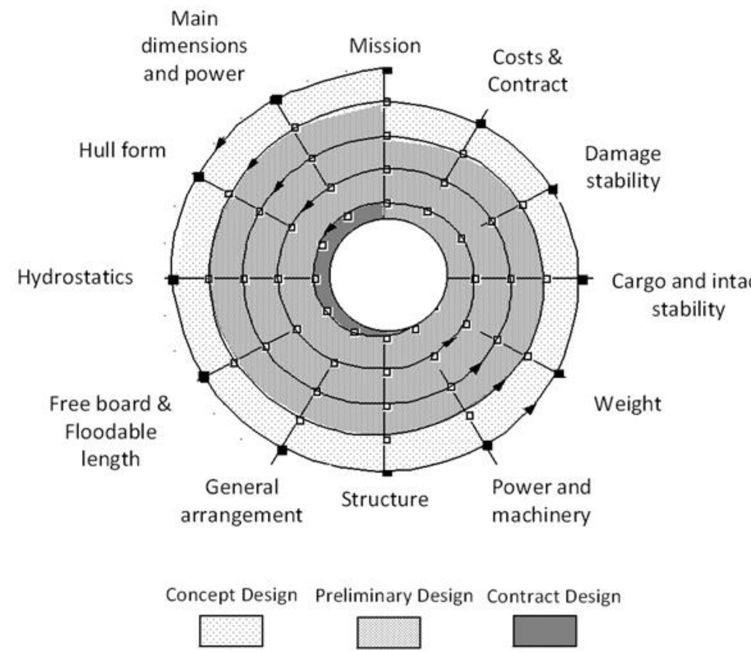
Aalto University
School of Engineering

MEC-E1004 Principles of Naval Architecture

Lecture 2 – Reference ship/data

What will you learn ?

- After the lecture, you will be able to
  - *List and explain the different principles of categorizing a ship*
  - *Categorize the ship you design in your group project*
  - *Explain the use of reference data*
  - *Apply the above to identify a suitable reference ship for your group project*



Assignment 2 – Reference ship/data

- Define and discuss your ship's category/type
- Collect and analyze technical information on your ship type
  - *General characteristics, requirements, challenges*
  - *Discuss 2 technical/scientific articles on related topics*
- Present a reference ship (or ships) and related data (e.g. main dimensions, machinery, cargo/passenger capacity)

Terminology – many definitions

Vessel
- A water-born vehicle that has its own or external power production and steering

Ship
- A large water-born vehicle that has its own power production and steering
  - *A ship is an vessel, but a vessel is not necessary a ship*

Yacht
- A medium-size water-born vehicle used for leisure
  - *Larger than a boat, smaller than a ship*

Boat
- A small water-born vehicle propelled by oars, paddle, sails, or motor for travelling, transport, leisure

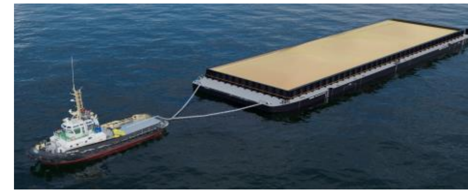


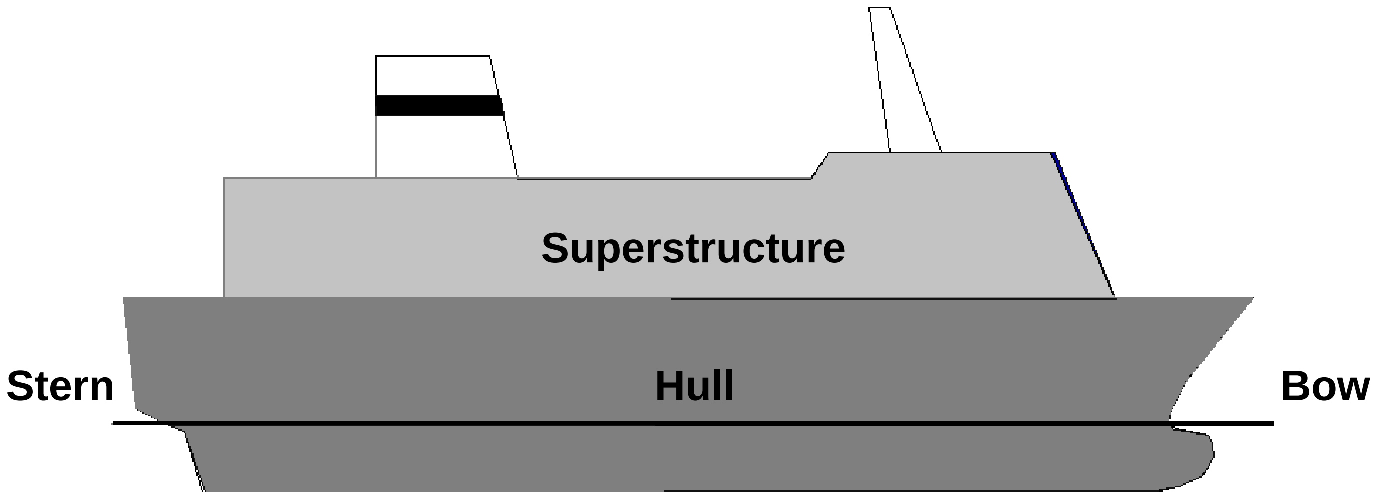
Image credit Damen

Image credit Viking Line

Image credit Nautor's Swan

Image credit Buster

Terminology



Main Dimensions

- Length (L)
  - *Horizontal distance between bow and stern*
    - Length over all (L_{OA})
    - Length between perpendiculars (L_{BP})
      - AP = Aft perpendicular
      - FP= Forward perpendicular
    - Design waterline length (L_{WL})

- Breadth / Beam (B)
  - *Horizontal distance between ship sides*
    - Maximum overall breadth B_{MAX}
    - Maximum (design) waterline breadth B_{DWL}

- Draught / Draft (T)
  - *Vertical distance between floating plane and keel*

- Depth (D)
  - *Vertical distance between main deck and keel*

- Freeboard (F)
  - *The vertical distance measured from the deck to the waterline*

