Research and reconstruction of Wooden Ships

01.01 Syllabus

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Last edited: June 2020

Hull Analysis

Lecture: Tonnage, Displacement, and Performance.

Hull Analysis

Readings: Steffy, *Wooden Ship Building*, Appendices A and B, pp. 251-255.

Gilmer, Thomas C. and Johnson, Bruce. *Introduction to Naval Architecture.* Annapolis, MD: Naval Institute Press, 1982, pp. 37-59.

Chapelle, Howard. *The Search for Speed Under Sail*. New York: W. W. Norton & Co., 1967, pp. 3-51.

Brown, David K. "The Form and Speed of Sailing Warships," *The Mariner's Mirror*, Vol. 84, No. 3, (1998), pp. 298-307.

Hull Analysis

Assignment: Begin Project No. 3 (calculate displacement and hull coefficients for the lines drawing of Project No. 2). Due by Week 5.

Hull Analysis

Definitions

Tonnage is the volumetric capacity of a ship;

Displacement is the weight of water that a ship displaces when floating freely;

Deadweight tonnage is the difference in the weight of the water displaced between the loaded and unloaded conditions.

A *measurement ton* measures space. Its value is 100 cubic feet (2.832 cubic meters).

A *freight ton* also measures space. Its value is 40 cubic feet (1.133 cubic meter).

A *long ton* measures weight. Its value is 2,240 pounds (1,016.05 kg). (The common *ton* in use in the Imperial and U.S. systems of measurements is the *short ton* of 2,000 pounds (907.18 kg).)

A *metric ton* (commonly written *tonne* and abbreviated **t**) equals 1,000 kilograms.

Hull Analysis

In the old Mediterranean, the capacity of a ship could be defined by the number of amphorae it could carry.

In Medieval Italy, the capacity of a ship was stated in many different units:

Venice (13^{th} century): Mastelli = 75.117 l

Anfora = 600 l. (8 Mastelli)

Botta = 750 l. (10 Mastelli)

Barilla = 6/7 Mastelli

Lane, *Venetian Ships and Shipbuilders*: 245-252

Hull Analysis

Genoa (13th century) – *Botta* = 467 l. = 10 *Cantars*

Cantar = 46.7 l.

Marseilles (13th century) – *Botta* = 480 l.

Crete (13th century) – *Cask* = 450 l.

Hull Analysis

In Portugal (16th century) the unit was the *tonel*, a cask 154 cm high and 102 cm wide, the *pipa* (1/2 *tonel*) and the *quarto* (1/4 of a *tonel*).

The ship's capacity was determined after its construction by a team of experts with 154 cm gauges and 102 cm hoops.

There were equivalences:

1 *tonel* was the equivalent of 750 roof tiles,

500 sugar *formas*,

14 *quintais* of metal,

…or half of an animal and its food.

Hull Analysis

In Spain, tonnage of a ship was measured in *toneles*, and defined in the middle 16th century by one of two formulas.

1 *tonel* was the equivalent of 8 cubic *codos* or 2 *pipas* of wine.

Seville: *Codo Castellano* = 32 *dedos* = 557 mm

Basque Country: *Codo Cantabrico* = 33 *dedos* = 575 mm

1 *tonel macho* = 8 *Codos Cantabricos*

1 *tonelada de carga* = 8 *Codos Castellanos*

1 *tonelada* was a unit of account obtained by adding 20% or 25% to the cargo capacity of a ship in *toneles*.

In England, tonnage of a ship was defined in the late 16th century by the formula:

Breath x Keel length x Depth of the hold / 94 =

Units were entered in feet and the tonnage was obtained in '*long tons*,' equivalent to a weight of 2,240 pounds (1.01605 tons).

Hull Analysis

Hanseatic League and Dutch ships' capacity was defined in the late Middle Ages by a volumetric unit used for cereals (*last*), which had a weight equivalent in pounds.

A *last* was initially the load of a four-wheel wagon. Then it was defined in different ways in different harbors:

Dantzig: 1 *last* of rye = 3.105 m^3 or 2,257 Kg.

Hamburg: 1 *last* of grain = 3.159 m3.

There was another unit: 1 *schiffslast* = 2,000 Hamburg pounds = 1,935 Kg.

… but 2,000 Amsterdam pounds = 1,976 Kg.

Today we use the notion of displacement:

1 m^3 of fresh water weights 1,000 Kg. = 1 t.

1 m^3 of salt water weights 1,024 Kg. = 1.024 t.

1 cu.ft. of fresh water weights or 62 pounds.

1 cu.ft. of salt water weights or 64 pounds.

1 cubic meter (m^3) contains 10.764 cubic feet (cu.ft.).

The same ship displaces more water in a fresh lake than in the sea.

Hull Analysis

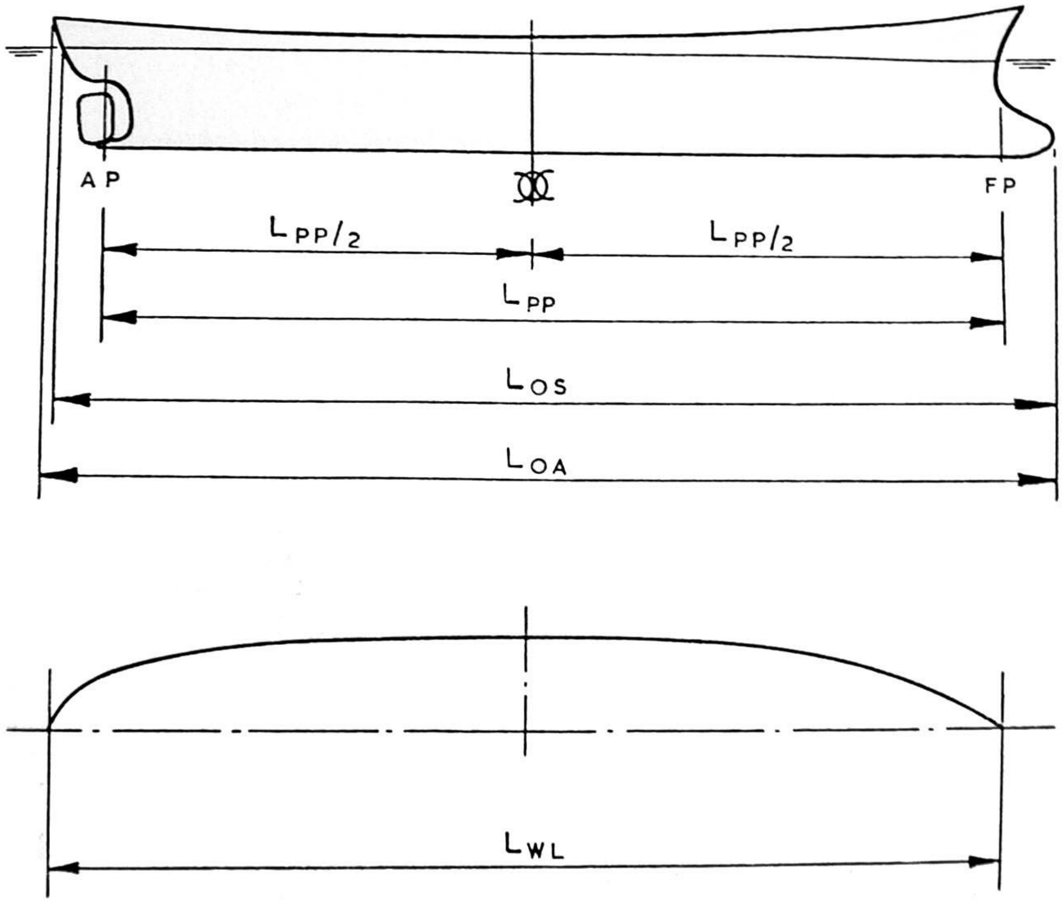
Hull Analysis

L_{PP} – Length between perpendiculars;

L_{OS} – Length overall submerged

L_{OA} – Length overall

L_{WL} – Length of the load waterline

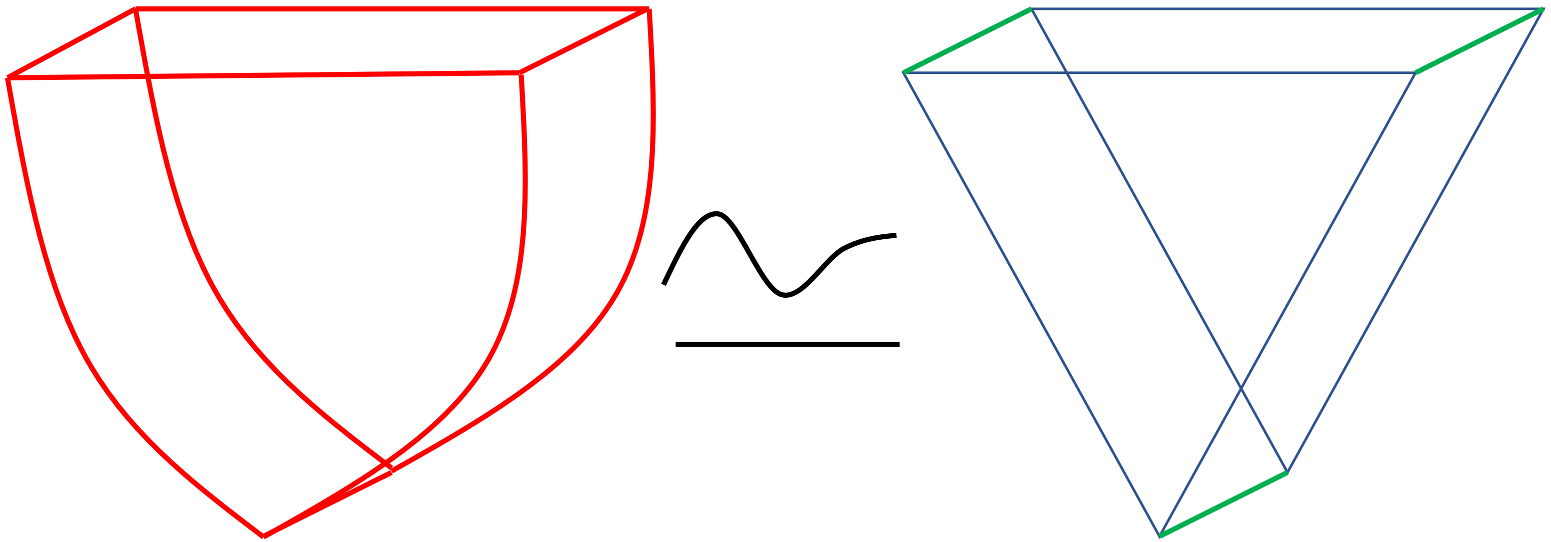


AP – After perpendicular

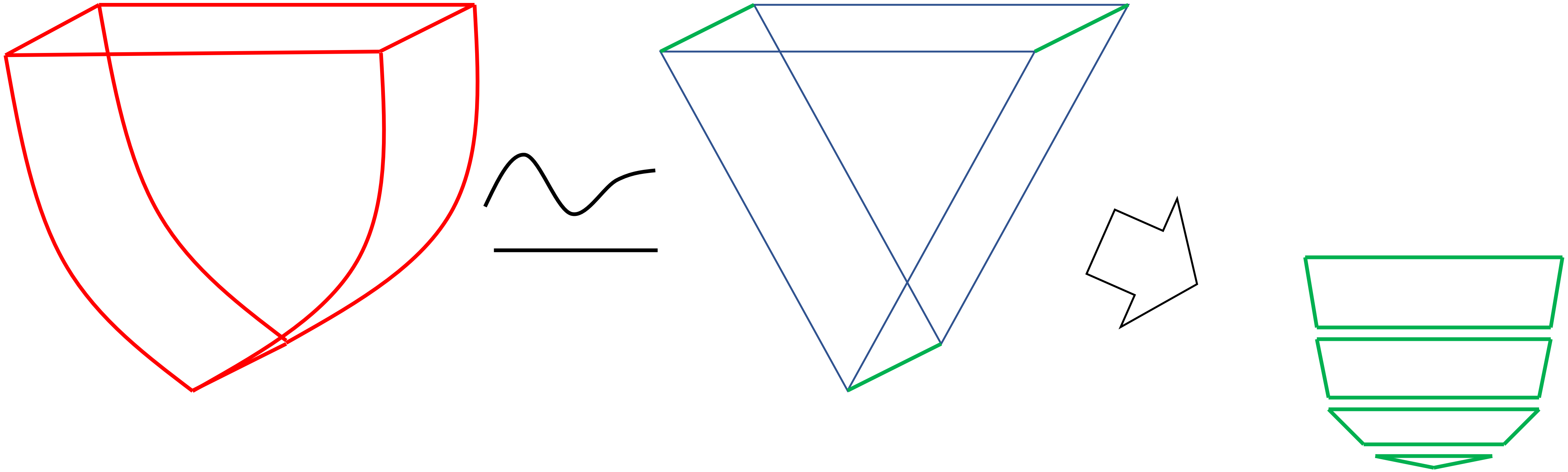
FP – Forward perpendicular

(L_{PP} is generally the same as L_{WL}, but for merchant ships AP is the axis of the rudder).

