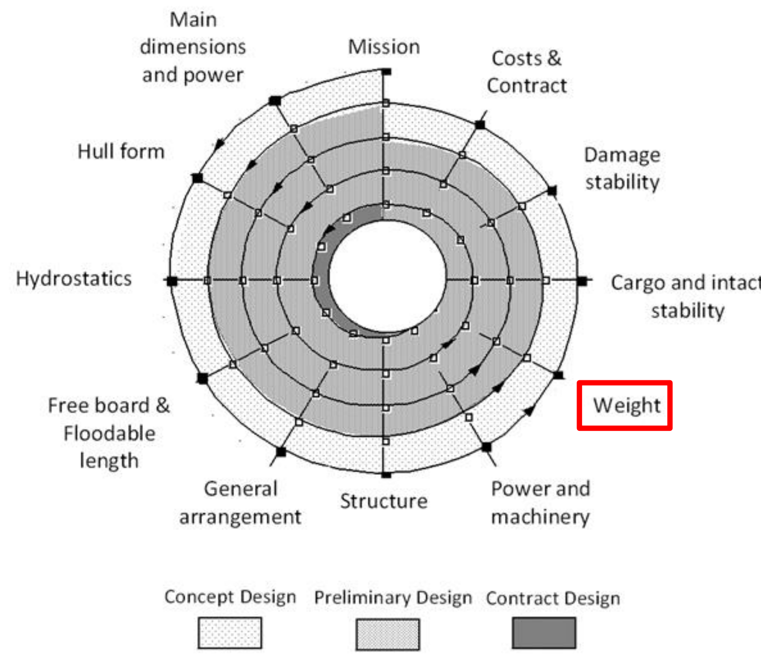
Aalto University
School of Engineering

MEC-E1004 Principles of Naval Architecture

Lecture 9 – Ship Weights

Learning points !

- After the lecture, you will be able to
  - *Explain the purpose of classification of ship systems and define classification standards*
  - *Explain the importance of weight calculations in ship design*
  - *Define the various stages of a ship weight calculation process and explain how they might be carried out*
  - *Carry out a preliminary weight assessment of your project ship*



Assignment 9 – Weights and stability

- Classify the main components and systems of your ship in accordance with the SFI system (1st and 2nd level only)

- Using the SFI classification, estimate your ship's lightweight, deadweight and the resulting displacement (considering her mission)

- Assess the level of uncertainty in your weight calculations and determine a "weight reserve"

- Calculate your ship's vertical center of gravity

Classification of systems

Question: Why do you think classification of ship systems is needed?

Classification of ship systems

- A functional subdivision/classification of technical ship information

- Needed for a systematic and standardized description of a ship (ship specification), for the purpose of
  - Weight assessment (using statistics)
  - Price estimation (using statistics)
  - Production planning and progress monitoring
    - Work breakdown system: Blocks – Grandblocks – Areas - Systems
  - ...

Image credit Turun Sanomat

- Used by shipyards, ship owners, suppliers, subcontractors,...

Classification of systems

- System components
  - *Hull, engineering and propulsion machinery, outfitting systems, navigation equipment, cargo management, maneuvering, etc.*
- Ship parts of relevance
  - *Bow, stern, parallel body, deck house, etc.*
  - *Might lead to deep hierarchies*

