier series | $X^F_j(1 + \operatorname{sgn} j)$<br>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:

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

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

Consequently among others the following fundamental relations hold:

$$F^4 = H^4 = 1.$$

**.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

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

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

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

and

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

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 | $E(g) = \int g(x) f_x(x) dx$<br>$x = -\infty \ldots \infty$ | |
| $x$, $y$ | *X*, *Y* | Random quantities | $x(\zeta)$, $y(\zeta)$ | |
| $x_i$, $y_i$ | *X*(I), *Y*(I) | Samples of random quantities | i = 1... n<br>n : sample size | |
| $x^{mE}$ | *X*mMR | m-th moment of a random quantity | $x^{mE}$ | |
| $x^D$, $x^{DR}$, $\sigma_x$ | *X*DR | Standard deviation of a random quantity | $x^{VR\ 1/2}$ | |
| $x^{DS}$, $s_x$ | *X*DS | Sample deviation of a random quantity | $x^{VS\ 1/2}$,<br>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 | $x\, y^E$ | |
| $x^E$, $x^M$, $x^{MR}$, $\mu_x$ | *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<br>unbiased random estimate of the expectation with<br>$x^{AE} = x^E$<br>$x^{VSE} = x^V / n$ | |
| $x^{PD}$, $f_x$ | *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 | $1/(n-1)\sum(x_i - x^A)^2$<br>i = 1...n<br>unbiased random estimate of the variance<br>$x^{VSE} = x^{V}$ | |
| $xy^{V}$, $xy^{VR}$ | *XY*VR | Variance of two random quantities | $x\,y^{E} - x^{E}\,y^{E}$ | |
| $\zeta$ | | 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 | $M(g(t)) = \lim(1/T \int g(t)dt)$<br>$t = -T/2 \ldots +T/2$<br>$T = -\infty \ldots +\infty$ | |
| $g^{MS}$ | *G*MS | Average or sample mean of a function of a random quantity | $A(g(t)) = 1/T \int g(t)dt$<br>$t = 0 \ldots +T$ | |
| $x$, $y$ | *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 | $x(t)x(t+\tau)^{E} = R_{xx}(\tau)$<br>$R_{xx}(\tau) = R_{xx}(-\tau)$<br>if $x$ is ergodic: $R_{xx}(\tau) = x(t)x(t+\tau)^{MR}$<br>$R_{xx}(\tau) = \int S_{xx}(\omega)\cos(\omega\tau)d\tau$<br>$\tau = 0 \ldots \infty$ | |
| $xy^{R}$, $R_{xy}$ | *XY*RR | Cross-correlation of two stationary stochastic processes | $x(t)y(t+\tau)^{E} = R_{xy}(\tau)$<br>$R_{yx}(\tau) = R_{xy}(-\tau)$<br>if $x$, $y$ are ergodic:<br>$R_{xy}(\tau) = x(t)y(t+\tau)^{MR}$ | |

| 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 | $xy^{RRSR}$ | |
| $\tau$ | TICV | Covariance or correlation time | | |
| $\zeta$ | | 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 | | |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

### 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 $m^2$ |
| $I_{xy}$ , $I_{12}$<br>$I_{yz}$ , $I_{23}$<br>$I_{zx}$ , $I_{31}$ | IXY, I2(1,2)<br>IYZ, I2(2,3)<br>IZX, I2(3,1) | Real products of inertia in case of non-principal axes | | kg $m^2$ |
| $k_x$, $k_{xx}$<br>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 | $M_{ij} = M^0_{ij}$<br>$M_{i,3+j} = M^{1T}_{ij}$<br>$M_{3+i,j} = M^1_{ij}$<br>$M_{3+i,3+j} = M^2_{ij}$ | |

