The Ship Design Problem

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Key References

1.1 Introduction to the Ship Design Problem

1.1.1 Introduction

The ship design problem can be considered under four separate groups. These groups identify for a particular vessel what is likely to be the critical design criteria. They can be considered as:

- Deadweight carriers;
- Capacity carriers;
- Linear dimension vessels;
- Rule ships.

However although one criteria might be the critical governing criteria with respect to the design, the other criteria also need to be considered as relevant. Although the ship and payload type might place the emphasis on one category of design problem, all ship designs need to seek a balance of all relevant design considerations. For example, a bulk carrier design would address the fundamental requirement of providing a solution to provide the required deadweight and to have proportions and form to meet the design speed while balancing the deadweight equation above, but the capacity of the design would also need to be considered to ensure a stowage rate appropriate to the range of cargos to be carried. Similarly a capacity carrier also needs to balance at the design draught. Additionally there could be linear constraints on dimensions and mandatory requirements to comply with additional rules.

1.1.2 Deadweight carriers

These are weight limited designs such as bulk carriers and general cargo. Weight is critical for designs intended to carry heavy cargoes in relation to the volume available to stow the cargo. The relationship between volume available for cargo stowage and cargo mass is stowage rate. The limiting value of stowage rate below which a design can be considered a deadweight carrier is dependent on several factors such as: deadweight to displacement ratio; the proportion of payload deadweight to the total deadweight; draught to depth ratio and the ratio of cargo capacity to total hull volume. Watson [1], by taking typical values, suggests a limit of 1.29 $m^3/\ tonne$. Although general cargo vessels are classed as such with stowage rates of between 1.40 and 1.80 $m^3/\ tonne$. Such vessels are therefore likely to have remaining hold volume when loaded with the design deadweight and floating at the corresponding design draught.

The fundamental governing weight equations relating to ships dimensions are simply:

$$\Delta_{Ext.} \approx 1.005(\rho C_B LBT) = Lightship + Deadweight$$

where

$$Lightship = Steel\ mass + Outfit + Machinery\ mass$$

and

$$Deadweight = Payload\ mass + Consumables.$$

The factor 1.005 allows for shell and appendage displacement to allow the extreme displacement to be estimated. This factor can be revised according to ship type and size.

1.1.3 Capacity carriers

Designs can be considered to be volume or capacity driven if the stowage rate is higher than those considered previously as the limiting criteria for deadweight carriers. Typical volume limited designs are passenger vessels, LNG, CNG, LPG, warships, MARPOL tankers etc.

The fundamental governing fundamental volume equation relating to ship dimensions is

$$\nabla_{Hull} = C_B^{'} LBD' = \nabla_{Cargo} + \nabla_{Other\,spaces}$$
$$= \frac{(Total\ volume\ cargo - Cargo\ volume\ above\ upper\ deck)}{(1-S)} + \nabla_{Other\,spaces}$$

Where $C_B^{'}$ is C_B at *D*, *D'* is the capacity depth including allowance for sheer and camber as appropriate, $\nabla_{Other\,spaces}$ includes volume required for accommodation, stores, machinery, tanks, non-useable spaces etc in the hull and *S* is a deduction for structure as a proportion of moulded volume.

It should be noted there is no explicit dependence on *T* in the above equation, however there is still an implicit relationship between the C_B required for the required form for the design speed at the design draught and the block coefficient at the depth, $C_B^{'}$.

Rather than a dependence on the mass components of lightship and deadweight the emphasis is on the capacity implications of these components, i.e. not just the payload volume but also the volume required for consumables, volume of machinery and outfit as well as the loss to moulded volume due to internal structure.

1.1.4 Linear Dimension Ships

Ship constrained due to trade, function, or route. Typical examples are containerships, RoRo, RoPax, seaway max vessels, car carrier, aircraft carrier etc.

These linear constraints can be considered in two groups: internal and external constraints.