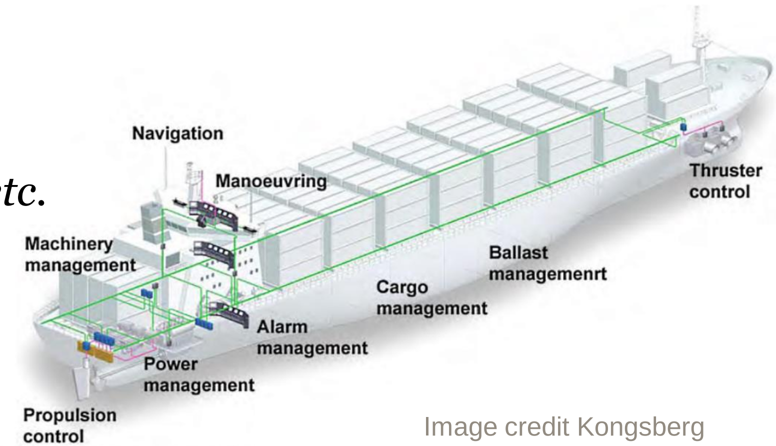


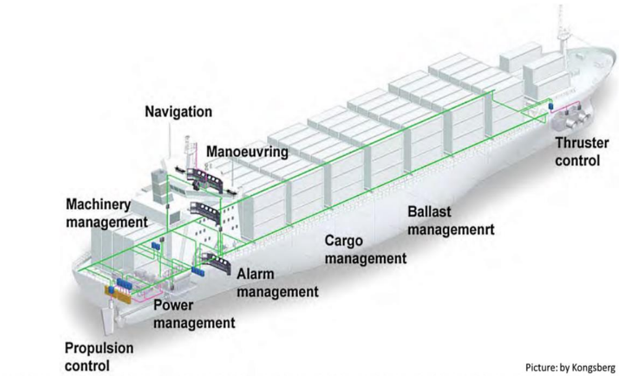
Image credit Kongsberg

- Engineering Disciplines
  - *Mechanical & Electrical engineering*
  - *Materials science and engineering*
  - *Naval Architecture and marine engineering (Stability, hydrodynamics, structures, risk, etc. etc.)*

Classification of systems

Developed to provide to the yards and to the companies involved in the management and operation of ships tools to support

- Ship Specifications
- Estimates of ship building (or repair) costs
- Estimates of the Lightship Weight
- Procurement of materials, equipment and services.



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Three basic systems:

- **MARAD-** MARitime ADministration, used by the U.S.A. administration
- **SWBS-** Ship Work Breakdown Structure, used by the USA Navy.
- **SFI–** developed by the Ship Research Institute, from Norway

SWBS and the SFI are organized in a number of main groups, which are divided in groups, sub-groups so on. The MARAD system is less defined and complete in its structure. In each of these systems, a classification number is assigned to each item or group of items of the ship, according to a tree structure.

The SFI system

Code letter system

- Also referred to as Littera systems
  - *Littera (Latin word !) is a code letter or number describing an object*

Example of code letter systems

- SFI Coding & Classification System
  - *A system for developed and published by the Norge Skips Forsknings Institutt (NSFI) from Noruway, and which is now property of XANTIC (www.xantic.net).*
  - *Shipyard specific*

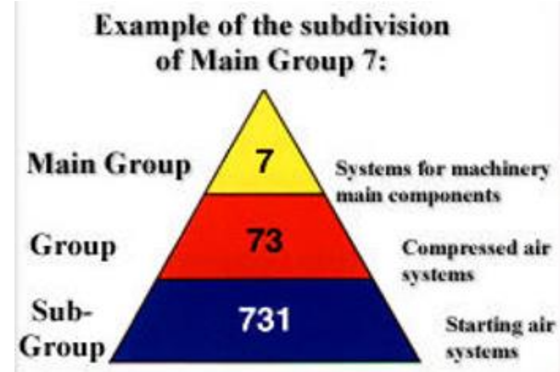


Image credit SFI Group System

The SFI system defines 10 main groups (only 8 are currently utilized for Ships)

0. (reserved)
1. Ship General
2. Hull
3. Equipment for Cargo
4. Ship Equipment
5. Equipment for Crew and Passengers
6. Machinery Main Components
7. Systems for Machinery Main Components
8. Ship Common Systems
9. (reserved)

