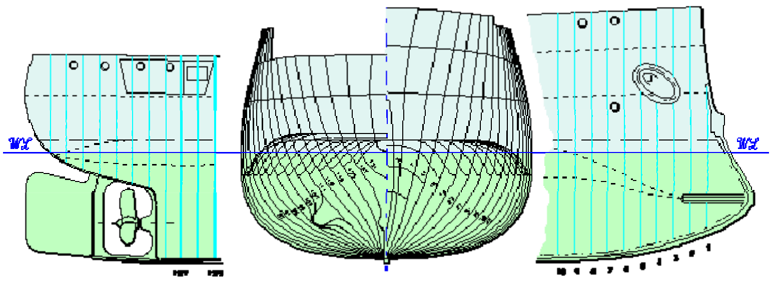
2. Bulbous Bow Design and Construction

Ship Design I

Manuel Ventura

MSc in Marine Engineering and Naval Architecture

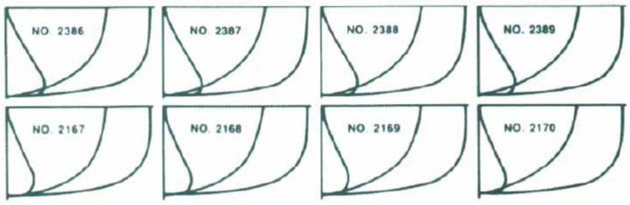
Historical Origin



- The bulbous bow was originated in the bow ram (*esporão*), a structure of military nature utilized in war ships on the end of the XIXth century, beginning of the XXth century.

Bulbous Bow

- The bulbous bow was allegedly invented in the David Taylor Model Basin (DTMB) in the EUA



Introduction of the Bulbous Bows

- The first bulbous bows appeared in the 1920s with the "Bremen" and the "Europa", two German passenger ships built to operate in the North Atlantic. The "Bremen", built in 1929, won the Blue Riband of the crossing of the Atlantic with the speed of 27.9 knots.

- Other smaller passenger ships, such as the American "President Hoover" and "President Coolidge" of 1931, started to appear with bulbous bows although they were still considered as experimental, by ship owners and shipyards.

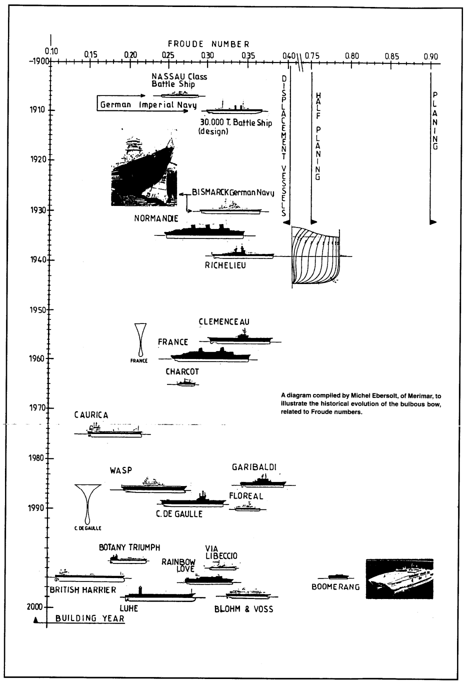
- In 1935, the "Normandie", built with a bulbous bow, attained the 30 knots.

Bulbous Bow in Japan

- Some navy ships from WWII such as the cruiser "Yamato" (1940) used already bulbous bows
- The systematic research started on the late 1950s
- The "Yamashiro Maru", built on 1963 at the Mitsubishi shipyard in Japan, was the first ship equipped with a bulbous bow.
- The ship attained the speed of 20' with 13.500 hp while similar ships needed 17.500 hp to reach the same speed.