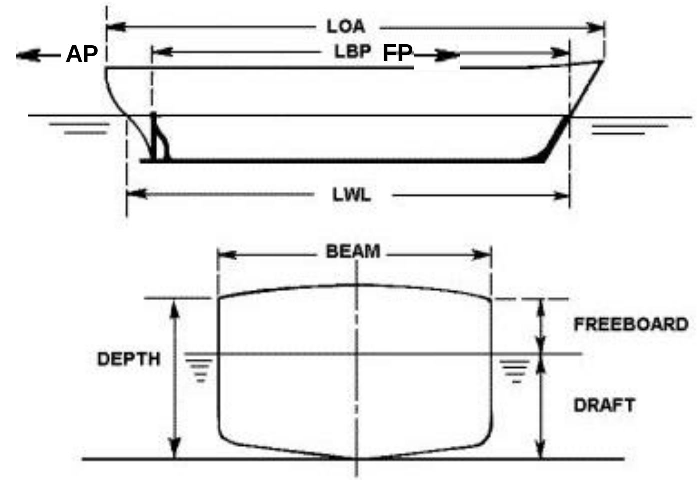


Image credit brighthubengineering.com

Main frame

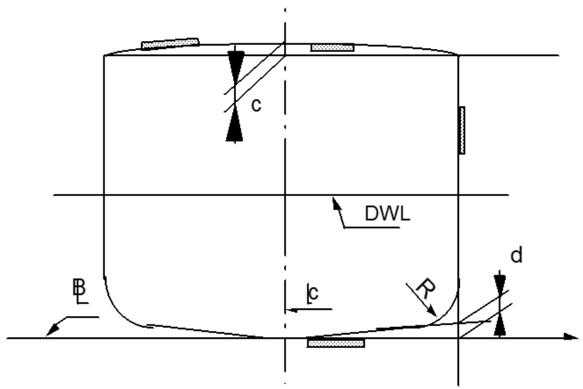
- Forward facing view (from stern to bow)
  - *Right hand side = starboard*
  - *Left hand side = port side*

Main frame terminology

- C – Camber (*kansimutka*)
  - *A measure how the deck's curvature*
  - *Needed to minimize water on deck*

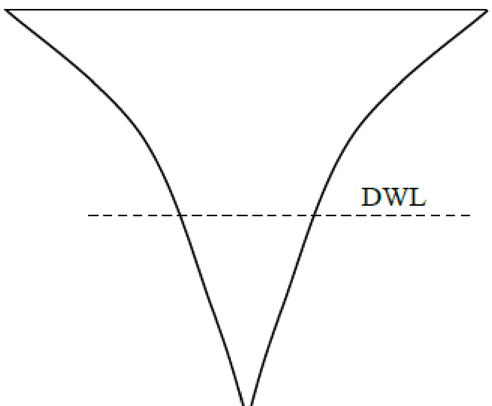
- R – Turn of bilge (*pallepyöristys*)
  - *Measure of the rounding between the ship side and bottom*
  - *It affects the water flow around the hull*

- d – Rise of floor / Deadrise (*pohjannousu*)
  - *A measure of the hull shape*

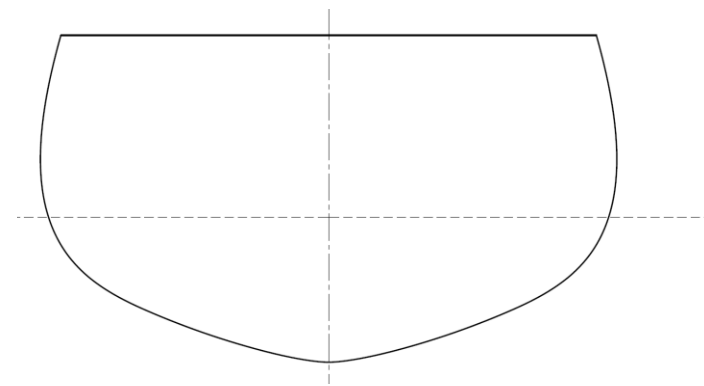


Flare and Tumble home

- Flare and Tumble home describes the shape of the main frame.
- Flare is the outward curvature of ship's hull surface above the waterline while the tumble home is opposite of flare.

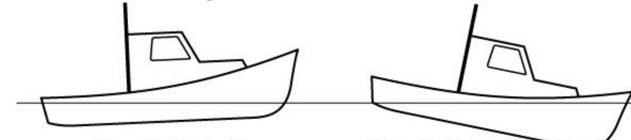


Flare



Tumble home

Image credit otenmaritime.com



Trim

- Draft **(T)** is measured both in the stern $\mathbf{T_A}$ **(aft end)** and bow $\mathbf{T_F}$**(fwd end)** of a ship
- The difference between forward and aft drafts is referred to as <u>trim</u> $\mathbf{(t = T_F - T_A)}$
- It may have significant impact on ship resistance

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Research on Influence of Trim on a Container Ship's Resistance performance

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Abstract. Faced with the double pressure of rising oil price and limitation of greenhouse gas emissions, many ship owners began to seek measures to minimize ship's resistance under specific conditions. Trim optimization has gained more and more attention in recent years for its flexibility and effectiveness in energy saving and emission reduction. The purpose of this paper is to perform trim optimization on a container ship. First, commercial CFD code of the ANSYS FLUENT was applied to calculate the target ship's total resistance. Then, in order to validate the effectiveness of CFD method, experimental result of ship model test was referred and it indicated that the numerical method was a reliable tool in prediction of the container ship's hydrodynamic performance. Finally, resistance corresponding to various trim conditions and speeds of three typical drafts were investigated, and it showed that trim did have impact on resistance. Based on the attained result, optimum trim value for actual navigation was suggested.

1. Introduction

Reduction of greenhouse gas emission has always been the focus of scientific research of environmental protection for many years, and shipping industry is one of the stakeholders in this issue. It is estimated that three percent of global carbon dioxide are caused by ships because of burning fuels [1]. Faced with double pressure of ever rising fuel prices as well as limitation of CO_2 emission from the International Maritime Organization (IMO), many ship industries take a lot of strategies to cut down fuel costs and reduce energy consumption, such as hull lines optimization, modification of bulbous bow, installation of energy-saving appendages, and trim optimization.

Among these measures, trim optimization is adopted by many ship owners for its advantages in reducing ship's resistance without changing structure of a ship or installing any equipment [2]. As we all know, a ship's resistance is closely related to its wetted surface area and underwater hull form, and different trim conditions would cause changes of a ship's streamline. Therefore, it is reasonable and feasible to reduce a ship's resistance by merely adjusting its trim value.