Classification of systems

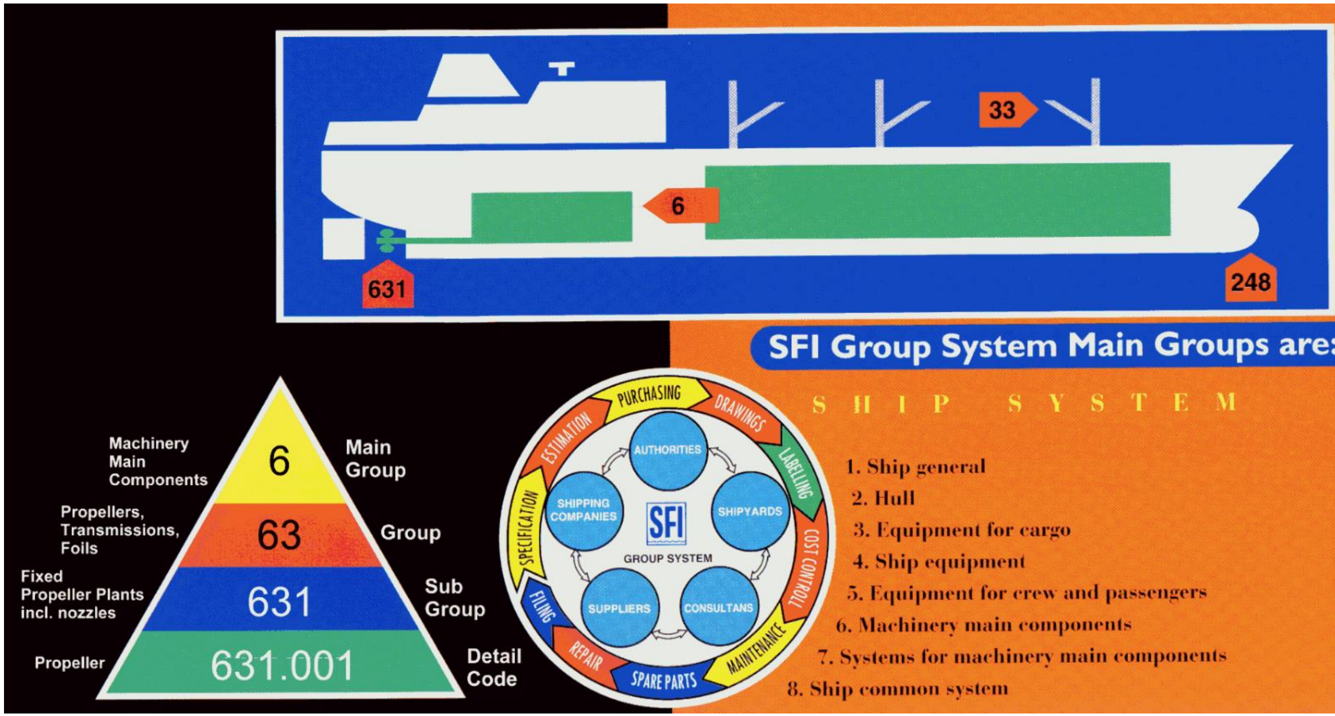


Image credit SFI Group System

Weight calculation

Question 1 : Can you mention any ship weight calculation related terms?

Question 2 : What’s the purpose of weight calculations in ship desing?

Important terminology

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

$$W_{LS} = W_S \text{ structural weight} + W_M \text{ propulsion machinery } + W_O \text{ outfitting } + W_{margin} \text{ Margin or reserve}$$

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*
- A measure of ship's ability to carry various items: cargo, stores, ballast water, provisions and crew, etc.

$$DWT = DWT_c \text{ cargo} + DWT_{FO} \text{ fuel oil} + DWT_{FW} \text{ Fresh water} + DWT_{C\&E} \text{ crew and their effects} + DWT_{PR} \text{ provisions}$$

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)

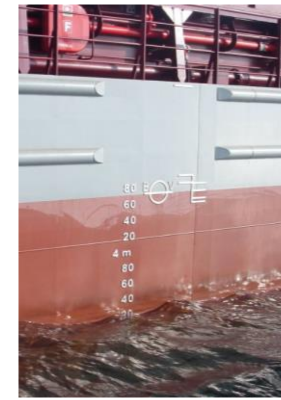
Important terminology

- Contract deadweight
  - *As specified by the shipbuilding contract*

- Deadweight acceptance limit
  - *Value below of which a shipyard has to compensate the owner (€/ton)*

- Deadweight rejection limit
  - *Value below of which the owner has the right to reject the ship*

- Legal deadweight
  - *Value resulting from agreed on design modifications*



Load line mark.
Image credit
boatdesign.net

Why weight calculations?