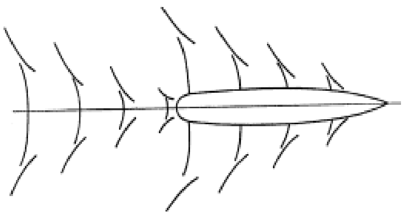
Evolution of the Bulb

- Diagram that relates the evolution of the application of bulbs as a function of the Reynolds Number, along the XX century
- Along the years the range of application of the bulb was extended up and down of the interval initially considered as useful



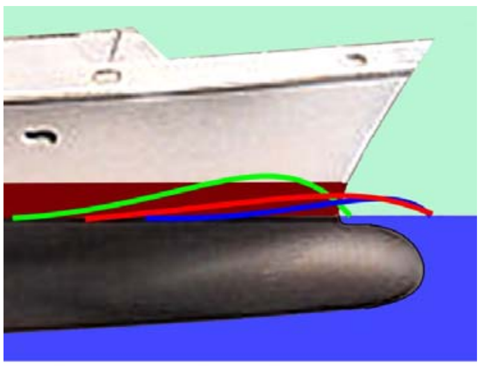
Systems of Waves from the Ship

- There are two types of waves generated by ships:
  - **Divergent Waves** – which are originated at the sides of the ship and have crests inclined in relation to the symmetry plane of the ship
  - **Transverse Waves** – which are originated at the sides fwd and aft (*amuras*) and have crests perpendicular to the symmetry plane of the ship



- These wave systems are generated both forward and aft
- The interference between these wave systems originates the characteristic bumps and hollows, as a function of the ratio (Vs/Lwl) of the ship.

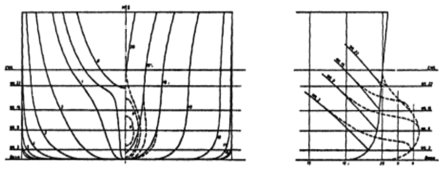
Wave Resistance



The green line represents the natural bow wave of the hull.
The blue line represents the wave created by the bulb.
The red line is the sum of these two.
The height of the bow wave is substantially reduced,
which reduces the hull drag associated with the bow wave.
This improves fuel economy, and increases range.

- The wave system generated by the bulb interferes with the wave system of the ship.
- The length of the bulb defines the phase of interference and its volume determines the width of its wave system.

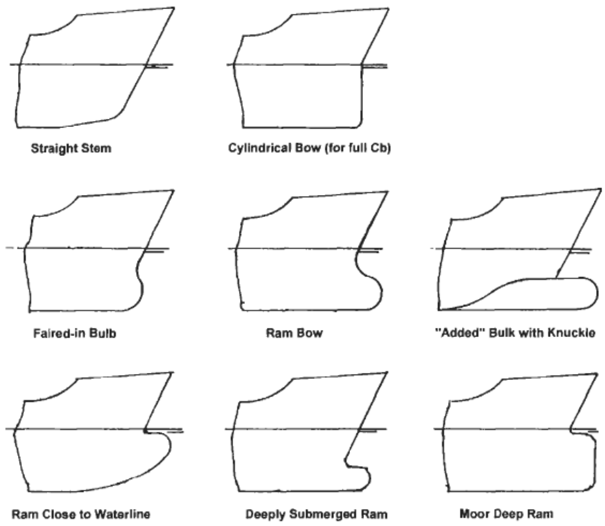
Usage of the Bulb



- The bulbous bow, by changing the entrance angles of the waterlines and the volume distribution, represents an effective mean of reducing the wave resistance
- Some authors (Wigley) limit the usefulness of the bulb to the interval

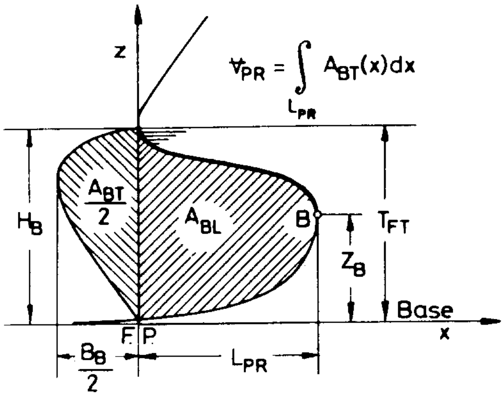
  $0.238 \leq Fn \leq 0.563$
- The bulb shape must be adjusted to the design conditions:
  - Generally at low speeds the effect of the bulb is negative. When the Froude Number (F_N) increases, its effect becomes positive and increases up to a maximum value.
  - From this point upwards, when the F_N tends to the infinity, the effect of the bulb tends to zero.