Owing to the improvement of computational power and parallel processing, computational fluid dynamics is now becoming more and more popular in simulation of complex flow. This paper chooses a 4250-TEU Container ship as research target, and optimization of searching for its minimum resistance

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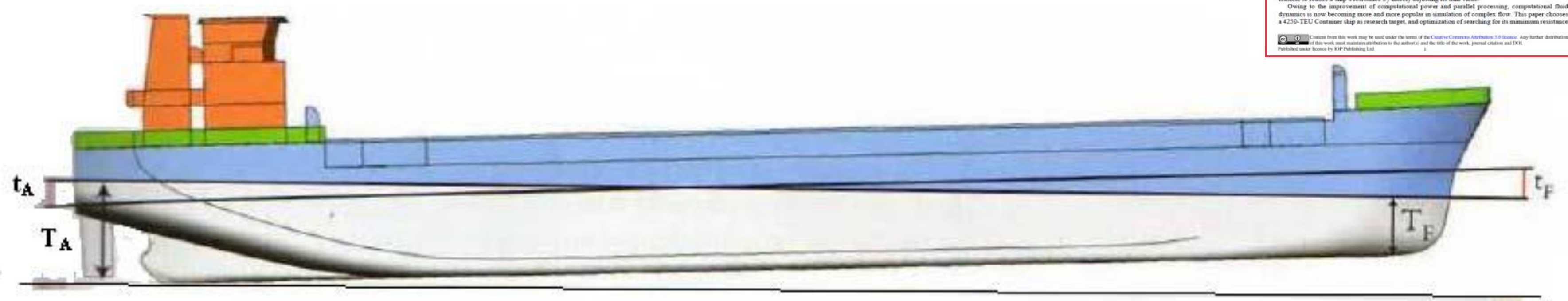
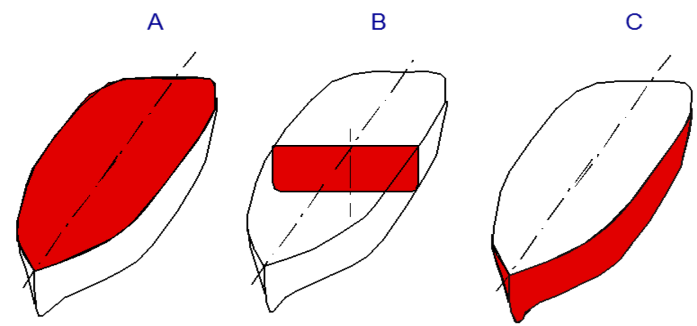


Area measures

A. Area of waterplane (AWP - *laivan vesiviivan pinta*) is horizontal section cut at floating position

B. Area at amidships (AM - *pääkaaren pinta*) is the area closed by molded hull line and the floating plane, usually equaling the main frame area at midship

C. Wetted surface, (S - *märkäpinta*), is the area in touch with surrounding water



Weights

Lightship weight (≈ a ships own weight)

- The weight of a ship in metric tons without cargo, fuel, lubricating oil, ballast water, fresh water and feed water in tanks, consumable stores, passengers and crew and their belongings
  - *Includes standard outfitting, inventory according to the List of Inventory, spare parts according to the Class Society requirements and with liquids in engine room systems*

Deadweight (≈ the weight of what a ship is carrying)

- Defined as the difference between an actual displacement and the lightship weight
  - *SOLAS: "Deadweight is the difference in tones between the displacement of a ship in water of a specific gravity of 1.025 at the load waterline corresponding to the assigned summer freeboard and the lightweight of the ship"*
  - *Expressed in either long tons or metric tons*
- It is a measure of ship's ability to carry various items: cargo, stores, ballast water, provisions and crew, etc.

Displacement (= Lightship weight + Deadweight = Total ship weight)

- The weight of water displaced by this vessel at any waterline
  - *The product of the volume of its underwater portion and the density of the water in which it floats*
- Expressed in long/imperial tons (1 long ton ≈ 1.01605 metric tons)

Displacement

- **Volume of Displacement ∇ [m3]**
  - *Volume of the part of the ship below the waterline including the appendices (propeller, rudder, etc.) and shell plating.*

- **Displacement Δ [ton]**
  - *The displacement is the weight of the volume of water displaced by the ship.*

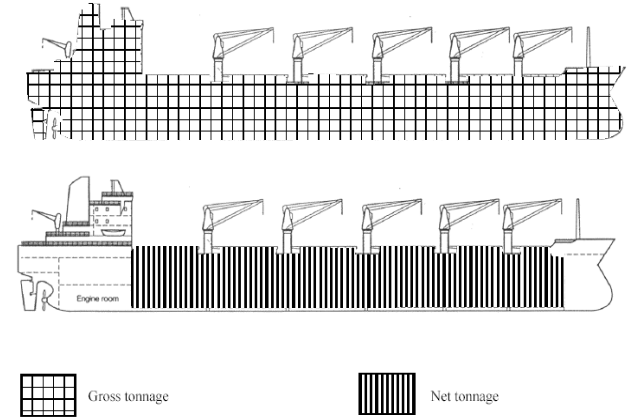
$$Displacement\ \Delta\ [ton] = water\ displacement\ \nabla\ [m^3] \times density\ of\ water\ \rho \left[\frac{ton}{m^3}\right]$$

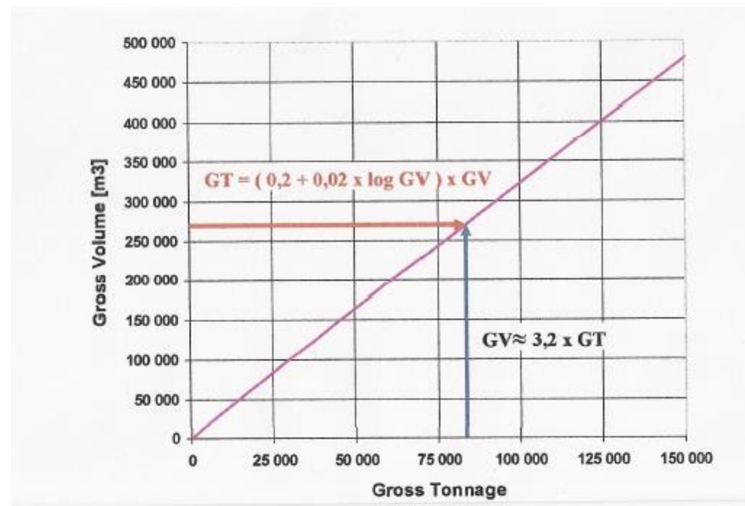
Tonnage

- Gross tonnage (GT)
  - *The volume of a ship's closed spaces*

- Net tonnage
  - *The volume of a ship's usable spaces*

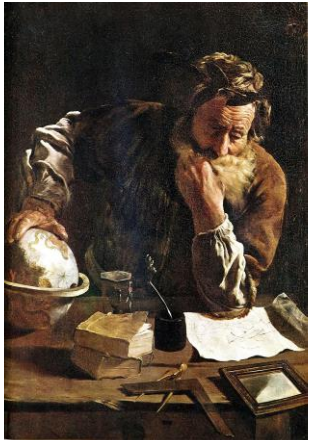
- Tonnage information is public
  - *No-physical measures*
  - *Many types of costs/tariffs (e.g. port costs, channel tariffs) are determined per GT*