### 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 | $M^F_u = M^M_u$<br>$F_i = F^0_i$<br>$F_{3+i} = F^1_i$ | n |
| $g_u$ | G(U) | Gravity field strength, generalized, in body coordinates | $g_i = g^1_i$<br>$g_{3+i} = 0$ | 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! | $G_u = m_{uv}\, g_v$ | |
| $G^0$i , $G_i$ | G0(I) | Gravity or weight force in body coordinates! | $G_i = G^0_i = m^0_{ij}\, g_j$<br>$= mg_i$ | N |
| $G^1_i$ | G1(I) | Gravity or weight moment in body coordinates! | $G_{3+i} = G^1_i = \epsilon_{ikj}\, x_k\, G^0_j$<br>$= m^1_{ij}\, g_j$ | 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! | $F^S_i = F^{S0}_i$<br>$F^S_{3+i} = F^{S1}_i = M^B_i$ | N<br>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** | | | |
| $p$ , $\omega_x$ , $v^0{}_1$ , $v_4$ | P, OMX, V0(1), V(4) | Angular (rotary) velocity around body axis x | | rad/s |
| $q$ , $\omega_y$ , $v^0{}_2$ , $v_5$ | Q, OMY, V0(2), V(5) | Angular (rotary) velocity around body axis y | | rad/s |
| $r$ , $\omega_z$ , $v^0{}_3$ , $v_6$ | 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 | $v_i = v^1{}_i$ <br> $v_{3+i} = v^0{}_i$ <br> s.Remark .2 | m/s <br> rad/s |
| $\dot{p}$ <br> $\dot{q}$ <br> $\dot{r}$ | PR <br> QR <br> RR | Rates of change of components of angular velocity relative to body axes | s.Remark .3 | rad/s$^2$ |
| $\dot{u}$ <br> $\dot{v}$ <br> $\dot{w}$ | UR <br> VR <br> WR | Rates of change of components of linear velocity relative to body axes | s. Remark .3 | m/s$^2$ |
| $\alpha$ | 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 | | |
| $\alpha$ | AT<br>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 |
| $\beta$ | DR<br>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 |
| $\gamma$ | RO<br>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 |
| $\phi$ | X(4), RO,<br>PHIR | Angle of roll, heel or list | Positive in the positive sense of rotation about the x-axis | rad |
| $\theta$ | X(5), TR,<br>TETP | Angle of pitch or trim | Positive in the positive sense of rotation about the y-axis | rad |
| $\psi$ | X(6), YA,<br>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 (quaternions) 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 | $\rho g$ (See 1.1.1) | |
| $\kappa$ | CK | Kinematic capillarity | $\sigma / \rho$ | $m^3/s^2$ |
| $\mu$ | VI | Viscosity | | kg/ms |
| $\nu$ | VK | Kinematic viscosity | $\mu / \rho$ | $m^2/s$ |
| $\rho$ | DN, RHO | Density | | $kg/m^3$ |
| $\sigma$ | 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 | $\Delta z_0$ , $z_0$-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, $v_x$ ,$v_1$<br>v,$v_y$ ,$v_2$<br>w,$v_z$ ,$v_3$ | VX, V1<br>VY, V2<br>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 |
| $\tau_w$ | 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** | | | | |
| $\Gamma^n$ | CN | Nomalized circulation | $\Gamma / (\pi D V)$<br>$\pi$ is frequently omitted | 1 |
| I | ID | Induction factor | Ratio between velocities induced by helicoidal and by straight line vortices | 1 |
| $\gamma$ | VD | Vortex density | Strength per length or per area of vortex distribution | m/s |
| $\Gamma$ | CC | Circulation | $\oint V\, ds$<br>along a closed line | $m^2/s$ |
| $\phi$ | PO | Potential function | | $m^2/s$ |
| $\psi$ | SF | Stream function | $\psi$ = const<br>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 $\rho$ , 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:

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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|

