Lecture 2 : Basic Naval Architecture terminology

This section represents definitions for the main characteristics of a ship, the terms and the basic design coefficients used in Naval Architecture. The aim is to familiarize students with terms that may help define a ship's general particulars (i.e. main dimensions, displacement), her shape and form.

1. Basic Terminology

Ship Length is defined as the most commonly used ship length definitions (see Figure 2.1) are:

- **Length between perpendiculars (L_{BP} or L_{PP}).** This is the distance measured along the summer load waterline from the aft to the fore perpendicular of the hull. The aft perpendicular is commonly taken as the line passing through the rudder stock. The fore perpendicular is the vertical line through the intersection of the forward side of the stem with the summer load waterline.

- **Length overall (L_{OA}).** This is the distance between the extreme points forward and aft measured parallel to the summer (or design) waterline. Forward the point may be on the raked stem or on a bulbous bow. Simply, the extreme length of the ship.

- **Design waterline length (L_{WL}).** This is the length on the summer load waterline, at which the ship happens to be floating between the intersections of the bow and aft end with the waterline.

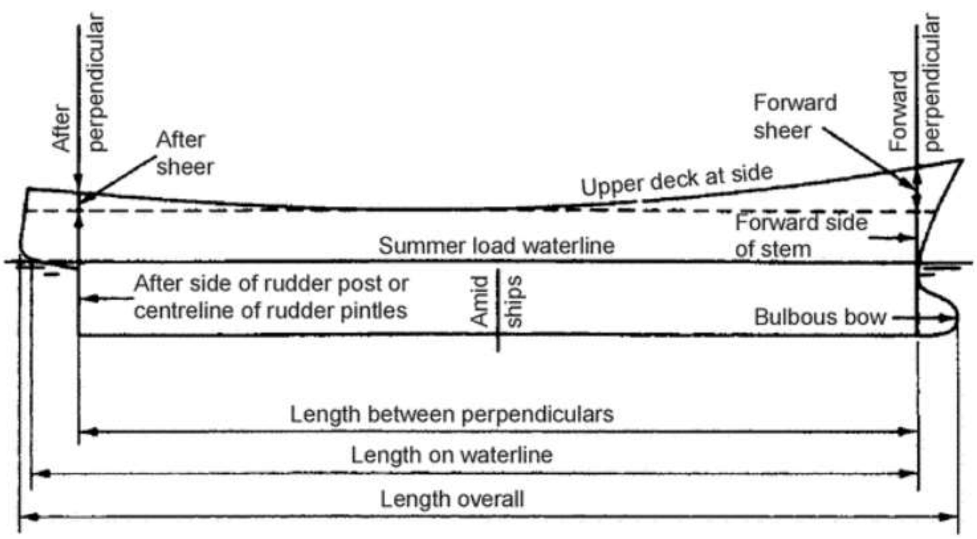

Figure 11.1 Principal Dimensions. Image Credits: (Tupper, 2013)

In literature there are various empirical dimensions for the estimation of ship length (e.g. see Papanikolaou, 2014 and Tupper and Table 2.1).

Developer	Empirical formulae
Ayre	$L_{pp}/\nabla^{1/3} = 3.33 + 1.67V/\sqrt{L_{pp}}$
Posdunine	$L_{pp} = C(V/(V+2)^2\nabla^{1/3}$ with C=7.25 for freighters with V in the range 15.5<V<18.5 knots
Schneekluth	Schneekluth: $L_{pp} = C.\Delta^{0.3}.V^{0.3}$ with C=3.2 if $C_b \approx 0.145/F_n$ in the range 0.48 – 0.85. Otherwise $C=3.2(C_b+0.5)/((0.145/F_n+0.5))$
Völker:	$L/\nabla^{1/3} = 3.5 + 4.5V/\sqrt{(g\nabla^{1/3})}$ with V in m/s. Formula is for dry cargo ships and container ships. For refrigerated cargo ships reduce L/∇1/3 by 0.5 and for coasters and trawlers by 1.5.

Table 12.1 Demonstration of empirical estimates for ship length

Ship Breadth (or **Beam, B**)**.** The most commonly used definitions for the breadth of the ship (Figure 2.2) are :

- **Moulded Beam** is the greatest distance between the inside of plating on the two sides of the ship at the greatest width at the section chosen (Figure 2.2).
- **Breadth extreme** is measured to the outside of plating but will also take account of any overhangs or flare (Figure 2.2).

