UNIT 5

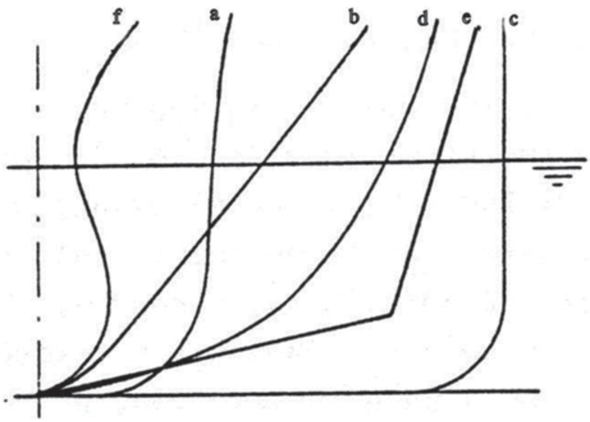


Fig. 3.17 Basic types of ship sections

3.3 Form of Sections

Besides the prismatic coefficient C_P and the slenderness coefficient $L/\nabla^{1/3}$ the type of sections, i.e., the transverse sections of ship's hull, provides the essential character of the vessel's hull form.

3.3.1 *Types of Sections*

Typical examples of sections of modern ship types are sketched in the following Fig. 3.17.

The common classification of the various types of ship sectional forms is given in the following:

a. U type
b. V type
c. Rectangular (midship sections)
d. Circular type (nearly constant radius of curvature, for sailing yachts)
e. Hard-chine (with one or two chines, application especially to high speed boats)
f. Bulbous type (applications: to bow and stern region, but in older times also applicable to the midship section of passenger ships and warships).

3.3.2 *Midship Section Form*

- **General Comments:** Regarding the selection of the midship sectional area coefficient C_M, as well as of the bilge radius r_B and the deadrise d_R, relevant comments were made earlier in Sect. 2.11.

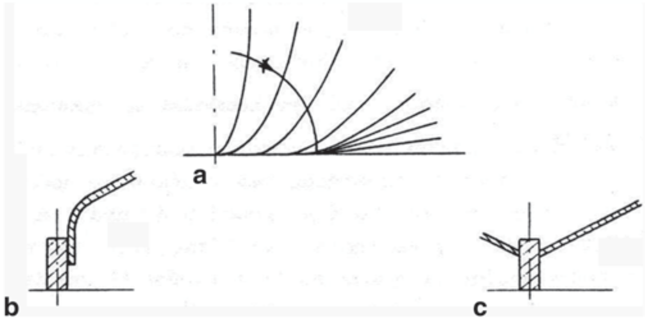


Fig. 3.18 Entrance ways of sections. **a** Flat keel. **b** Demanding vertical keel. **c** Simple vertical keel

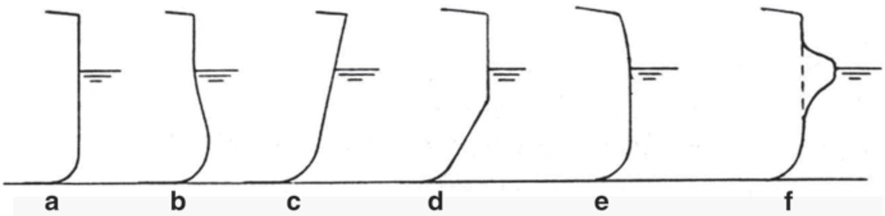


Fig. 3.19 Basic midship section forms

- **Entrance Ways of the Bottom of Midship Section:** For ships with a flat keel, (i.e., for all large ships) and elevated bottom (with deadrise) it is recommended that the deadrise starts from the edge of the keel (see Fig. 3.18a). In contrast, for small vessels, with vertical keel, it is appropriate to avoid demanding curvatures to the keel, because it will not improve significantly the flow around the keel, whereas it will cause difficulties in the construction/fitting of the keel (see Fig. 3.18b, c).

- **Sides of Midship Section (Fig. 3.19):**

  a. Common midship section with vertical sides
  b. Bulbous underwater section to improve the stability at small drafts according to the German Naval Architect Foerster (applied to old transatlantic passenger ships). Also, it offers the possibility of fitting additional underwater armor to the hull (old warships).
  c. Flared V section (ferries, icebreakers, flare especially above the waterline)
  d. V sections below the waterline and vertical sides at and above the waterline (applied to some containerships, see lines drawing of contemporary German containership, Sec. 3.4). They ensure reduced GM for small drafts, when this is desirable (for avoiding excessive transverse accelerations in seaway).
  e. Retreating sections of tumble-home type above waterline; applied to old ocean liners and large passenger/ferry/cruise ships in general for weight savings

on superstructures, thus reducing/controlling the height of the weight center of the ship.

f. Fitted sponsons around ship's waterline to improve ship's stability in cases of insufficiency after a ship's conversion (e.g. in cases of conversion of cargo ships to passenger ferry ships; also, old warships: armored shield against torpedoes).

3.3.3 Form of Bow and Stern Sections

General Comments

- **Relationship with the Midship Section/Body:** If the middle body section is full, the character of the sections at bow and stern may be U or V type according to the specific implemented criteria. On the contrary, a relatively sharp middle section of V type allows the connection to only V sections both at the bow and at the stern.
- **Relationship with the Shape of Bow and Stern:** The character of the bow and stern, e.g., the existence of a bulb at the bow/stern, or transom stern, affects only those directly neighboring sections, but without this influence to reach the middle body area.
- **Relationship with the Type of Ship:** For specific ship types characteristic section types have emerged, namely:
  - Ferries: Due to the requirement of large deck area pronounced V-type sections arise, both at the ends (stern and bow) of the vessel, as well as in less extreme form at the middle body region.
  - Tankers/bulkcarriers: In contrast to the ferries, the requirements for the deck area are not a decisive criterion for the design of the lines of tankers. Thus U sections with as possible vertical walls on the side are applied, allowing best use of enclosed spaces.

The relation of the hull form to the ship type is elaborated in the following:

• **Shaping of the sections' entrance ways at the bottom area:** The criteria for the shaping of the sections' entrance ways at ship's bottom are (sometimes contradictory effects):

- Avoidance of generation of intense vortices
- Positive influence on the damping of pitch and roll motions
- Minimum wetted surface to minimize frictional resistance

The recommended design measures for the layout of sections' bottom entrances are:

- The way of arrangement of the sections in the bottom region
- The radii of curvature of the entrances of the sections
- The height of deadrise

In Fig. 3.20, illustrative examples of correct and wrong shaping of the sections' entrances are described in the spirit of above criteria.

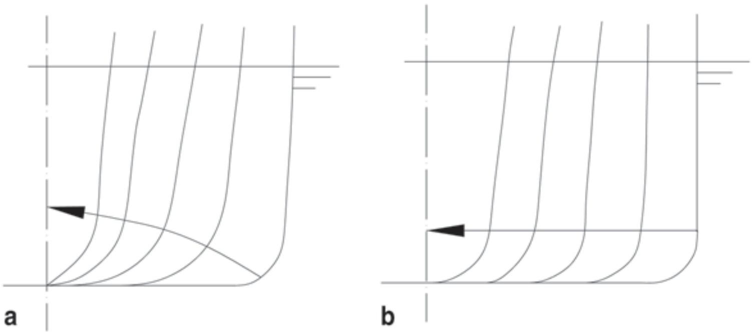
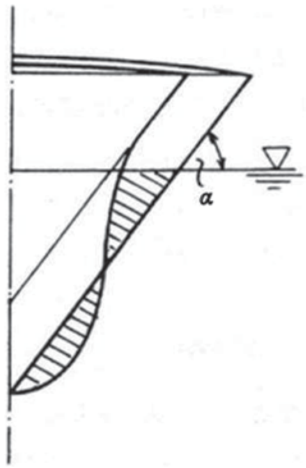


Fig. 3.20 Fictitious/virtual line of maximum curvature. Body plan: **a** Correct layout. **b** Wrong

Impact on Stability: Generally for fixed displacement, U-type sections lead to a smaller design waterplane area, compared to the V-type sections. Thus they lead to smaller metacentric radii $\overline{BM}$. In addition, the vertical position of the center of buoyancy $\overline{KB}$ is reduced, compared to the corresponding of V-type sections. In conclusion, for the same initial stability, i.e., the same $\overline{GM}$, ships with pronounced U sections require a higher B/T ratio (lower L/B), than those with V sections. It should be noted that for the same displacement, or the same displacement per meter section, the weight (mass) center $\overline{KG}$ of a V section is higher than that of a U section, due to the positioning of significant steel mass higher up above the design waterplane. However, this negative effect regarding the stability properties of V type sections is overcompensated by the analog increase of the "form stability," i.e., of $\overline{KM}$.

Impact on the Construction, the Exploitation of Space and Other Criteria: Comparing the two basic types of sections with character of U and V, of the same displacement per meter, the same draft and side depth (hence the same height of freeboard) and the same flare angle α (see Fig. 3.21), we observe the following:

Fig. 3.21 Comparison of bow sections of type U and V for the same underwater area and flare angle



Compared to an U-type section, the V-type section offers:

- Larger exploitable volume above the design waterline and larger deck area
- Relatively smaller side area of the shell (reduction of steel structure weight)
- Limited curved area of the plates (easier and more economical to construct)
- Larger reserve buoyancy
- Larger width at waterline (thus increase of $\overline{BM}$, see previous paragraph: "Effect on stability")

The V-type section is inferior to U-type on the following criteria:

- Limited exploitable space below the waterline
- Creation of intense waves (intense free surface disturbance at waterplane) and generally increased wave resistance
- An increased height of center of gravity due to the transfer of significant steel mass above the waterplane. This is usually accompanied by increased weight centroids of superstructures and of equipment on deck
- Problems of slamming and seakeeping for pronounced sections V at the bow, when sailing in head waves
- Significant loss of waterplane area during the emergence of part of the vessel due to ship motions in waves (heave-pitch) or in the case of trim and/or in ballast condition.

3.3.4 Bow Sections Below Waterline

Effect on Resistance and Seakeeping For relatively slow vessels, due to high block coefficients, the need of applying relatively full sections with strong U character is apparent, especially in the bow section of the vessel. For relatively fast ships, the main requirement being to minimize the wave resistance, which is a significant part of the overall resistance, leads to shifting the displacement downward (well below the free surface), which means that again sections of U-type come to application. Even more, bulb-type sections are applied at the bow itself (see Sect. 3.4.2).

Vessels with relatively sharp midship section of type V (e.g., ferries, fishing boats) are distinguished for the V-type sections also at the bow part of the ship, despite the negative effect on wave resistance. Certainly, because of the relatively reduced wetted surface, the increases in wave resistance are partly balanced by the reduction of the frictional resistance.

The effect of the bow sections on ship's seakeeping performance (magnitude of wave induced ship motions, speed loss due to added resistance in waves, structural loads and loads on cargo, etc.) is significant. Because of the large local motions of the bow in waves about the mean waterplane, a proper configuration of the bow sections considering only the wetted part is not sufficient; rather the form of the whole section up to the deck must also be taken into account. For relatively small drafts of the bow, as they present in ballast operational conditions, it has been shown that full U-type sections with large projected bottom area may lead to severe slamming phenomena. For larger drafts it shows that the decay of ship's roll motion is more drastic with V sections, than with U sections. However, strong above waterline section flares cause slamming at the bow sides of the ship and severe structural loads/vibration phenomena. Thus the combination of less pronounced sections of U and V type are regarded as the appropriate solution to serve the above, partly contradicting hydrodynamic criteria.

Other Criteria:

- Exploitation of spaces
- Stability
- Simplicity of construction

The abovementioned criteria have been elaborated in the previous paragraph "Influence on the construction, the exploitation of space and other criteria" during the comparison of typical characteristics of U and V type sections (see Sect. 3.3.3).

3.3.5 Stern Sections Below Waterline

Effect on resistance: Generally V type sections at the stern region are more favorable for the demands of resistance due to the smooth transition and adaptation of the aft shoulders of the vessel to the water flow, which takes place mainly in the way of ship's hull diagonals. Thus, an early separation of the flow and vortex generation is avoided.
Effect on the Flow to the Propeller and on Propulsion: Due to the nonuniform distribution of the wake of the ship (nominal wake), every blade of the propeller, when turning, experiences an alternating (in magnitude and direction) stream/onset flow velocity (see Fig. 3.22).

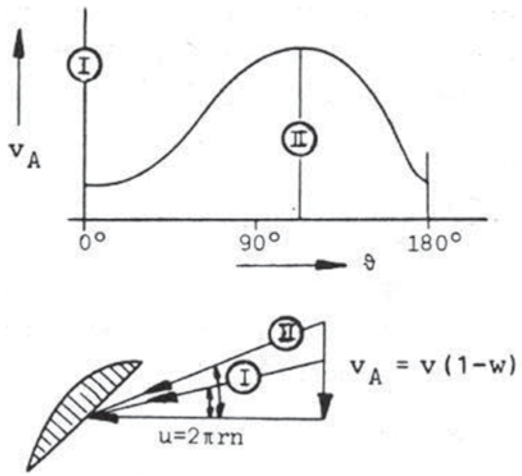


Fig. 3.22 Effect of wake nonuniformity (change of speed of flow incidence) on the propeller blades

This leads to time-varying hydrodynamic pressures on the propeller blades, varying moments on the propeller shaft as well as time dependent irregularities of the thrust force to the ship.

The nonuniformity/heterogeneity of the flow to the propeller is expressed mainly by the "relative rotative efficiency":

$$\eta_R = \eta_B/\eta_0\,(\text{relative rotative efficiency})$$

where:

η_0: Propeller's efficiency in open water
η_B: Propeller's efficiency behind hull (in vessel's wake flow)

The effect of the hull form below waterline at the stern is expressed by the "hull efficiency factor":

$$\eta_H = \frac{1-t}{1-w}\ \text{(hull efficiency)}$$

where

t: thrust deduction factor
w: effective wake factor

As shown by model experiments and theoretical considerations, the flow to the propeller is influenced positively by the application of U-type sections in the final part of ship's hull in front of the propeller, as this ensures more homogeneous distribution of the wake compared to V type sections.

- **Configuration of Single-Propeller Ships:** Efforts are spent on reconciling the aforementioned contradictory requirements, i.e., reducing the eddy resistance and assuring uniform/smooth flow to the propeller. This results in V-type sections around the hips (aft shoulders) of the hull, which change to U-type sections in the end part of the vessel in front of the propeller (low eddy resistance and good propulsive efficiency).