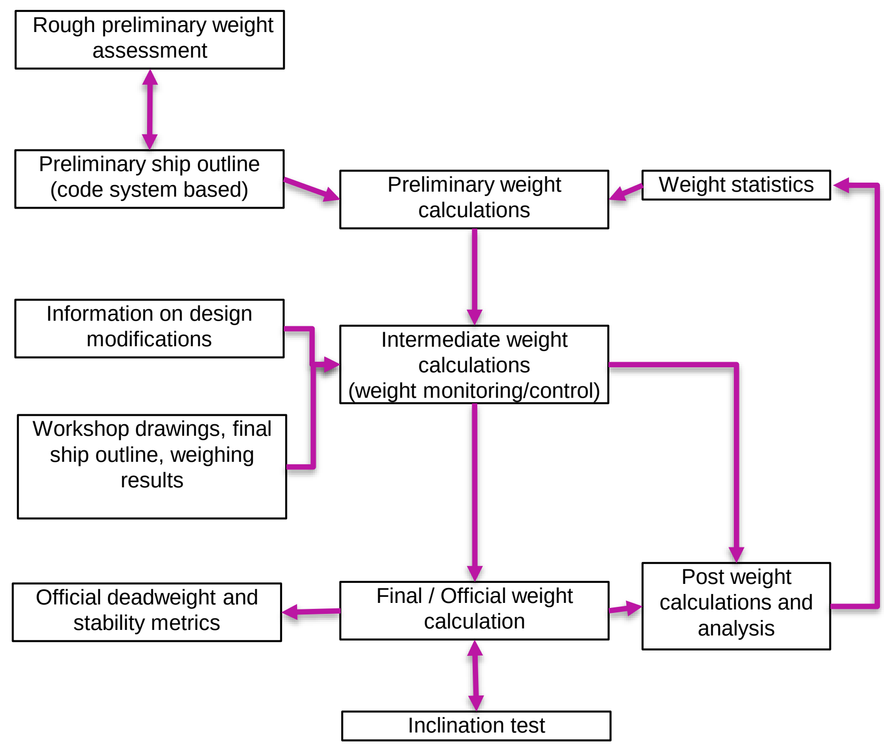
Weight calculations aim to determine a ship's weight, center of gravity (*in horizontal, vertical and transversal directions*), and weight distribution

- Help make sure that a ship floats and is stable

- Help determine a ship's
  - *Floating position (trim)*
  - *Intact, damage, and dynamic stability*
  - *Maneuverability*
  - *Power demand*
  - *Seakeeping*
  - ...

- Therefore, they are needed in the determination of a ship's
  - *Hull proportions and lines*
  - *Cargo carrying capability*
  - *Hull girder strength*
  - *Resistance / Propulsion power demand*
  - *Building costs (weight and building costs are strongly related)*
  - ...

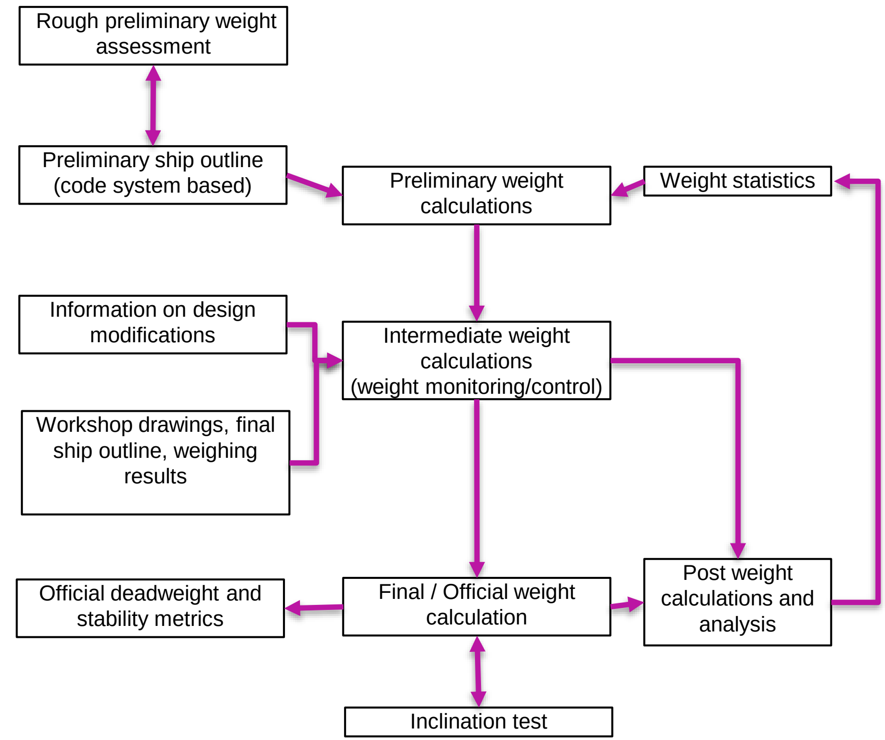
→ Weight calculation errors might have very significant technical and economic consequences