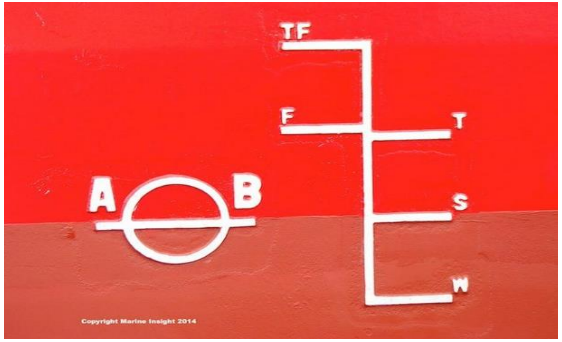




Load line mark

- Define the maximum legal limit to which a ship can be loaded for various operating conditions
  - *Salt/sea water*
    - T – Tropical waters
    - S – Summer temperate water
    - W – Winter temperate water
  - *Fresh water*
    - F – Fresh water
    - TF – Tropical fresh water
- Plimsoll mark”
  - *Summer salt water line*
  - The maximum legal limit to which a ship can be loaded in salt water in “summer” conditions

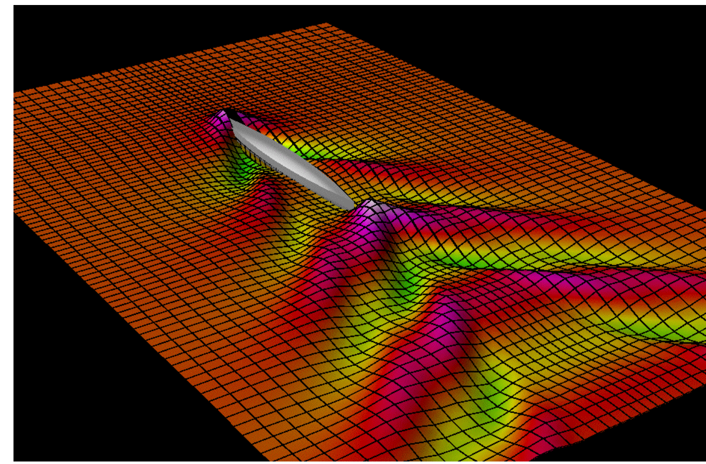




Ship Speed - Definition

A ship's speed is measured in knots

- *1 knot = 1 nautical mile / per hour*
- *1 nautical mile = 1 852 m*
- *1 knot =1,852 km/hr ≈ 0.514 m/s*



- Hydrodynamic speed
  - *Froude Number (dimensionless)*

$$F_N = \frac{v}{\sqrt{gL}}$$

Block Coefficient (C_B)

It is the ratio of the underwater volume of a ship to the volume of a rectangular block, the dimensions of which are the length between perpendiculars, the mean draught and the breadth extreme. The relationship is expressed as a decimal figure.

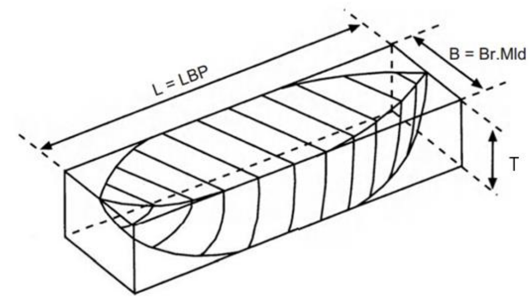
- **Determined considering**
  - *Resistance and speed*
    - In passenger ship C_B≈0,55 while in slow bulk-carrier C_B≈0,85
  - *Buoyancy*
    - An increased higher C_B value provides an increased buoyancy
  - *Manufacturing related factors*

Typical C_b values at fully loaded drafts

Ship Type	Typical C_b Fully Loaded	Ship Type	Typical C_b Fully Loaded
ULCC	0.850	General cargo ship	0.700
Supertanker	0.825	Passenger liner	0.575–0.625
Oil tanker	0.800	Container ship	0.575
Bulk carrier	0.775–0.825	Coastal tug	0.500

Medium-form ships (C_b approx. 0.700), full-form ships (C_b > 0.700), fine-form ships (C_b < 0.700).

$$C_B = \frac{\nabla}{LBT}$$



Block Coefficient (C_B)

$$C_B = \frac{\nabla}{LBT}$$

A ship 64 meters long, 10 meters maximum beam, has a light draft of 1.5 meters and a load draft of 4 meters. The block coefficient of fineness is 0.600 at the light draft and 0.750 at the load draft. Find the deadweight.

$$\begin{aligned}
\text{Light displacement} \quad &= (\text{L} \times \text{B} \times \text{ draft } \times \text{C}_\text{b})\ \text{m}^3 \\
&= 64 \times 10 \times 1.5 \times 0.6 \\
&= 576\ \ \text{m}^3 \\
\text{Load displacement} \quad &= (\text{L} \times \text{B} \times \text{ draft } \times \text{C}_\text{b})\text{m}^3 \\
&= 64 \times 10 \times 4 \times 0.75 \\
&= 1920\ \ \text{m}^3 \\
\text{Deadweight} \quad &= \text{Load displacement} - \text{Light displacement} \\
&= (1920 - 576)\text{m}^3 \\
\text{Deadweight} \quad &= 1344\ \ \text{m}^3 \\
&= 1344 \times 1.025\ \text{tonnes}
\end{aligned}$$

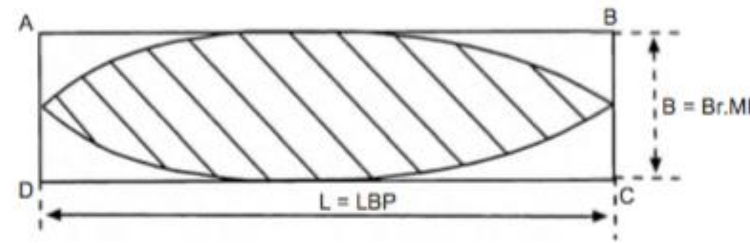
Deadweight = 1378 tonnes

Waterplane area coefficient (C_W)

It is the ratio of the actual area of the waterplane to the product of the length and breadth of the ship.

$$\boldsymbol{Area\ of\ water-plane\ C_W = \frac{Area\ of\ water-plane}{Area\ of\ rectangle\ ABCD} = \frac{A_W}{L \times B}}$$

$$\boldsymbol{Area\ of\ water-plane = C_W \times L \times B}$$



Find the area of the water-plane of a ship 36 metres long, 6 metres beam, which has a coefficient of fineness of 0.8.

$$\text{Area of water-plane} = L \times B \times C_w$$
$$= 36 \times 6 \times 0.8$$