Typical external dimensional constraints:
Panama Canal; $L \leq 289.56m, B \leq 32.31m, T \leq 12.04m, T_{AIR} \leq 57.91m$

St. Lawrence Seaway; $L \le 225.5m, B \le 22.86m, T \le 7.9m, T_{AIR} \le 35.5m$
Kiel Canal; $L \le 315.0m, B \le 40.0m, T \le 9.5m$
Dover and Malaca straits; $T \le 22.86m$
Suez canal; $T \le 18.29m$

Typical internal dimensional constraints:
20’ Container; $6.1 \times 2.44 \times 2.59 = 1$ *TEU* (20 / 24 tonnes).
40’ Container, $12.2 \times 2.44 \times 2.59 = 2$ *TEU* (30 tonnes).
Non standard containers includes 35’, 45’, 48’ and 53’variants.
Lane width and length for RoRo dependent on vehicle/ trailer/ swap body/ cassette widths/length

1.1.5 Rule Ships

Benford proposal of ships where specific rules drive the design size.

These can include vessels meeting specific vessel class rules such as formula racing craft, fishing vessels etc.

1.2 Deadweight Displacement Ratio and Capacity Hull Volume Ratio

1.2.1 Deadweight Displacement Ratio, K_D

As introduced, for deadweight carriers

$$\Delta_{Ex} \approx 1.005 \rho C_B LBT$$

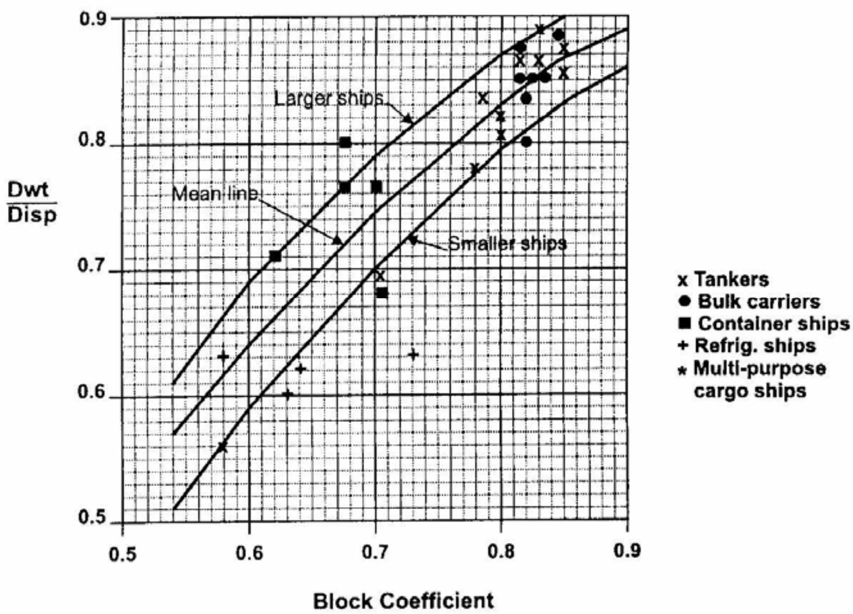
where $\Delta_{Ex} = Lightship + Deadweight$. This can alternatively be expressed in the form of deadweight to displacement ratio:

$$\Delta = \frac{Deadweight}{K_D}$$

where K_D is deadweight displacement ratio.

This ratio is a common starting point for a design although it relies on a correct estimate of K_D, which is almost impossible for modern cargo ships. The advantage of K_D is that it gives an immediate estimate of displacement for a specified deadweight.

It most commonly based on total deadweight rather than cargo deadweight (payload) as total deadweight is a more readily available figure and is independent of estimating consumable mass. The data is sometimes presented graphically as a plot of K_D against Δ.



[1]

The ratio varies for with type of ship, speed, endurance and ‘quality’. In general the larger the vessel, the slower and more basic the ship the higher the value.