Contemporary Developments

- Application of *bulbous stern/stern bulb* according to patents of A.G. Weser and Schneekluth (see Fig. 3.23a, b). This results in an acceleration of the flow to the propeller and in uniformity of the wake (reduction of vibrations, increase of the efficiency of propulsion system).
- Application of *asymmetric stern* according to a patent of the German naval architect Nönnecke (see Fig. 3.24). The objective is herein to impart a swirl to the flow in front of the propeller to counter the flow induced by the propeller

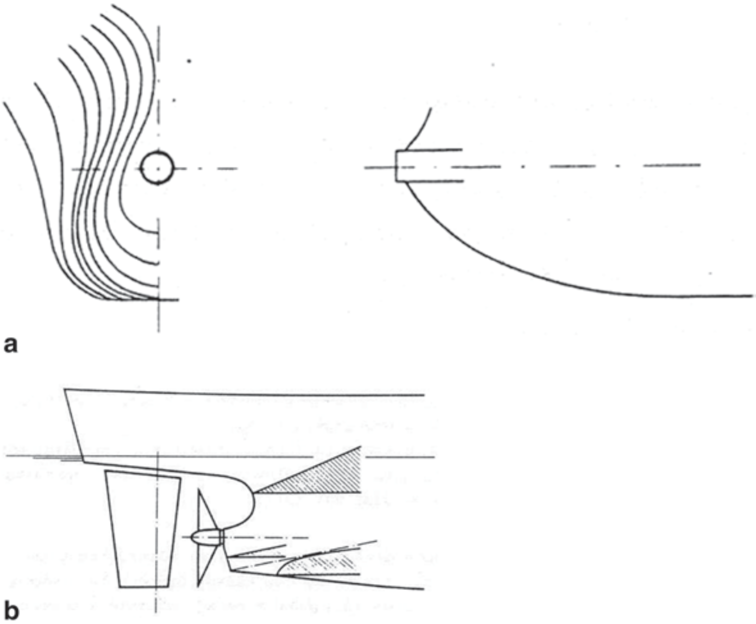


Fig. 3.23 **a** Stern bulb according to A.G.Weser yard (Germany). **b** Simplified stern bulb

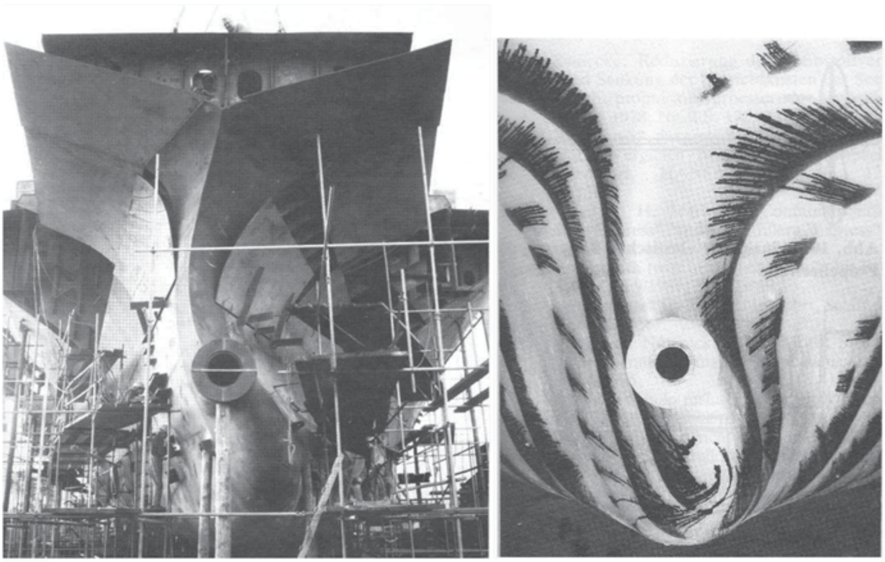


Fig. 3.24 Asymmetric stern according to Nönnecke (Journal Schiff and Hafen Sept 1987)

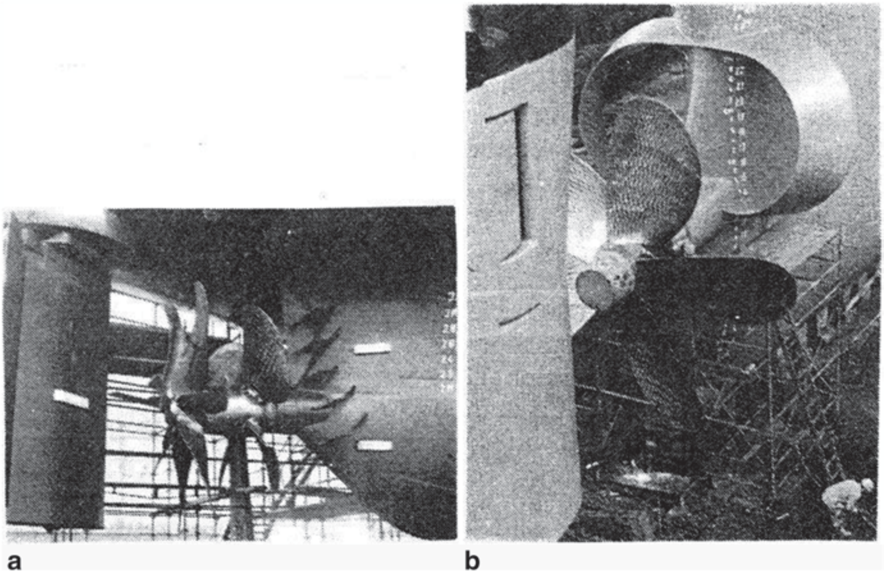


Fig. 3.25 Smoothing of flow to the propeller. **a** Propeller/stern fins and Grim's "vane wheel" behind the propeller. **b** Semi-duct according to Schneekluth (likewise the Becker-Mewis duct with integrated fin system within the duct)

itself. An improvement of the propulsive efficiency in the range of 5–7 % may be obtained by the fitting of an asymmetric stern, at the expense of higher construction cost.

- Stern fins and ducts. The objective is herein the smoothing and acceleration of the onset flow to the propeller (see Fig. 3.25a, b).

- **Configuration of Twin-Propeller Ships:** The propellers of twin-propeller ships work to a great extent outside of ship's wake field, i.e., outside the domain where the undisturbed stream velocity reduces due to (mainly)[3] the effect of water's viscosity, namely friction between ship's hull and water. Thus the stern sections of twin-screw ships are configured on the basis of the minimum resistance criterion (here minimizing the eddy resistance) and are mostly sections of V-type. Special attention should be paid to the configuration and placement of the brackets of the propeller shafts on the hull surface of the vessel, because of the resulting flow separation at protruding points of the hull.

Modern twin-propeller ships (mostly passenger ships) are fitted nowadays with *tunneled* sections at the stern, which enable both a more uniform wake field and the installation of large-diameter propellers (high propulsive efficiency, see Fig. 3.26).

[3] Of course, there are further effects on actual flow velocity to the propellers (and ship's wake), like free-surface effects due to the action of the ship-bound and the incoming sea waves and local hull form effects.

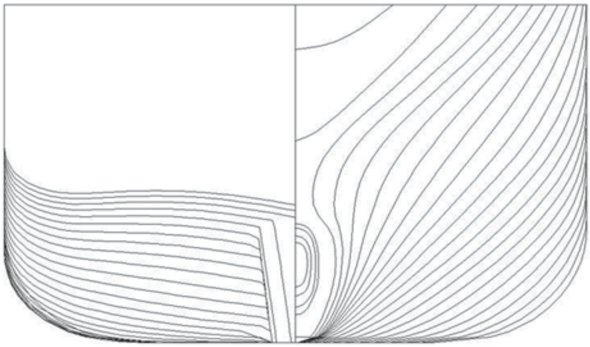


Fig. 3.26 Body plan of a modern Ro-Ro passenger ship with *tunneled* stern sections (Ship Design Laboratory-NTUA)

3.3.6 Form of Sections Above Waterline

Basic Criteria

- Exploitation of the deck area
- The seakeeping behavior of the vessel, e.g., amplitude of heave/pitch motion, vertical local movement of bow, added resistance, wetness of deck (green water or periodical immersion/flooding of deck)

It is noted that, the form of the sections above waterline affects the aforementioned hydrodynamic phenomena/criteria to a lesser degree than the more important effects of the freeboard height at the bow, ship's mass moment of inertia, the added/hydrodynamic mass/moment of the vessel, the natural frequency of heave/pitch motions, and possible resonance/tuning with the frequency of the incident wave.

Configuration of the Bow Sections Above Waterline

1. The application of V type sections provides more reserve buoyancy and restoring ability to ship motions, than U type sections, because of the strongly increasing buoyancy force above waterline. Nevertheless, it is common to use for cargo ships U type sections, with some moderate flare above DWL, as a U form fits better to the section form of the bow below waterline.
2. Strong above waterline flares may prevent easy deck wetness (green sea), but may cause severe vibrations on the bow's hull due to slamming during pitch.
3. The application of sections with chine above the waterline reduces the intense flare on deck; however, it increases the probability of "spraying" of the deck due to separation of the flow at the chines. Instead, the use of earlier patented sections by Deutsche Werft ("tulip" sections, see Fig. 3.27b) is suggested.
4. Generally, regarding the seakeeping performance and ship's bow hydrodynamics, an insufficient freeboard height at the bow cannot be counterbalanced by any optimization of the section form above waterline.

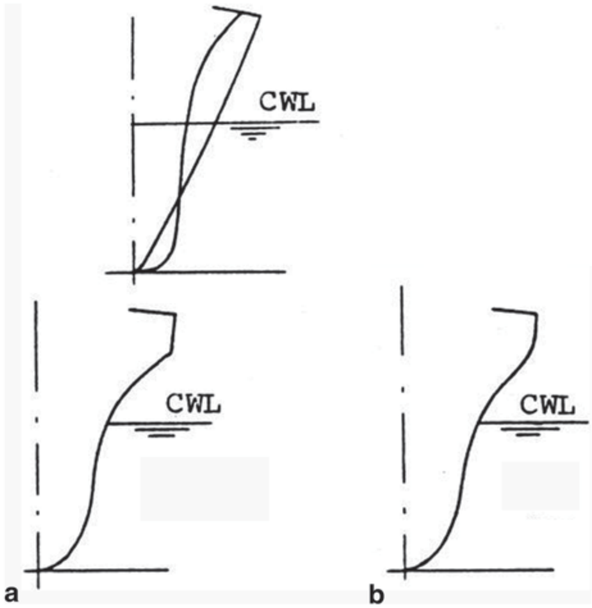


Fig. 3.27 Configuration of above waterline bow sections. **a** Above waterline section with hard chine. **b** Patented Deutsche Werft ("tulip" type) section

Configuration of Stern Sections Above Waterline The aspect of *green* water on/wetness of deck applies as well to the configuration of the stern part of the ship (for the stern incident waves—following seas).

Significant dynamic stability problems occur especially with small boats (fishing vessels)[4] and are typically induced in following seas (though also in head waves) due to the partial emergence of ship's hull and the loss of waterplane area (and of effective metacentric height), which is particularly pronounced on ships with V type sections. The reported dynamic phenomena are particularly dominant in resonance/tuning conditions, which occur when ship's natural roll period (or fractions thereof) becomes equal to the encounter wave period, causing *pure loss of stability* and *parametric roll phenomena*;[5] the latter can be explained mathematically by consideration of the "Mathieu instabilities" problem (Spanos-Papanikolaou 2006). The result of such events can be catastrophic for the ship and may lead to ship's capsize or cargo movement or the loss/damage of cargo on deck (deck containers, see Figs. 3.28 and 3.29).

[4] Nevertheless, dynamic stability problems have surfaced in recent time also with the operation of larger ships, e.g., containerships.

[5] The most prominent, recent large ship accident related to parametric roll happened in October 2008 with the 4,832 TEU containership *APL China* on the way from Taiwan to Seattle; during her trip the ship experienced parametric roll resonance and barely survived foundering; when she arrived in Seattle it was realized that more than sixty percent of her cargo was lost at sea or damaged. The following multi-million USD liability case was settled out of court for an undisclosed amount. Thanks to the conduct forensic studies that attributed the disaster to parametric roll, the liability of the operator APL (American President Lines) was limited to reasonable levels.

Fig. 3.28 Containership

Fig. 3.29 Shift of containers due to parametric roll

3.4 Form of Bow

3.4.1 Types of Bow

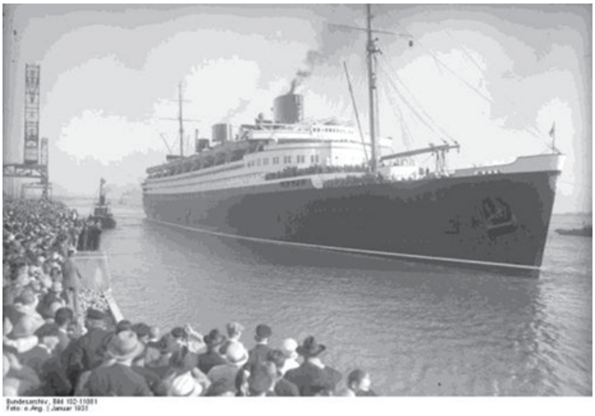
a. Profile of Bow—Historical Evolution of Bow Types

Old times: termination of the bow in a vertical or slightly protruding straight line profile (flared bow profile) above the waterline (see examples Figs. 3.30 and 3.31).

Sometimes on older warships, the profile above the waterline was backwards (*tumble home*) bow profile and below the waterline they disposed a protruding bow with a bulbous profile *without or with slight protrusion in the transverse direction* (*"piston" type bow of antique Greek triremes*) (Fig. 3.32).