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 |
| $\delta_f$ | ANFL | Flap deflection angle | | rad |
| $\delta_s$ | ANSL | Slat deflection angle | | rad |
| $\delta$ | DELTT | Thickness ratio of section (general) | $t / C$ | 1 |
| $\delta_B$ | DELTB | Thickness ratio of trailing edge of struts | $t_B / C_S$ | 1 |
| $\delta_F$ | DELTF | Camber ratio of mean line (general) | $f / C$ | 1 |
| $\delta_{FL}$ | DLTFL | Angle of flap deflection | | 1 |
| $\delta_L$ | DELTL | Camber ratio of lower side of foil | $f_L / C$ | 1 |
| $\delta_S$ | DELTS | Thickness ratio of strut | $t_S / C_S$ | 1 |
| $\delta_{STH}$ | DELTT | Theoretical thickness ratio of section | $t_S / C_{STH}$ | 1 |
| $\delta_U$ | DELTU | Camber ratio of upper side | $f_u / C$ | 1 |
| $\gamma$ | ANSW | Sweep angle | | rad |
| $\lambda$ | TA | Taper ratio | $c_t / c_r$ | 1 |
| $\Lambda$ | 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 |
| $\alpha$ | AA, ALFA | Angle of attack or inci-dence | Angle between the direction of undisturbed relative flow and the chord line | rad |
| $\alpha_E$ | AAEF, ALFE | Effective angle of attack or incidence | The angle of attack relative to the chord line including the effect of induced velocities | rad |
| $\alpha_G$ | AAGE, ALFG | Geometric angle of attack or incidence | The angle of attack relative to the chord line neglecting the effect of induced velocities | rad |
| $\alpha_H$ | AAHY, ALFI | Hydrodynamic angle of attack | In relation to the position at zero lift | rad |
| $\alpha_I$ | 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 |
| $\alpha_0$ | 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 |
| $\epsilon$ | 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 | $\delta^* / \Theta$ | 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 |
| $R_\theta$ | 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 | | $U / u_\tau$ | 1 |
| $u_\tau$ | 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 |
| $U_\infty$ | 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 |
| $\Delta U$ | 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 |
| $\beta$ | BETE | Equilibrium parameter | $\delta^* / (\tau_w dp / dx)$ | 1 |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\delta_{995}$ | DEL | Thickness of a boundary layer at $U=0.995U_e$ | | m |
| $\delta^*$, $\delta_1$ | DELS | Displacement thickness of boundary layer | $\int (U_e - U) / U_e \, dy$ | m |
| K | K | von Karman constant | 0.41 | 1 |
| $\Lambda$ | PRGR | Pressure gradient parameter | $\delta_{995} / (\nu \, dU_e / dx)$ | 1 |
| $\theta^*$, $\delta^{**}$ | ENTH | Energy thickness | $\int (U / Ue) (1 - U^2 / U_e^2) dy$ | m |
| $\Theta$ | THETA | Momentum thickness | $\int (U / U_e) (1 - U / U_e) dy$ | m |
| $\tau_w$ | 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 | $\alpha / \alpha_S$ | 1 |
| $\alpha$ | GC | Gas content | Actual amount of solved and undissolved gas in a liquid | ppm |
| $\alpha_S$ | GS | Gas content of saturated liquid | Maximum amount of gas solved in a liquid at a given temperature | ppm |
| $\sigma$ | CNPC | Cavitation number | $(p_A - p_C) / q$ | 1 |
| $\sigma_V$ | 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 |
| $\delta_C$ | 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 |
| $k$, $\kappa$ | WN | Wave number | $2\,\pi / L_W$ | 1/m |
| $L_W$ , $\lambda_W$ | LW | Wave length | Measured in the direction of wave propagation | m |
| $T_W$ | TW | Basic wave period | $1 / f_W$ | s |
| $\alpha$ | WD | Wave direction | | rad |
| $\eta$ | EW | Instantaneous wave elevation at a given location | z-axis positive vertical up, zero at mean water level; s. Remark .3 | m |
| $\eta^a_i$ | EWAM(I) | Amplitudes of harmonic components of a periodic wave | $\eta^{FSa}$ | m |
| $\eta^p_i$ , $\epsilon_i$ | EWPH(I) | Phases of harmonic components of a periodic wave | $\eta^{FSp}$ | rad |
| $\eta_C$ | EC | Wave crest elevation | | m |
| $\eta_T$ | ET | Wave trough depression | Negative values! | m |

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $\lambda_W$ , $L_W$ | LW | Wave length | Measured in the direction of wave propagation | m |
| $\zeta$ | DW | Instantaneous wave depression | z-axis positive vertical down, zero at mean water level | m |
| $\omega_W$, $\sigma$ | 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 |
| $\eta_C$ | EC | Maximum of elevations of wave crests in a record | | m |
| $\eta_T$ | ET | Elevations of wave troughs in a record | Negative values! | m |
| $\lambda_d$ | LD | Wave length by zero down-crossing | | m |
| $\lambda_u$ | 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 |
| $H_\sigma$ | 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 | $1 / f_S$ ,<br>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 |
| $H_\sigma$ | 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

| ITTC Symbol | Computer Symbol | Name | Definition or Explanation | SI-Unit |
|---|---|---|---|---|
| $D(f,\theta)$, $D(\omega,\mu)$ | DIRSF | Directional spreading function | $S(f,\theta)=S(f)D(f,\theta)$ <br> $\int_0^{2\pi} D(f,\theta)d\theta=1$ | 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 | | $m^2/Hz/rad$ |
| $\alpha$ | CWD | Component wave direction | | rad |
| $\mu$ | 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 $\eta$ 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 $\eta_i$ 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