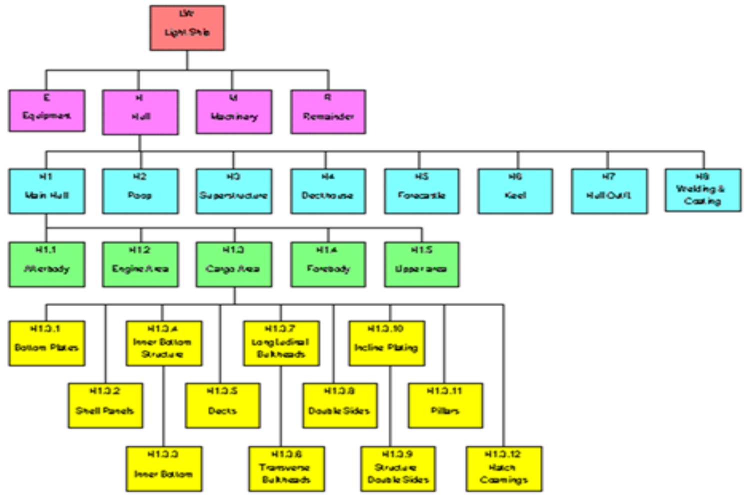
Weight calculation process

Weight calculations are carried out throughout ship - design / building

- The accuracy of the calculations increases as the design and building processes advances
  - *Preliminary weight assessment → Intermediate weight calculation → Official weight calculation*
- The weight calculation process can be roughly divided into
  - *Rough preliminary weight assessment*
  - *Preliminary calculations*
  - *Intermediate/ control calculation*
  - *Final / Official calculations*
  - *Post-calculation to study i.e. how the weight changed during the building process*
  - *Statistical analysis → weight statistics for future shipbuilding projects*
  - *Inclining experiment to validate the weight calculations*



Preliminary weight assessment



Simplified estimation based on statistics

- Empirically determined “Rule of thumb formulas”
  - ✓ *Hull weight = factor x LBH*
  - ✓ *Machine weight = factor x power*
  - ✓ *Outfitting weight = factor x LBH*
  - ✓ *Interior weight = factor x interior area*

Using empirical formulas, the calculation accuracy depends on the quality of the applied statistics

- *Empirical values are accurate only for designs that are similar to those based on which they were determined*
- *Standardized ship system / equipment / part categories needed*

Ship design for efficiency and economy/H. Schneekluth and. V. Bertram. — 2nd ed. p. cm. Includes bibliographical *references* and index. ISBN 0 7506 4133 9.

Preliminary weight calculations

Can be carried out by dividing a ship's lightweight into parts whose weights are estimated using

- Empirically determined weight coefficients
- Volumes and areas determined based on the ship's (preliminary) general arrangement
- Known/estimated weights of individual major components
- <u>Calculation time:</u> a few days

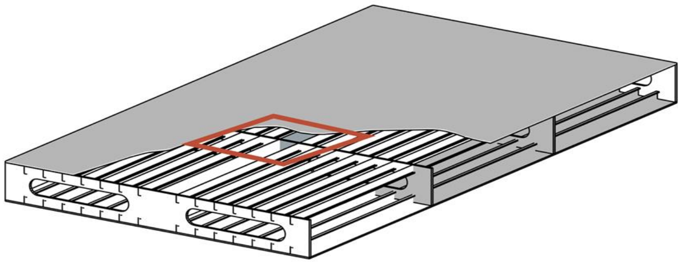
Example formulas:

Ship part	Weight formula
Aft ship	C 211x LBH
Fore ship	C 212x LBH
Double bottom	C213 x LBH
Bulkhead	C214 x A
Deck structures	C215 x A
Side structures	C216 x L(B + 2H)
Superstructure	C 221 x V
Funnel structure	C 223 x V
Machine platforms	C23 x LBH

Home exercises on weight calculations

- Unit weight for stiffened plate field, in which the plate includes longitudinal stiffeners, longitudinal girders and transverse web frames

$$W = t + \frac{1}{S_{FR}} W_{FR} + \frac{1}{S_{GIR}} W_{GIR} + \frac{1}{S_{STIF}} W_{STIF} [ton/m^2]$$



✓ t – plate thickness [ton/m2]
✓ W_{xx} – weight of the component in [ton/m]
✓ S – section modulus

- Please reflect upon the above and also Q 6,7 from Lecture 9 in course book

- The following slides explain Watson and Gilfillan equations for **preliminary estimation of ship weights**

Preliminary structural weight (W_S)

- **The structural weight consists of (1) the basic hull, (2) extensions of the hull above the depth amidships** (e.g., forecastle and the poop deck), **(3) superstructures and deckhouses** that may affect considerably the ship's vertical and longitudinal centers of gravity

- **The *"modified Lloyd's equipment number E"* used to estimate the structure weight.**

$$E = E_{hull} + E_{SS} + E_{dh} = L(B+T) + 0.85L(D-T) + 0.85\sum_{i} {}_i h_i + 0.75\sum_{j} {}_j h_j$$