Fig. 3.30 British passenger ocean liner "Mauretania" (1907), L = 232 m, Displacement = 38,600 t, Tonnage: 32,000 GRT, Shaft Horsepower = 68,000 HP, V = 27.2 kn (average speed, "blue ribbon" winner for crossing the Atlantic in year 1909)

Fig. 3.31 German passenger ocean liner "Bremen" (1929), L = 270.7 m, Displacement = 51,860 t, Tonnage: 51,656 GRT, Shaft Horsepower = 96,000 HP, V = 28.5 kn (average speed, "blue ribbon" winner for crossing the Atlantic in year 1929)



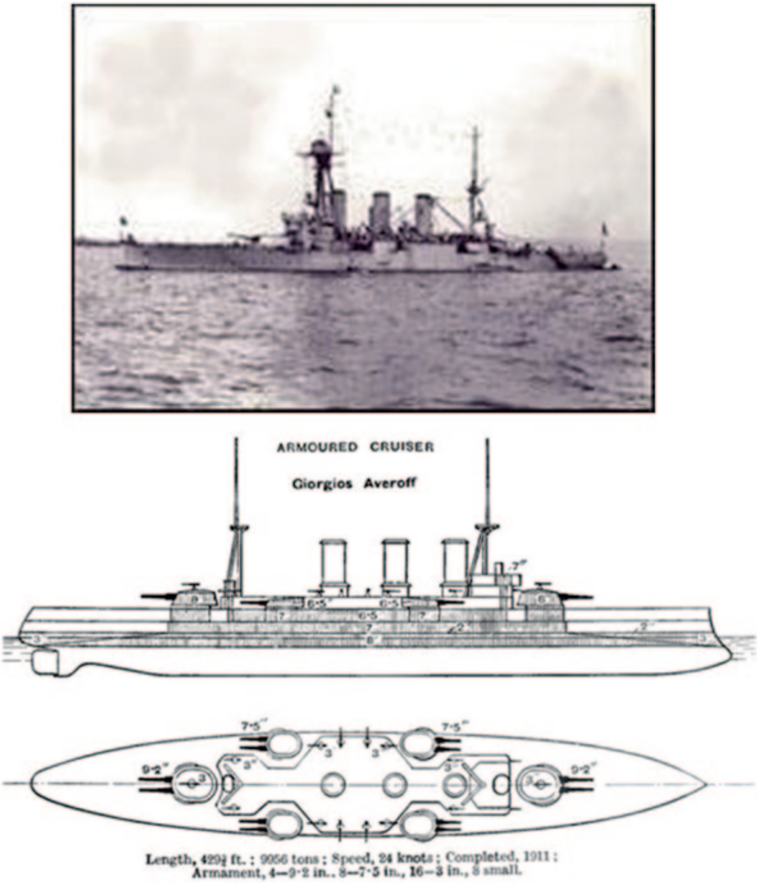


Fig. 3.32 WWI Greek battleship "Georgios Averof" (1910), $L_{BP}=140.5$ m, $B=21$ m, $T=7.5$ m, $\Delta=10{,}118$ t, $P_S=19{,}000$ HP, $V=23.0$ kn

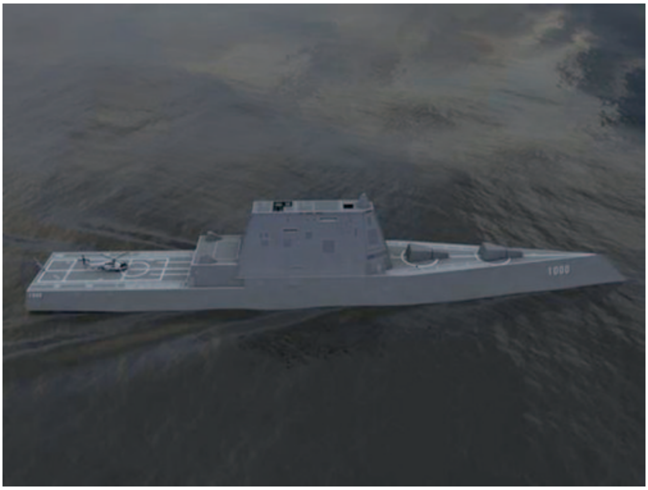
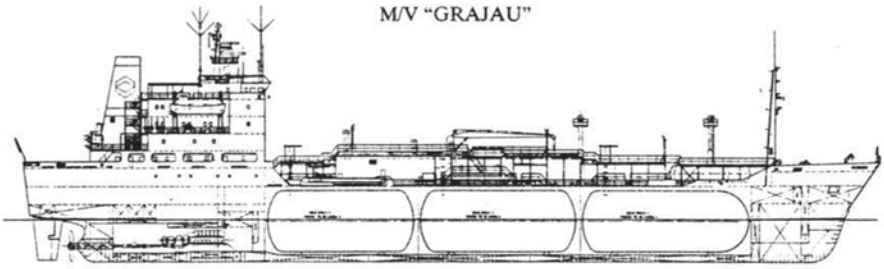


Fig. 3.33 Contemporary cruiser design of US Navy DDG 1000

Fig. 3.34 Contemporary super luxury mega-yacht SIGMA A, shipyard Blohm and Voss (Germany 2008)—LOA 119 m, B 18.87 m, Tmax: 5.15 m, NPASS: 14, NCR: 37

The above waterline backward slope and below waterline protruding bow resurfaced recently as a *wave-piercing* bow on modern warships and mega-yachts (Figs. 3.33 and 3.34).

Latest Developments—Commercial Vessels (last 20–30 years): Above the waterline we observe a protruding straight line (Fig. 3.35), slightly curved bow (Figs. 3.36 and 3.37) or more strongly curved bow ("Falcon type").



Builders: Meyer Werft, Papenburg
Owner: Petroleo Brasileiro S.A. – Petrobras, Rio de Janeiro, Brazil
Yard number: 604
Type: LPG-carrier
Delivery: 30th January 1987

Tonnage	8 075 GT 2 422 NT
Deadweight	8 875 t
Length o.a.	134.00 m
Length b.p.	124.40 m
Breadth moulded	19.00 m
Depth to main deck	11.70 m
Draught	8.40 m
Speed	14.6 kn

Classification:
LR +100 A 1 liquefied gas carrier for the carriage of defined cargoes as per approved list in independent tanks at max. S.G. of 1.0, max vapour pressure 5.0 bar and a min. temp. −48 °C + LMC – UMS + Lloyd's RMC (IG), IGS

Main engine:
1 MAN/B&W diesel engine, type 7L 35MC, 3920 kW at 200 rpm
1 Tacke gear HSU – 950 D
Vulkan RATO couplings 5011, 3741, 2521

Auxiliary engines and generators:
2 Daihatsu diesel engines, type 6DL-22, 820 kW each
2 Nishishiba generators
1 Siemens shaft generator, 1500 kW
1 CJC lubricating oil fine filter HDU 427/54 L (Karberg & Hennemann)
1 Atlas-Denmark fresh water evaporator AFGU 1-S15-B3 (Karberg & Schmitz)

Equipment:
Steering gear type TELERAM R4V 340 (Hatlapa)
Electromagnetic log NAVIKNOT II/NF
Gyrocompass NAVIGAT VII
Automatic pilot NAVIPLOT II
Mainsteering NAVIGUIDE FN/AP (C. Plath)
Satellite navigator MX 4102 (Elna)
Heat exchanger (Prang)
Radiotelephone system, 2 VHF, echo sounder, 2 radar units with ARPA

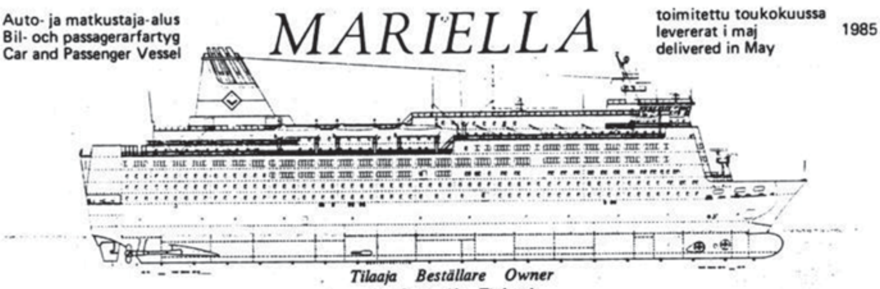
Deck machinery:
2 Comb. LPH windlasses and mooring-winches 80/32, 50 mm K3 stud link chain
2 LPH mooringwinches 80 (Hatlapa)

Accommodation for 46 persons

Capacities:	total cargo capacity	8 140 m³
	total pump capacity	720 m³/h

The ship is capable of carrying the following products:
Propane, N-butane, propylene, butylene, butadiene, ammonia, vinyl chloride and propylene oxide as well as various products from the chemical code

Fig. 3.35 LPG tanker, Meyer Werft (Germany)



Tilaaja Beställare Owner
SF Line Ab, Finland
Rakentaja Byggare Builder
WÄRTSILÄ Finland

Päämitat:		**Huvuddimensioner:**		**Principal Particulars:**	
Suurin pituus	177,00 m	Största längd	177,00 m	Length, overall	177,00 m
Leveys	28,40 m	Bredd	28,40 m	Breadth	28,40 m
Syväys	6,42 m	Djupgång	6,42 m	Draught	6,42 m
Bruttovetoisuus	37799 brt	Bruttodräktighet	37799 brt	Gross tonnage	37799 grt
Koneteho	23000 kW (31280 hv)	Maskineffekt	23000 kW (31280 hk)	Machinery output	23000 kW (31280 hp)
Nopeus	22,0 solmua	Hastighet	22,0 knop	Speed	22,0 knots
Päädieselit	4 x Wärtsilä S.E.M.T. Pielstick 12 PC 2.6 V	Huvuddieslar	4 x Wärtsilä S.E.M.T. Pielstick 12 PC 2.6 V	Main diesels	4 x Wärtsilä S.E.M.T. Pielstick 12 PC 2.6 V
Apudieselit	3 x Wärtsilä 6 R 32	Hjälpdieslar	3 x Wärtsilä 6 R 32	Aux. diesels	3 x Wärtsilä 6 R 32
Matkustajia	2500	Passagerare	2500	Passengers	2500
Miehistö	214	Besättning	214	Complement	214

Fig. 3.36 North Sea RoPax ferry of former shipyard Wärtsilä (Finland)

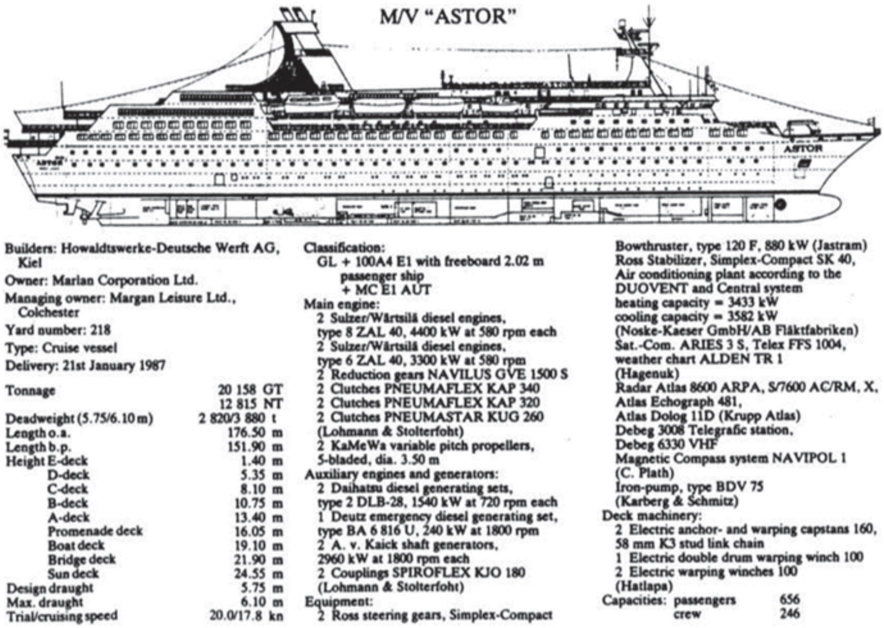


Fig. 3.37 Cruise ship of shipyard HDW (Germany)

Fig. 3.38 Large icebreaker of former shipyard Wärtsilä (Finland)

Also, bulbous bows fitted with various types of bulbs are common (see Sect. 3.4.2 for details).

Special forms:

- Icebreaker bow (Fig. 3.38)
- Sailing boat bow (Fig. 3.39)

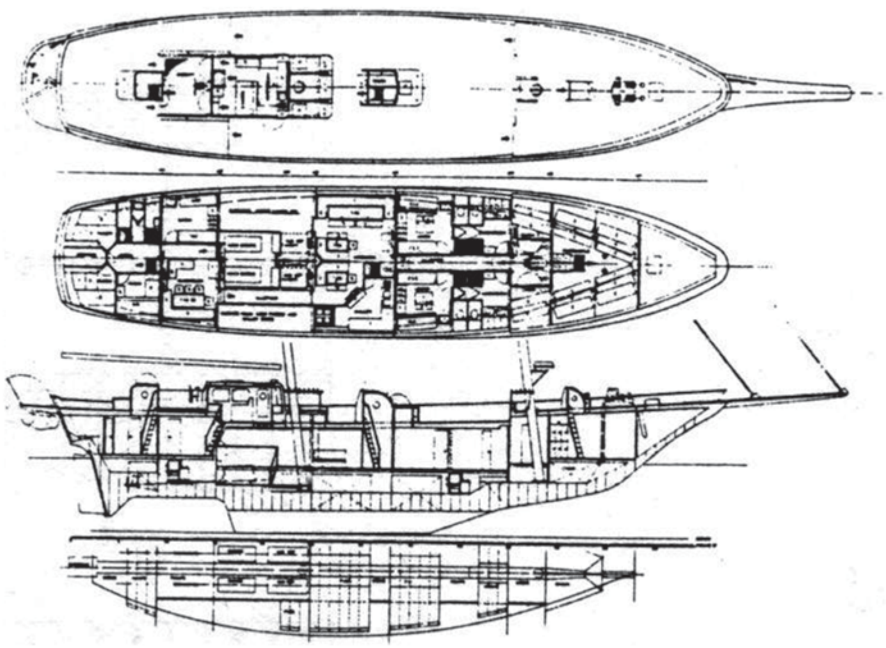


Fig. 3.39 General arrangement plans of "Young Endeavour," designed by Colin Mudie, with a cutaway external ballast keel

b. Factors Affecting the Configuration of Bow Form

- Smooth adaptation of the bow to the forward sections
- Favorable seakeeping performance in waves
- Exploitation of deck at forecastle
- Safety of underwater bow part against collision (see Sect. 3.4.2 for bulbous bows)
- Easy construction

c. Horizontal Cross Section of Bow Relationship with the Way of Construction: In older times the bow ended in strengthening beams of rectangular or trapezoidal cross section (see Fig. 3.40a). In this way the desired thin line tip of the bow could be achieved both at the design/construction WL and the neighboring waterlines around the DWL. In contemporary types the ending is more curved and the sharpness of the ending on the DWL depends on the radius of curvature of the fitted bow panels (see Fig. 3.40b).

More ideal, but expensive, is the type of casted stem (foremost part of the bow), at which the bow plate panels are welded at appropriately prepared notches, so as to produce a fine ending of the waterlines (see Fig. 3.40c, common in naval vessels).

Finally, the type of ending at a stiffener of circular cross section (see Fig. 3.40d) is an economic and satisfactory engineering solution, which is often implemented today at the bow part around the DWL.