Bulbous Bow Shapes



Bulb Geometry (1)

Linear Form Coefficients



$$C_{BB} = \frac{B_B}{B}$$ Breadth Coefficient

$$C_{LPR} = \frac{L_{PR}}{L_{PP}}$$ Length Coefficient

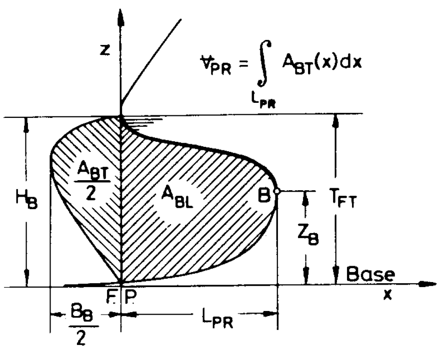
$$C_{ZB} = \frac{Z_B}{T_{FP}}$$ Height Coefficient

L_{PR} = protruding length of bulb

B_B = bulb breadth at FP

Bulb Geometry (2)

Non-Linear Form Coefficients



$$C_{ABT} = \frac{A_{BT}}{A_{MS}}$$ Cross-section Coefficient

$$C_{ABL} = \frac{A_{BL}}{A_{MS}}$$ Longitudinal Section Coefficient

$$C_{VPR} = \frac{V_{PR}}{\nabla}$$ Volumetric Coefficient

Taylor Coefficient (for fast ships)

$$t = L_{PP} \cdot \left| tg\left(sac\right) \right| / \left[2 \cdot \left(A_{MS} - A_{BT} \right) \right]$$

sac = angle of the standardized SAC with the horizontal, at the FP

Bulb Geometry (3)

Typical values of the Linear Coefficients (Kracht, 1970)

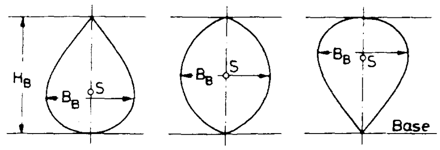
	MIN	MAX
C_{BB}	0.170	0.200
C_{LPR}	0.018	0.031
C_{ZB}	0.260	0.550

Typical values of the Non-Linear Coefficients (Kracht, 1970)

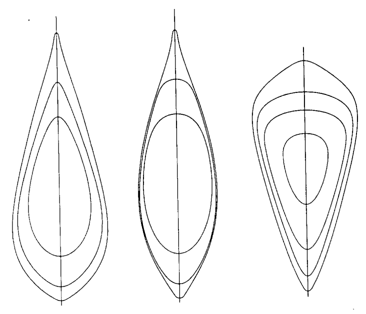
	MIN	MAX
C_{ABT}	0.064	0.122
C_{ABL}	0.068	0.146
C_{VPR}	0.0011	0.00272

Types of Bulb Sections (1)

Delta type Oval type Nabla type



a, Δ-Type b, O-Type c, ∇-Type

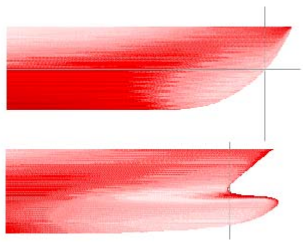


Types of Bulb Sections (2)

	Type ∆	Type ()	Type ∇
Examples	Taylor bulbs Pear shaped bulbs	Elliptical Circular Cylindrical Lens shaped	More common
Application	"U" shaped hulls Large variations of draught	"U" or "V" shaped hulls	"V" shaped hulls Clearly defined loaded and ballasted draughts
Observations	More susceptible of slamming	Less susceptible of slamming	

Integration in the Hull

- **Addition Bulbs**
  - The bulb shape is completely independent from the hull shape
  - Typically there is a knuckle resulting from the intersection of the bulb and the hull
- **Implicit Bulbs**
  - Sectional Area Curve is changed, part of the volume of the bulb is distributed aft of the FWD PP
  - No knuckles required



Bulb Design (1)

Height of Point of Maximum Protuberance

$$0.35 < H_B/T < 0.55$$

Length Coefficient

- Bulb for Ballast Condition

$$C_{LPR} = 0.1811 \cdot C_B \cdot B/L_{PP} + 0.0074$$

- Bulb for Loaded and Ballast Conditions

$$C_{LPR} = 0.2642 \cdot C_B \cdot B/L_{PP} + 0.0046$$

- Bulbs from a Similar Ship

$$C_{LPR} = C_{LPP0} + 0.08 \cdot (C_B - C_{B0}) - 0.004 \cdot \left(L_{PP}/B \cdot L_{PP0}/B_0 \right)$$