Variations in breadth for a particular design may give rise to : (1) ship resistance changes so there has to be an optimum B/T and L/B; (2) potential increase in production costs for increased B; (3) changes in stability criteria, roll amplitude and acceleration ; (4) draught changes - e.g. smaller T if B×T = constant while B is increased.

Ship Depth (or **moulded depth, D**) varies along the length but is usually quoted for amidships. It is measured from the underside of the deck plating at the ship's side to the top of the inner flat keel plate (Figure 2.2). Unless otherwise specified, the depth is to the uppermost continuous deck. **D** is used to determine the ship's volume and the freeboard. It also influences the longitudinal strength.

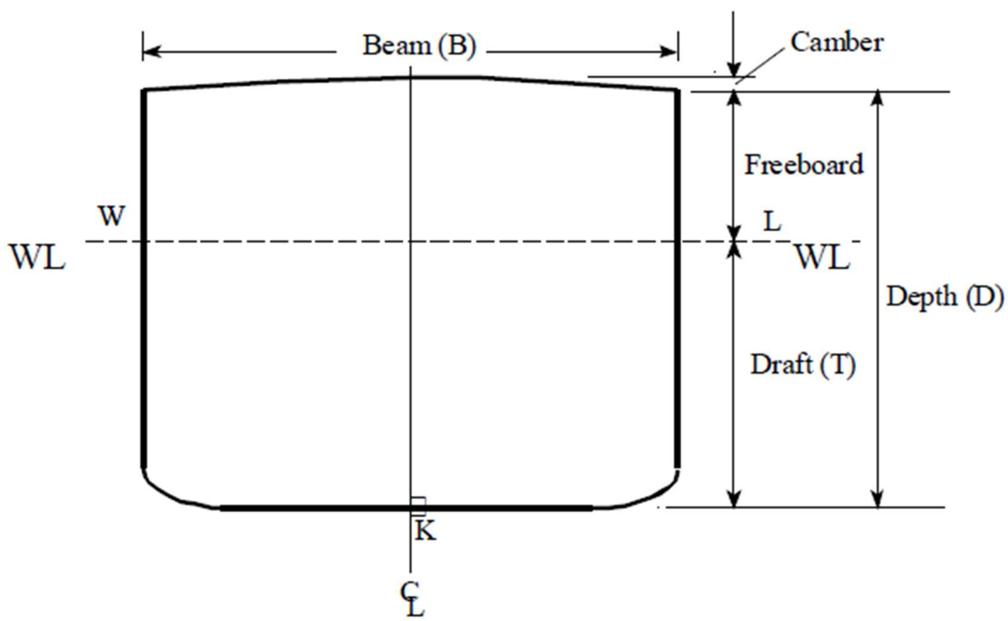

Figure 2.2 Hull characteristics (transverse view):

Ship Draught (or **moulded draught/draft, T)** is the distance from the keel to the surface of the water (the waterline). **Mean draft (Tm)** is the average of the bow and stern drafts at the perpendiculars. Mean draft is typically the draft at amidships.

$$T_m = \frac{T_{fwd} - T_{aft}}{2} \quad (2.1)$$

Given that the draught must relate to the displacement equation, a large draught will benefit a low resistance and also give greater freedom to the propeller design and the selection of large propeller clearances.

Camber is defined as the rise of the deck in going from the side to the center (Figure 2.32.3). Decks are cambered to enable water to run off them more easily. For ease of construction, and reduce cost, camber is applied usually only to weather decks, and straight-line camber often replaces the older parabolic curve.

Rise of floor/Deadrise is the bottom of a ship, in the midships region. It is usually flat but not necessarily horizontal. If the line of bottom is extended out to intersect the moulded breadth line, the height of this intersection above the keel is called the rise of floor or deadrise (Figure 2.32.3).

Flat of Keel. Most ships have a flat keel and the extent to which this extends athwartships is termed the flat of keel or flat of bottom (Figure 2.3).

Flare and Tumble home. The forward sections of most ships have a bow characteristic called flare. On a flared bow, the half-breadths increase as distance above the keel increases. Flare improves a ship's wave piercing performance, resistance to roll, and increases the available deck space. Tumblehome is the opposite of flare and the beam at the deck is smaller than the beam at the waterline. In some ships, the sides are not vertical at amidships. If the upper deck beam is less than that at the waterline, it is said to have tumble home (Figure 2.32.3).