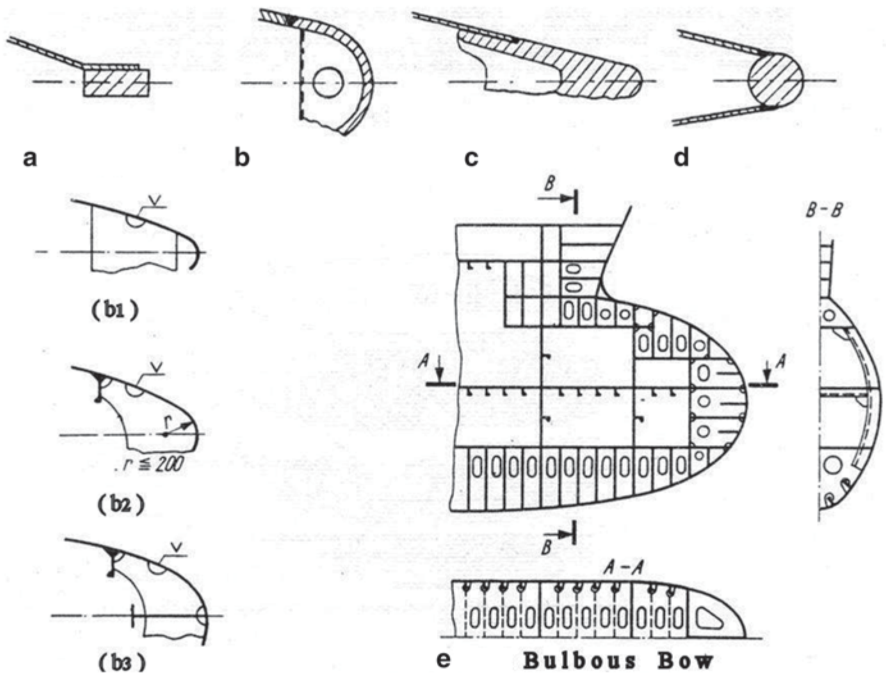


Fig. 3.40 Possible construction solutions of cross section of bow

Impact of cross section of neighboring waterlines: The influence of the form of the bow cross section at neighboring waterlines (around the design waterline) on the resistance is relatively small, particularly as the distance from DWL increases. However, regarding the wave breaking phenomenon at the bow and the corresponding wave breaking resistance, a fine cross section has to be preferred both on the design waterline and adjacent waterlines, especially for fast ships and for small freeboard heights.

Cross section above the waterline: Around the region of ship's forecastle (back), an as large as possible deck area is targeted for fitting the vessel's anchoring and mooring equipment (winches, hawse pipes, capstans, bitts). This is achieved by a relatively large radius of curvature, but not to the extent that it hinders the transition to smaller radii of curvature at the design waterline, as the fairing process of ship lines (see Fig. 3.40a diagram (b1) to (b3)).

Below waterline cross section: The expansion of the bow below the waterline is not considered unfavorable; on the contrary we may assume that under certain conditions it leads to a reduction of wave resistance (see bulbous bow). However, regardless of the existence of a bulbous bow, a voluminous bow form below the waterline facilitates the fairing of the ship lines around the keel (flat plate keel) and offers more flexibility in construction and maintenance; it allows, also, the fitting of horizontal stringers for strengthening of the bow.

Fairing of bow curvature: The radii of curvature of the waterline entrance at the bow, which vary with height, should be controlled with the introduction of virtual control lines connecting points of maximum curvature and helping to achieve smoothness of the resulting bow.

3.4.2 Bulbous Bow

a. Historical Evolution The bulbous bow is nowadays a common feature of contemporary merchant ships. The main reason for applying bulbous bows is to reduce the wave resistance, when sailing in calm water, which is an important component of ship's total resistance for relatively fast ships. For certain speeds, the resulting significant reductions of the required propulsion power are confirmed with model tests; it can be also explained with theoretical considerations and numerical simulations, at least qualitatively and to a lesser degree quantitatively (it depends on the reliability of the employed numerical prediction method) (Kerlen 1971, p. 1031; Eckert and Sharma 1970, p. 129; Kracht 1978).

The positive effect of the bulb, i.e., of a transverse and longitudinal expansion at vessel's bow below the waterline, was discovered accidentally in the early twentieth century during naval ships' model testing in the USA.[6] They were implemented initially by D. Taylor (1912) in U.S.N. naval ships. Analogous developments with German naval ships were first noted in 1914. The first non-military vessels equipped with a bulb were built in Germany, namely the fast passenger ocean liners "Bremen" and "Europa" (1929); they were followed by the French "Normandie" and Italian "Rex". The first applications to cargo ships were presented in the 1950s, initially to fast reefer ships and after about 1955 to tankers and bulk carriers. The first tanker fitted with a bulb is considered to be the Norwegian "Grena" (1957), built at the German shipyard Bremer Vulkan (Schneekluth 1985). The application of bulbous bows has now prevailed in all types of ships and is implemented even to relatively small vessels, such as oceangoing fishing ships, trawlers (oceanic fisheries), etc.

b. Form and Size of the Bulb

Typical geometry features of the bulbs are the following:

1. Transition way to the remaining part of the vessel (fairing)
2. Form of sections
3. Longitudinal profile
4. Protrusion in front of forward perpendicular
5. Position of centroid and axis
6. Area rating compared to A_M (ratio of sectional area at the fore perpendicular to midship section area)

[6] Of course, bulb/piston type bows (without transverse expansion) were found in the antique Greek "triremes" and were used for ramming enemy ships; they were applied to naval ships until the beginning of the twentieth century.

Some of the above mentioned characteristics are expressed numerically and others are purely qualitative characteristics.

c. Fairing of Bulb

c.1. Faired-In Bulb Features: faired waterlines at all drafts; bow profile was previously an almost vertical line (ocean liner "United States", Fig. 3.41), or slightly protruding (Fig. 3.42), or more strongly protruding in newer forms (Fig. 3.43).

c.2. Attached Bulb Features: cylindrical body attached to a "normal" bow; waterlines and sections in the region of the connection with the rest ship body without fairing (knuckled lines) (Fig. 3.44).

d. Form of Bulbous Bow Sections—Vertical Position of Centroid

d.1. Standard Type
Features: faired bulb; droplike shape (known as *Taylor* bulb or in German *Tropfenwulst*); centroid low, high bottom entrance ways of sections (see Fig. 3.45a).

d.2. Blohm and Voss Shipyard Type
Features: elliptical cross section, centroid at a medium height, bulb attached (see Fig. 3.45b).

d.3. VWS-Berlin Towing Tank Type: circular cross section, centroid low, bulb attached (see Fig. 3.45c).

d.4. SV Type by Maier-Form Patent: Wedge/V type cross section, high centroid, maximum width near the waterline, thin design waterline entrance, lateral profile resembling S-shape (see Fig. 3.45d). A variant of SV type is the "goose—neck, water-piercing" bulb that pierces the waterline; the latter is nowadays often applied to modern fast Ro/Ro passenger ships (see Fig. 3.45e).

The standard ending of bulb types (a) to (c) is to circular or elliptical lateral profiles, depending on the easiness of construction.

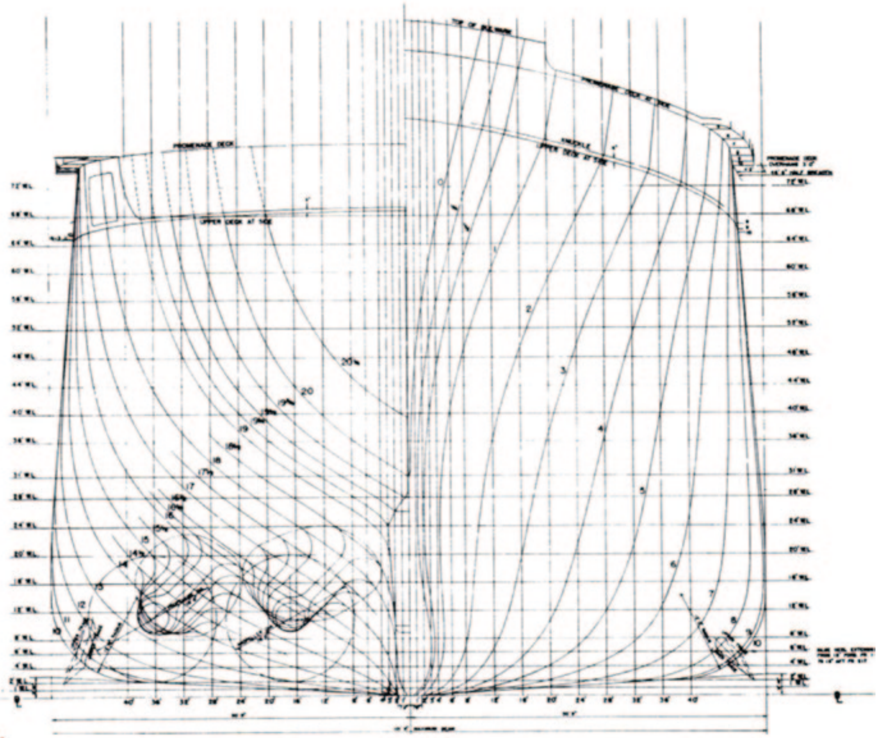
Certain bulb types, such as the wedge-type forms (e), are connected to V-type sections in the bow region, while the circular or drop (Taylor) types of bulbs fit better to U-type sections (Fig. 3.46).

e. Sectional Area of Bulb The ratio of the sectional area of the bulb at fore perpendicular A_{BT} to the midship section area A_M usually ranges between 5 and 15 %, depending on the bulb type and the design speed.

The influence of the sectional area of bulb on resistance is shown in the following indicative figure, which applies to Taylor-type bulbs and cannot be generalized. The optimum and minimum values of the ratio (A_{BT}/A_M) to achieve a minimum wave resistance generally increase with speed.

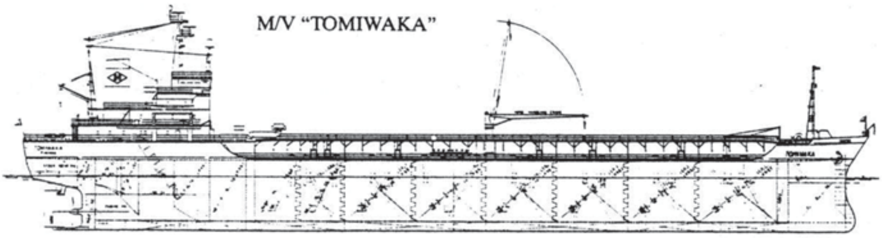
Regarding the indicated upper limits and the ratio (A_{BT}/A_M), the following should be noted:

a



b

Fig. 3.41 Lines plan of historic large passenger ship "United States"



Builders: Shikoku Dockyard Co. Ltd., Kagawa, Japan
Owner: T & M Navigation S.A.
Yard number: S 837
Type: Chemical tanker
Delivery: 25th September 1986

Tonnage	9 792 GT
	5 729 NT
Deadweight	16 933 t
Length o.a.	143.04 m
Length b.p.	133.00 m
Breadth moulded	22.40 m
Depth to main deck	11.80 m
Draught	9.015 m
Speed (full load)	abt. 13.5 kn
Speed (trial)	14.3 kn

Classification:
NK NS* (Tm or ob & C II & III) MNS*

Main engine:
1 Mitsui/B&W diesel engine, type 5L50MCE, 4600 kW at 133 rpm

Auxiliary engines and generators:
1 Yanmar diesel engine, type S185AL-UT, 441 kW at 1200 rpm
1 Generator, 500 kVA, 450 V, 60 HZ
1 Yanmar emergency diesel engine, type 4T112L-H, 53 kW at 1800 rpm
1 Generator, 55 kVA, 450 V, 60 Hz
2 Yanmar diesel engines, type M200AL-ET, 662 kW at 900 rpm each

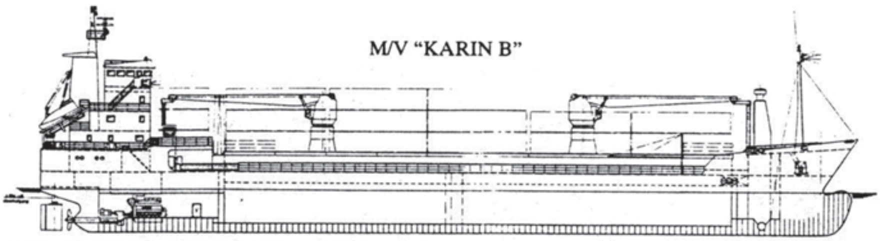
Boiler:
1 Gadelius oil fired boiler, package type, 12.0 t/h
1 Exhaust gas eco. forced circ. multi tube type, 0.6 t/h

Cargo handling:
2 Twin screw type cargo pumps, driven by diesel engine 750/400 m³/h
5 Twin screw type cargo pumps, driven by diesel engine, 400/200 m³/h
1 Twin screw type slop pump, driven by elec. motor, 120/60 m³/h
1 Strip pump, 1-tank cleaning pump, 1-ballast pump
1 Tank cleaning heater

Equipment:
Gyrocompass and autopilot, doppler log, echo sounder, N.N.S.S., Loran C

Accommodation for 29 persons
Tanks: 23 (7-CR.C.T., 14-WG.C.T., 2-Slop T)
Loading gear: 1 Hose handling crane 5 t/10 m
Total cargo capacity: 19 854 m³

Fig. 3.42 Chemical Tanker, Shikoku Shipyard (Japan)



Builders: Paul Lindenau GmbH & Co. KG Schiffswerft und Maschinenbabrik, Kiel-Friedrichsort
Owner: Emetha-Reederei GmbH & Co. KG, MS „Karin B", Emden
Yard number: S 224
Type: Multipurpose vessel
Delivery: 6th January 1987

Tonnage	3 420 GT
Deadweight	4 250 t
Length o.a.	100.00 m
Length b.p.	94.20 m
Breath moulded	14.00 m
Depth to main deck	7.45 m
Depth to tween deck	5.45 m
Draught	5.44 m
Speed (at draught 5.21 m)	12.5 kn

Classification:
GL +100 A4 E1, containerfitted, strengthened for heavy cargo, dangerous goods IMO-class 3-8 +MC E1 AUT

Main engine:
1 MWM diesel engine, type TBD 510 L 6, 1660 kW at 600 rpm
1 Reintjes reduction gear
1 Vulkan RATO coupling 2811 for main drive and one 1241 for PTO drive
1 Schaffran c.p. propeller plant type VKG 75/4, dia 2800 mm, 4 blades, material G-NiA1Bz

Auxiliary engines and generators:
2 MWM diesel engines, type TBD 234 V8, 212 kW at 1500 rpm each
2 Van Kaick generators, 245 kVA each
1 MWM Emergency diesel engine, type D 266-6, 45 kW
1 Van Kaick generator, 50 kVA
1 Van Kaick shaft generator, 245 kVA
1 CJC Filter separator WFU 27/54 (Karberg & Hennemann)
Atlas-Denmark freshwater evaporator AFGU 1-E7-80 (Karberg & Schmitz)

Equipment:
Bowthruster type 20 F, 154 kW (Jastram)
Flaprudder
Elec/hydr. steering gear
Gyrocompass and autopilot (Anschütz)
2 Radars Kelvin Hughes KH 1610
Echosounder Furuno FE 606 N (Elna)
Sat.-Nav. Navstar 602 S

Accommodation for 12 persons
1 Hold

Hatch:
62.30 × 11.10 m

Hatch covers:
Weatherdeck Multi Piggy-Back type
Tweendeck Pontoon type (Lift-on/Lift-off) (Kvaerner Brug)

Loading gear:
2 Elec/hydr. deck cranes, 25 t/16.5 m or 18 t/19.0 m (Neuenfelder Maschinenfabrik)

Total cargo capacity:

grain	5 773 m³
bale	5 631 m³

Container:

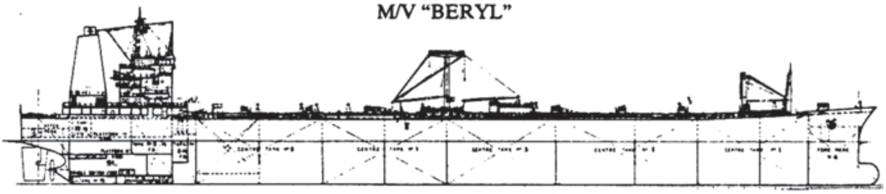
on deck	123 TEU
in hold	117 TEU
total	240 TEU

Conver-OSR container lashing and securing equipment

Reefer plugs: 9

Fig. 3.43 Multipurpose Cargo Ship, Lindenau Shipyard (Germany)

M/V "BERYL"



Builders: Gdynia Shipyard, Gdynia, Poland

Owner: First Aframax Tanker Corp., Monrovia, Liberia

Managing owner: Maritime Overseas Corp., New York, U.S.A.