Ans. Area of water-plane = 173 sq.m

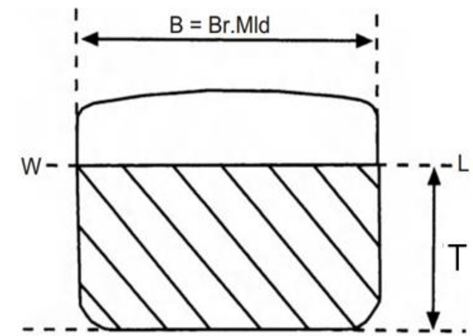
Mid ship section area coefficient (C_M)

It is the ratio of the actual area of the immersed portion of the ship's midship section to the product of the breadth and the draught of the ship.

$$C_m = \frac{Midship\ area\ A_m}{Area\ of\ rectangle}$$

$$C_m = \frac{Midship\ area\ A_m}{B \times T}$$

$$A_m = \mathrm{L} \times B \times C_m$$



The Midships Coefficient

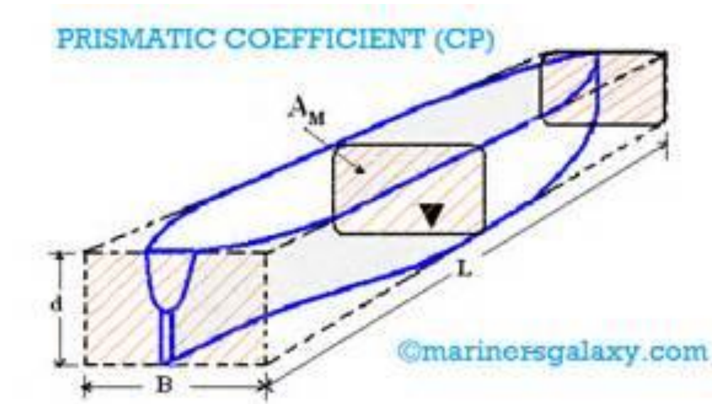
Prismatic coefficient (C_P)

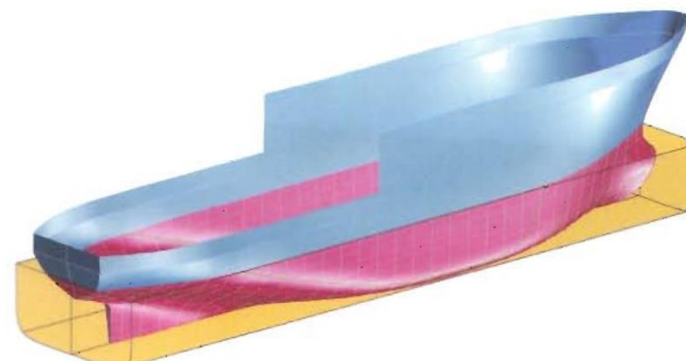
The ratio of the volume of displacement at that draft to the volume of a prism having the same length as the ship and the same cross-sectional area as the ship's midships area.

$$C_P = \frac{volume\ of\ ship\ \nabla}{volume\ of\ prism}$$

$$C_P = \frac{volume\ of\ ship\ \nabla}{L\ \times\ A_m}$$

$$volume\ of\ ship\ \nabla = \ C_P \times L \times\ A_m$$





Relationship between coefficients

$$C_M \times C_P = \frac{A_m}{B \times T} \times \frac{\nabla}{L \times A_m}$$

$$C_M \times C_P = \frac{\boldsymbol{\nabla}}{\boldsymbol{B \times T \times L}} = \boldsymbol{C_b}$$

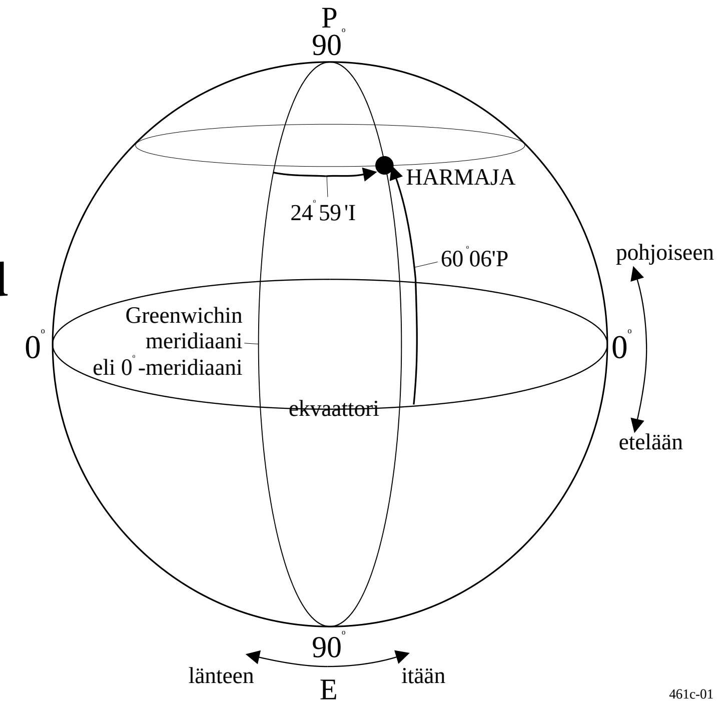
Home exercises

- Define 'coefficient of fineness of the water-plane'.
- The length of a ship at the waterline is 100 m, the maximum beam is 15 m and the coefficient of fineness of the water-plane is 0.8. Find the TPC at this draft.
- Define 'block coefficient of fineness of displacement'.
- A ship's length at the waterline is 120 m when floating on an even keel at a draft of 4.5 m. The maximum beam is 20 m. If the ship's block coefficient is 0.75, find the displacement in tonnes at this draft in salt water.
- A ship is 150 m long, has 20 m beam, load draft 8 m, light draft 3 m. The block coefficient at the load draft is 0.766, and at the light draft is 0.668. Find the ship's deadweight.
- A ship 120 m long × 15 m beam has a block coefficient of 0.700 and is floating at the load draft of 7 m in fresh water. Find how much more cargo can be loaded if the ship is to float at the same draft in salt water.
- A ship 100 m long, 15 m beam and 12 m deep is floating on an even keel at a draft of 6 m, block coefficient 0.8. The ship is floating in salt water. Find the cargo to discharge so that the ship will float at the same draft in fresh water.
- A ship's lifeboat is 10 m long, 3 m beam and 1.5 m deep. Find the number of persons which may be carried.