The subscript <0> refers to the base ship

Bulb Design (2)

Section Area Coefficient

- In the range of values 0.22 < F_N < 1.45 the section area at FP can be related to the Froude number by the expression

$$C_{ABT} = 40 \cdot F_N - 3.5$$

- Typical values of C_{ABT}

General Cargo	7 - 10%
Bulk Carriers	9 - 12%
Tankers	10 - 14%

Bulb Design (3)

Breadth Coefficient (C_{BB} x 100)

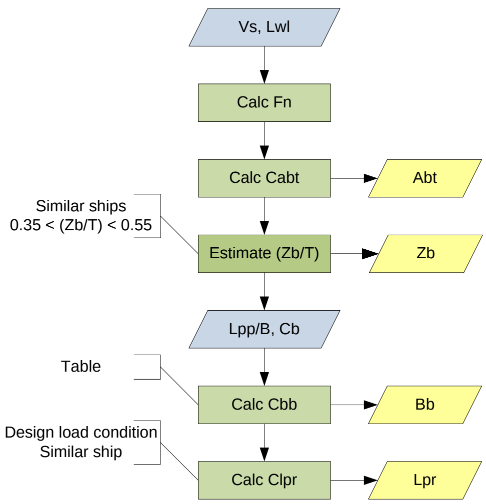
L_{pp}/B	C_B						
	0.55	**0.60**	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**
4.80	5.6	6.2	6.6	7.2	7.9	8.6	9.3
5.00	5.8	6.4	6.9	7.4	8.2	8.8	9.5
5.20	6.1	6.7	7.3	7.8	8.4	9.0	9.8
5.40	6.3	6.9	7.6	8.1	8.6	9.3	10.1
5.60	6.5	7.2	7.8	8.4	8.9	9.6	10.4
5.80	6.7	7.4	8.0	8.6	9.2	9.9	10.7
6.00	6.9	7.6	8.2	8.8	9.5	10.2	11.0
6.20	7.2	7.9	8.5	9.1	9.7	10.5	11.3
6.40	7.5	8.1	8.7	9.3	10.0	10.8	11.6
6.60	7.8	8.4	9.0	9.6	10.3	11.1	11.9
6.80	8.0	8.6	9.2	9.8	10.5	11.4	12.2
7.00	8.2	8.8	9.4	10.0	10.7	11.6	12.5
7.20	8.4	8.9	9.6	10.2	11.0	11.8	12.8

NOTES:

- The values from the table can be applied to bulbs with approx. $Z_B/T = 0.45$.
- For higher or lower values, the coefficients shall be increased or reduced by 0.1% for each 0.01 difference, respectively.

19

Determination of Main Bulb Dimensions



Suggested methodology (Alvarino & al, 1997)

$$L_{PR} = C_{LPR} \cdot L_{PP}$$
$$B_B = C_{BB} \cdot B$$
$$Z_B = C_{HB} \cdot T$$
$$A_{BT} = C_{BB} \cdot B \cdot T \cdot C_M$$

Bulbous Bow

20

Advantages of the Bulbous Bow (1)

- The bulbous bow has several important advantages and does not present relevant disadvantages:
  - Reduces the bow wave, due to the wave generated by the bulb itself, making the ship more efficient in terms of energy
  - Increases the ship's waterline length, slightly increasing the ship speed, reducing the installed power requirements and so the fuel oil consumption

Advantages of the Bulbous Bow (2)

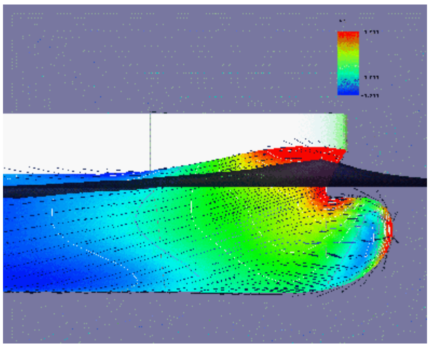
- Works as a robust "bumper" in the event of a collision
- Allows the installation of the bow thrusters at a foremost position, making it more efficient
- Allows a larger reserve of flotation or a larger ballast capacity forward
- Reduces the pitch movement (*cabeceio*)