Yard number: B557/3

Type: Oil tanker

Delivery: 19th May 1986

Tonnage	52 518 GT
	24 588 NT
Deadweight	84 406 t
Length o.a.	247.20 m
Length b.p.	236.00 m
Breadth moulded	41.60 m
Depth moulded	18.75 m
Design draught	12.20 m
Scantling draught	12.45 m
Speed	14.0 kn

Classification:
LR + 100 A 1 Oil Tanker + LMC, UMS, IGS, SBT-PL, PT-HT

Main engine:
1 Cegielski/Sulzer diesel engine, type 6RND90M, 14 042 kW at 112 rpm
1 Zamech 5-bladed propeller of special nicel-aluminium bronze, dia. 6400 mm

Generators:
2 Cegielski/Siemens diesel engine generating sets, type 6AL25/30, 1 FC5-566-3TA-Z, 900 kVA, 450 V, 60 Hz, 720 rpm each
1 Turbogenerator type 18, "multi-stage", 900 kVA, 450 V, 60 Hz make: Brotherhood Ltd.
1 Emergency generating set, diesel engine MAN type D2542, alternator type GA 7446, 356 kVA, 450 V, 60 Hz, 1800 rpm make: DEMP

Boiler:
2 Water-tube, double drum oil fired boilers, types KW 17330A-50/KW 17330B-50, evaporation 33 000 kg/h, make: Gdansk-Shipyard
1 Exhaust gas boiler, type Diesecon. superheat steam 5560 kg/h. Satured 1025 kg/h, make: E. Green & Son Ltd.

Equipment:
1 Kawasaki elec./hydr. steering gear, type F-21-250 IMO 50
Tiwimor windlasses and winches
Transmitters and receivers, Japan Radio
VHF-Radiotelephone, W. G. Schulz
Magnetic compass, autopilot, gyrocompass,
2 radars, Sat.-Nav., Doppler log, Sperry
Radio direction finder NAVIGON III
SFP 7000 (C. Plath)
Echosounder, Simrad
Weather facsimile receiver, Raytheon
Loran C receiver, Skipper
Decca Navigator type Mark 21

Cargo handling:
3 Cargo pumps, steam turbine driven, vertical centrifugal type C42BB16-20, cap. 3000/2500 m³/h, make: Thune Eureka
1 Stripping pumpe type KPH-275, cap. 300 m³/h, make: Shinkokinzoku

Tanks: 5 center tanks
5 PS and 5 SB tanks
2 slop tanks

Total cargo capacity: 103 510 m³

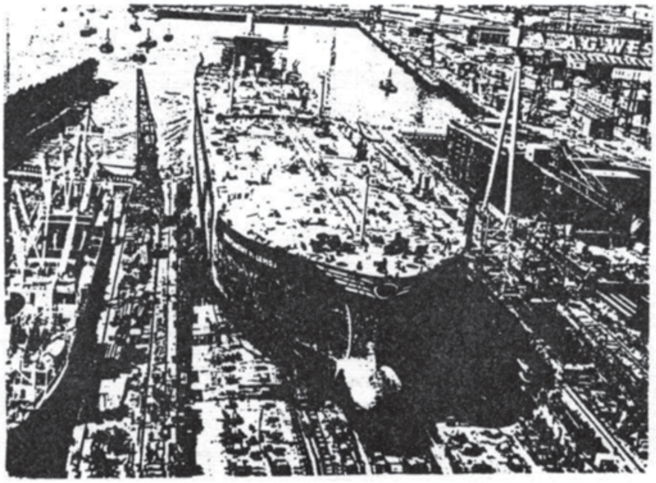


Fig. 3.44 Crude oil tanker, Gdynia shipyard (Poland)

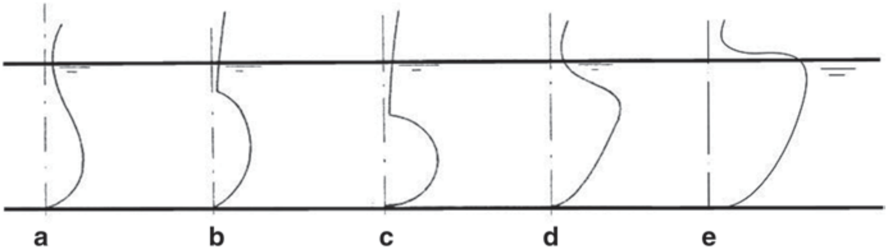


Fig. 3.45 Alternative cross sections of bulbous bows

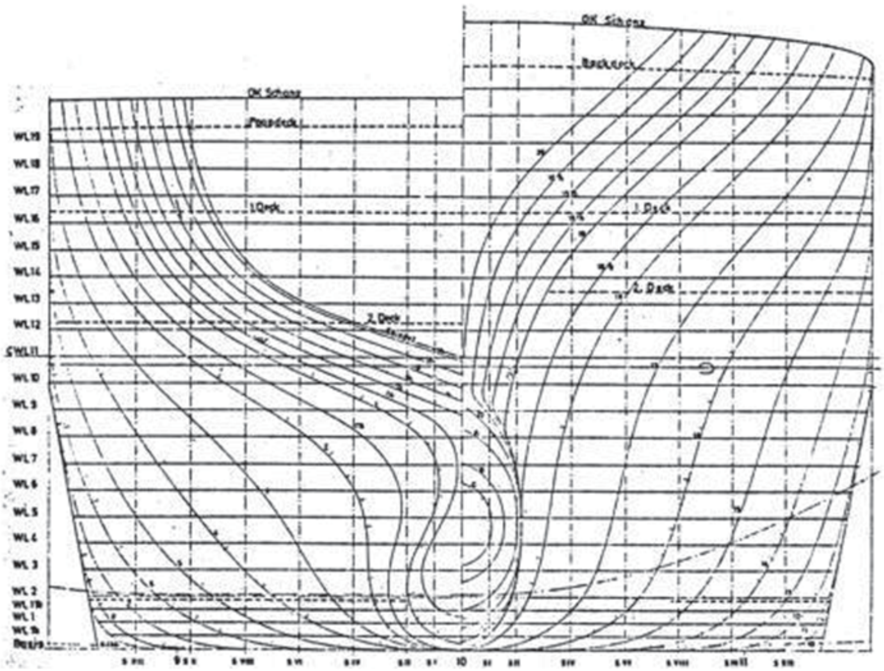


Fig. 3.46 Containership body plan with elliptical bulbous bow and drop type stern bulb (Blohm and Voss Shipyard)

- In ballast condition, the possible emergence of a large bulb can reverse but even further enhance the positive effects on (the reduction of wave) resistance. The same applies to every draft (and trim) different from the design draft.
- In heavy seas, extensive bulbs are sensitive to slamming phenomena.
- During anchoring and docking, it may induce contact damage problems with the anchor falling on bulky bulbs, if a satisfactory position of the anchor hawses at the bow is not ensured, and contact/collision damages with the peer.

The optimum ratio (A_{BT}/A_M) and generally the efficiency of a bulb can eventually be verified only by model tests, despite recent developments in computational fluid dynamics CFD for the calculation of a ship's resistance; the latter however helps to identify the optimal design of a bulb and to reduce considerably the model experimental effort (Fig. 3.47).

f. Protrusion of the Bulb in Front of Fore Perpendicular The extent of protrusion of the bulb in front of FP depends on the type of bulb and ship's speed (Froude number). For safety reasons the lateral projection of the below waterline bulb must not exceed the foremost edge of the forecastle deck. As an illustrative measure, the size of the projection may be taken about 20% B. It should also be noted that the length of the ship to be used in the calculation of ship's required freeboard (according to the International Load Line regulation), for ships with low freeboard deck,

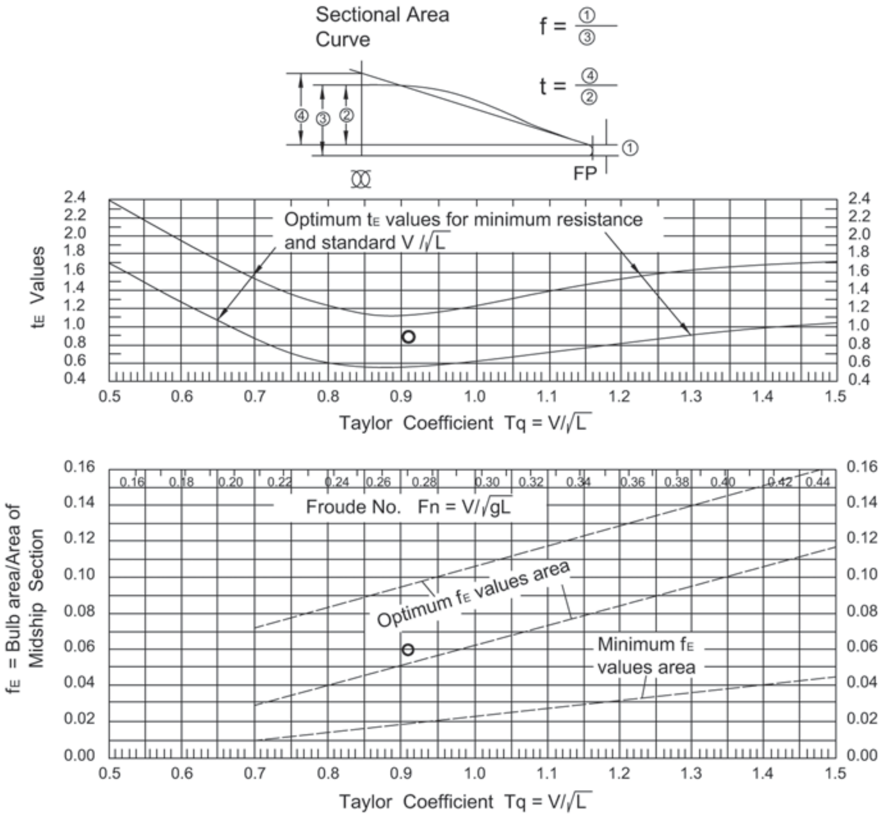


Fig. 3.47 Optimal and minimum values of the area ratio $(A_{BT}/A_M) = f_E$ for Taylor drip bulbs

may be significantly influenced (*increased*) by the extent of the lateral projection of the bulb (see Figs. 3.48, 3.49, 3.50, SV and "goose—neck" bulb).

g. Position of Centroid and Axis The centroid height of the bulb's cross section at forward perpendicular and the associated maximum width of the bulb depend on the type of bulb. Thus, for cylindrical or drop like bulbs, with relatively small effects on the disturbance of free surface and moderate reductions of wave resistance, the centroid is low; on the contrary, for wedge-type bulbs (SV type, and goose—neck) the main volume of bulb is close to the waterline.

According to the US hydrodynamicist Wigley, for drop or cylindrical bulbs, the waterline corresponding to the highest point of the bulb should be located around one bulb width below of the DWL.

Regarding the axis of the bulb, this is an imaginary line passing through the maximum transverse-ordinates of the bulb; this line can be straight (e.g., cylindrical bulbs) or continuously retreating to the aft. As a criterion for the bulbs shaping the

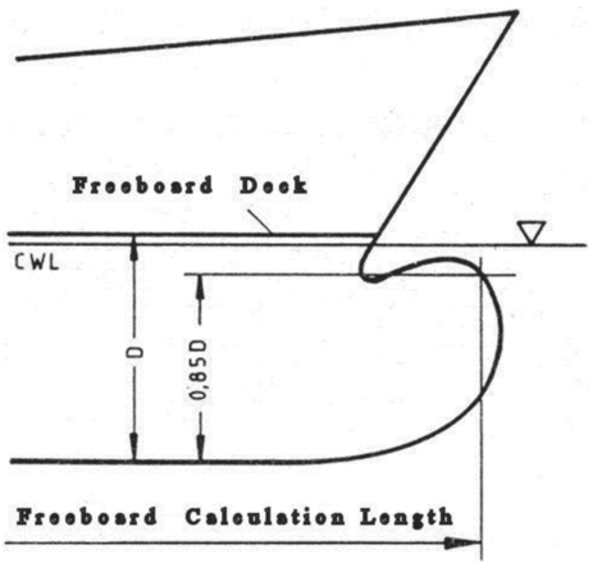


Fig. 3.48 Effect of bulbous bow protrusion on freeboard length (ICLL)

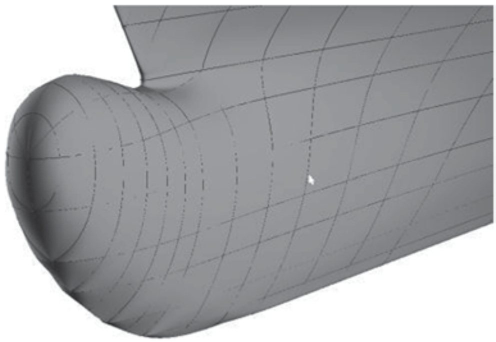


Fig. 3.49 Bulb goose-neck (Deltamanin, Finland)

direction of the stream lines of water around the bulb may be taken, which is mainly going from above the bulb toward the bottom, as can be observed in experiments.

h. Influence on Resistance and Propulsion The effects of a bulb on ship's resistance and propulsion, compared to the same ship without a bulb, are significant and complicated, thus a simple explanation is not enough to cover all effects. Especially it should be noted that the various effects of the bulbous bow on the flow around the ship vary according to the type of ship (and of different hull forms) in relation to the type of fitted bulb, in dependence on the cruising speed and ship's loading condition (actual drafts and trim).