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Preliminary weight calculations

$$W_S = KE^{1.36}[1 + 0.5(C_B - 0.7)]$$

Ship type	K mean	K range	Range of E
Tankers	0.032	±0.003	1500 < E < 40000
Chemical tankers	0.036	±0.001	1900 < E < 2500
Bulk carriers	0.031	±0.002	3000 < E < 15000
Container ships	0.036	±0.003	6000 < E < 13000
Cargo	0.033	±0.004	2000 < E < 7000
Refrigerator ships	0.034	±0.002	4000 < E < 6000
Coasters	0.030	±0.002	1000 < E < 2000
Offshore supply	0.045	±0.005	800 < E < 1300
Tugs	0.044	±0.002	350 < E < 450
Fishing trawlers	0.041	±0.001	250 < E < 1300
Research vessels	0.045	±0.002	1350 < E < 1500
RO-RO ferries	0.031	±0.006	2000 < E < 5000
Passenger ships	0.038	±0.001	5000 < E < 15000
Frigates/corvettes	0.023		

Preliminary weight calculations (W_m)

- **Commercial machinery weight includes only the propulsion machinery** ; i.e., the prime mover, the reduction gear the shafting and the propeller.

- The Watson and Gilfillan equation for machinery weight is

$$W_M = W_{ME} + W_{rem}$$

W_M is the main engines weight $\quad W_{ME} = \sum_i 12(MCR_i/N_{ei})^{0.84}$

W_{rem} is the remaining items weight $\quad W_{rem} = c_m(MCR)^{0.7}$

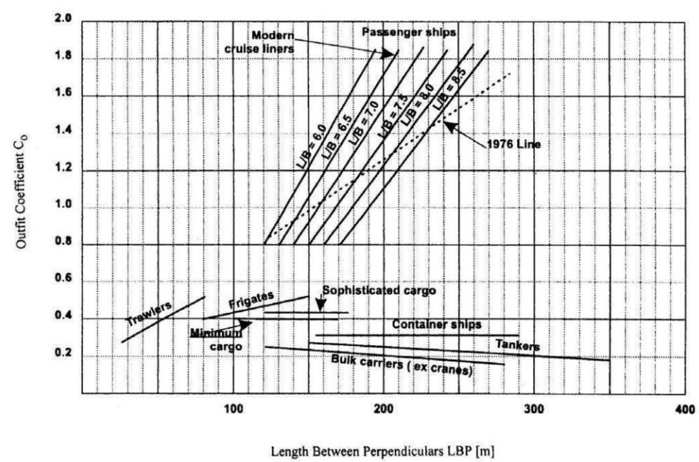
N_{ei} in rpm, MCR is in KW and c_m coefficient depends on the ship type

Preliminary weight calculations (Wo)

- **Outfitting weights involve electrical plants auxiliary engineering systems and hull engineering items (e.g. winches, bolts etc.)**

- Watson and Gilfillan introduced the equation

$$W_o = C_0 L B$$



- The outfitting weight coefficient C_0 is a function of the ship type and length

Preliminary weight calculations (W_{dwd})

- **Cargo deadweight (usually an owner requirement)**

- **Lube oil weight**
  - ✓ Depends on the type of machinery
  - ✓ Derived based on existing vessel records

- **Fresh water weight** $W_{FW} = 0.17t/(Person \times day)$
  - ✓ Depends upon the designer's intents (using distillation plant and/or storage).
  - ✓ Commercial vessels usually use storage tanks
  - ✓ Naval and cruise vessels use distillation plants and storage tanks
  - ✓ 45 gallons per person per day

- **Weight of the crew and their effects** $W_{C\&E} = 0.17\ t/person$

- **Weight of provisions** $W_{PR} = 0.01t/(person \times day)$

Intermediate & final weight calculations

Carried out based on

- Weight coefficients C determined accurately from
  - *Final general arrangement*
  - *Construction / as-built drawings*
  - *System drawings*

- Measured/given weights of specific ship components / blocks

The related detailed calculations produce a lot of data

General constants/assumptions

- Density of the seawater
  - *Baltic Sea 1,01 ton/m3,*
  - *North Sea 1,025 ton/m3*
  - *Helsinki 1,0038 ton/m3, see Finnish maritime law p.960*
- Density of oils (at approx. 20 C)
  - *Heavy fuel 0,93 ton/m3*
  - *Lubricant 0,91 ton/m3*
  - *Diesel fuel 0,83 ton/m3*
- Steel density
  - *7,8 ton/m3 (unmanufactured)*
  - *8,0 ton/m3 (manufactured)*