Aspects of the Initial Bulb Design

- The bulb shall never emerge completely. The point at the forward extremity shall be at the level of the waterline
- Distribution of the bulb volume
  - Too much immersion doe not produce any effect
  - Volume concentrated longitudinally near the free surface increases the effect of interference in waves
- The waterlines at the bulb extremity should have a thin shape but not circular, to avoid the flow separation
- The bulb is advantageous in ice navigation – the ice blocks slide along the bulb with their "wet" side, which has a lower friction coefficient

Use of CFD on Bulb Design and Analysis

Bulb Hydrodynamic Analysis



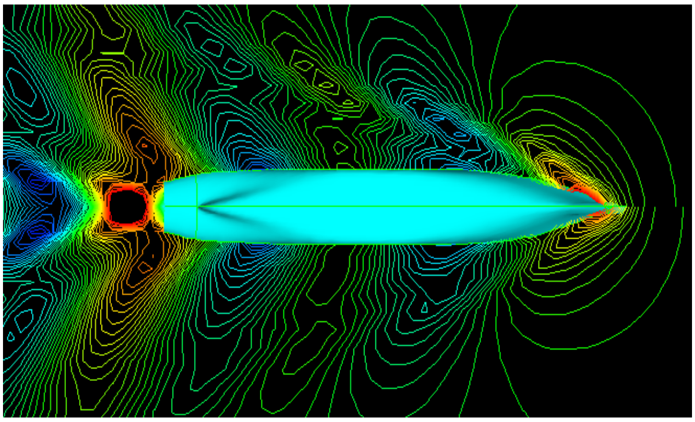
Combined representation of the wave profile, the distribution of the hydrodynamic pressure (colors) and of the flow lines

- Based on the experience, the designer must evaluate if:
  - The length of the bulb is adequate to the considered speed
  - The overpressure generated at the sides of the bulb is adequate
  - The bow flare does not increase too much the height of the wave at the bulb

Optimization of the Bulb with CFD (1)

- The bulbs shall be designed for the operational profile os the ship and not only to the full load condition
- The bulb that reduces the most the fuel needed for the required operational profile shall be the one selected

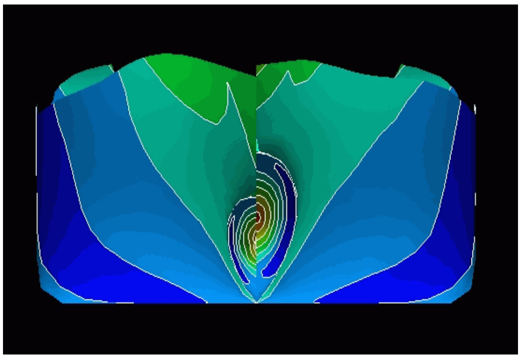
Optimization of the Bulb with CFD (2)



Representation of the contours of wave height

Bulbous Bow 27

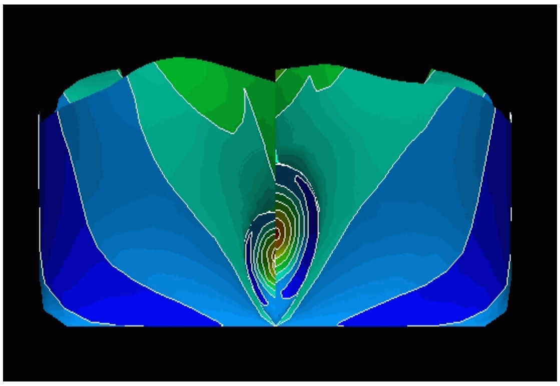
Non-Linear Analysis do Potential Flow (1)



- The figure shows two different bulbs, the one PS much larger than the SB.
- The contours on the hull represent the gradients of the dynamic pressure

Bulbous Bow 28

Non-Linear Analysis do Potential Flow (2)



- It can be concluded from the figure that the side of the smallest bulb has larger crests and deeper caves, resulting in a larger resistance

Examples of Bulb Shapes

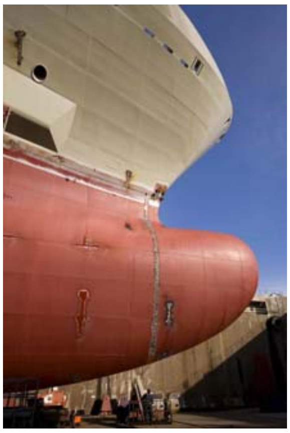
Bulbs in Merchant Ships (1)

Example of a bulb of addition, with a knuckle in the intersection with the hull.