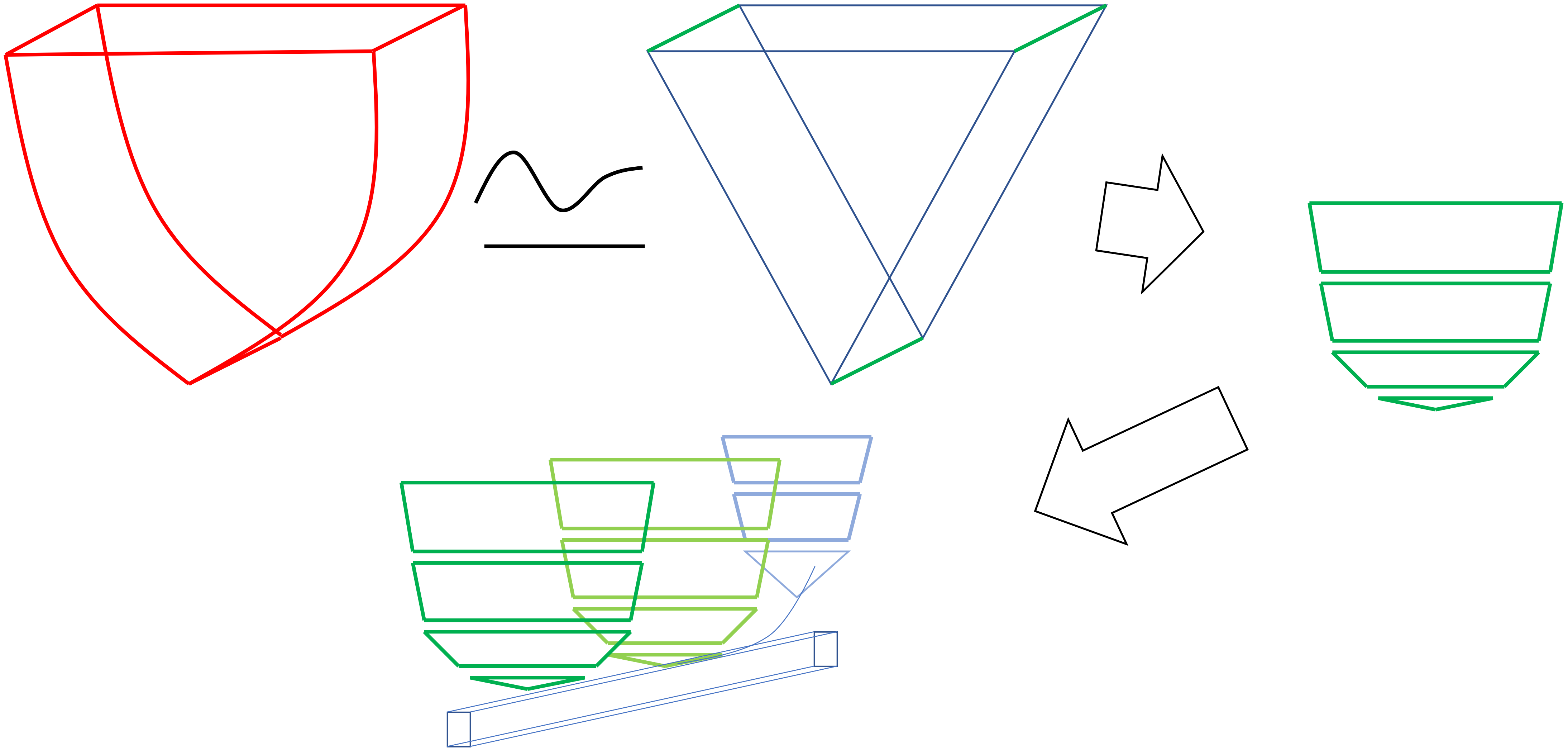
Hull Analysis



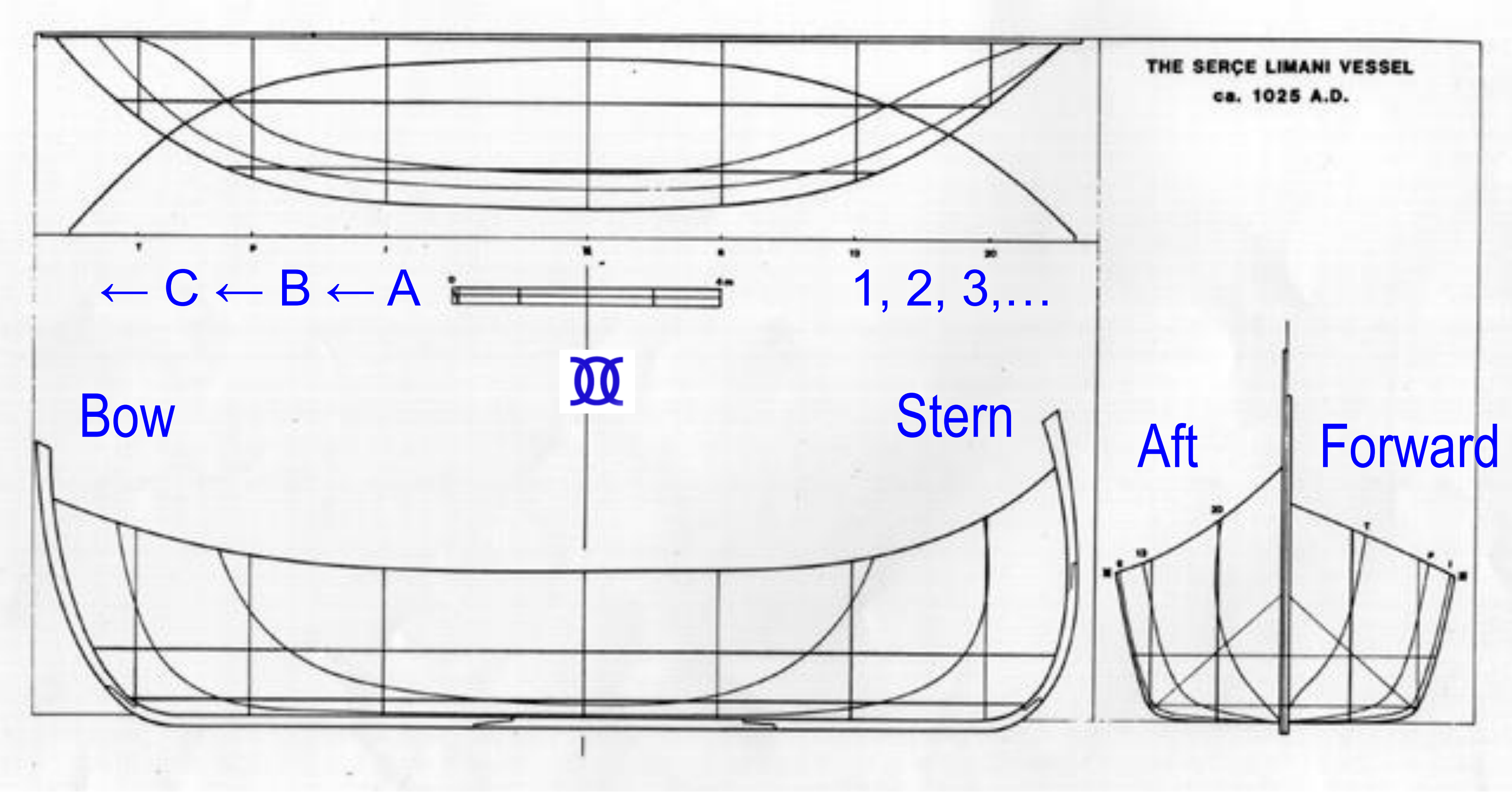
Hull Analysis



Hull Analysis

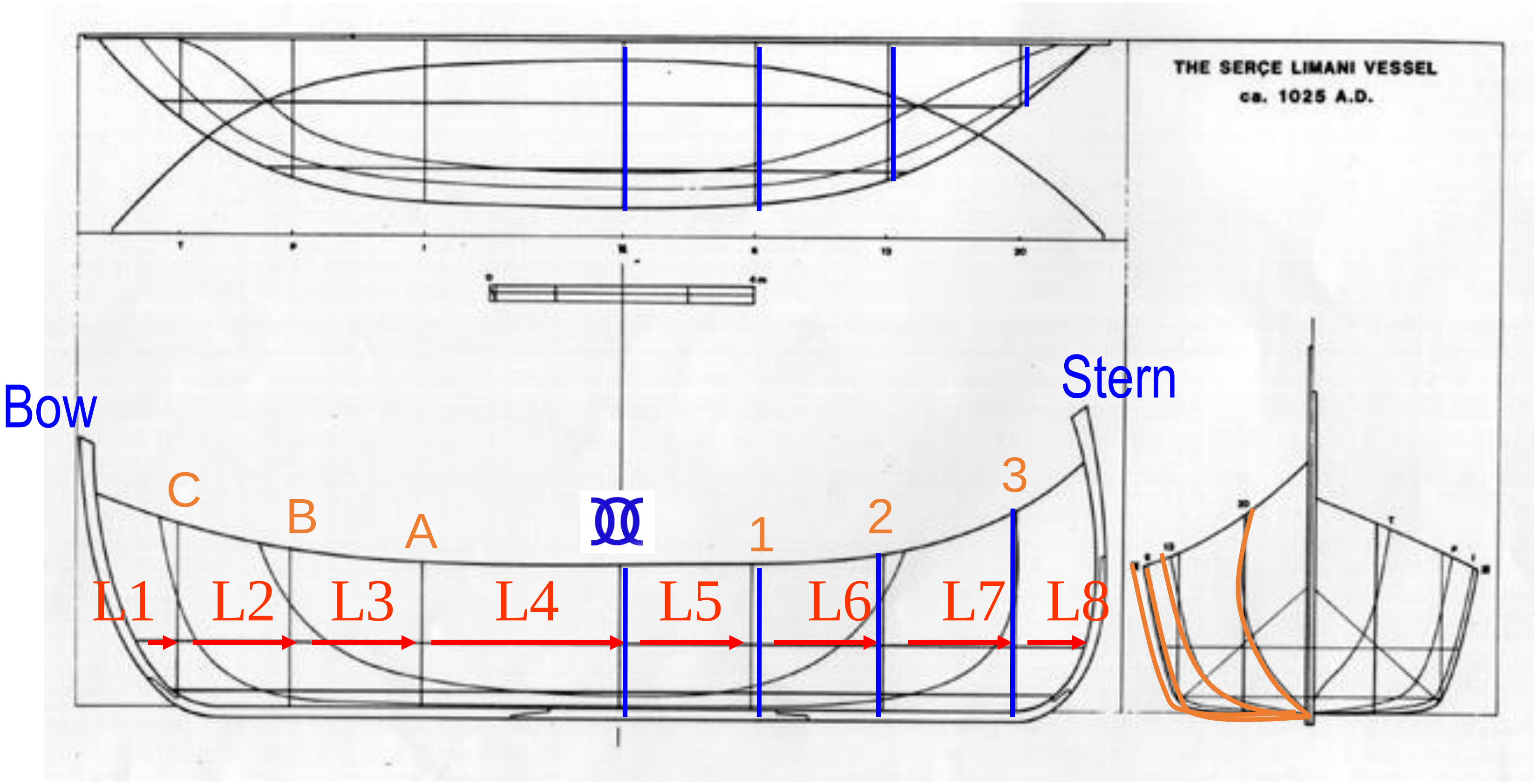


Hull Analysis

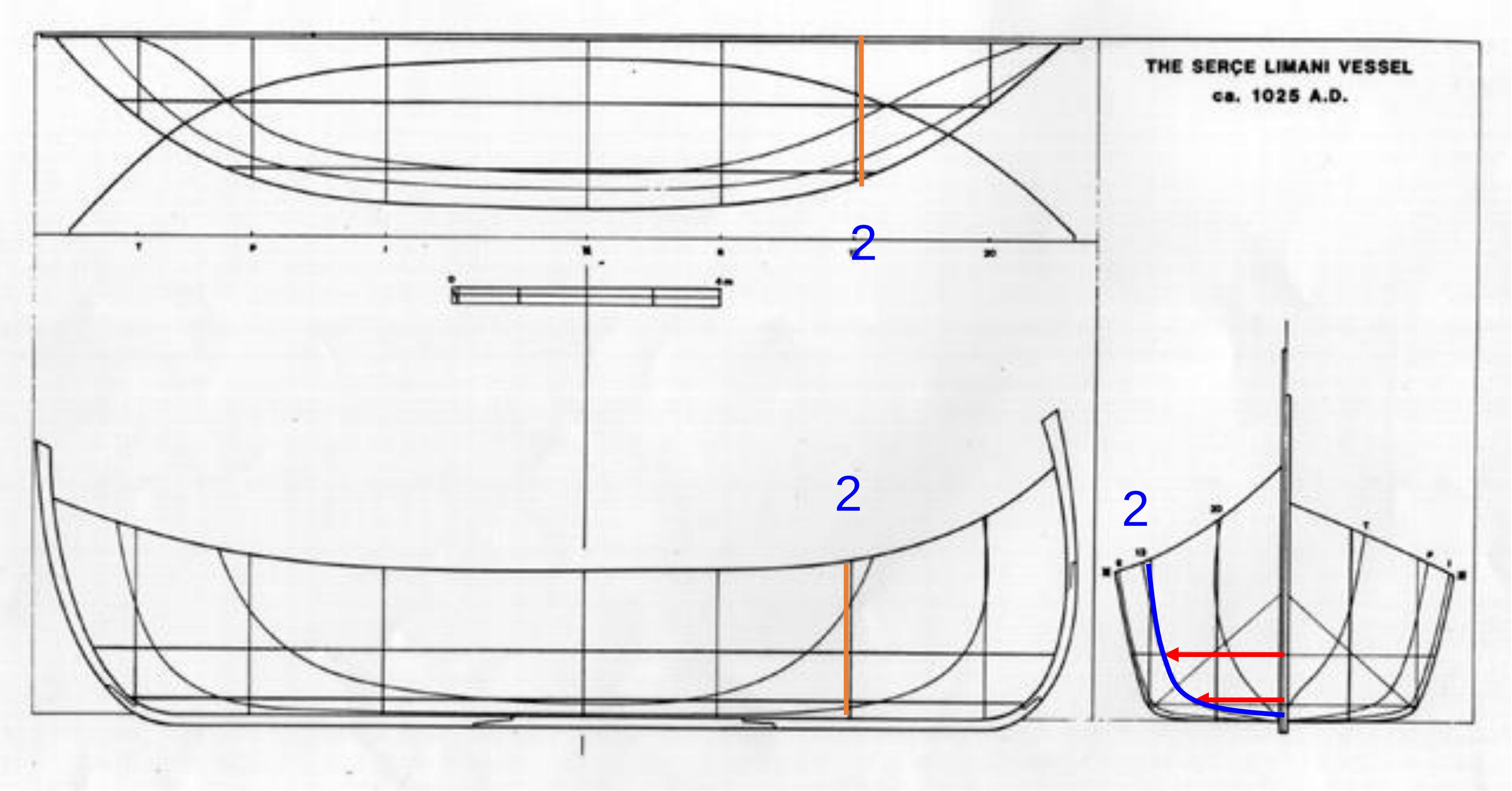


Convention

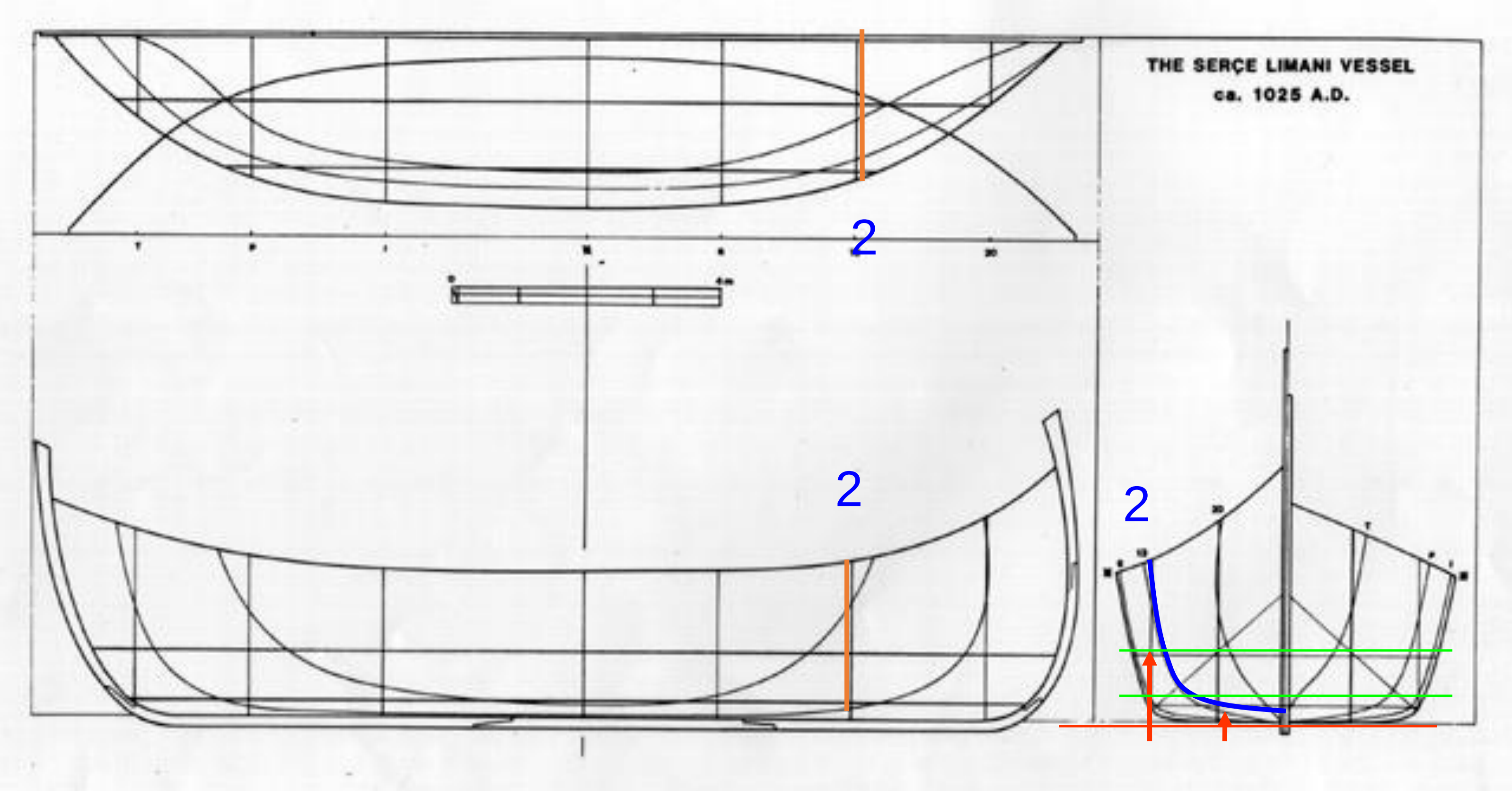
Hull Analysis