Values of K_D vary considerably for similar ship types and designs, this can be due to:

- Ship speed: For given dimensions and increase in speed will increase the installed power. Accordingly machinery weight increases the lightship and hence reduces the available deadweight. It is also likely that an increase in power will results in higher fuel consumption and the need to bunker more fuel, which will also reduce the payload mass for a given deadweight.
- C_B: If C_B is reduced the available displacement is reduced but there is little accompanying reduction in lightship with the result the deadweight is reduced.
- Voluntary reduction of draught: The operating draught may be less than the maximum allowed by the freeboard rules or by the choice of scantlings. The vessel is therefore carrying less deadweight than the maximum possible.
- Variations in propulsion machinery: Different machinery arrangements for a given power can result in significantly different machinery mass and hence K_D. For example a slow speed diesel would be heavier than a medium speed diesel and gearbox. Even greater differences can result with more contemporary machinery systems such as diesel electric and podded drives.
- Variations in construction: Differences can range for reasons such as variation in scantling choice, e.g. the inclusion of additional strengthening for an ore carrying bulk carrier. This can also be influenced by choice of classification society, different societies can result in different scantlings. Better analysis and understanding has also resulted in the scantlings required by the class societies for some ship types changing with again an influence on lightship and K_D.
- Variations in equipment and outfit: Outfit varies with special requirements such as refrigeration or level of handling gear. Contemporary outfit tends to be lighter in accommodation spaces than older vessels again resulting changes in K_D between older design and more contemporary ones.

K_D is based on deadweight and displacement at a particular T. It is normally considered in four general groups:

- Bulk carriers;
- Tankers;
- Container ships;
- Reefers.

For bulk carriers design and full load displacement are identical. Tankers also used to comply with this but now are volume based designs due the MARPOL requirement for segregated water ballast tanks. It is good practice when comparing designs on the basis of K_D to use *design deadweight* at the design draught as the governing deadweight for design purposes (i.e. the dimensions and C_B are considered at this displacement).

- Bulk carriers and tankers (C_B = 0.8 to 0.86): $K_D \approx$ 0.78 to 0.88 for deadweight of 15000 tonnes to 200000 tonnes (For ore carrier it is lower; $K_D \approx$ 0.72 to 0.77 and general purpose cargo $K_D \approx$ 0.62 to 0.72).
- Container ships (C_B = 0.65 to 0.72): $K_D \approx$ 0.69 to 0.78 for deadweight of 10000 tonnes to 90000 tonnes.
- Reefer ships (C_B = 0.55 to 0.65): $K_D \approx$ 0.59 to 0.64 for deadweight of 6000 tonnes to 15000 tonnes.

The variation in K_D for the first group is in the order of 5% to 15%. For the other two groups the variation can be more significant as a capacity based problem with large variation in K_D.

1.2.2 Capacity Hull Volume Ratio, K_C

For capacity carriers, where the the design equation was previously stated as:

$$\nabla_{Hull} = C_B^{'} LBD' = \nabla_{Cargo} + \nabla_{Other\,spaces}$$
$$= \frac{(Total\ volume\ cargo - cargo\ volume\ above\ upper\ deck)}{(1-S)} + \nabla_{Other\,spaces}$$

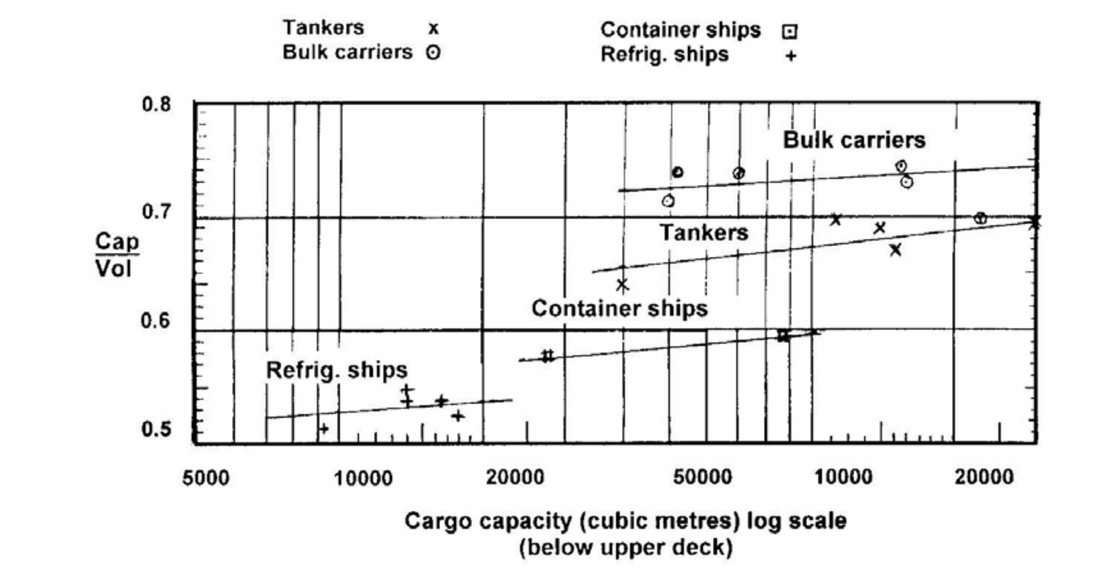
where $C_B^{'}$ is C_B at D, D' is the capacity depth including allowance for sheer and camber as appropriate, $\nabla_{Other\,spaces}$ includes volume required for accommodation, stores, machinery, tanks, non-useable spaces etc. in the hull and S is a deduction for structure as a proportion of moulded volume.