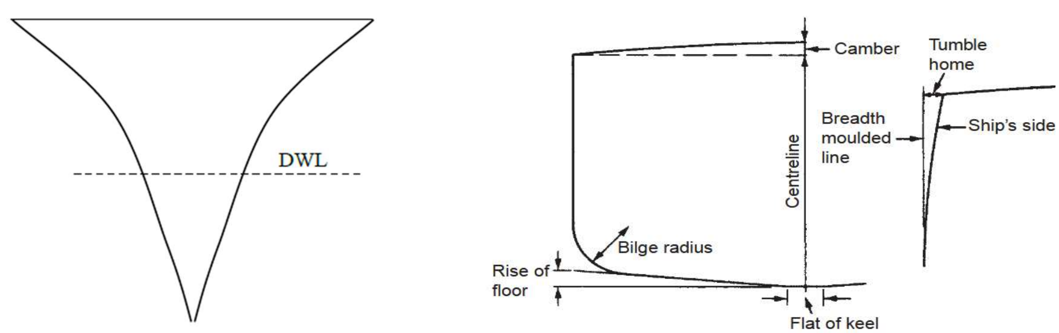

Figure 2.3. Ship section idealizations (Tupper, 2013)

Freeboard is the difference between the depth at side and the draught. In other words, it is the height of the deck at side above the waterline. It influences the shape of the righting arm and hence it is important in determining intact stability at large angles. It may be also useful in damage stability situations where reserve buoyancy is essential. **Sheer** (see Figure 2.1) permits a distribution of freeboard along the length of the ship thus giving increased freeboard forward and aft. In this way it assists avoidance of deck wetness in poor weather conditions. The basic freeboard of the ship is calculated based on the **International Load Line Convention (ILLC)**[2] contained in IMO SOLAS and its value depends on whether the ship carries liquid cargoes or bulk cargoes. **The summer freeboard** represents the distance measured down from a line denoting the top of the freeboard deck at side and a second line is painted on the side with its top edge passing through the center of a circle. This marking is known as the **Plimsoll mark**. To allow for different water densities and for severe conditions in different seasons a series of lines are painted on the ship's side to represent the maximum allowed draught in each condition. These paintings are known as **load line marks** (Figure 2.42.4). In general the evaluation of freeboard is very complex and depends on the ship type. Nevertheless it is worthwhile mentioning that the evaluation of freeboard for ships longer than 100 m is a function of C_B, D, Shear, Superstructure, Bow Height and – in general - comprises of the following steps :

[2] For further information on IMO ILLC please refer to : http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-on-Load-Lines.aspx

- Determine a preliminary freeboard estimate from the tables contained in IMO ILLC based on a standard ship with a $C_B = 0.68$; L/D = 15 ; no superstructure; a parabolic shear and minimum bow height.
- Correct the tabular freeboard for the C_B of the ship you design to obtain the ship's basic freeboard.
- Apply D, deck shear, superstructure corrections based on the ship designed.
- Check the minimum bow height and the reserve buoyancy
- When all of the corrections have been applied to the basic freeboard this results in the minimum summer freeboard for the ship.

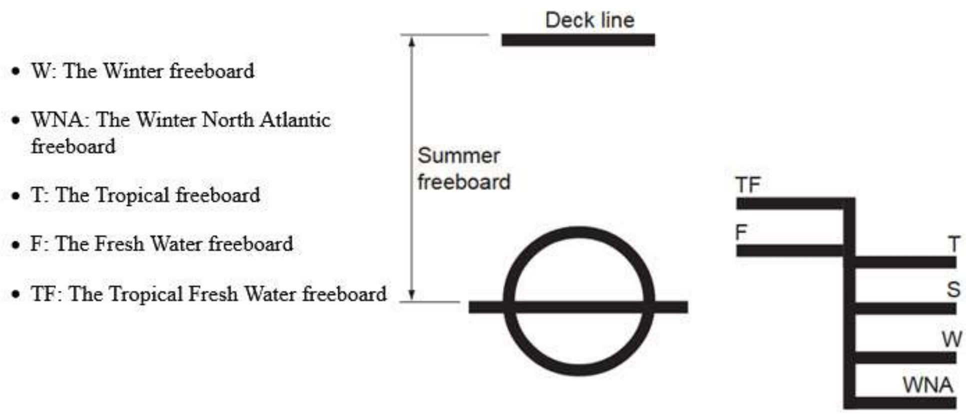

Figure 2.4. Plimsoll Marks/Load line marks. Image Credits: (Tupper, 2013)