Hull Analysis

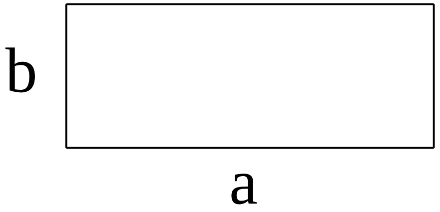


Hull Analysis

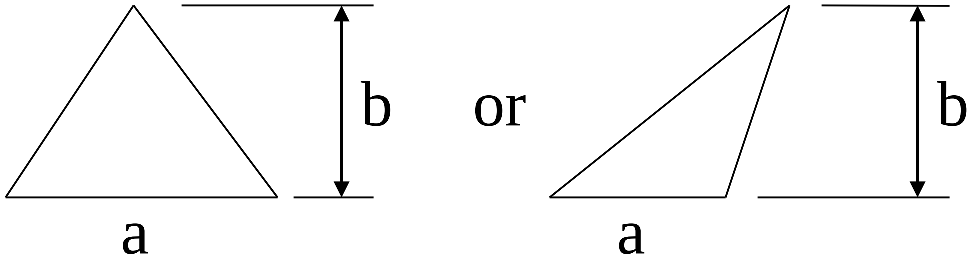


Hull Analysis

Areas:

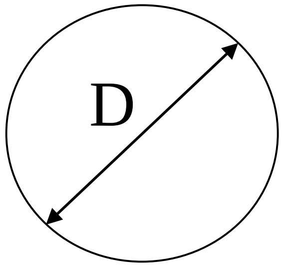


$A = a \times b$



$A = (a \times b) / 2$

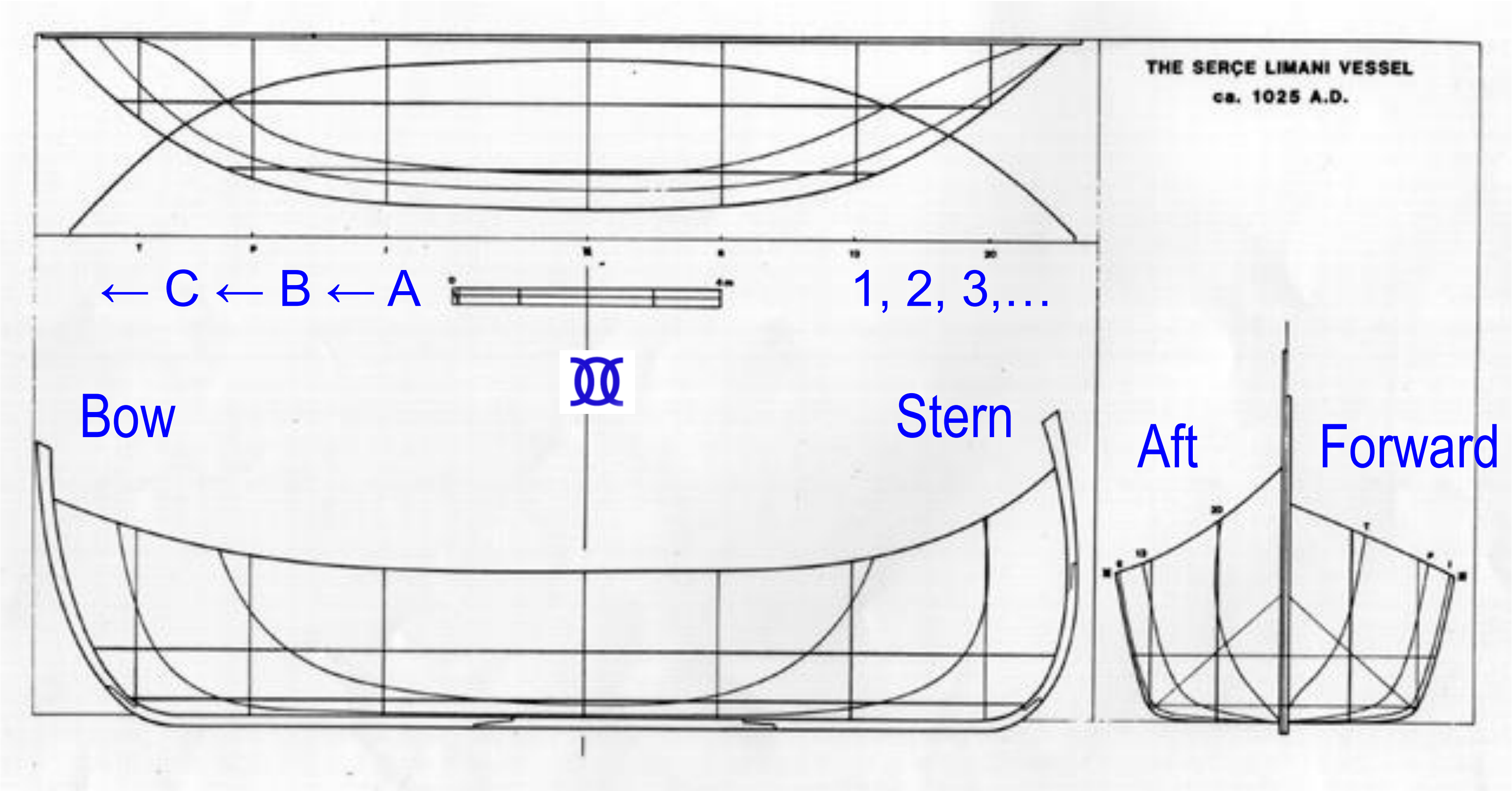
(shape does not matter)