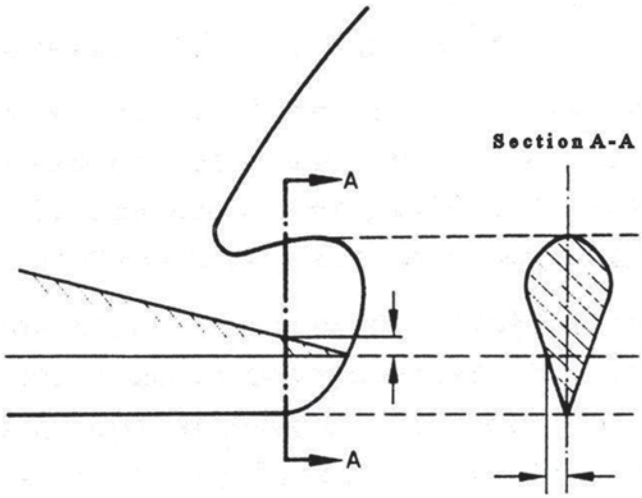


Fig. 3.50 Configuration of SV bulb

The basic qualitative hypotheses regarding the effects of a bulb on the resistance and propulsion of a ship are as following:

h.1. The bulb displaces an amount of water in front of ship's bow, thus it changes the pressure field around the hull, particularly at the bow region. Theoretically, the "hydrodynamic length" of the vessel increases and the "effective" Froude number decreases, moving the "effective" speed of the ship to regions of reduced resistance.

h.2. As mentioned above, the pressure distribution in the bow region changes and the *bow wave system* is shifted forward. The interference of the resulting bow wave system (starting with a wave crest) with the corresponding one of the forward shoulder (starting with a wave trough) and to a lesser degree with that of the stern shoulder and the hips, may attenuate the induced wave profile around the ship, so as to reduce the wave resistance at a specific design speed of a bulb (to a lesser degree for speeds different from design speed).

h.3. An independent wave system is generated by the fitting of the bulb, which can be simply considered as an independent pressure point according to Kelvin, which corresponds to a local negative pressure (due to the accelerated flow around the bulb according to Bernoulli); its superposition with the bow wave system leads to a decrease of the height of the induced wave at the bow and hence of the corresponding wave resistance. The bulb must of course be configured so that an optimum superposition of the two wave systems is achieved (see Fig. 3.51).

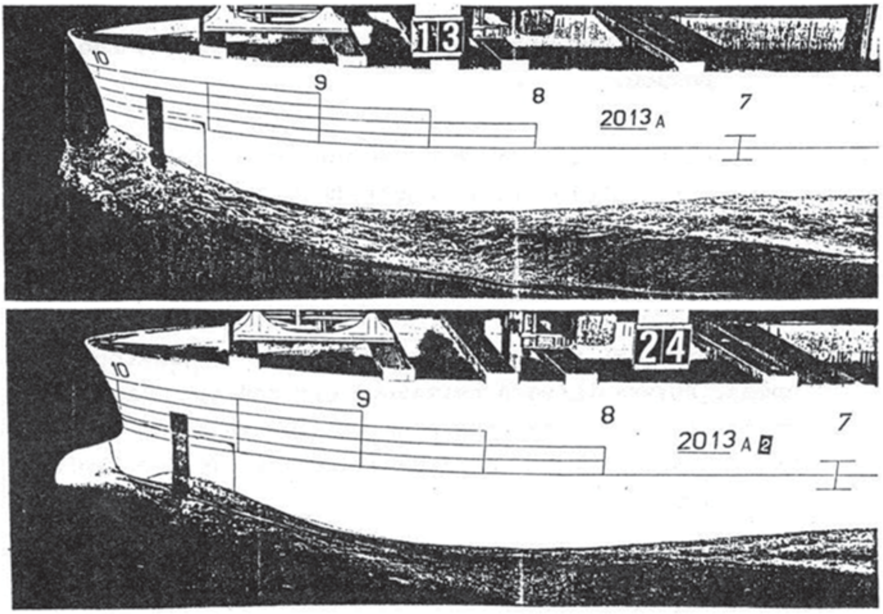


Fig. 3.51 Comparison of bow wave systems of a ship model without (*top*) and with (*bottom*) bulb at the same Froude number, $F_n = 0.218$ (experiments VWS—Berlin)

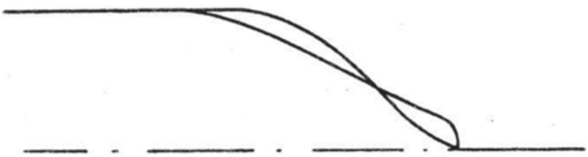


Fig. 3.52 Refinement of shoulders of sectional area curve of bulky ships with the application of a bulb

h.4. Bulky and slow ships ($F_n \cong 0.15$), like tankers and bulkcarriers, may present (without bulb) significant wave resistance, up to 40 % of the total, due to the steep slopes of the hull around the shoulders. With the implementation of the bulb, a part of the displacement corresponding to the bow region is transferred from the shoulders to the bulb, resulting in a refinement of the waterlines and a reduction of the wave resistance, as well as of the eddy making resistance (smoothing of the flow at forward shoulders) (see Fig. 3.52).

h.5. The bulb affects in addition the so-called *wave breaking resistance* related to the flow around the bow. Appropriately configured bulbs, with sharply formed waterline entrances and section profiles, reduce the breaking of the generated bow waves and the corresponding resistance.

h.6. In particular, wedge-type bulbs with much of the volume near the DWL, exhibit 'steering' properties due to induced "lift/steering" forces at the bow. Specifically, the

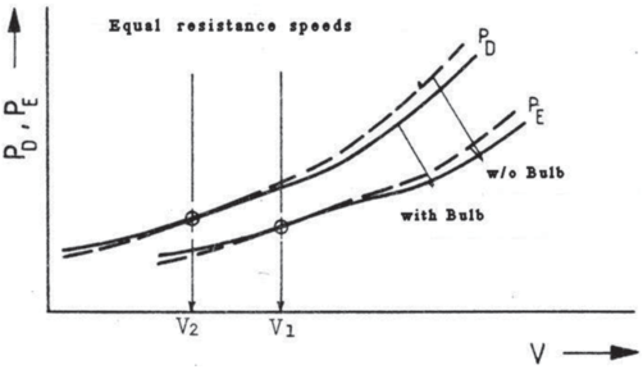


Fig. 3.53 Comparison of the required *effective power* P_E and *delivered power* P_D for a ship with and without bulb

accelerated flow around the bulb, with flow velocity components directed backward and downward, induces lift forces on the bulb and reduces the height of the bow wave.

h.7. With the existence of a bulb and the transfer of displacement below the waterline in the bow region, intense hull form changes around the waterline, which create significant transverse flow accelerations and consequently separations of the flow and generation of vortices, are reduced. The changes arising in the magnitude of the energy loss due to eddy making and the manner of recovering of the energy loss at the stern, i.e., in the region of the wake of the ship and the flow to the propeller, may explain qualitatively the positive effect of a bulb on the *propulsion* (in addition to resistance) of a ship.

h.8. The positive effects of a bulb on the efficiency of the propeller, as shown repeatedly in experiments, may be explained with the following assumptions:

The reduction of total resistance leads obviously to a reduction of the required thrust and the degree of loading of the propeller.

It has been observed in experiments that for ship speeds, which correspond to the same resistance for ship with and without the bulb (see speed V_1 in the Fig. 3.53), the propeller efficiency of the vessel with bulb is higher. This is explained by a better distribution of the wake in the propeller region (as shown by model experiments of Kracht 1978).

h.9. With the implementation of a bulb, the wetted surface of the vessel increases slightly and consequently the frictional resistance; however, this is considered insignificant in comparison to the aforementioned positive effects on other components of total resistance.

i. Magnitude of Reduction in Propulsion Power The exact rate of reduction of the required propulsion power for achieving a certain speed, by comparing a ship with and without the bulb, is practically impossible to be accurately predicted without ship model tests. In such comparisons the following should be observed:

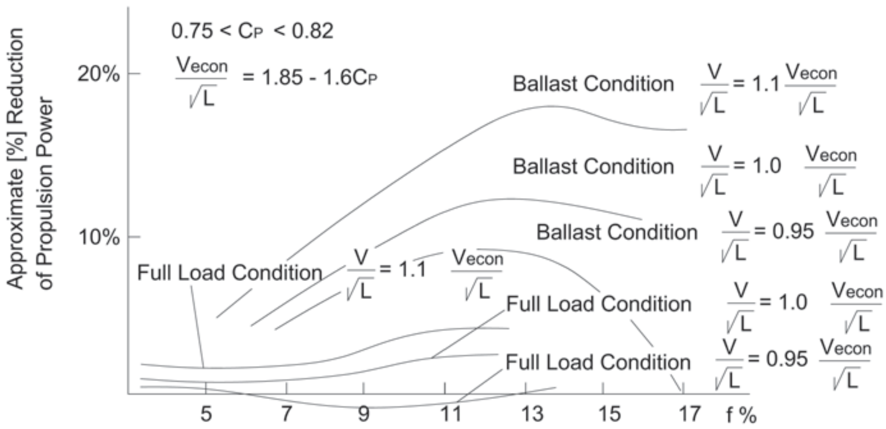


Fig. 3.54 Reduction of the required propulsion power as a function of sectional area of bulbous bow for tankers (illustrative)

- To compare ship's performance with bulb with the corresponding *optimized* hull *without bulb*
- The geometric features of the bulb and the design speed of the bulb
- The loading condition of the vessel and likely trim

Generally, the achieved reductions in required power are for vessels with high Froude numbers (≥0.27), where there is a significant wave resistance, more drastic (6–15%) than for small Froude numbers ($F_n \approx 0.15$), where the rates range between 2% and 5% at full load, but 8–15% in ballast condition. An illustrative example is shown in the following figure; it relates the rate of powering reduction to the sectional area of the bulb section expressed by $f=(A_{BT}/A_M)$, the speed and loading condition of tankers; the example holds for deeply submerged bulbs (see Fig. 3.54).

Some approximate methods for calculating ship's resistance, e.g., the FORMDATA (Guldhammer) or Dankwardt method (see Papanikolaou 2009a, Vol. 2), provide corrections of the resultant resistance in case of fitting of a bulb.

j. Optimal Position of Buoyancy Center The effect of the longitudinal position of the buoyancy center LCB for ships with bulb has not been systematically examined yet. It is considered that if the LCB position for a vessel without a bulb is optimal with respect to resistance, then the shifting of its position forward due to the fitting of a bulb (by about 0.5–0.8% L_{PP} for a bulb with $(A_{BT}/A_M)=0.10$) does not adversely affect the resistance. Instead, it is particularly favorable for bulky vessels (tankers) because of the offered flexibility in the balancing of trims by ballasting the enhanced forepeak tank.

k. Further Hydrodynamic Criteria

k.1. The course-keeping ability of the ship is hampered to certain extent with the existence of a bulbous bow. The turning capabilities and maneuvering properties of the vessel are improved due to the shift of the centroid of the lateral underwater profile to the bow. In addition, the possibility for installing a bow-thruster to improve the maneuverability is enhanced.

k.2. Performance in Waves: The effect of the bulb on ship motions in waves is complicated. Basically three phenomena are of interest:

a. Mitigation of pitch motions
b. Added resistance in waves
c. Maintaining the speed and course in waves

The decay of pitch motions increases undoubtedly with the existence of bulb due to the triggered separation of the flow around the vertically moving bulb and the disturbance of the free surface during the emergence-diving of extensive bulbs (increased wave damping). Thus, particularly in resonance/tuning regions of pitch motions (length of the incident wave length approximately equal to the ship length), a reduction of bow motion amplitude is observed. The added resistance of the ship in waves is related to the amplitude of motions, theoretically to the square of the amplitude of motions in heave and pitch, but also to the loss of energy due to motions (equivalence of damping). Thus, the effects of a bulb on added resistance are a function of the incident wave length, with respect to the length of the vessel, of the natural frequency of the vessel in all relevant degrees of freedom (especially pitch and heave), of the wave encounter frequency (which depends on the incident wave frequency, wave heading and ship's speed), the form of the hull and the bulb, and finally the displacement weight and weight distribution of the ship (longitudinal mass moment of inertia).

The maintenance of ship's speed in waves is, besides related to the added resistance, a function of the sensitivity of bow with respect to slamming in head seas. It has been shown in experiments that wedge-type bulbs with sharp bottoms shift slamming phenomena to more intense waves, compared to bulbs that are distinguished by extended, nearly flat bottoms. The latter can trigger strong slamming phenomena, vibrations, and dynamic loads on the structure.

Generally, it is believed that, vessels with bulb are not superior to those without bulb with respect to their performance in waves; however, with proper theoretical/numerical and experimental studies, they can be designed to exhibit comparable or even better seakeeping performance.

k.3. Trim: It has been observed that ships with bulb are characterized by the absence of the undesirable stern trim at high speeds. This is explained by the functionality of the bulb as a "submerged" bow-rudder due to the flow around the bulb and the induced hydrodynamic pressure/lift force.

l. Other Parameters

l.1. Bending moments: increase slightly with the lengthening of the vessel due to the bulb. Particularly important are the dynamic loads on extended/flat bottom bulbs.

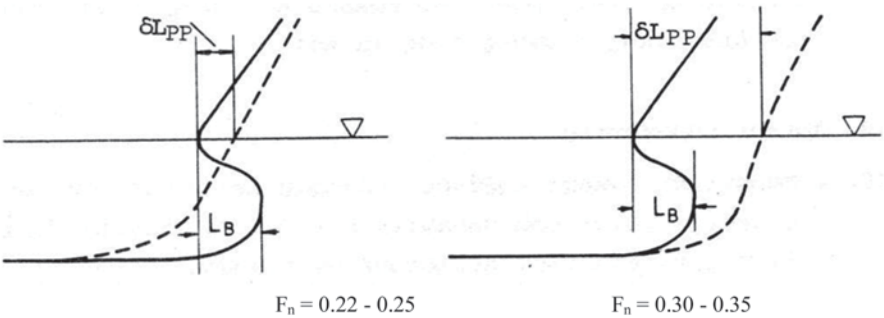


Fig. 3.55 Bow forms of the same hydrodynamic efficiency

l.2. Restrictions on Lengths: are determined by the dimensions of docks, canals, etc.

l.3. Risks of Collision:

Correct layout of the anchor chain hawseholes to avoid collision with anchors when released on the sides
Risk of bulb's contact with the end of slipways during launching
Risk of underwater collision with fixed boundaries (docking walls, piers, rocks, contact with other vessels).

l.4. Navigation in Ice: Generally the possibility of navigating in ice improves with the existence of bulb, especially when it comes to wedge shaped bulbs, which act like an icebreaker.

m. Conclusions

When considering the application of a bulb to a ship under design in view of economic criteria, in addition to the hydrodynamic factors, the designer must be account for the additional construction cost in relation to the anticipated reduced operating costs.