2. Displacement and tonnage

Displacement represents the mass of the ship in tonnes or her weight in KN. A ship's displacement varies mainly with the draft (T). There are different displacements for different loading conditions. Usually the fully loaded ship condition is assumed to study the performance. Key nomenclature is as follows:

Δ : mass displacement (tonnes)

∇: volume of the displaced water (m^3)

ρ : density of water (usually taken for seawater 1.025 t/m^3 , for fresh water 1.0 t/m^3 and for the Finnish coast 1.05 t/m^3)

$\Delta = \rho \cdot \nabla$ (tonnes) or $\Delta = \rho \cdot \nabla \cdot g$ (KN)

The ship **deadweight** is defined as her profitable cargo carrying capacity. Thus as a quantity it also defines the earning power of the ship. In deterministic terms, deadweight is the difference between the displacement of the ship and her lightship weight. **Lightship weight** is mainly the weight of the hull, machinery, and outfitting. **Cargo deadweight** refers only to the weight of cargo the ship can carry. **Tonnage** is a volume measure. Formerly, the standard tone was about 100 cubic feet (2.83 m^3). Nowadays, two terms represent tonnage are commonly used and are known as : (a) **Gross Tonnage (GT)** based on the volume of all enclosed spaces and representing the overall size of a vessel; (b) **Net Tonnage (NT)** based on the volume of cargo spaces plus the volume of passenger spaces multiplied by a coefficient so representing its carrying capacity. The empirical equation used is :

$$NT = k \times GT \tag{2.2}$$

where k = 0.3 – 0.5 for Container Ships and 0.5 for other ships

2.1 Ship coefficients

In naval architecture, comparison of different hull forms is achieved with the aid of coefficients.

2.1.1 Fineness Coefficients.

Fineness coefficients express the fullness of the hull form (e.g. some hulls have a very full rounded ends and some have very sharp knife-like ends). The fineness coefficients of a vessel are dependent on the speed she is designed for and the seakeeping conditions that are considered for the vessel. This means that the faster the ship is the finer her hull form. The typical fineness coefficients for different types of ships summarized in Table 2.1 are defined as follows:

Block coefficient (C_B) is the ratio of the volume of displacement to the product of the length, breadth, and draught of the ship as shown below (see Figure 2.5).

$$C_B = \frac{\text{Displacement Volume}}{Lengt\ \times Breadth \times Draug} = \frac{\nabla}{L \times B \times T} \tag{2.3}$$

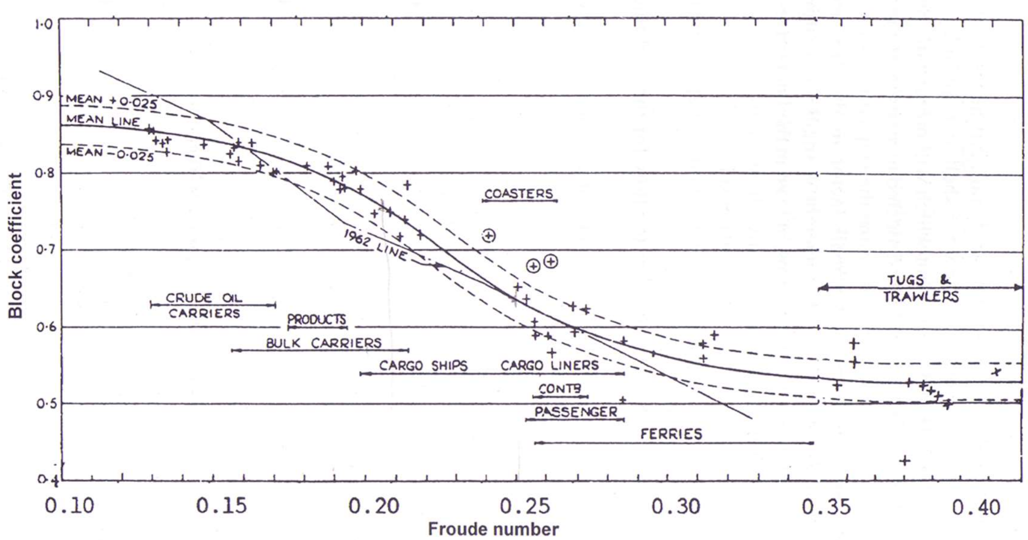

Figure 2.5. Demonstration of the variation of C_B to ship speed (Froude No.): (Tupper, 2013)