$A = \Pi \times R^2; \quad R = D/2$

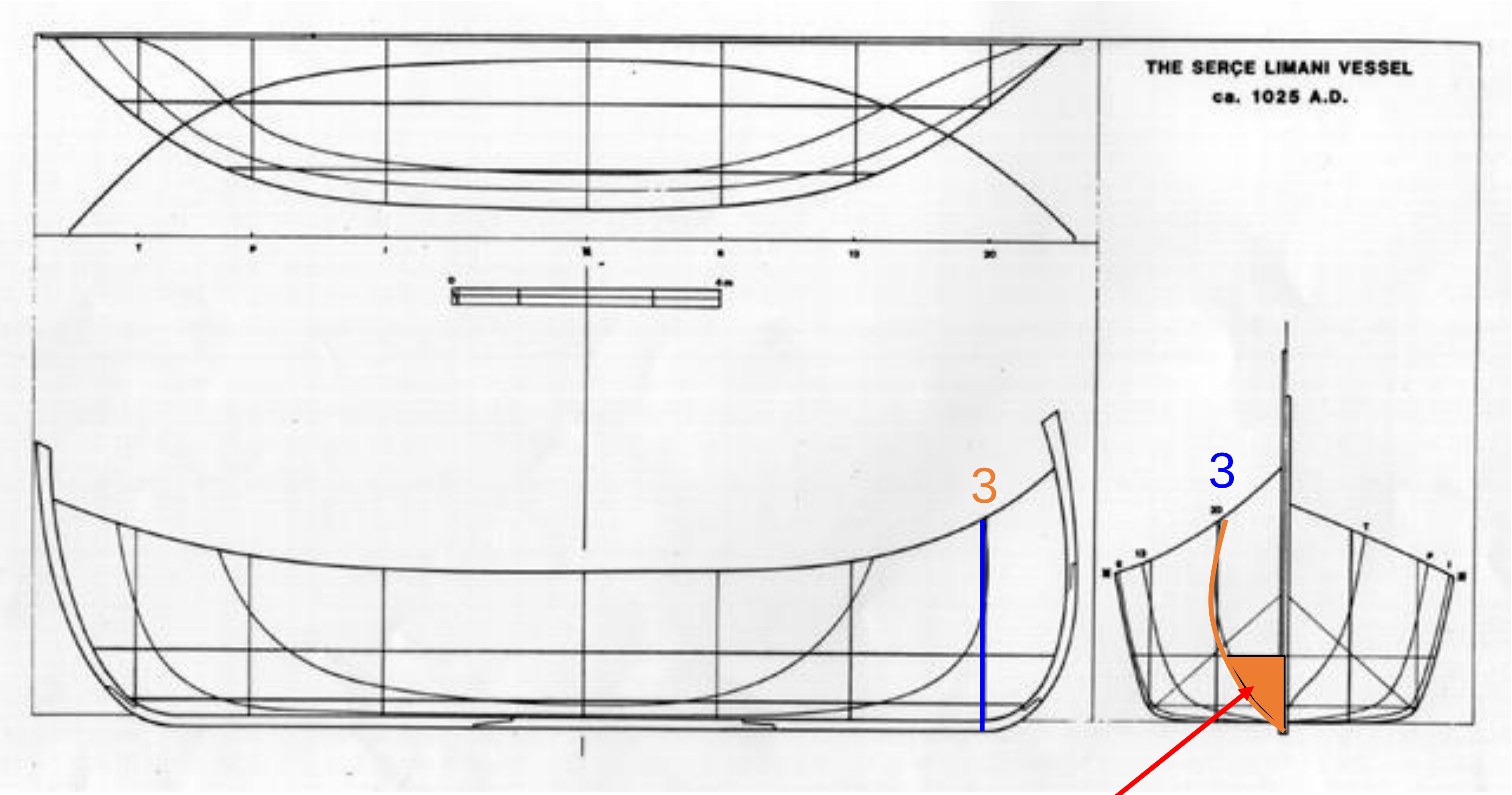
NADL

I. AREA OF A SECTION



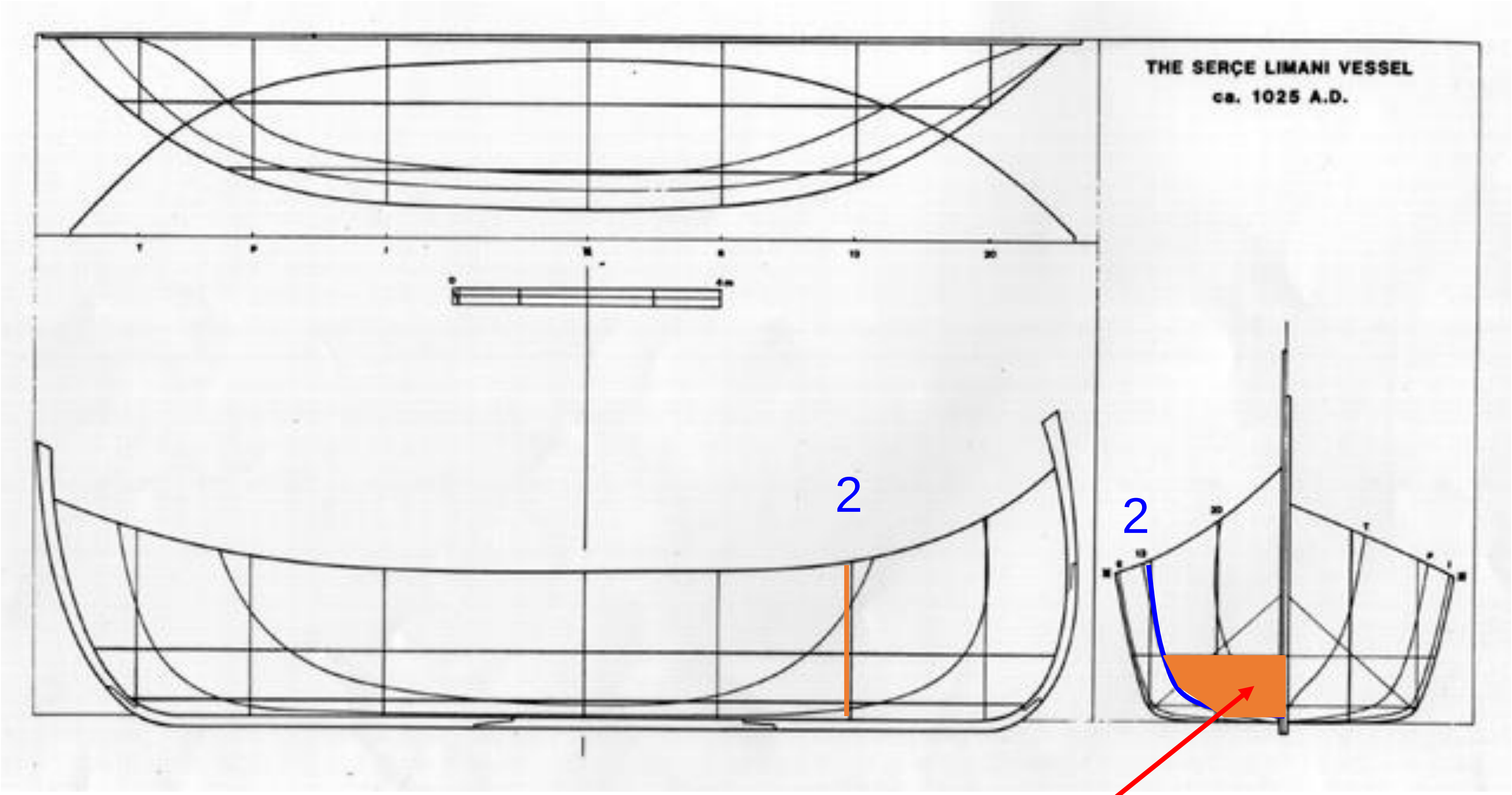
Convention

Hull Analysis



½ of area of section 3

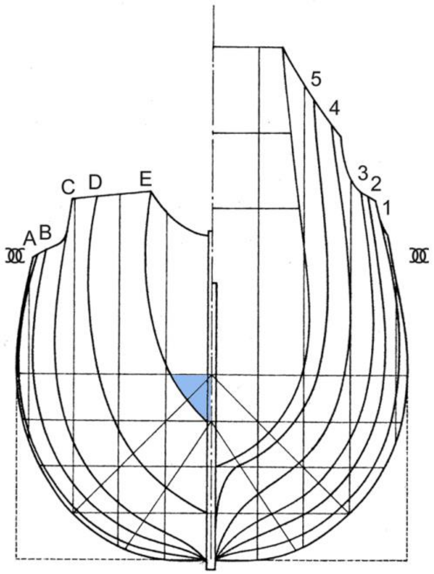
Hull Analysis



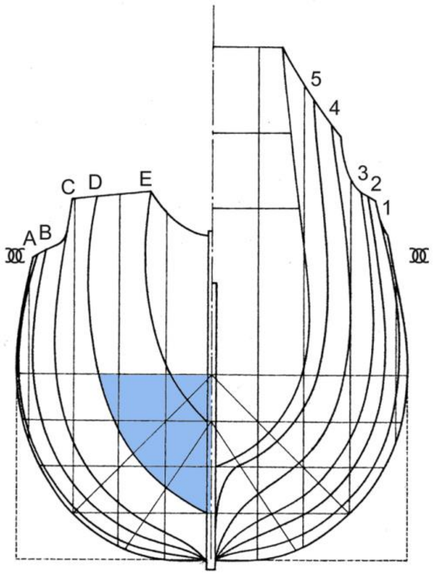
½ of area of section 2

Areas: Computation

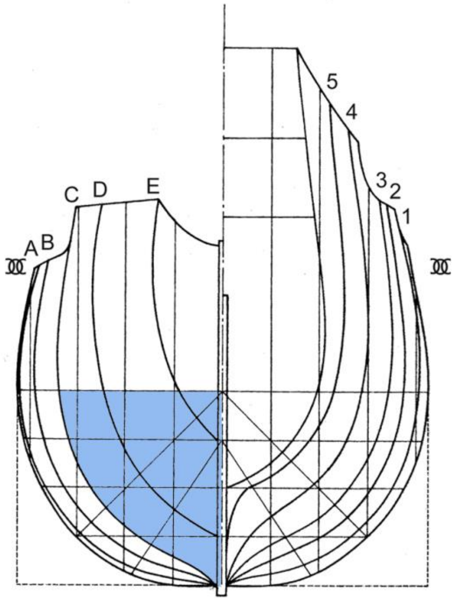
1st step: Section areas



A_E



A_D



A_C

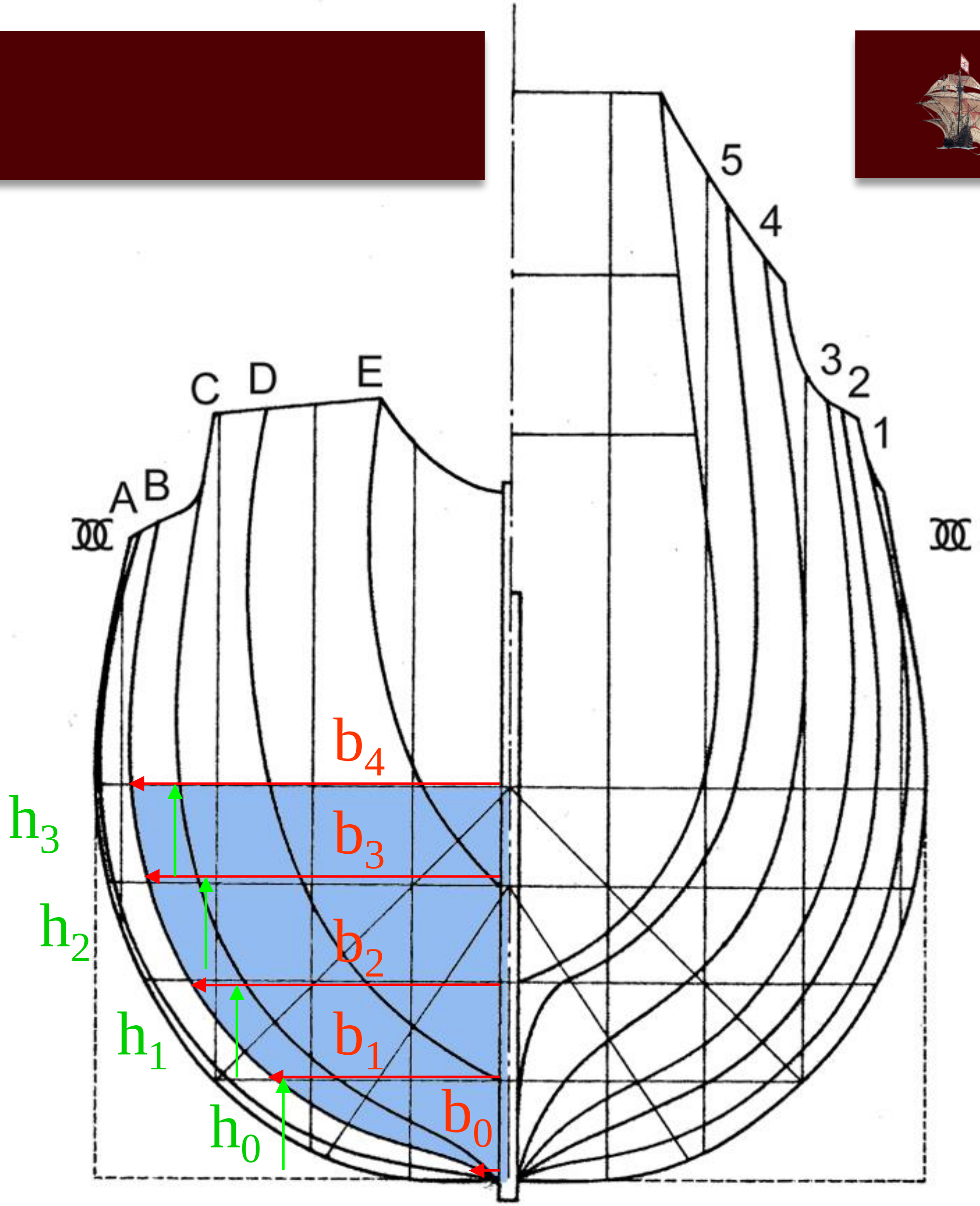
…etc.