Weight calculations – *Lessons learnt*

Vasa

- Launched 1627, capsized and sank on its maiden voyage in 1628
- The original design was determined by the Dutch shipbuilder Henrik Hybertsson using an empirical method
  - *The theory of intact ship stability did not yet exist*
- Design modifications (e.g. a larger number of cannons) ordered by King Gustaf II Adolf during the building process → Too low freeboard

Image credit Vasamuseet

Ro-pax ferry Berlin /Copenhagen

- Built by P+S Yards for Scandlines
- Ordered 2010, launched for the first time in 2012
- The owner (Scandlines) cancelled the vessels because they were 200 tons overweight
- In 2014 Scandlines bought the ferries from the now bankrupt shipyard for 31,6 M€ instead of the original contract price of 184 M€

Image credit Scandlines

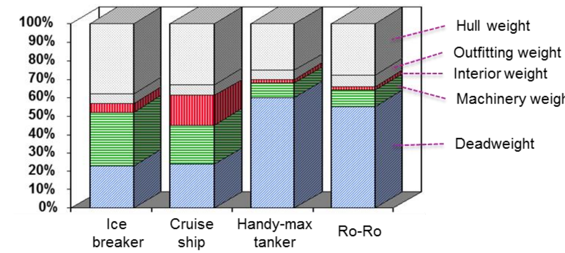
Weight calculations – *Risks*

- An innovative (new) ship type (or an inexperienced designer)
- A small Deadweight/Displacement ratio in combination with a complex lightweight composition
  - *Relative small mistakes might have huge consequences*
- An unclear division of responsibilities between designer and builder
- A highly competitive shipbuilding market situation
- Economic troubles at the shipyard
  - *Efforts to reduce man-hours → Mistakes*
- …

Weight calculation – *Calculation errors*

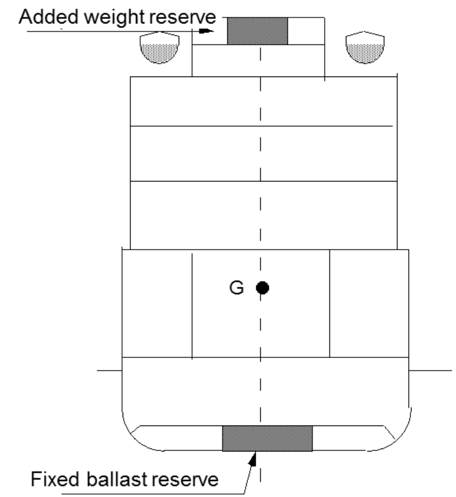
Weight calculation errors may be critical if

- Ratio between deadweight and displacement is small
  - *E.g. icebreakers*
- Ratio between outfitting weight and total lightweight is large
  - *E.g. cruise ships, ferries*