Midship Coefficient (C_M) is the ratio of the area of the immersed portion of the midship section to the product of the breadth and the draught of the ship (Figure 2.62.6).

$$C_M = \frac{\text{Midship sectional area}}{Beam \times Draught} = \frac{A_m}{B \times T} \tag{2.4}$$

Prismatic Coefficient (C_P) is the ratio of the volume of displacement to the product of the length and the immersed portion of the midship section (

Table 2.1 Typical fineness coefficients for different ship types

2.7).

$$C_P = \frac{\text{Displacement Volume}}{Length \times \text{Midship sectional area}} = \frac{\nabla}{L \times A_m} \tag{2.5}$$

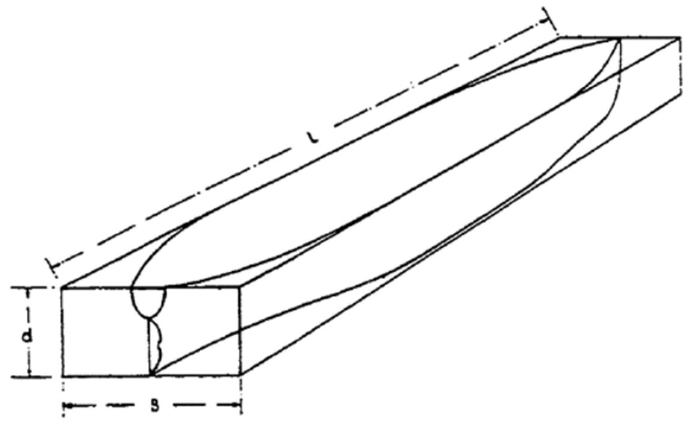

Figure 2.5 Ship Block Coefficient (Tupper, 2013)

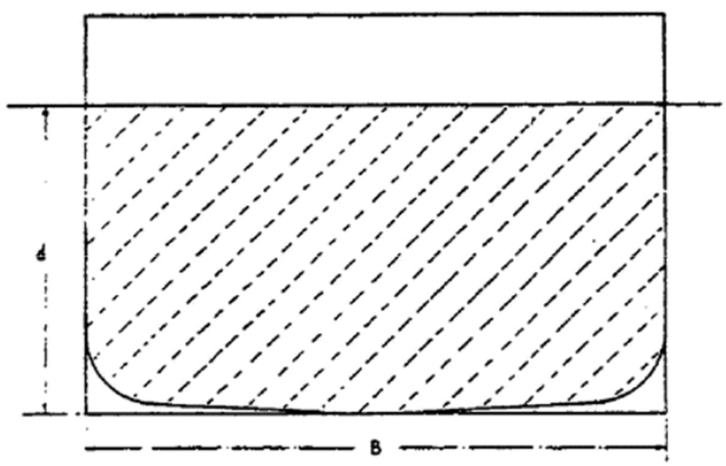

Figure 2.6 Explanation of Midship area coefficient (Tupper, 2013)

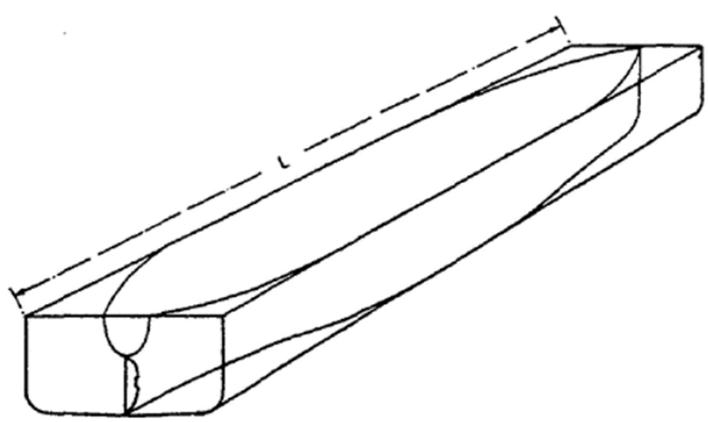

Figure 2.7 Explanation of Prismatic coefficient. Image Credits: (Tupper, 2013)