NADL

Areas: Computation

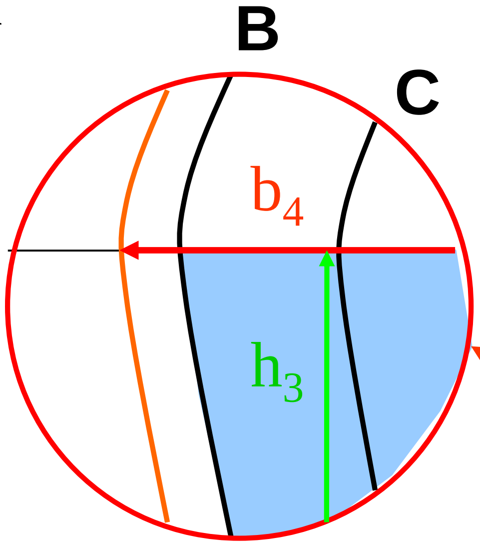
For each
section area:

Section B
b_0 =
b_1 =
b_2 =
b_3 =
b_4 =
h_0 =
h_1 =
h_2 =
h_3 =

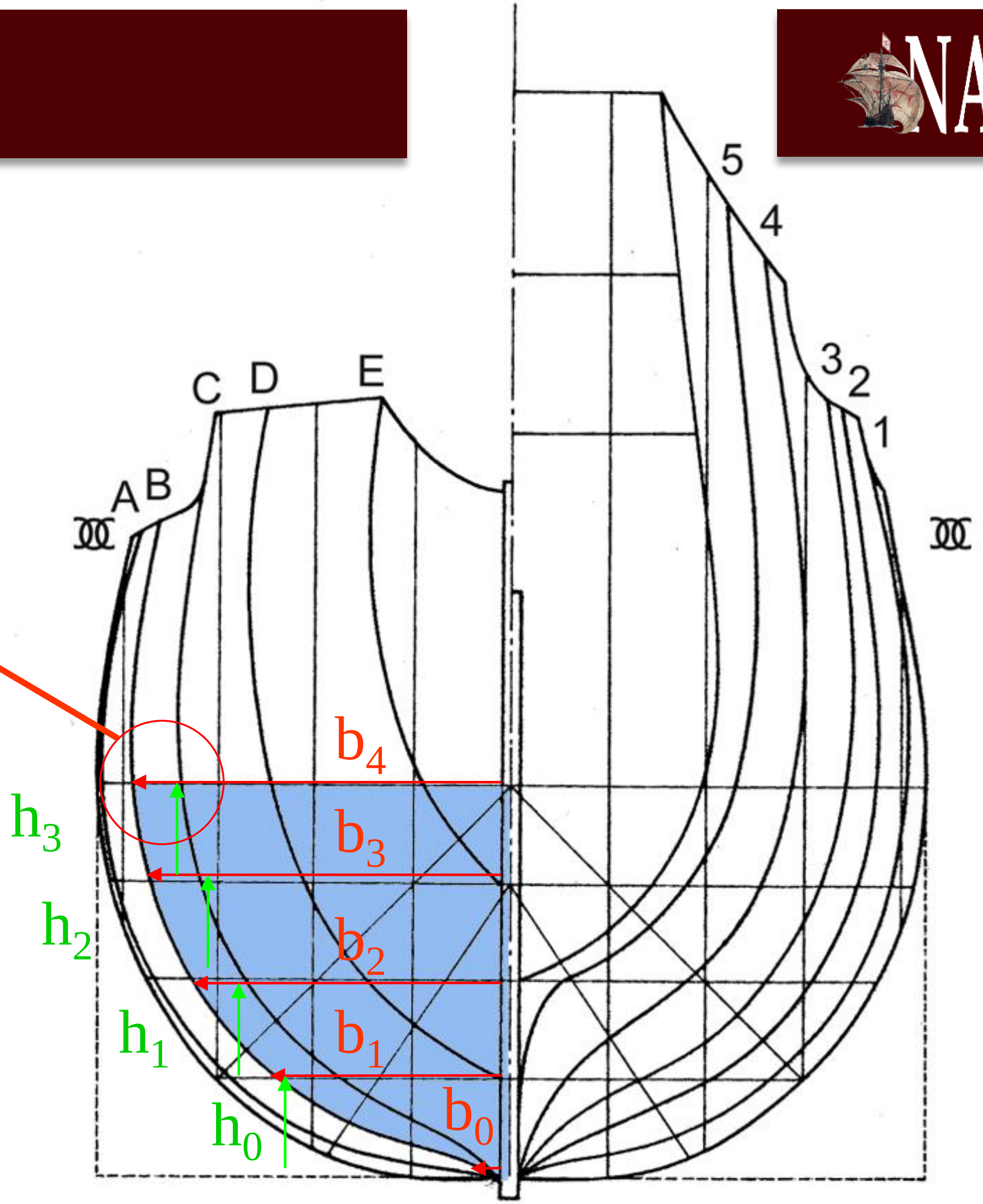


Hull Analysis

Areas: Computation



Add the thickness of the planking to the b_i values, measured horizontally.

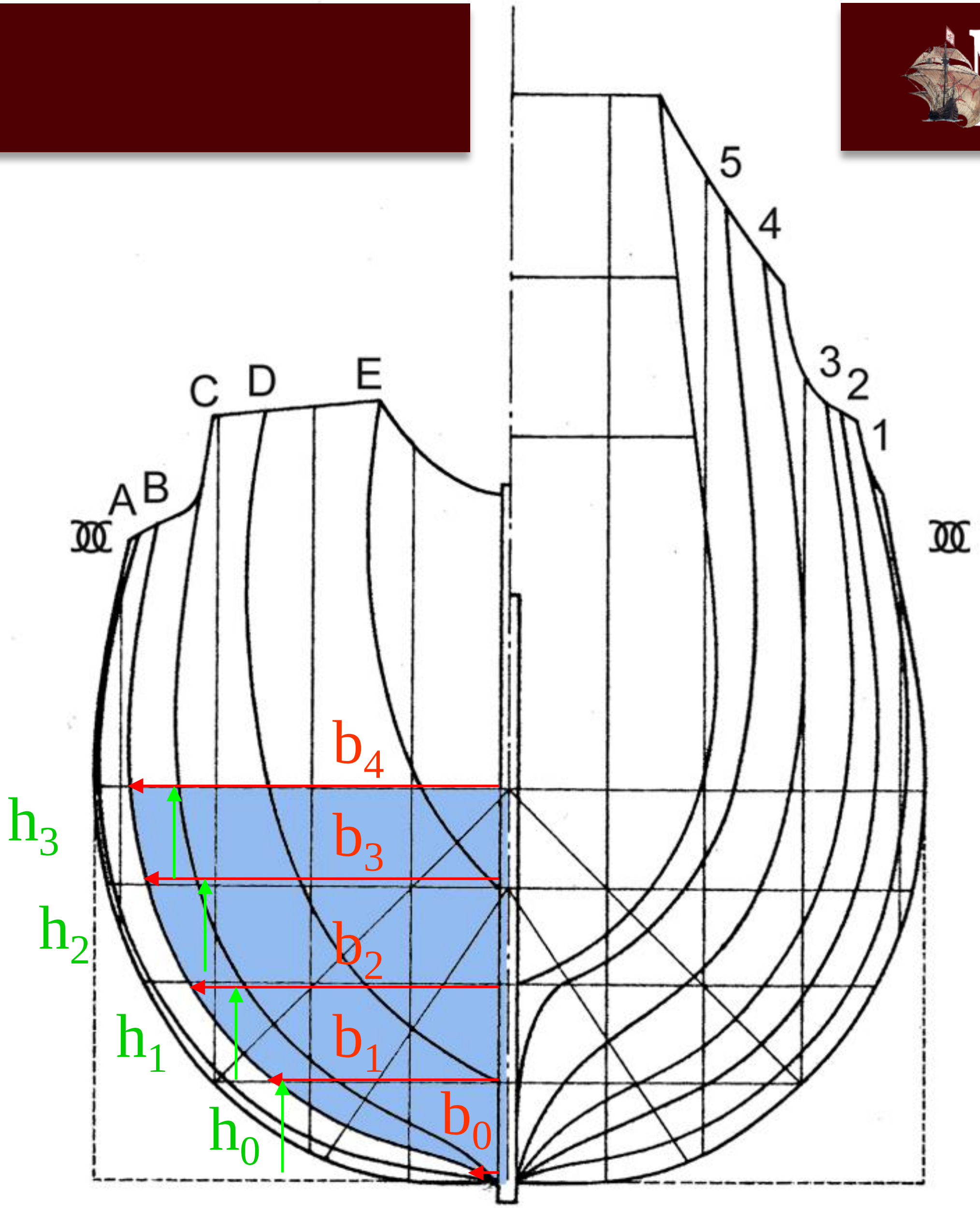


Hull Analysis

Areas: Computation

Section area:

$$A_B = (b_0+b_1)/2 \times h_0 + (b_1+b_2)/2 \times h_1 + (b_2+b_3)/2 \times h_2 + (b_3+b_4)/2 \times h_3$$

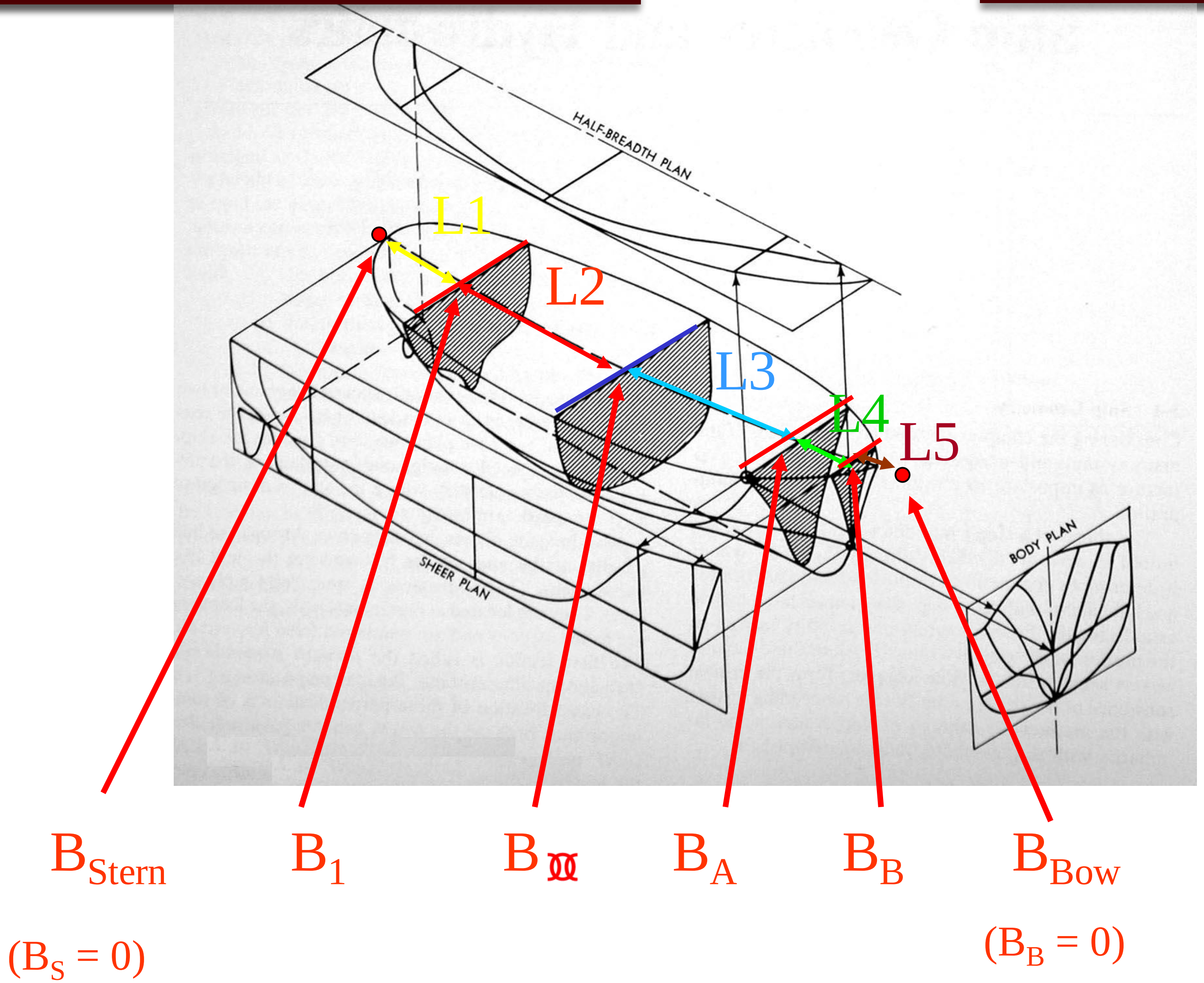


NADL

Areas

II. AREA ON THE WATERLINE

$$A_1 = (B_{Stern} + B_1)/2 \times L_1$$
$$A_2 = (B_1 + B_{MS})/2 \times L_2$$
$$A_3 = (B_{MS} + B_A)/2 \times L_3$$
$$A_4 = (B_A + B_B)/2 \times L_4$$
$$A_5 = (B_B + B_{Bow})/2 \times L_5$$



Hull Analysis

Areas

III. AREA OF THE WET SURFACE

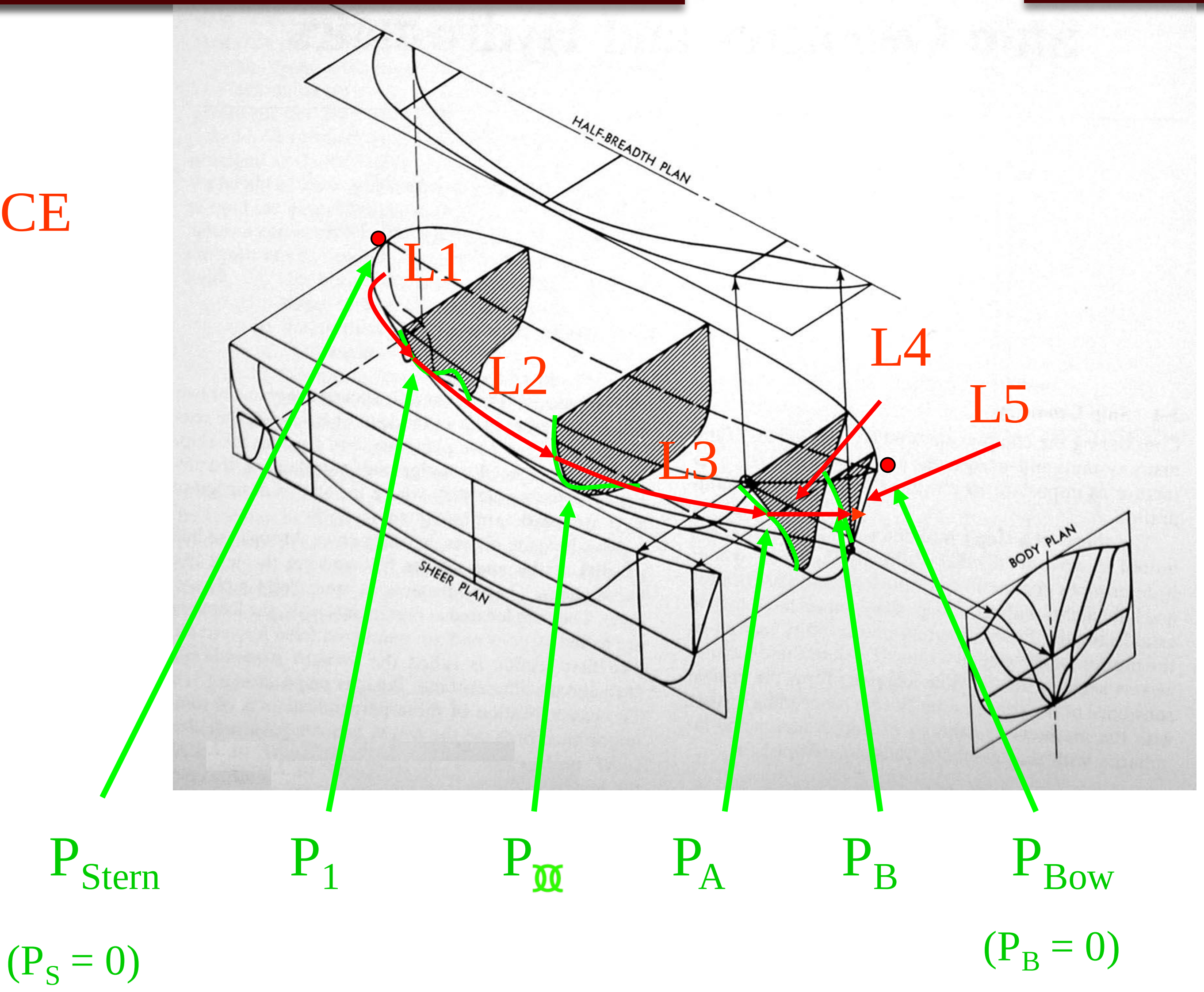
$$A_1 = (P_{Stern} + P_1)/2 \times L_1$$