Bulbs in Merchant Ships (2)

Examples of bulbs integrated in the hull.

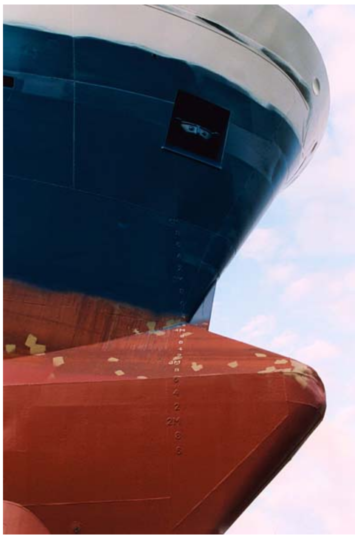
Bulbs in Merchant Ships (3)



Examples of bulbs integrated in the hull shape.

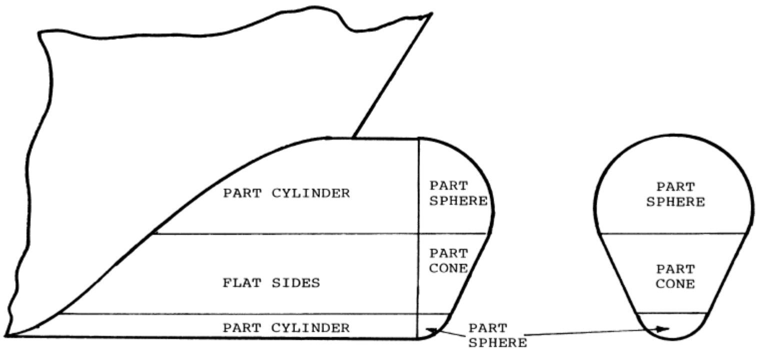
Bulbs in Merchant Ships (4)

Simplified Bulb Shapes (1)



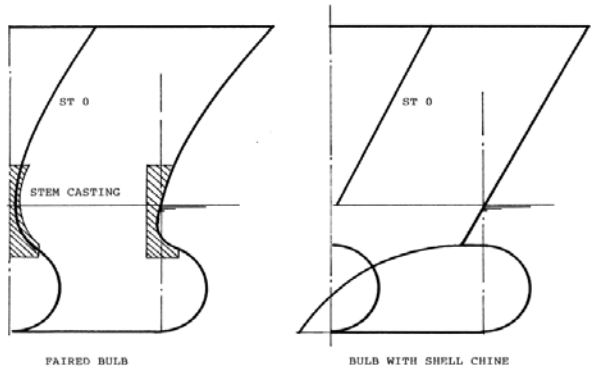
- To reduce the production costs, several simplified bulb forms have been developed
- These bulbs are compromises between the hydrodynamic efficiency and the reduction of the production costs
- Some guidelines, to be used as possible:
  - Avoid plates with double curvature
  - Use conic plates
  - Decrease the curvature of the free-form curved plates, decomposing them into smaller ones

Simplified Bulb Shapes (2)



Bulb built from simplified conic shapes (Lamb, 1986)

Simplified Bulb Shapes (3)



Bulb integrated and bulb of addition, with knuckle, avoiding a stem with a component in cast steel (Lamb, 1986).

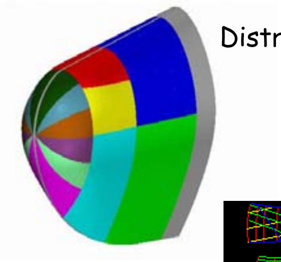
Bulbs in Military Ships

Aircraft Carrier George Washington

Bulbs in Small Craft (1)