Ship type	C_P	C_m	C_B	C_W
Trawler	0,648	0,880	0,570	0,720
Car Ferry	0,551	0,920	0,507	0,640
Fast Cargo Liner	0,664	0,980	0,650	0,749
Cargo Tramp.	0,735	0,980	0,720	0,803
Tanker	0,842	0,985	0,830	0,887
Sailing Yacht ex fin keel	0,550	0,680	0,374	0,700

Table 2.1 Typical fineness coefficients for different ship types

Waterplane Area Coefficient (C_W) defined as the ratio of the area of the waterplane to the product of the length and breadth of the ship (Figure 2.8).

$$C_W = \frac{\text{Waterplane area}}{Length \times Beam} = \frac{A_W}{L \times B} \quad (2.6)$$

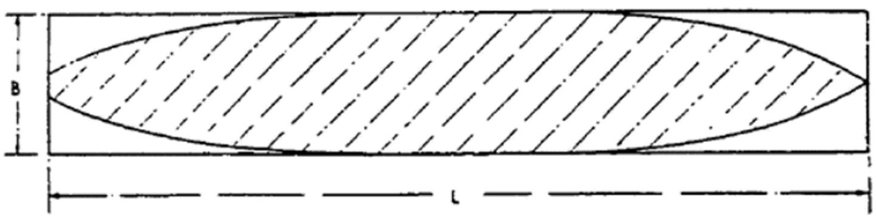

Figure 2.8 Explanation of waterplane area coefficient. Image Credits: (Tupper, 2013)

Deadweight coefficient (C_D) is defined as the ratio of the ship's deadweight to displacement :

$$C_D = \frac{payload}{\text{the total weight}} = \frac{\text{Cargo } Deadweight}{Dispalcement} \quad (2.7)$$

Here the deadweight means the weight of a loaded ship without the lightweight i.e. weight of the items that are not a part of the hull or fittings. Typical values of C_D of certain types of vessels are summarized in Table 2.2.

Ship Type	C_D
Super tanker	0,78
Container Ship	0,65
Hydrofoil Ferry	0,30

Table 2.1 Typical values of the Deadweight Coefficient

Speed Parameters. A ship's speed is dependent on ship size. The most commonly used speed parameter is Froude Number (F_n). It is a dimensionless parameter representing the speed to length ratio of a ship. Froude number is commonly used in resistance and propulsion analysis.

$$F_n = \frac{V}{\sqrt{gL}} \quad (2.8)$$

2.1.2 Slenderness coefficients

Slenderness coefficients express the relation between displacement and hull length. The most common ones are:

- **Taylor Displacement to Length Ratio** $= \frac{\text{Displaced Mass (tons)}}{[Length(ft)/100]^3} = \frac{\Delta}{(\frac{L}{100})^3}$ (2.9)
- **Volumetric Coefficient** (C_V) $= \frac{\text{Displacment Volume}}{Length^3} = \frac{\nabla}{L^3}$ (2.10)

- **Froude Displacement Coefficient** (M) = $\frac{Length}{\text{Displaced Volume}^{1/3}} = \frac{L}{\nabla^{1/3}}$ (2.8)

It is noted that C_v and M are non-dimensional and therefore useful in general design. Typical values are given in Table 2.3.

Ship Type	M	C_V	Taylor Displacement /Length Ratio
Racing VIII	17,00	0,2	6
Frigate/Destroyer	7,5	2,5	70
Light Displacement Racing Yacht	7,0	3,0	80
Container Ship	6,5	3,5	105
Large Tanker	5,0	8,0	230
Cruising Yacht	4,75	9,5	270
Salvage Tug	4,25	13,0	370
	4,00	15,5	450

Table 2.2 Typical Values of Slenderness Coefficients

3. Ship type characteristics

There are various ways to categorize ships namely : mission, applied technologies, operational area, design limiting factors, cargo handling system, number of hulls etc. (see Figure 2.9 and Table 2.4). **The mission and service** category assumes that a ship can operate for commercial services (e.g. to carry cargo for trade) or for defense (naval ship) or for leisure and tourism (passenger ship) or for special purpose (e.g. ice breakers, Yaughts and leisure boats).