$$A_2 = (P_1 + P_{MS})/2 \times L_2$$

$$A_3 = (P_{MS} + P_A)/2 \times L_3$$

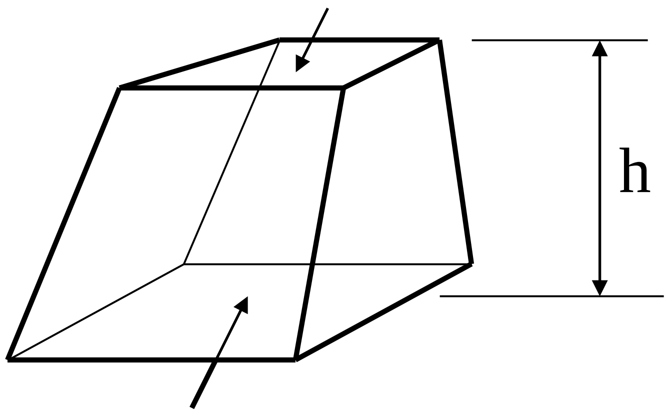
$$A_4 = (P_A + P_B)/2 \times L_4$$

$$A_5 = (P_B + P_{Bow})/2 \times L_5$$

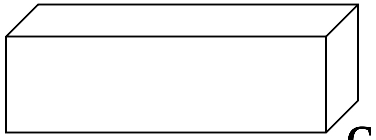


Hull Analysis

Volumes



V = (A1 + A2)/2 x h

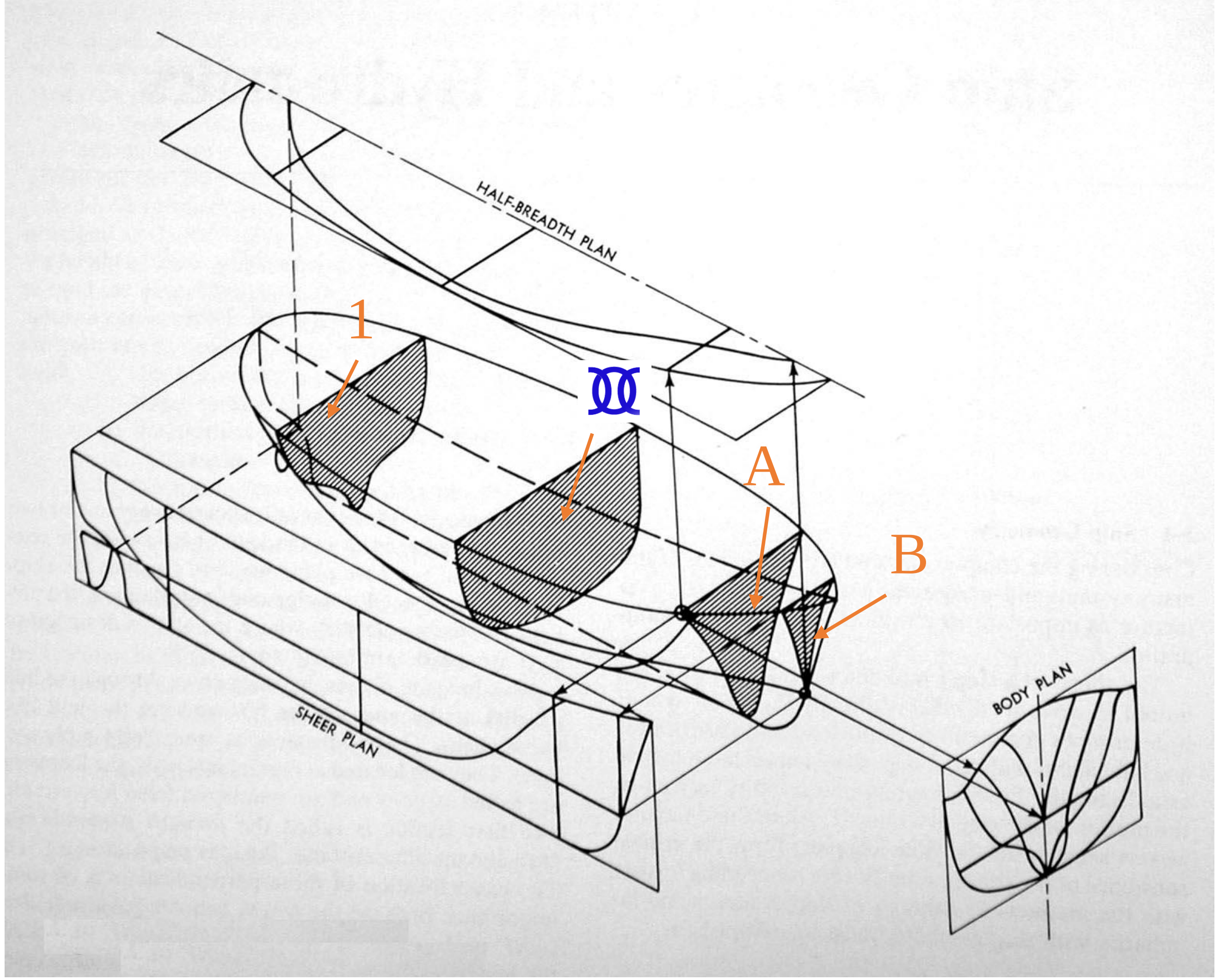


V = a x b x c

(particular case)

NADL

Volumes

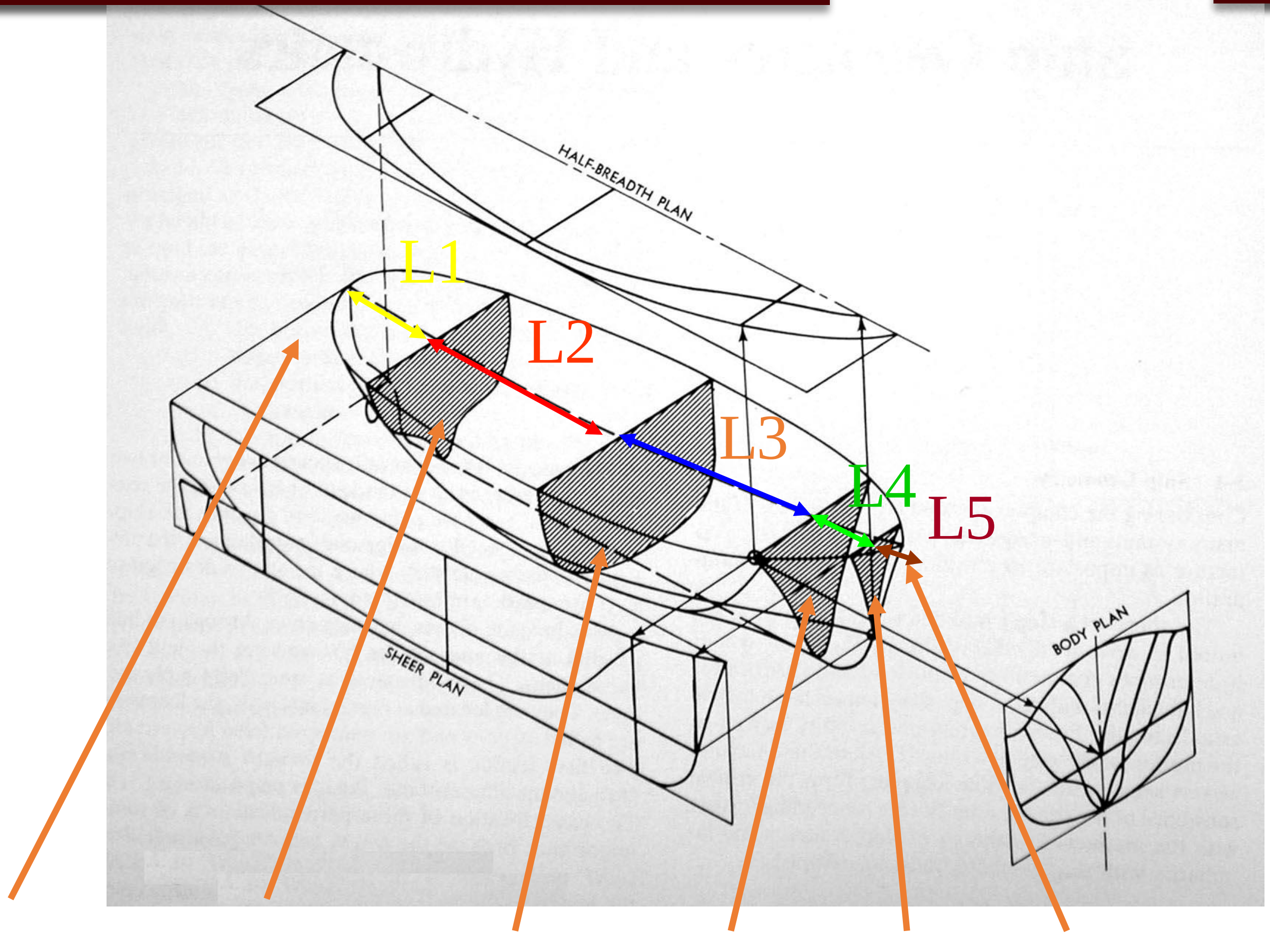


From Gilmer, Thomas C. and Johnson, Bruce. *Introduction to Naval Architecture.* Annapolis, MD: Naval Institute Press, 1982.

Hull Analysis

NADL

Volumes



Hull Analysis

Volumes

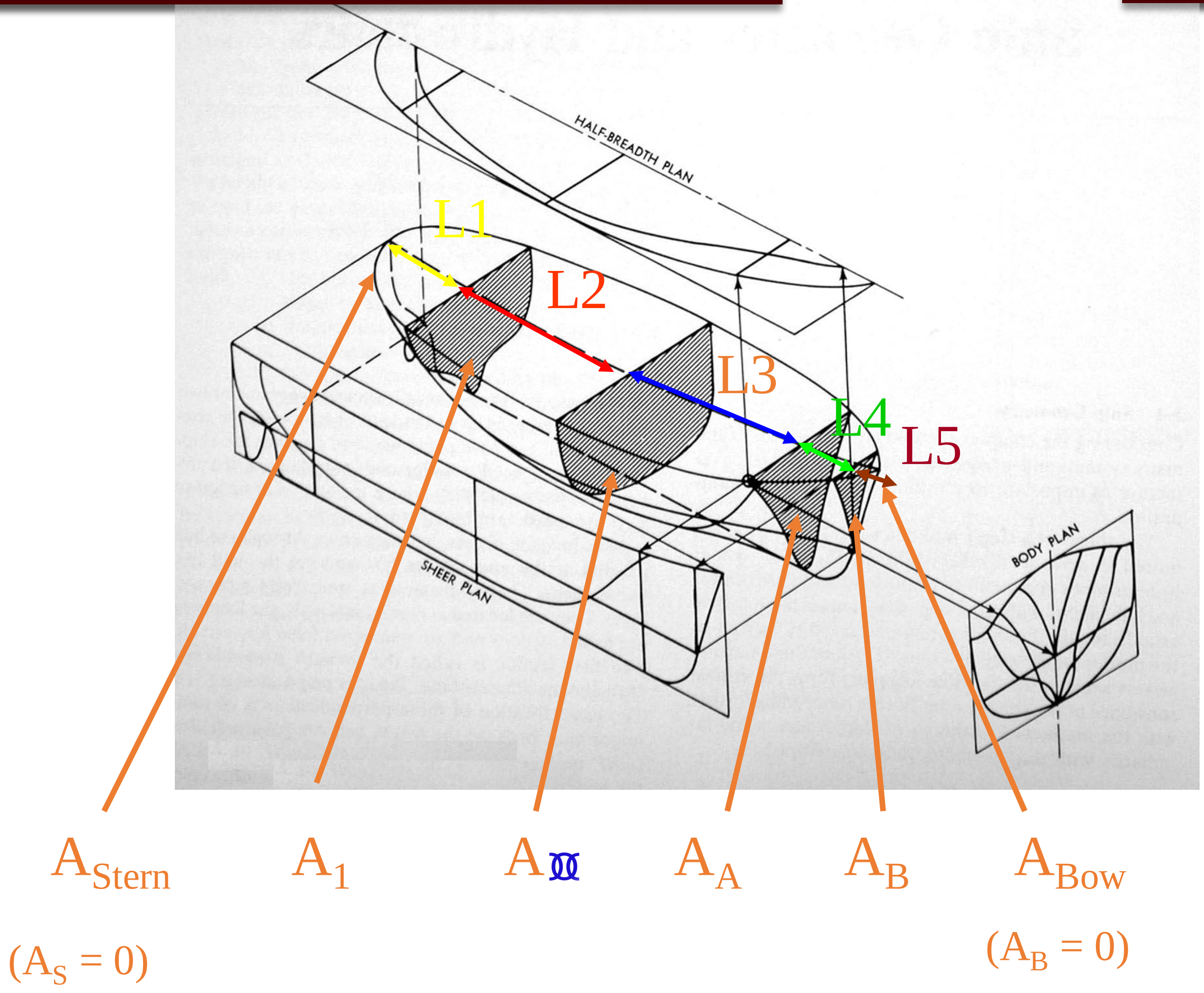
$$V_1 = (A_{Stern} + A_1)/2 \text{ x } L_1$$