Schneekluth (1985) proposes the comparison of a lengthened ship by δL_{PP}, without bulb, with a ship with bulb at length L_{PP} for the same hydrodynamic "efficiency" (i.e., the same required propulsion power for certain speed) (see Fig. 3.55).

Considering comparative data regarding the propulsive power for relatively slow ships ($F_n \leq 0.24$), a lenthening by δL_{PP}, compared to a comparable bulb protrusion by L_B, was sufficient for achieving the same reduction in propulsion power, while for fast ships ($F_n \geq 0.25$) this is different (see Fig. 3.56 by Schneekluth).

Regarding the associated construction cost, what should be compared is the additional cost of the steel structure due to the elongation by δL_{PP} in relation to the cost for fitting the bulb of the presumed size of protrusion L_B (Fig. 3.57).

The designer's decision regarding the possible application of a bulb to a ship, if not specified by the owner or determined by other factors, must take into account the following:

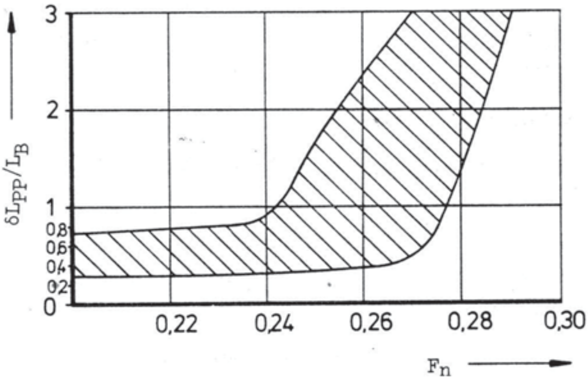


Fig. 3.56 Required lengthening of normal bow by δL_{PP} as a function of Froude number for achieving the same hydrodynamic performance with a ship with bulb of protrusion by L_B. (Schneekluth 1985)

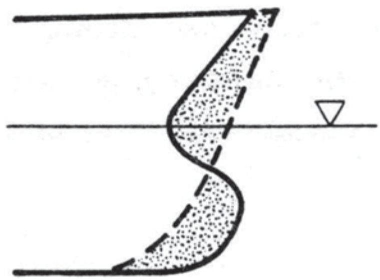


Fig. 3.57 Possible bow forms of the same steel weight

1. When it concerns deadweight carriers (like tankers and bulkcarriers) without margin with respect to the freeboard height (loading to the maximum allowable draft), the lengthening, instead of the application of a bulb, is difficult to implement due to the caused increase of the basic freeboard height according to the International Load Lines regulation.
2. For volume carriers or generally for ships without problems with respect to sufficient freeboard, it is recommended to consider the feasibility of the vessel with bulb and alternatively a lengthening without bulb based on the equivalence of required propulsion power and the additional construction cost (which is function of the built steel weight and the construction effort).

3.4.3 Parabolic Bow

For considerably full type ship hulls with $C_B \geq 0.80$, and low speeds $F_n \leq 0.18$, *parabolic* bow forms have been developed with applications to not only to tankers and bulk carriers, but also to ships with less full hulls, but with high B/T or low L/B ratios. The parabolic bow is distinguished for the parabolic or elliptical form of the design waterline, where the minor axis of the imaginary ellipse corresponds to the width of the ship. With the parabolic bow a significant part of ship's displacement

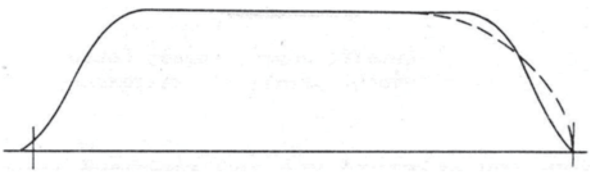


Fig. 3.58 Comparison of the sectional area curve of a tanker with normal and parabolic bow (*dashed line*)

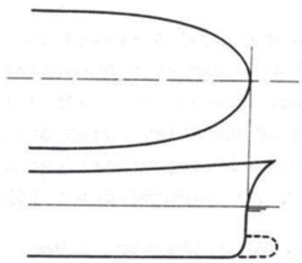


Fig. 3.59 Combination of parabolic bow and cylindrical bulb

Fig. 3.60 Example of parabolic bow on tanker

is transferred to the bow region, resulting in refinement of the forward shoulder and smoothness of the flow in this area (see Fig. 3.58).

The parabolic bow can be combined with a cylindrical, well submerged bulb (tankers and bulkcarriers, see Figs. 3.59 and 3.60).

It has been demonstrated in experiments of tanker and bulkcarrier models with parabolic bows, with $C_B > 0.8$ and small L/B ratios, that the resulting reductions of the required propulsion power, for $F_n = 0.11–0.18$ are significant. The easiness of construction and reduced building cost should be also noted.

3.5 Form of Stern

3.5.1 Forms of Stern

a. Factors Affecting the Stern Form:

- Calm water performance: low resistance, and minimization of flow separation at the stern
- Good efficiency of propulsion system (propeller/vessel interaction)
  - Streamlined flow to the propeller
  - Good relationship of wake to the thrust reduction factor, expressed by the hull efficiency coefficient:

$$h_H = \frac{1-t}{1-w}$$

- Avoidance of hull and propeller vibrations, sufficient margins/clearances between propeller, rudder and the hull of vessel
- Loss of stability in waves
- Exploitation of stern's deck area
- Construction simplicity

b. Basic Types: The various types of stern are characterized not only with respect to their above waterline form (main characteristic), but also by the wetted part of the hull.

The widely-applied basic stern types, as they have been historically developed/introduced for commercial ships, are as follows (see below Fig. 3.61):

1. The elliptical or elevated stern (Fig. 3.61a)
2. The cruiser stern (Fig. 3.61b)
3. The transom stern (Fig. 3.61c)

Of course there are many variations of these types.

c. Correlation of Stern with the Form of Sections-Waterlines: As mentioned in other sections in more details (see Sect. 4 and 3.2), there is no direct relationship of the form/type of sections and of waterlines with the type of fitted stern in the wider region of the stern of the ship. However, approaching closer the region of the stern end, which influences directly the flow to the propeller, and looking into a ship's body plan, it is observed that the way of closure of the end sections (change of curvature) is for the elliptical stern mainly in the direction of the waterlines; for the cruiser stern type this happens in the direction of the diagonals, while for the transom stern in the direction of the buttocks.

d. Applications: The *elliptical* (elevated) type of stern has almost disappeared in modern ships. It is found sometimes in the traditional Greek wooden boats of type

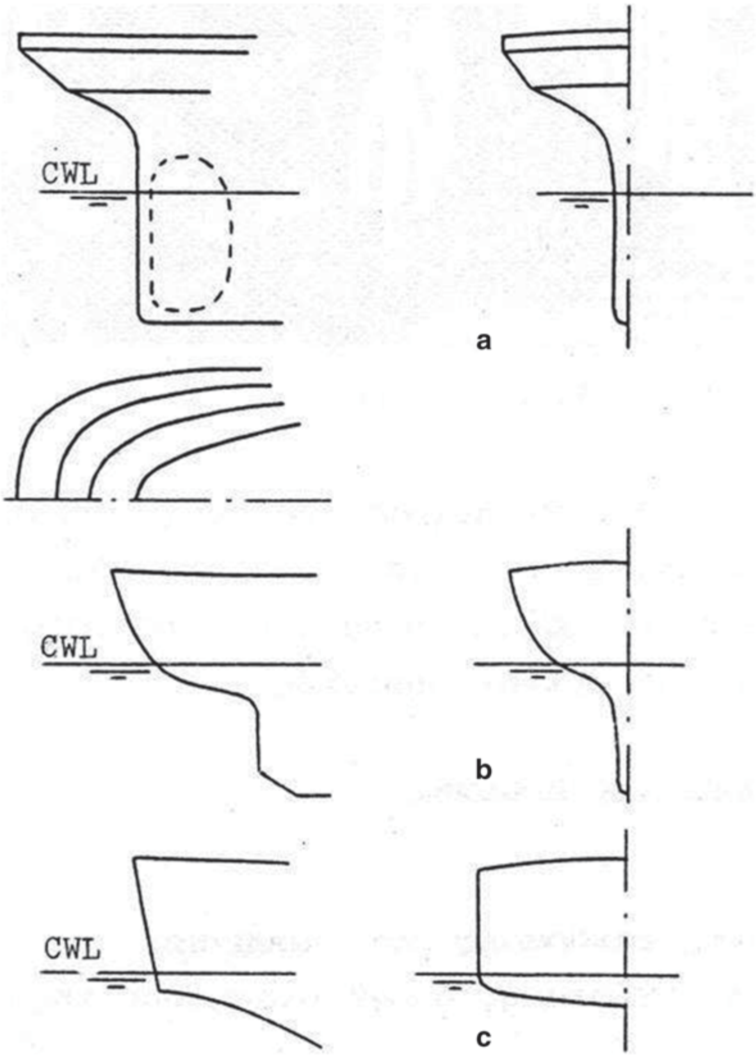


Fig. 3.61 Basic stern types

"*καραβόσκαρο*" (Fig. 3.62). The *cruiser* type of stern was practically widespread and applied to all types of commercial ships (cargo and passenger) for prolonged time after WWII; however, in the last decades, it has been displaced by the *transom* stern type. The latter type was initially preferred only for high speed small craft, but is nowadays applied to practically all types of ships, large cargo ships, ferries, naval ships, fishing boats, and even to small traditional Greek vessels of "Liberty" type.

Fig. 3.62 Traditional Greek wooden boat of type "*καραβόσκαρο*" (karavoskaro) with elliptical/elevated stern

3.5.2 Elliptic or Elevated Stern

a. **Description** Its main characteristic feature is the vertical rudder/stern-post which ends above the waterline at the bottom of the stern. The inclination of the stern, which is significant, starts above the waterline and presents a sharp change of curvature with a chine at the height of the upper deck. The termination of the waterlines, at all the levels along the sternpost is sharp (at acute angle) while it takes the form of an ellipse at the height of the upper deck.

b. **Evolution of Type** It was applied to all commercial ships since the mid-nineteenth century until the first decades of the twentieth century. During the period between the two world wars it was gradually replaced by the cruiser type stern. A peculiar type of elliptical stern can be found today on tugs; it allows the fitting of rudders of large area/height, which enhances ship's maneuverability (see Fig. 3.63).

3.5.3 Cruiser Stern

a. Historical Evolution The development of this type as a further development of the elliptical stern began in the mid-nineteenth century and was originally applied only to naval ships (hence the name). The main reason for this development was the fitting of rudder's driving mechanism/steering gear, which was at that time at the

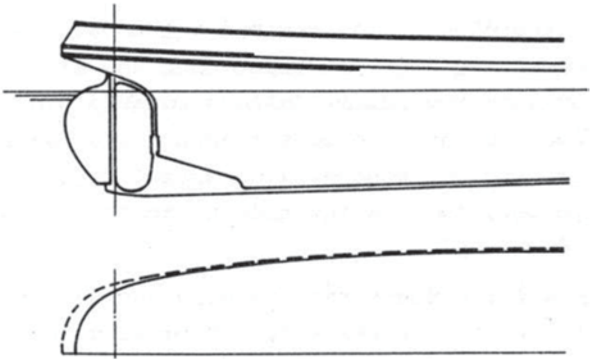


Fig. 3.63 Elliptical stern of tug boat

level of the DWL, below the armored deck. Thus the sloping part of the elliptical stern and its displacement was transferred to below the waterline. The first merchant ships fitted with cruiser stern were built in the beginning of the twentieth century. This type prevailed completely after the Second World War, but was recently displaced by the transom stern.

b. Advantages over the Elliptical Stern

- For a given length between perpendiculars the "hydrodynamic length" increases; as a result, the Froude number F_n reduces and this leads generally also to a reduction of resistance.
- The waterlines are smoother near the propeller.
- The moment of inertia of the waterplane area increases significantly, especially in case of stern trim, as the value of initial stability (GM).
- The exploitation of the stern spaces is improved.

c. Recommendation for the Shaping

- The extent at the level of the CWL should not exceed certain limits: it is usually selected as 2~3 % L_{PP}, while 4 % L_{PP} is considered as upper limit (e.g., guidelines of German Classification Society GL) (Fig. 3.64).
- The stern inclination above waterline should not be pronounced. An appropriate termination of the deck and of close waterlines may be at an almost straight profile line with a slight slope/flare to the vertical (in the lateral plan).
- Regarding the clearances between the propeller and surrounding hull structure, for ships with sternpost, the following values are recommended, according to German (GL) and Norwegian Classification Society (DNV) (Table 3.2):

For twin-propeller ships the following modifications are applied:

$$c > (0.30 - 0.01z) \cdot D \text{ (DNV)}$$

$$a > 2 \cdot D\left(\frac{A_E}{A_0}\right)/z \text{ (German navy specifications)}$$

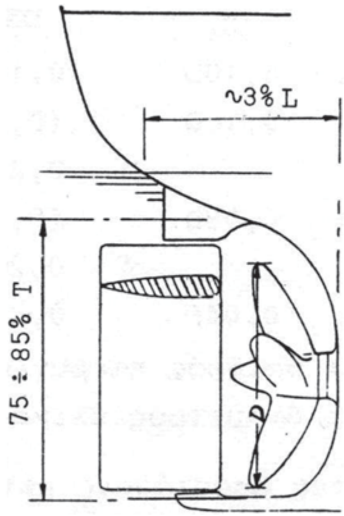


Fig. 3.64 Shape of cruiser stern

Table 3.2 Minimum distances between propeller and stern hull according to GL and DNV for single propeller ships with sternpost

	GL		DNV
a	0.10D		0.10D
b	0.18D		$(0.35-0.02\cdot z)$ D
		or	0.27D for z=4
c	0.09D		$(0.24-0.01\cdot z)$ D
		or	0.20D for z=4
e	0.04D		0.035D

z number of blades
D propeller diameter

where (A_E/A_0) is the ratio of propeller areas (expanded to disk area).

The above values are the minimum clearances of the propeller from the stern hull to avoid vibrations, impact of noise, etc. The increase of clearances, beyond the minimum requirements, has the following consequences on the efficiency of the propeller and propulsion system:

- Increase of the vertical clearances c and e implies a reduction of feasible diameter of the propeller and consequently a reduction of the propeller efficiency. However, it has been observed that the dynamic loads on the hull due to the oscillatory hydrodynamic pressure caused by the rotation of the propeller is proportional to the distance c^n, where $n \cong -1.5$ (Schneekluth 1985).
- Increase of the horizontal clearances, a, b, and f, for a given length L_{PP}, implies a more voluminous termination of the waterlines and increased resistance. However, due to the simultaneous movement of the propeller away of the sternpost the rate of thrust reduction t is reduced more strongly than the wake coefficient w, so that generally the hull efficiency coefficient $\eta_H=(1-t)/(1-w)$ increases.