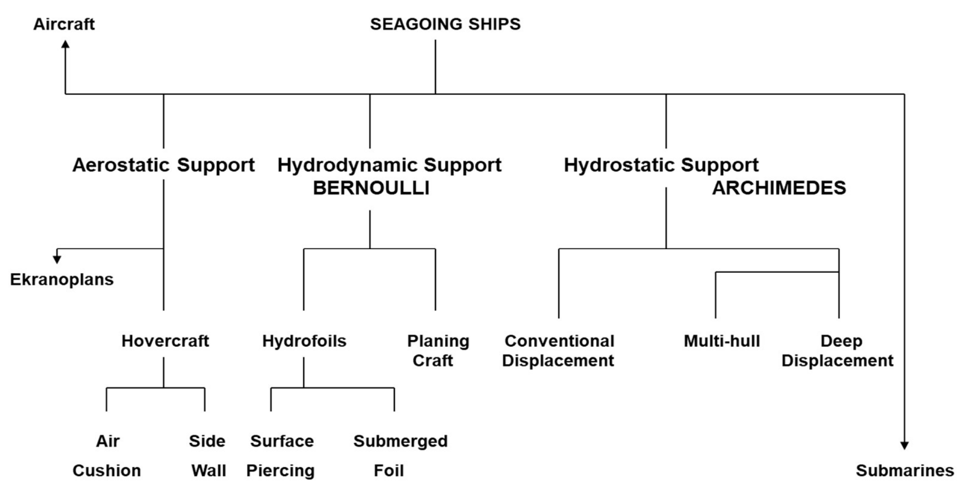

Figure 2.9 Overview of ship categories

On the other hand, the **applied technologies** category comprises of the following sub-categories :

- *Hydrodynamic capability and material type*. An example segment under this sub – category are innovative High Speed Crafts (HSC). Such vehicles are sensitive to hydrodynamic-lift / loads and the use of lightweight hull materials (aluminum, composites, carbon-fiber).
- *Cargo handling and storage* sub - category has broad application on a variety of vessels. For example, LNG/LPG and Tanker ships use piping systems for the transfer of liquid cargo during loading. Container ships and bulk carriers use vertical lifting equipment (pallets and cranes); On In Roll on Roll off (Ro-Ro) ships cargo is rolled onto and rolled off the ship on trucks or vehicles.

- *Propulsion capability* applies on LNG and passenger ships with single or twin screw propeller. HSC is another segment where the use of high performance waterjets is broadly spread. Use of sails or Fletner rotors that could be used for energy efficient ocean going ships or for small boats are other examples.
- *Power generation methods* (e.g. diesel engine, steam turbine, gas turbines, batteries, hydrogen fuel cells) is another key sub - category that is expected to expand over the years to come mainly because of shipping sustainability requirements.

Ship Type	Advantages	Limitations
Monohulls	• Many empirical design data available • Low building cost per unit displacement • Small relative wetted area	Speed in heavy weather is limited by roll and pitch motions , slamming, green seas and longitudinal bending moments
Catamarans	• Low building cost per unit displacement • High altitude cruising in waves and thus low wave resistance • Low probability of slamming	• Wide overall beam • High metal weight per unit displacement • Speed limited by pitch motion, wet deck slamming and longitudinal bending moments
Trimarans	• Wide cargo deck well above water line • Satisfactory initial transverse stability • Lower wave resistance than mono-hulls • Low probability of bottom slamming • Transverse bending moments less than catamarans	• Large wetted deck area • High longitudinal bending moment especially in high seas • Maneuvering / directional control problems

Table 2.4 Some ship type characteristics

Ships can also be categorized based on their **area of operations.** For example, ships designed to operate worldwide or ships that operate in restricted areas (e.g. Canadian Great Lakes, Baltic or South China seas, the ice infested regions of the Arctic and the Southern Ocean, coastal areas or inland waterways). **Ship categorization based on limiting design factors** accounts for weight/space/size limited ships. Weight limited ships are those carrying heavy cargo (e.g. bulk carriers, timber cargo ships). Space limited ships are those which are transporting people (e.g. cruise ships, RoPax ships) and light cargo ships (e.g. high speed craft). Size limited ships are ship designs affected by infrastructure in specific areas of the world (e.g. draft and beam constraints for operation in Panama or Suez canals or draft limits in ports). The final main category clasifis ships according to their **hull numbers**. Two main ship types are considered here namely the mono-hull vessels (e.g. classic designs of bulk carriers, tankers, cruise liners, etc.) and innovative multi-hull vessels (see Table 2.4). Examples of multi-hull vessels are Single Water Plane Area Twin Hull - SWATH ships designed for relatively high speed and a stable platform in moderately rough weather (Table 2.5), Wave Piercing Catamarans – WPC design for short sea high speed coastal service and trimaran war ships (Table 2.4) or even pentamaran container ship designs for transatlantic service (Figure 2.10).