$$V_2 = (A_1 + A_{MS})/2 \text{ x } L_2$$

$$V_3 = (A_{MS} + A_A)/2 \text{ x } L_3$$

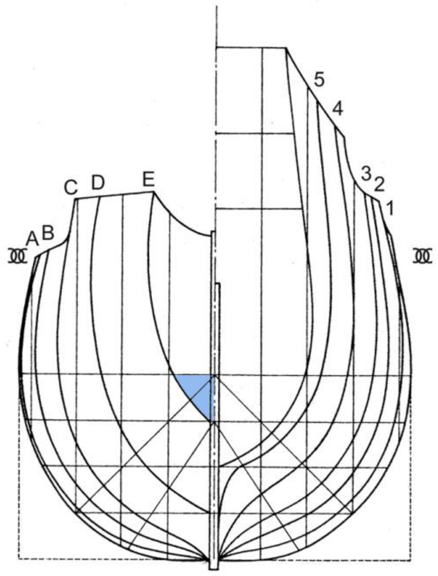
$$V_4 = (A_A + A_B)/2 \text{ x } L_4$$

$$V_5 = (A_B + A_{Bow})/2 \text{ x } L_5$$

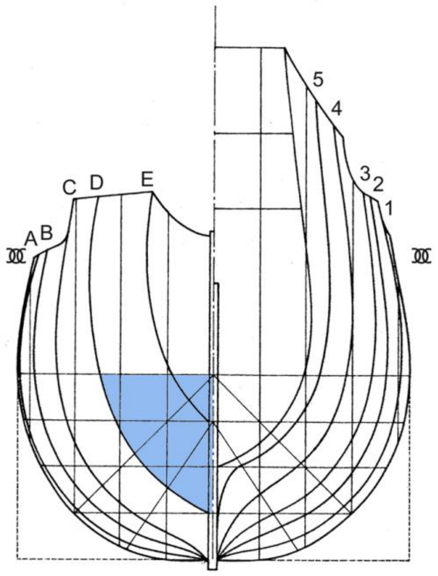


Volume: Computation

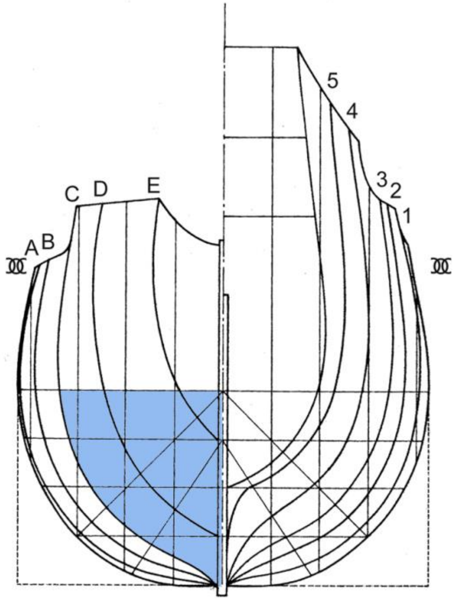
1st step: Section areas



A_E



A_D



A_C

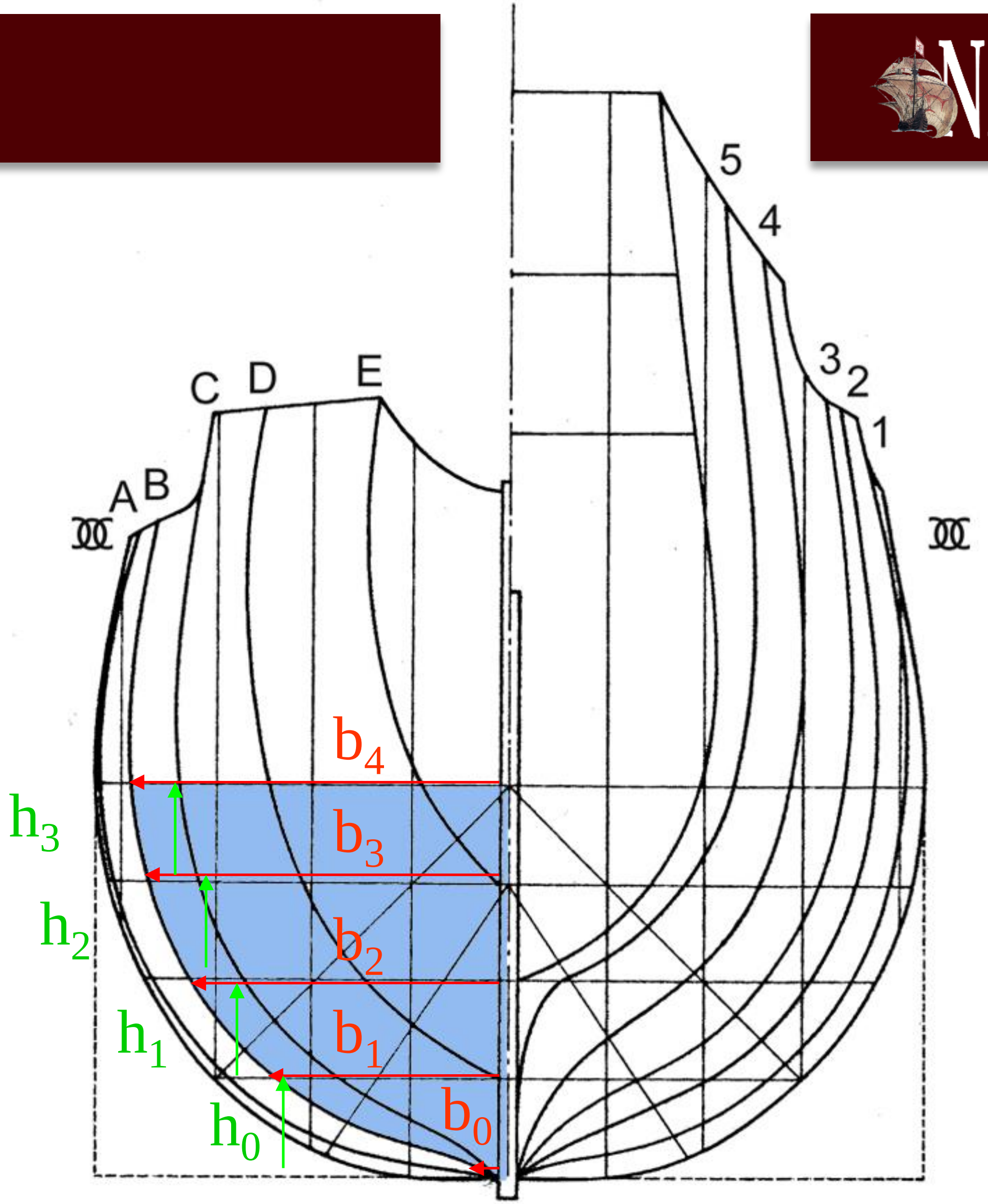
…etc.

Hull Analysis

Areas: Computation

For each section area:

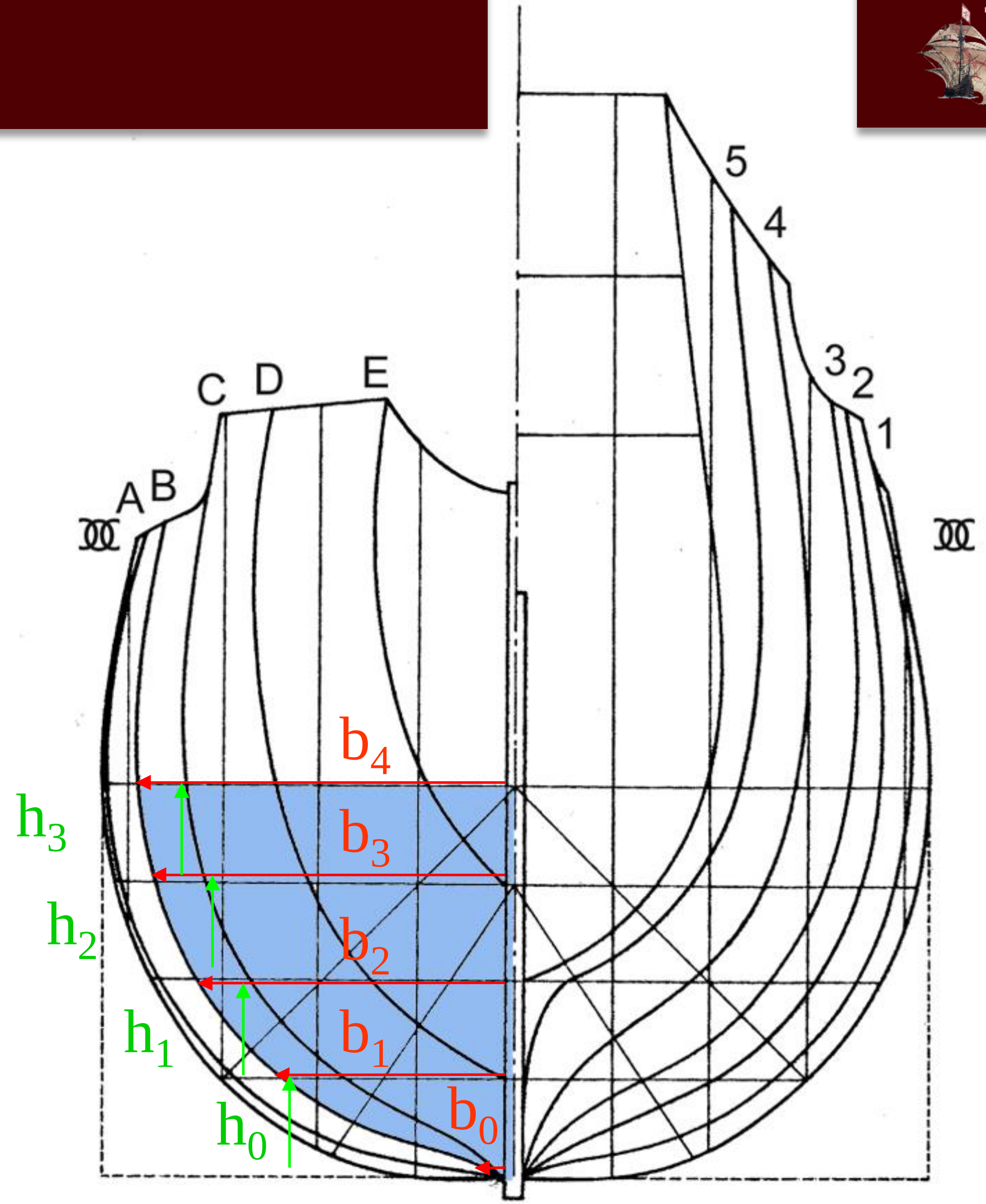
Section B
b_0 =
b_1 =
b_2 =
b_3 =
b_4 =
h_0 =
h_1 =
h_2 =
h_3 =



Areas: Computation

Section area:

$$A_B = (b_0+b_1)/2 \times h_0 + (b_1+b_2)/2 \times h_1 + (b_2+b_3)/2 \times h_2 + (b_3+b_4)/2 \times h_3$$