Design space coordinates

- Position coordinates are given in degrees and minutes
  - *One degree = 60min*
- Longitudes and latitudes are equal, but one should notice that in reality longitudes get shorter towards the poles
- 1 Nautical mile = 1 852 m
- Background
  - *Circumference of earth around equator ~40000 km*
  - *1 Nautical mile = one minute (1/60) of one degree of latitude (1/360)*

$$\frac{40000 \text{ Km}}{360 \cdot 60} = 1.852 \times 10^3 \text{ m}$$



Harmaja lighthouse coordinates:
60^o 06' N (North), 24^o 58' E (East)

Ship categories

Question: Can you mention any ship category/type? For what design purpose(s) is it useful to divide ship into categories?

Ship type categories - general

- Ship mission
- Applied technologies
- Operational area
- Design limiting factors
- …

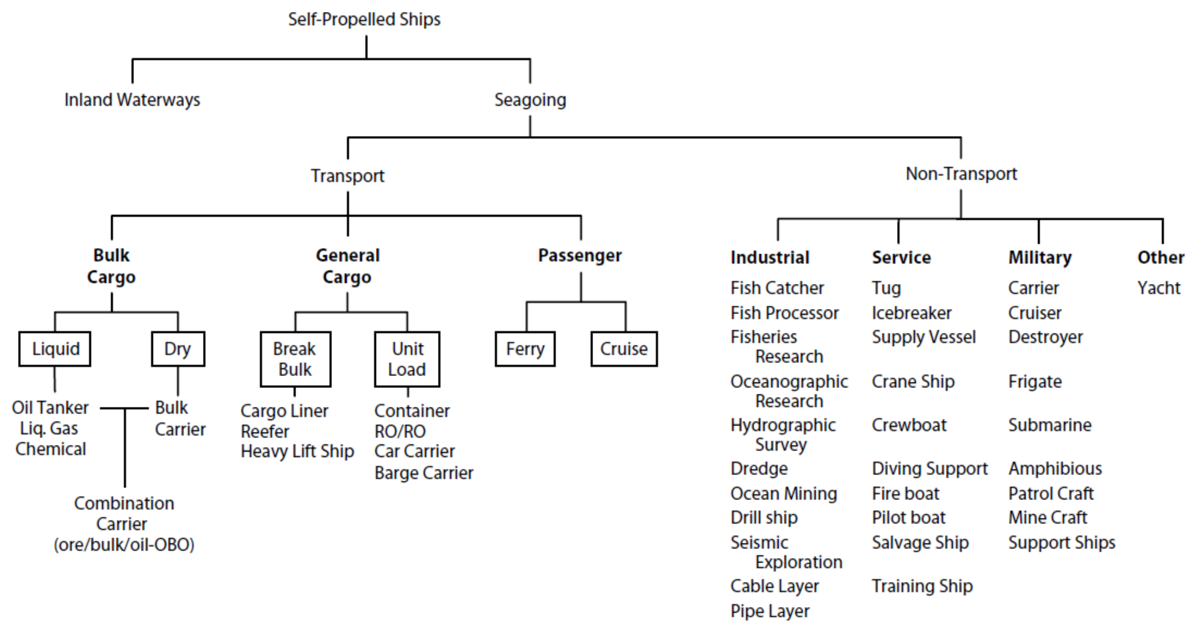
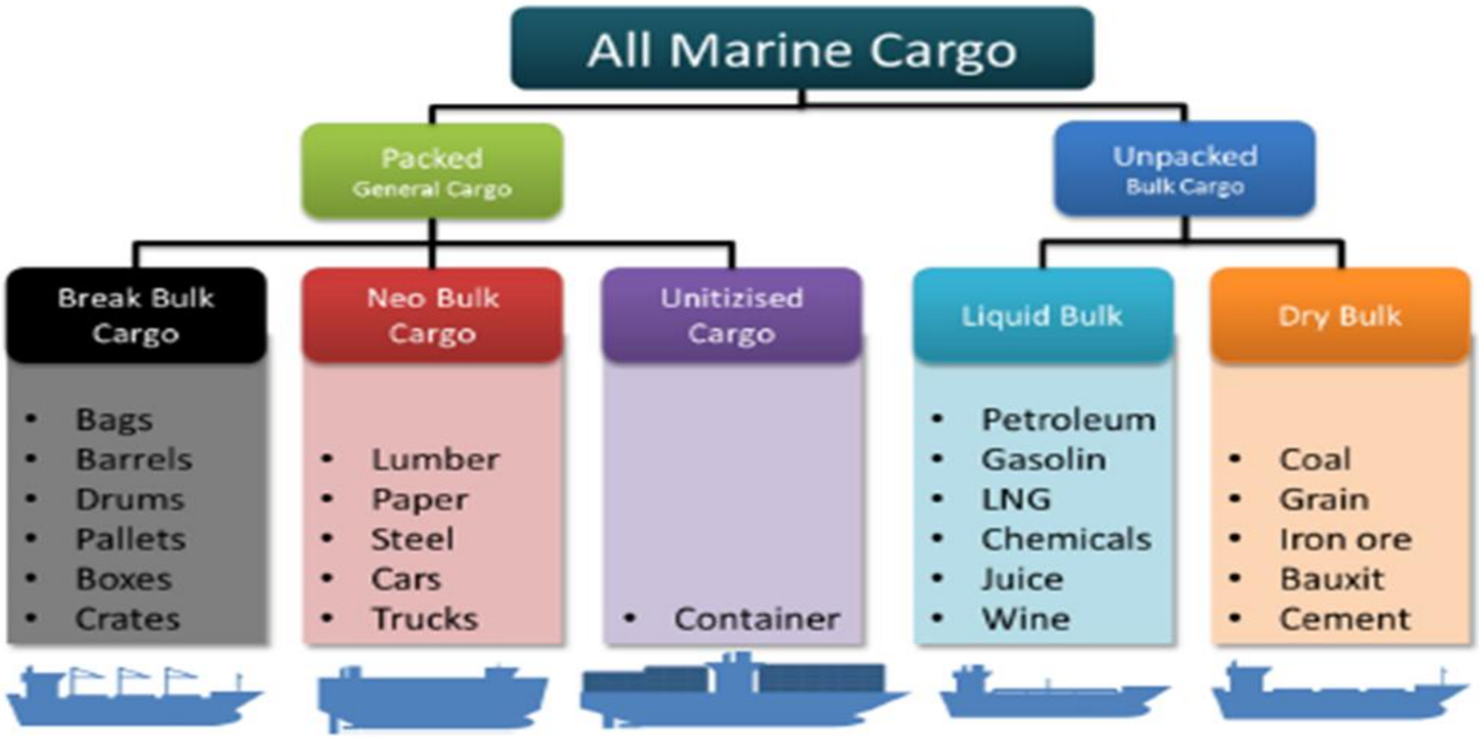


Figure 5.5 Ship Type Categories

Image credit Lamb, T. Ship design and Construction, SNAME 2003

Ship type categories – cargo based



Ship type categories – mission based

- Commercial / merchant ships
  - ✓ Bulk carriers, tankers, cruise ships, feeders,...
  - ✓ Industrial ships
- Non-commercial ships
  - *Navy ships, research ships, coastguard ships,...*
- Special-purpose / service ships
  - *Icebreakers, multi-purpose icebreakers...*
- Industrial ships
- Leisure ships/ yachts/ boats
- ...