Advantages	Limitations
Wide and well elevated deck area with excellent initial stability, roll and pitch motions.	Wide overall beam.
Low longitudinal bending moment which drops at higher speed in head seas.	Transverse bending moment is greater than for a catamaran.
Low wave resistance.	Greater relative wetted area
Low slamming probability	Narrow struts and gondolas make it difficult to place and access the main engines.
Low additional resistance in waves	

Table 2.15 Advantages and limitations of Small Waterplane Area Twin Hull ships (SWATH)

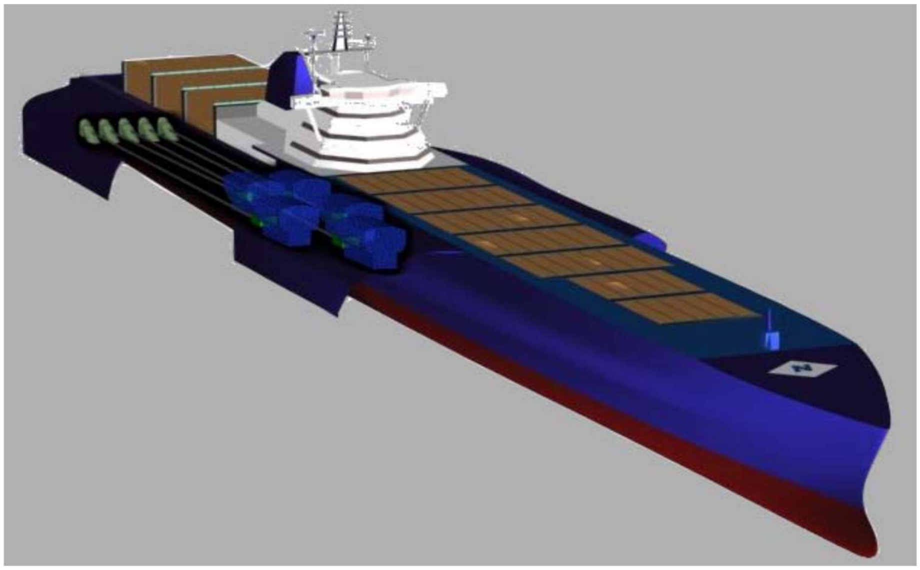

Fig. 2.10 Artist impression of a pentmaran container ship © British Maritime Technology, UK

4. Questions

1. A box barge 65m long and 12m wide floats at a draught of 5.5m in sea water. Calculate the displacement in sea water and in fresh water.
2. A ship has a constant triangular cross-section floats in sea water. The ship is 85m long, 12m wide, at the deck and has a depth from keel to deck of 9m. Draw a curve of displacement as a function of draught using 1.5m intervals of draught up to 7.5m waterline. Use the curve to obtain the displacement at 5.5m draught.
3. A cylinder 15 m long and 4 m outside diameter floats in sea water with its axis in the waterline. Calculate the mass of the cylinder.
4. A two-man sailing dinghy displaces volume of $0.27m^3$. Its load waterline length is 4.25m and the waterline beam at amidships is 1.1m. Assuming C_P = 0.58 and a midship section area coefficient C_M =0.63 calculate the values of M, C_B and draught.
5. A luxury motor yacht is to have a displacement volume of $350m^3$ and a beam to draught ratio of 3.5. Assuming Froude number F_n =0.40 use the design, trend lines to estimate suitable length (L_{BP}), beam (B_{mld}) and draught (T_{mld}) for this vessel. Also calculate the vessel speed corresponding to the proposed Froude number.
6. Sketch and explain the ship's main dimensions and their different definitions.
7. Define: Sheer, Camber, Rise of floor, flat of keel, tumble home, and freeboard.
8. Explain and write the equations of the fineness coefficients.
9. Explain briefly the ship's different classifications.
10. Explain the difference between displacement, deadweight, and lightship weight.