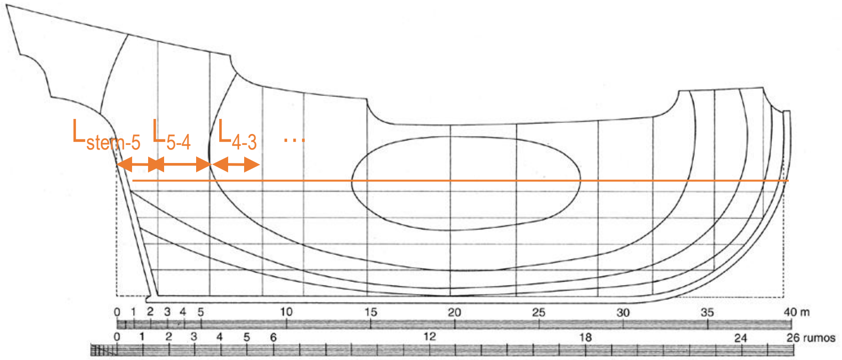


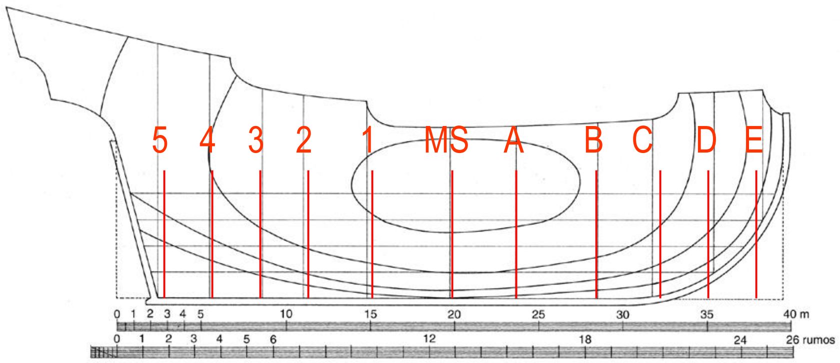
Hull Analysis

Areas: Computation

$L_{stern-5}$	L_{5-4}	L_{4-3}	L_{3-2}	…

Total Areas (partial areas x 2)
A_{stern} =
A_5 =
A_4 =
A_3 =
A_2 =
A_1 =
A_{MS} =
A_A =
A_B =
A_C =
A_D =
A_E =
A_{Bow} =

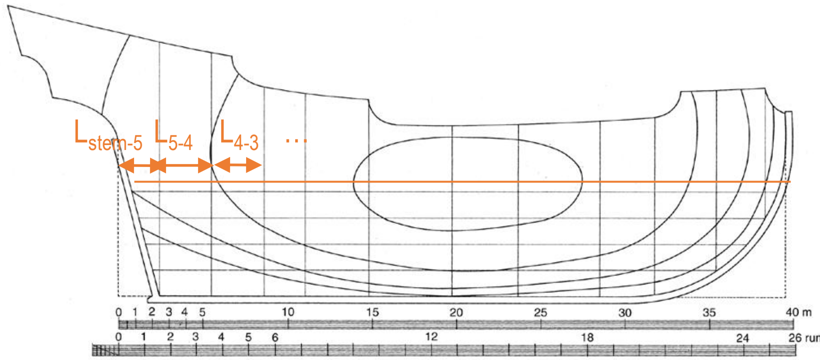




Volume: Computation

$L_{stern-5}$	L_{5-4}	L_{4-3}	L_{3-2}	…

Total Areas (partial areas x 2)
A_{stern} =
A_5 =
A_4 =
A_3 =
A_2 =
A_1 =
A_{MS} =
A_A =
A_B =
A_C =
A_D =
A_E =
A_{Bow} =

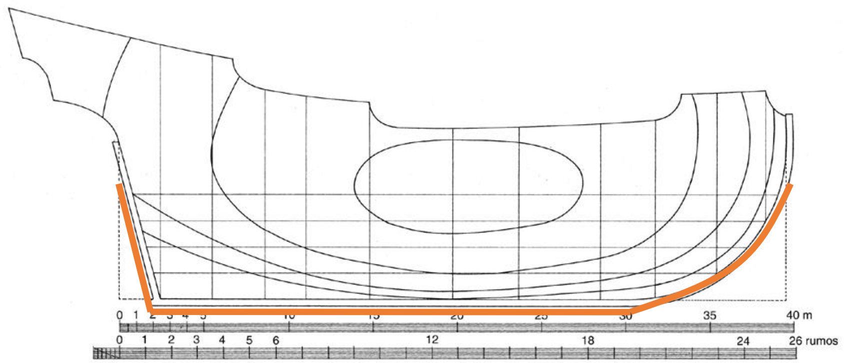


$$
\begin{aligned}
V_{hull} = {} & (A_{Stern}+A_5)/2 \text{ x } L_{Stern-5} + \\
& (A_5+A_4)/2 \text{ x } L_{5-4} + \\
& (A_4+A_3)/2 \text{ x } L_{4-3} + \ldots \\
& \ldots + \ldots + \\
& (A_E+A_{Bow})/2 \text{ x } L_{E-Bow}
\end{aligned}
$$

Hull Analysis

Volume: Computation

Partial volumes
$V_{stern\text{-}5}$ =
$V_{5\text{-}4}$ =
$V_{4\text{-}3}$ =
$V_{3\text{-}2}$ =
$V_{2\text{-}1}$ =
$V_{1\text{-}MS}$ =
$V_{MS\text{-}A}$ =
$V_{A\text{-}B}$ =
$V_{B\text{-}C}$ =
$V_{C\text{-}D}$ =
$V_{D\text{-}E}$ =
$V_{E\text{-}Bow}$ =
V_h *(Total $_{hull}$)* =



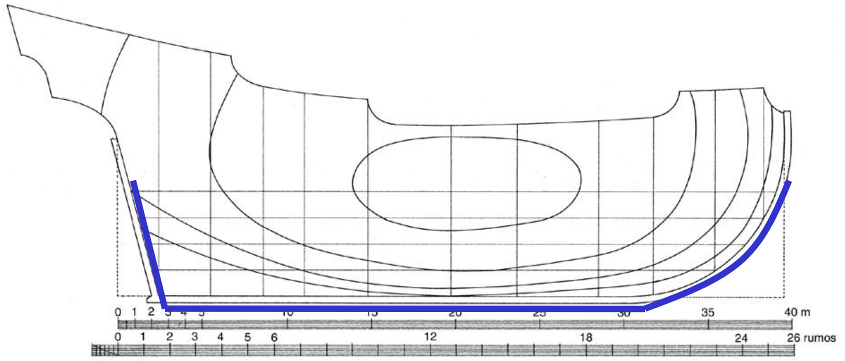
Volume Keel & Posts:

Keel section x keel length =

Sternpost section x sternpost length =

Stem post section x stem post length =

Volume: Computation



Total Volume:

Keel section x keel length +

Sternpost section x sternpost length +

Stem post section x stem post length +

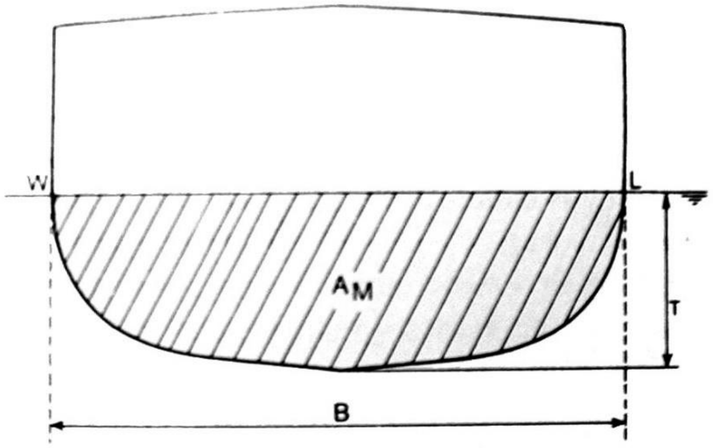
V_h (Volume of the hull)

In m^3, which multiplied by 1,024 t/m^3 will give the displacement in metric tons (tf. or simply t).

Hull Analysis

Coefficients

Midships coefficient

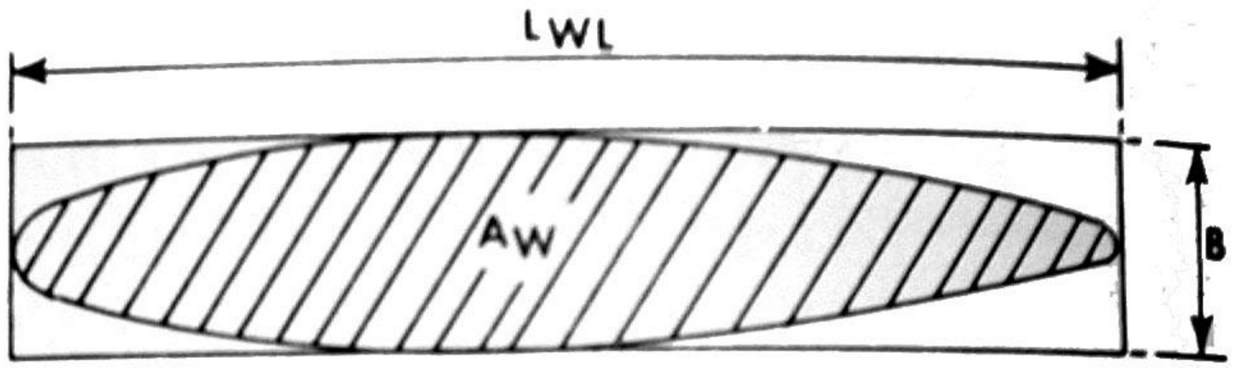


The relation between the submerged area amidships and the rectangle in which this area is contained:

$$C_{MS} = A_{ꝏ} / B \text{ x } T$$

Coefficients

Waterplane coefficient



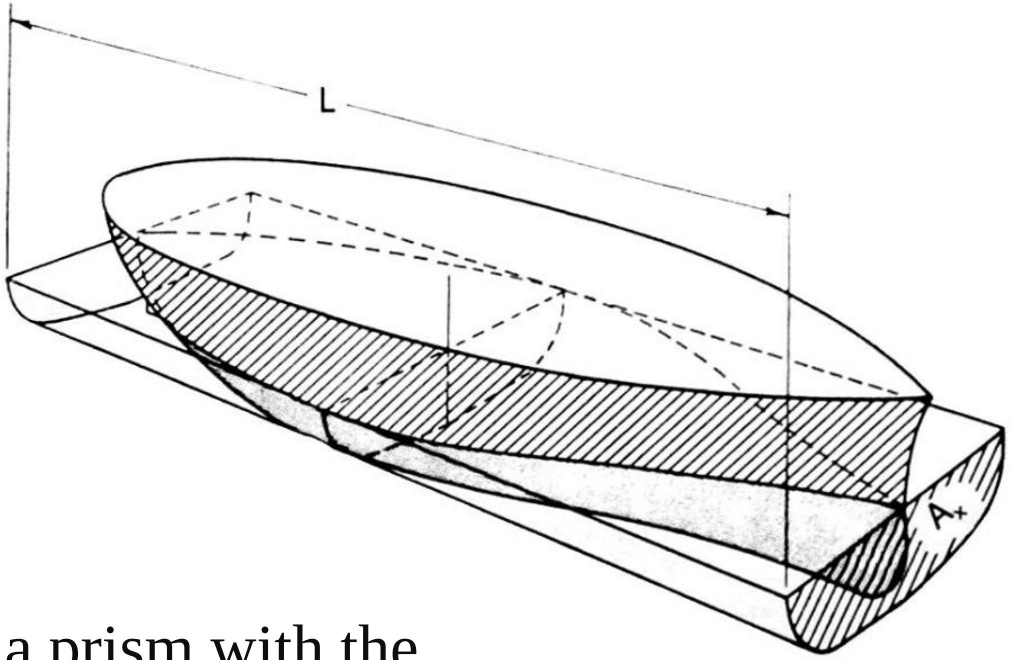
The relation between the area on the waterline and the rectangle in which this area is contained:

$$C_W = A_W \ / \ L_{WL} \times B$$

Hull Analysis

Coefficients

Prismatic coefficient



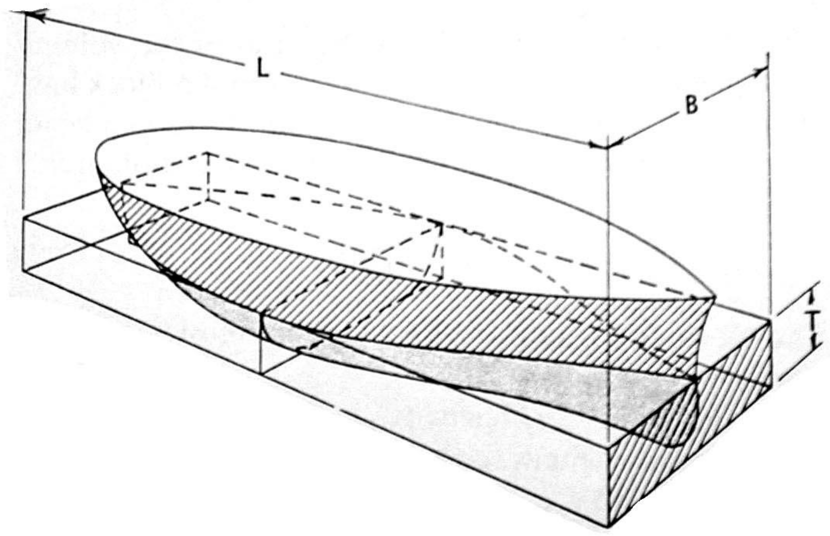
The relation between the submerged volume and a prism with the shape of the midships' section:

$$C_P = V_h / A_{\otimes} \times L_{WL}$$

Hull Analysis

Coefficients

Block coefficient



The relation between the submerged volume and the block in which the submerged volume is contained:

$$C_B = V_h / B \times T \times L_{WL}$$

Next Class: Mapping

Lecture: Introduction to surveying and mapping.

Reading: Review articles in Supplemental Reading Bibliography.

Assignment: Begin Project No. 3 (calculate displacement and hull coefficients for the lines drawn for Project No. 2).

Projects No. 1, 2 and 3 due next week, **before class**!