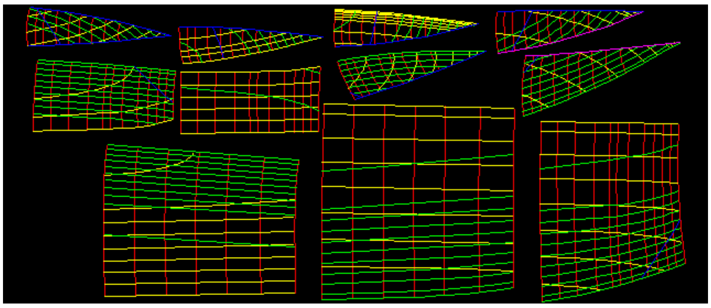
Bulbs in Small Craft (2)

Design for Construction



Distribution of plates

Development of the Bulb Plates



Manufacture and Assembly

Adding a Bulb

Addition of bulb to a pleasure craft in composite material

Bibliography (1)

- ✓ Alvarino, Ricardo; Azpíroz, Juan José e Meizoso, Manuel (1997), "El Proyecto Básico del Buque Mercante", Fundo Editorial de Ingeniería Naval, Colegio de Ingenieros Navales.
- ✓ Chen, P-F, Huang, C-H, Fang, M-C, Chou, J-H (2006), "An Inverse Design Approach in Determining the Optimal Shape of Bulbous Bow with Experimental Verification", Journal of Ship Research, Vol.50, No.1, pp.1-14. (CD-ROM#41)
- Couch and Moss (????), "Application of Large Protruding Bulbs to Ships of High Block Coefficient", SNAME Transactions.
- Hoyle, Cheng, Hays, Johnson and Nehring (????), "A Bulbous Bow Design Methodology for High-Speed Ships", SNAME Transactions.
- Kracht (1970), "A Theoretical Contribution to the Wave-Resistance Problem of Ship-Bulb Combinations: Verification of the Negativeness of the Interaction Term", Journal of Ship Research, March.

Bibliography (2)

- ✓ Kracht (1978), "Design of Bulbous Bows", SNAME Transactions.
- ✓ Kyriazis, Georgios (1996), "Bulbous Bow Design Optimization for Fast Ships", MSc Thesis, MIT. (CD-ROM#70)
- Lamb, Thomas (1986), "Engineering for Ship Production", SNAME.
- Lee, K.J. and Sarath, E.S. (2005), "Optimized Design of Hull Form and Bulbous Bow for ULCS", Proceedings of The Fifteenth (2005) International Offshore and Polar Engineering Conference, Seoul, Korea.
- ✓ Pérez, Francisco; Suárez, José A.; Clemente, Juan A. and Souto, Antonio (2007), "Geometric Modelling of Bulbous Bows with the use of Non-Uniform Rational B-spline Surfaces", Journal of Marine Science and Technology, Vol.12, Number 2, June 2007, pp. 83-94.
- ✓ Sharma, R. and Sha, O.P. (2005), "Practical Hydrodynamic Design of Bulbous Bows for Ships", Naval Engineers Journal, Vol.117, No.1, pp.57-76.

Bibliography (3)

- Smith and Salvesen (1970), "Comparison of Ship-Motion Theory and Experiment for Destroyer with Large Bulb", Journal of Ship Research, March 1970.
- Yim, B. (1974), "A Simple Design Theory and Method for Bulbous Bows of Ships", Journal of Ship Research, Vol.18, No.3, pp.141-152.

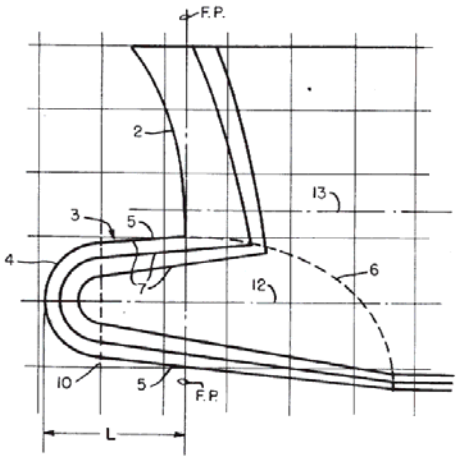
Annex A. Some Bulb Design Patents

Conical Bulbous Bow (1)

- A novel bulbous bow for bulk carriers comprises a conical bulb with a faired nose, with the axis of the cone substantially parallel to the longitudinal axis of the ship.
- In a preferred embodiment the cone is a right circular cone and the faired nose is substantially a hemisphere. More particularly, the included angle of the cone is in the range of five to twenty degrees.
- Although the cone could be faired into the hull, preferably it is not.
- The longitudinal centerline of the bulb is located between 45 and 60 percent of the design draft below the design waterline.
- The preferred extension of the bulb, beyond the forward perpendicular, is proportional to the square of design speed with the proportionality factor in the range of 0.015 to 0.04 and preferably 0.035.