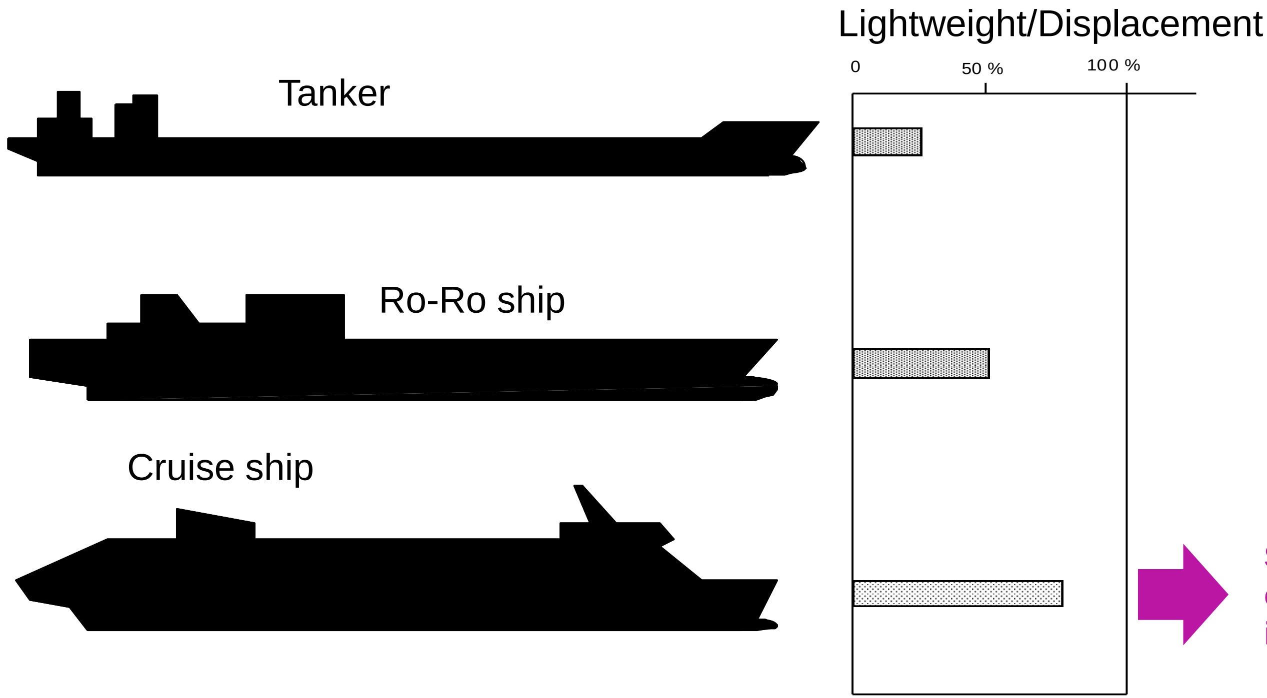


The risk of calculation errors can be minimized by

- Order of magnitude assessments
- Use of statistics, comparisons
- Performing separate calculations using different methods
- By adding weight reserves
  - *The lightweight and the height of center of gravity often increase during the building process (e.g. stiffeners are bigger than planned)*
  - *Needed to allow for possible design modifications as requested by the owner*
  - *The lightweight reserve can vary depending on the ship type, the shipyard experience, and ship owner*
- By adding “scantling reserves”



Lightship weight - *Displacement*



Sensitive towards calculation errors/ inaccuracies

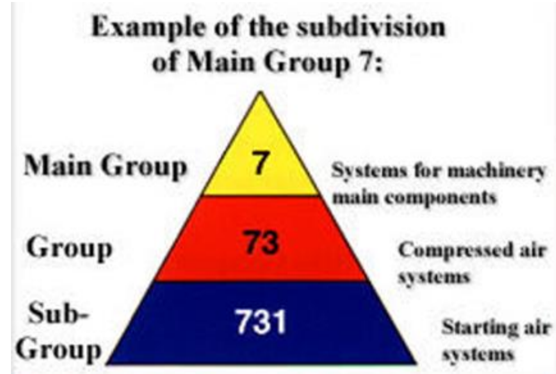
Weight calculation reserves

- Weight reserves are expressed as a percentage of a ship's total lightship weight
- Reserves in vertical center of gravity (G) are expressed in meters
- Often determined so that at delivery time, the reserve weight is 0 % and the reserve in vertical center of gravity is 0.1 m
  - *A residual reserve for the center of gravity is needed since it is difficult to determine the GM value accurately for the operation environment*
- The reserve amount needed is determined considering the Deadweight/Displacement – ratio
  - *Example (prototype ship with a DWT/Δ ratio of 0.2-0.3)*
    - ✓ Preliminary weight calculations: 15 % weight reserve and 1 m reserve in G
    - ✓ Fixing of lines drawings: 10 % weight reserve and 0.6 m reserve in G
    - ✓ 6 months prior to ship delivery: 3 % weight reserve and 0.3 m reserve in G
- For non-prototype ships (if a sister ship has already gone through the inclining test), smaller reserves are possible

Summary

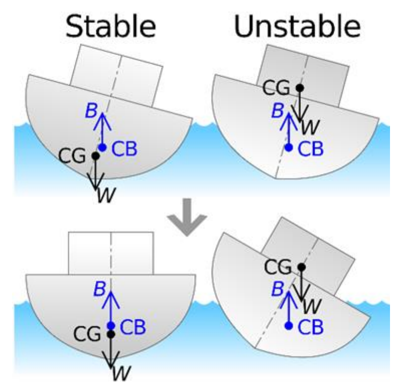
Classification of systems

- ✓ A standardized classification of ship systems and equipment such as the SFI standard is useful for design, construction, weight estimation



Weight calculations

- ✓ Very important as a ship's weight and weight distribution have a very significant impact on its technical and economical performance
- ✓ Watson and Gilfillan equations satisfactory at preliminary design
- ✓ Reserves important to mitigate risks at different stages



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Thank you !