Special-purpose / service ships

Commercial ship types

Industrial ships

Non-commercial ship types

Ship type categories – tech based

- Type of lift (how the lift is achieved)
  - *Hydrostatics, hydrodynamics, lift equipment (e.g. hydrocopter)*
- Applied structures and materials
  - *Welded steel, bolted steel, composites, light metal alloys, wood, concrete,...*
- Type of cargo handing
  - *On-board crane, ...*
- Type of propulsion device
  - *Single/twin screw (most common), water jet, sail/kite, air propeller,...*
- Type of energy source
  - *Diesel engine(s) (M/S , Motor Ship)*
  - *Steam turbine(s) (STS, Steam Turbine Ship)*
  - *Gas Turbine(s) (GTS, Gas Turbine Ship)*

Image credit Yachting World / C. Launay

Image credit Wärtsilä

Ship type categories – operations based

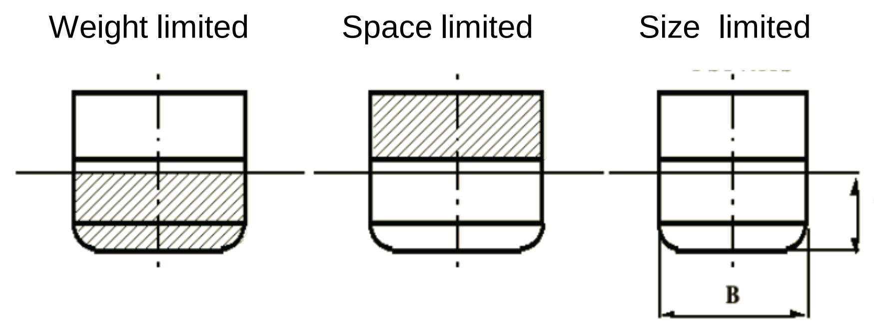
- *The operational area determines the assumed worse environmental conditions (e.g. wave height, ice conditions) and sets constraints in terms of ship draft and size…*
- *The design conditions are determined considering ship building costs (overly conservative vs. weak), flexibility with regards to ship usage, etc.*
- *Examples of operational-area based ship types*
  - Ocean going vessels with unlimited range of operation conditions
    - Basis for design: Winter conditions in the North Atlantic (most severe environment)
  - Ships designed for specific areas (Baltic Sea, North Sea,…)
  - Ships designed for protected seaways (max. distance to shore)
  - Inland waterway vessels (rivers and lakes)
    - Limited draught (channels) and maximum height (bridges)
    - No large waves

SHIPS IN STORM COMPILATION -MONSTER WAVES

https://www.youtube.com/watch?v=aBM7NgMhg90

Ship type categories – limiting factors based

- Weight limited ships
  - *DW ~80 % of displacement*
  - *Heavy cargo carriers*
- Space limited ships
  - *DW ~20 % of displacement*
  - *Light cargo ships (e.g. cruise ships), RORO ships, ROPAX ships*
- Size limited ships
  - *Limited by main dimensions*
  - *Panamax, New Panamax, Aframax, Chinamax, Suezmax ,...*



Comparison of Tanker sizes

Image credit maritime-connector.com/

Ship type categories – cargo handling based

- *Vertical lifting*
  - Lift on-Lift off = Lo-Lo
- *Horizontal transport*
  - Roll on- Roll off = Ro-Ro
- *Pumping*

Image credit Viking Line

Image credit offshore-fleet.com

Image credit
Turkey SeaNews

Ship type categories – hull no. based

- Mono/single hull
- Catamaran (two hulls)
- Trimaran (three hulls)

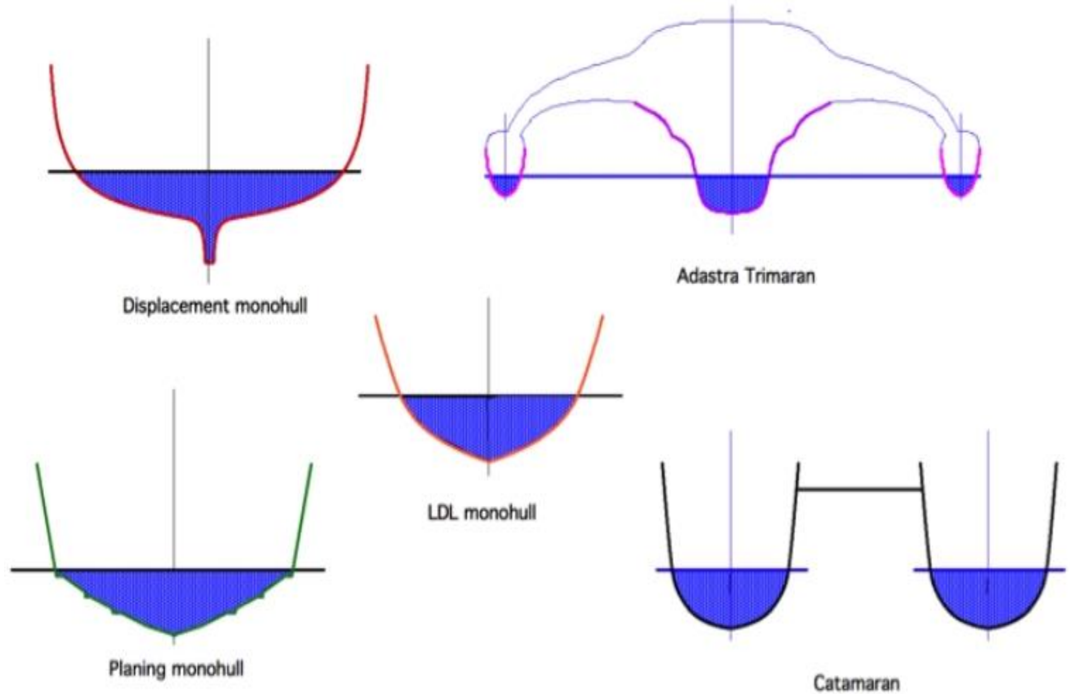
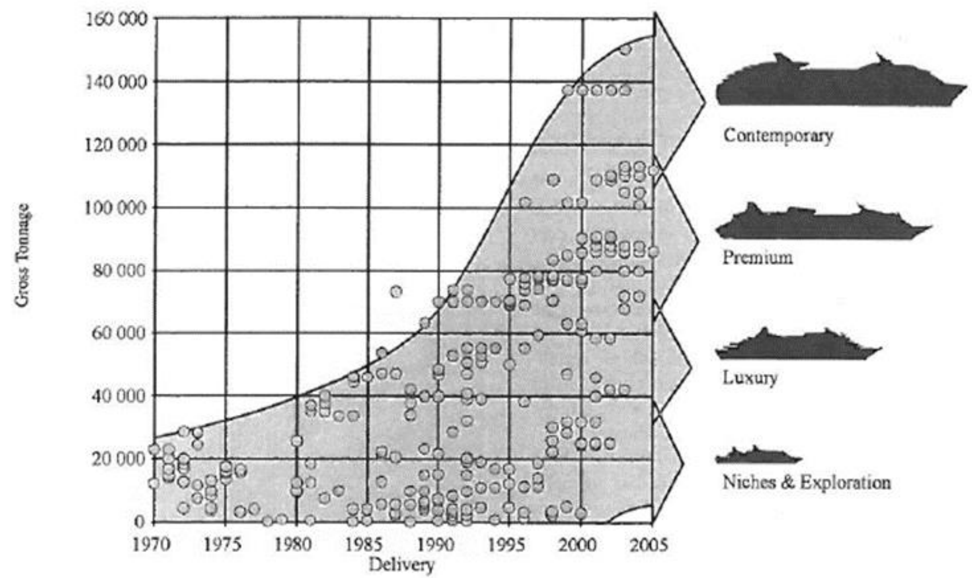