| | | | | |
|---|---|---|---|---|
| $T_{rt}$ | 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 |
| $\beta_{aw}$ | BETWA | Apparent wind angle (relative to vessel course) | see section 2.6 | |
| $\beta_{tw}$ | BETWT | True wind angle (relative to vessel course) | see section 2.6 | |
| $\theta_{W}$ | 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 |
| $t°_A$ | TEAI | Temperature of air | | °C |
| $t°_I$ | TEIC | Local temperature of ice | | °C |
| $t°_W$ | TEWA | Temperature of water | | °C |
| $\delta_I$ | ELIC | Deflection of ice sheet | Vertical elevation of ice surface | m |
| $\epsilon_I$ | STIC | Ice strain | Elongation per unit length | 1 |
| $\dot{\epsilon}_I$ | STRTIC | Ice strain rate | $\partial\epsilon / \partial\tau$ | 1/s |
| $\mu_I$ | POIIC | Poisson's ratio of ice | | 1 |
| $\nu_A$ | POAI | Relative volume of air | Volume of gas pores per unit volume of ice | 1 |
| $\nu_B$ | POBR | Relative volume of brine | Volume of liquid phase per unit volume of ice | 1 |
| $\nu_O$ | POIC | Total porosity of ice | $\nu_O = \nu_A + \nu_B$ | 1 |
| $\rho_I$ | DNIC | Mass density of ice | Mass of ice per unit volume | $kg/m^3$ |
| $\rho_{SN}$ | DNSN | Mass density of snow | Mass of snow per unit volume | $kg/m^3$ |
| $\rho_W$ | DNWA | Mass density of water | | $kg/m^3$ |
| $\rho_\Delta$ | DNWI | Density difference | $\rho_\Delta = \rho_W - \rho_I$ | $kg/m^3$ |
| $\sigma_{CI}$ | SCIC | Compressive strength of ice | | Pa |
| $\sigma_{FI}$ | SFIC | Flexural strength of ice | | Pa |
| $\sigma_{TI}$ | SNIC | Tensile strength of ice | | Pa |
| $\tau_{SI}$ | 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)
Naval Architecture, Ocean and Marine Engineering Department
590 Holloway Road, U.S. Naval Academy
Annapolis, MD 21402, USA
Phone +1 410 293 6457
Fax +1 410 293 2219
E-mail: johnson@nadn.navy.mil

Prof. Carlo Podenzana-Bonvino (Secretary, 1985-1993)
Dipartimento di Ingegneria Navale e Tecnologie
Marine (DINAV), Universita di Genova
Via Montallegro 1
16145 Genova, Italy
Phone +39 10 353 2426/2430
Fax +39 10 353 2127
E-mail: podenzana@dinav.unige.it

Prof. Michael Schmiechen (Secretary, 1993-1996)
Versuchsanstalt fü r Wasserbau und Schiffbau
Mü ller-Breslau-Strasse (Schleuseninsel)
10623 Berlin, Germany
Phone +49 30 311 84 270
Fax +49 30 311 84 200
E-mail schm@vws.tu-berlin.de

Dr. David Clarke
Department of Marine Technology
University of Newcastle upon Tyne
Newcastle upon Tyne, NE1 7RU, United Kingdom
Phone +44 191 222 6721
Fax +44 191 261 1182
E-mail David.Clarke@ncl.ac.uk

Dr. Norihiro Matsumoto (Member, 1985-1990)
Electronics Research Center
Nippon Kokan K.K.
1-1 Minamiwatarida-cho, Kawasaki-ku
Kawasaki 210, Japan
Phone +81 44 322 6276
Fax: +81 44 322 6523

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)
6-3-5 Hachihanmatsu-Minami
Higashi-Hiroshima 739-01 Japan
Phone +81 824 28 8865
Fax +81 824 28 8867

and as a new member was appointed:

Dr. Kostadin Yossifov (Member 1990-1993, Consulting member 1993-)
Bulgarian Ship Hydrodynamics Centre
9003 Varna, Bulgaria
Phone +359 52 776390 / 600293
Fax +359 52 600294

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

Prof. Kazuhiko Hasegawa
Department of Naval Architecture & Ocean Engineering
Osaka University
2 - 1 Yamada-oka Suita
Osaka 565, Japan
E-mail hase@naoe.eng.osaka-u.ac.jp
Phone +81 6 879 7588
Fax +81 6 878 5364

## 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*

| | | | | |
|---|---|---|---|---|
| $A_j$ | 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 |
| $\Delta M$ | 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 |
| $\alpha$ | ALFA | Angle between centerline of jet and horizontal plane | | 1 |
| $\eta_{inst}$ | ETAIN | Pump installation efficiency | | 1 |
| $\eta_P$ | ETAP | Pump efficiency | | 1 |
| $\eta_{WJ}$ | ETAWJ | Effective jet system efficiency | | |
| $\zeta_{13}$ | ZETA13 | Inlet and diffusor loss coefficient Station 1-3, based on E0 | | 1 |
| $\zeta_{57}$ | ZETA57 | Duct and nozzle loss coefficient Station 5-7, based on E7 | | 1 |