Table 3.3 Effects of horizontal distances of propeller-rudder (a) and of propeller-sternpost (f) on the propulsive efficiency η_D by Schneekluth (Fig. 3.65)

a (%D)	$\delta\eta_D$ (%)	f (%D)	$\delta\eta_D$ (%)
3	+5.2	6	−0.5
4	+2.7	7	−0.2
4	+0.7	8	Basis
6	Basis	10	+0.5
10	−2.3	15	+1.6
15	−5.2	20	+2.8

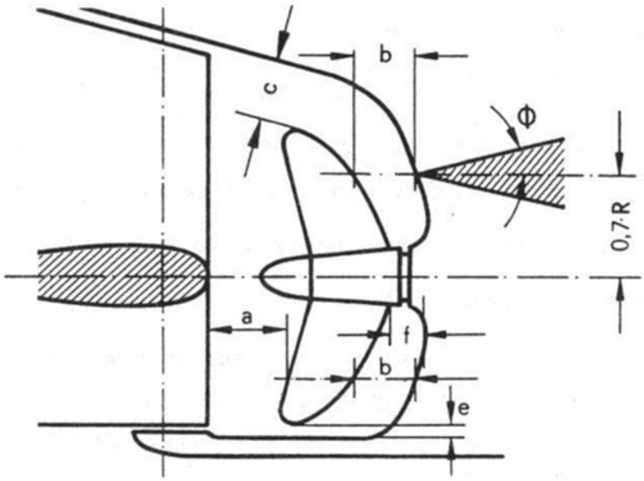


Fig. 3.65 Clearances between propeller and stern hull for ships with sternpost

- Increase of the horizontal clearance from the rudder a (%D) can lead to an increase or decrease of the propulsive efficiency η_D. Depending on the form of the rudder and stern, the following phenomena arise and needs to be assessed:
- Influence of induced forces on the rudder
- Regaining of energy of angular momentum in the wake of the propeller
- Regaining of energy of vortices generated behind the propeller

These effects can be clearly observed in model experiments of self-propelled models with and without a rudder.

In the following table the effects of clearances on the propulsive efficiency factor η_D are given by Schneekluth (1985; Tables 3.3 and 3.4):

- For ships without sternpost (suspended rudder), the values given in Table 3.4 for the tolerances are proposed, which apply equally to transom sterns (see Fig. 3.66).

The advantages of a stern without stern/rudderpost are:

1. Reduction of resistance due to the absence of rudderpost and the possibility of lengthening of the waterline
2. Reduction of surfaces that are receptors of dynamic, thrust excitations

Table 3.4 Clearances between propeller and stern hull for suspended/hanging rudder by Abrahamsen (Fig. 3.66)

a = 0.09D
b = 0.15D or D (1 + Cs)
c = 0.08–0.15D
Where
$Cs = T/(\rho n_P^2 D^4)$ nondimensional thrust coefficient
T: Propeller thrust force
n_P: Propeller revolutions

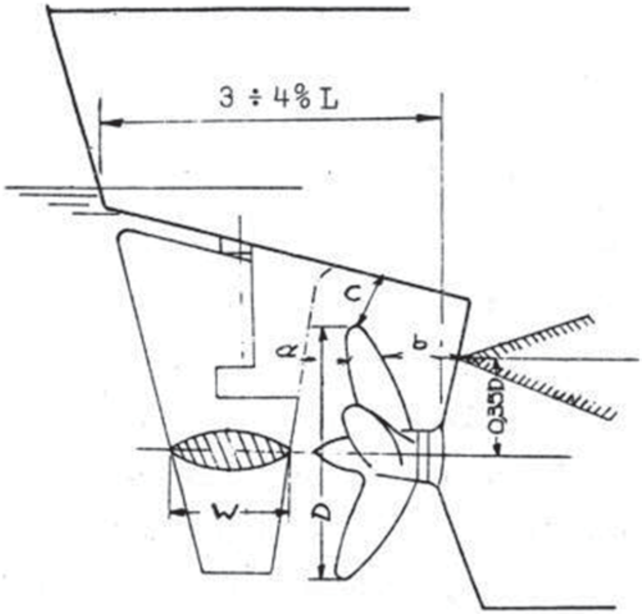


Fig. 3.66 Clearances between propeller and stern hull for suspended rudder (without sternpost)

3. Fitting/use of larger diameter propeller

The disadvantages include:

1. More difficult mounting/bearing of the rudder axis
2. Particular rudder vibrations due to way of rudder mounting

d. Special Forms of Cruiser Stern

- “Canoe” type stern on sailing boats.
- Ellipsoidal on tugboats, pilot boats, and small boats.

3.5.4 Transom Stern

Evolution of Type The transom stern (German: Spiegelheck) may be regarded as a further development of the cruiser stern; it is also an independent development of

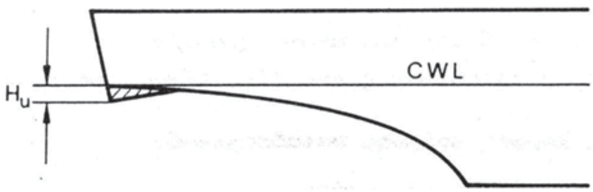


Fig. 3.67 Transom stern with wedge

a stern type required for the operation for high speed crafts. As an evolution of the cruiser stern it was created by cutting off the curved termination of the stern and replacing it with a flat surface, which simplified the fitting of ship's end of stern panel plates. Initially, it has been applied to several fast cargo ships, like fast reefer ships (in the 1960s), but nowadays is applied to all known types of commercial and navy ships.

As stern type for high speed craft, e.g., small attack and naval ships operating at high Froude numbers, it is designed to reduce resistance via two main effects:

- For fully submerged transom stern and high speeds the separation/detachment of the flow should takes place deliberately at the edges of the transom without generation of strong vortices (in contrast to the situation at low speeds).
- Especially, when adding a stern wedge at the bottom of the transom (see Fig. 3.67), a reduction of the height of the generated wave behind the stern is achieved, while in addition a stern-up moment is created (due to the induced lift forces on the wedge), so as to balance the developed running (dynamic) stern trim of the vessel.

Various types of transom stern are shown in the Fig. 3.68 below:

a. (a): high-speed boat
b. (b): naval ships
c. (c): cargo ships
d. (d1) to (d5): various forms

b. Advantages Against Cruiser Stern

1. Better exploitation of deck area
2. Simplification of construction
3. Additional buoyancy/lift at the stern with the possibility of balancing stern trims
4. Increase of waterplane moment of inertia and of initial stability ($\overline{BM}$)
5. For high speeds, reduction of resistance due to control of flow separation point and the creation of vortices
6. For high speed boats ($V/\sqrt{L} > 1.5$) the following also holds:

   a. Decreased ventilating of propeller and rudder
   b. Ensuring at least atmospheric pressure at the height of sternpost
   c. Smooth flow to the propeller
   d. Shifting the cavitation point of the propeller to higher speeds

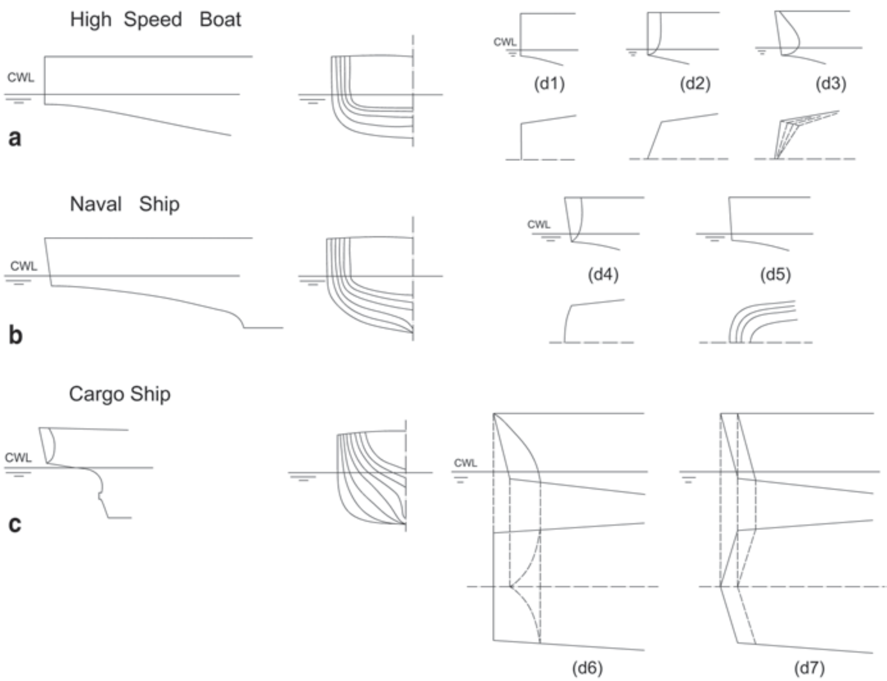


Fig. 3.68 Various types of transom sterns

c. Disadvantages Compared to Cruiser Stern

1. Increase of resistance at low speeds (not always)
2. Decrease of propulsive efficiency η_D and hull efficiency factor η_H due to the anticipated reduction of the wake coefficient w compared to cruiser stern hulls.
3. Increase of hull vibrations due to larger projected area to the propeller, resulting in requirements to increase the clearances between propeller and stern hull or to reduce the diameter of the propeller. Thus, for fast ships ($F_n > 0.3$), with transom stern form, the following is applied to the clearances according to Germanischer Lloyd (see Fig. 3.66):

$$a \geq 2(A_E/A_D) \cdot D/z$$

and

$$c \geq 0.25D$$

4. Worse performance in waves due to:

a. The shift of the pitching axis to the stern (increased movements of bow)
b. Drastic reduction of dynamic stability in waves by the possible emergence of the stern (loss of waterplane area)

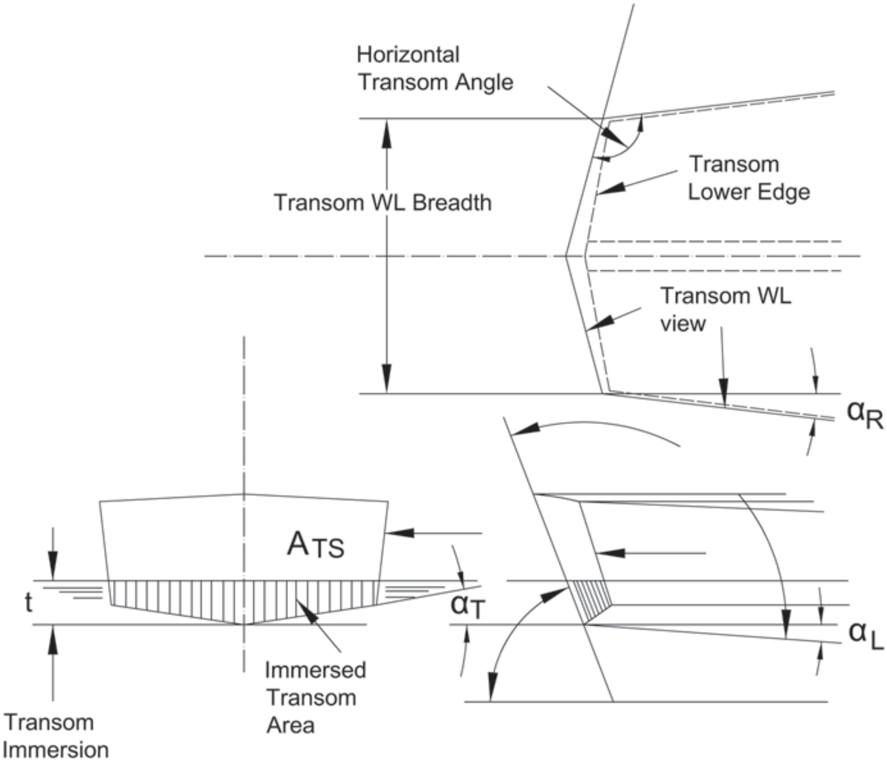


Fig. 3.69 Schematic representation of transom arrangement

c. Slamming at the stern (pounding) in the case of excitation by following seas and severe deck wetting

d. Guidelines for Transom Stern Design

d.1 Submergence Extent: Targeting a possible resistance reduction by control of the flow separation at the edge of the transom, the submergence of the lower edge of the transom is recommended to be taken according to the following guidance values:

$F_n < 0.3$: The lower edge of the transom should be located slightly above the CWL, so as to submerge slightly in the generated stern wave

$F_n \cong 0.3$: Also relatively small transom, lower edge slightly submerged

$F_n \cong 0.4$: Transom is recommended with a wedge-shaped ending, submergence of lower edge $t \cong (0.1 - 0.15) \cdot T$ or $A_{TS}/A_M \cong 0.09$, where: A_{TS}: projected area of submerged transom (see Fig. 3.69)

$F_n \geq 0.5$: Transom is recommended with a wedge of width about the beam of the vessel and submergence of lower edge $t \cong (0.15 - 0.20) \cdot T$ or $A_{TS}/A_M \cong 0.10$

$F_n = 0.6$: Further increase of the immersion of lower edge $A_{TS}/A_M \cong 0.13$

Remarks:

1. The above values are certainly indicative.
2. The possible reduction of resistance can be expected only for high Froude numbers ($F_n \geq 0.30$) and well submerged lower edge of the transom (mainly for high-speed craft, torpedo boats, less for cargo ships or ferries).

d.2 Breadth at Waterline: The breadth of the transom at the design waterline is a function of the slope of the waterlines (against ship's symmetry plan) around the CWL. This inclination should be as small as possible to avoid early flow separation at the hips of the vessel. Typical maximum values of the inclination angle of the waterlines at the transom are: $\alpha_R \cong 12-13°$. The same also applies to the angles of the diagonals with respect to the plane of symmetry. Thus the width of the transom in the waterline can be up to 80–90 % of the maximum vessel's beam.

d.3 Inclination of Transom Bottom: The inclination of the bottom of the transom α_T, measured in the transverse plane between transom's bottom and waterline (see Fig. 3.69), should be between 15° and 20° to avoid intense pounding. Also, the corresponding inclination of bottom α_L in a horizontal reference plane parallel to the longitudinal sections (buttocks), should be kept relatively constant, especially near the transom (max = 15°). Finally, a slight inclination in the lateral profile of transom (corresponding to a protrusion of the deck) against the vertical is recommended for improving ship's protection against deck wetness by incoming following seas.

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