United States Patent 3946687 (1976)

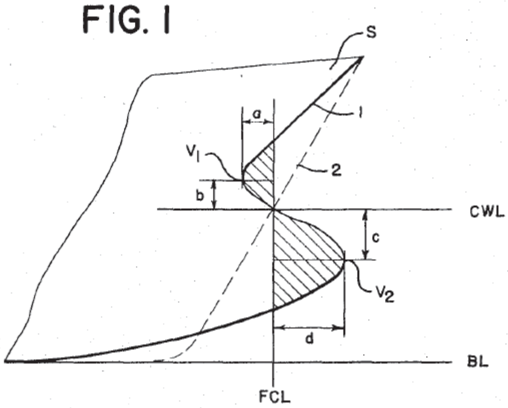
Conical Bulbous Bow (2)



- The cross-sectional area of the bulb at the forward perpendicular may be in the range from 10 to 20 percent of the amidships cross-sectional area.
- The bulb, comprising conical and hemispherical sections, is easier and less expensive to fabricate than some of the more complex shapes shown in the prior art.

Bulb Construction (1)

FIG. I

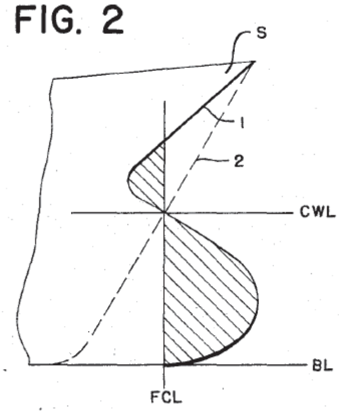


- Bulb for a ship with small variations of the waterline
- Parameters <a> and <b>, where <b> has the order of magnitude of the height of the bow wave

United States Patent 3455262 (1969)

Bulb Construction (2)

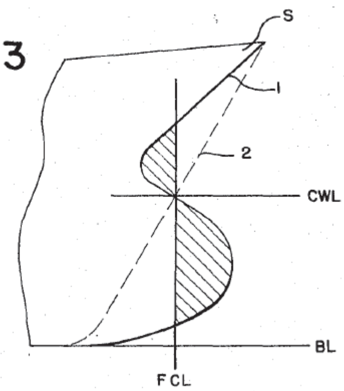
FIG. 2



- Bulb for ship with larger variations of the waterline

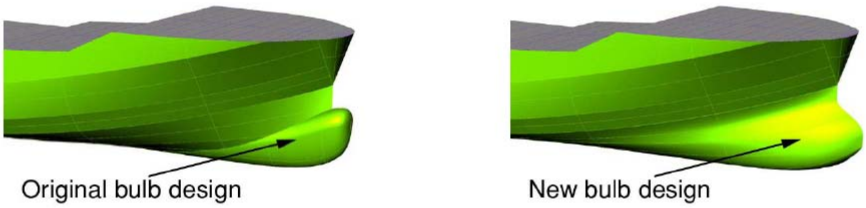
Bulb Construction (3)

FIG. 3



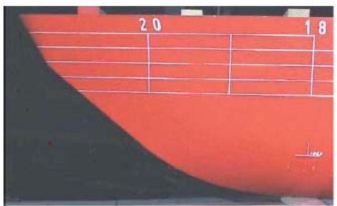
- Bulb for ships with larger variations of the waterline

Bulb for Navigation in Ice (1)

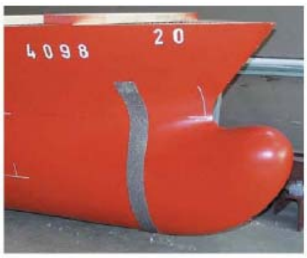


- Bow shape patented by EcoShip Engineering based on studies done at HSVA
- Presents a low resistance in ice and simultaneously a low resistance in open waters

Bulb for Navigation in Ice (2)



Classical icebreaking stem



Conventional bulbous bow

Icebreaking bulbous bow

Bows tested in the HSVA