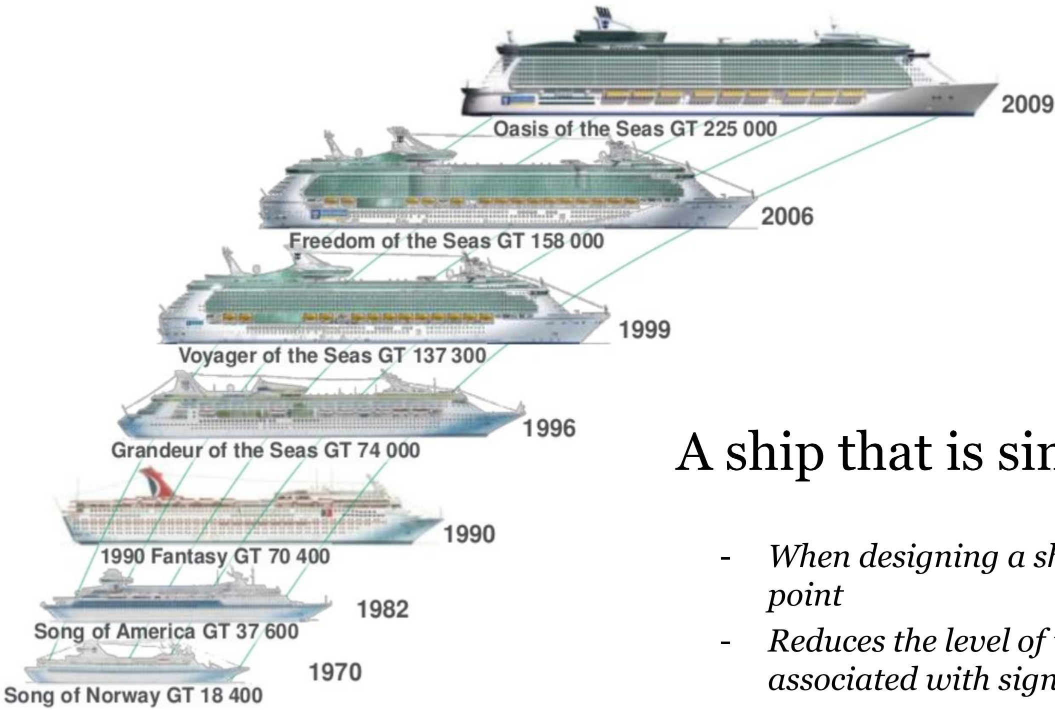
Image credit shuttleworthdesign.com

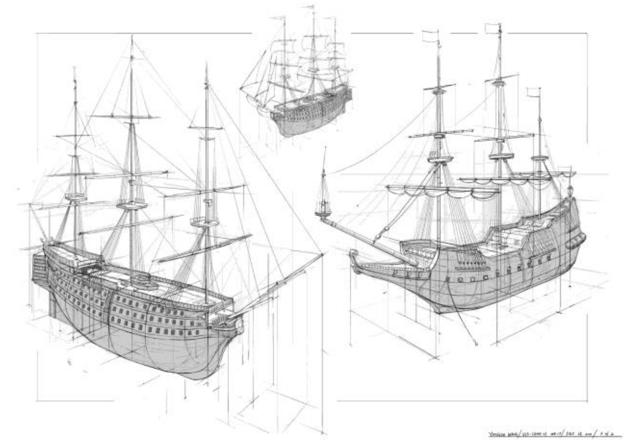
Ship type categories – market based

- Makes it possible to determine and analyze various category/segment-specific
  - *Technical solutions*
  - *KPIs (e.g. crew size/number of passengers, space/passenger)*
  - *Trends*
- Example of cruise segments
  - *First class (mass market lines)*
  - *Premium*
  - *Luxury*
  - *Niches & exploration…*



What is a Reference Ship ?





A ship that is similar to the ship designed

- *When designing a ship, reference ships are commonly used as starting point*
- *Reduces the level of uncertainty - Important !! as a ship generally is associated with significant technical and economic risks*

Image credit STX Europe / Meyer Werft

Reference ships / data

Question: Can you mention any drawbacks of using reference data/ships?

Out-of-box” thinking still allowed


RP FLIP (Research vessel)


SAILING YACHT A (Prive yacht)


RAMFORM TITAN (Seismic ship)


M80 STILETTO (Stealth US Navy ship)

DOCKWISE VANGUARD (Heavy lift vessel)


BOTTSAND (Navy Oil Recovery Ship)

Source: https://www.ntd.tv/2017/03/07/strangeness-seas-worlds-weirdest-ships/

Summary

Ships can be divided into categories/types in various ways

- *Ship mission*
  - Commercial, non-commercial ships, special-purpose ships,...
- *Applied technology*
  - Type of lift / structural solution / cargo handling / propulsion / energy source /...
- *Operational area*
  - Ocean going vessels, inland waterway vessels,...
- *Design limiting factors*
  - Weight/ space / size limited ships
- *Cargo handling system*
- *Number of hulls*
- ...

A ship's main features are largely determined by its category / type

- Categorization is useful e.g. for the selection of reference ships

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Thank you !!

Lecture 2 – Reference ship/data