A similar ratio to the deadweight based K_D can be derived for capacity carriers:

$$\nabla_{Hull} = \frac{Total\ volume\ cargo - cargo\ volume\ above\ upper\ deck}{K_C}$$

- Bulk carriers (C_B = 0.8 to 0.86): $K_C \approx$ 0.73.
- Tanker (C_B = 0.8 to 0.86): $K_C \approx$ 0.68.
- Container ships: (C_B = 0.65 to 0.72): $K_C \approx$ 0.55. Better optimized containership design might achieve $K_C \approx$ 0.58 to 0.59 (based on 38.5 m^3 for 1TEU).
- Reefer ships: (C_B = 0.55 to 0.65): $K_C \approx$ 0.53.

It can provide an easier approach for determining the required ∇_{Hull} and so enable an estimate of dimensions and form. It can be plotted as K_C against cargo capacity below upper deck.



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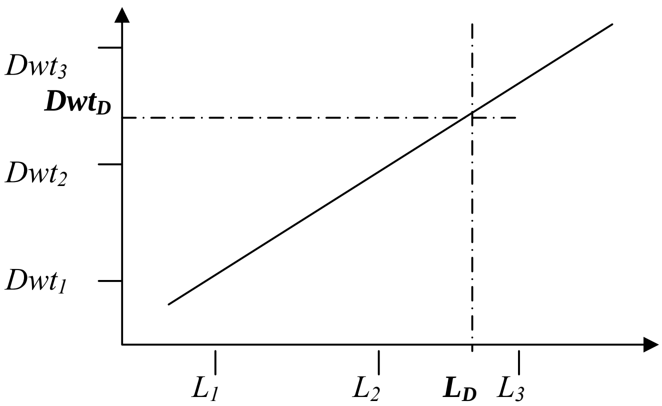
It is interesting to note that bulk carriers proved to be the most efficient in terms of K_C. The need for segregated ballast tanks explains the slightly lower value for MARPOL tankers. Reefers have the lowest value as a consequence of high speed, fine lines, insulation capacity etc.

The problems discussed at length with respect to K_D also apply to K_C; with the relevant arguments now being in terms of the capacity implications of the issues raised. The expressions for K_D and K_C are a useful means of describing the problem and providing understanding of existing designs but they do not necessarily provide a sufficiently rigorous basis for more than the simplest of design purposes. They do not necessarily reflect contemporary influences on the design, such as innovation in structure outfit or machinery, unless the basis vessel on which their estimate is based reflects such features of the design vessel. However there is a change to producing ships of more standard type designs driven by the need to produce vessels more competitively so in such circumstances where there is less variation in designs the use of such design ratios becomes a more relevant approach.

1.3 Initial Point Design Methods

The original **Watson (1962)** approach to solving the deadweight problem was based on taking 'three trial ships', for which dimensions and weights were estimated encompassing the likely required design point to provide a solution for the required deadweight and speed. This method is involved but has the advantage that variations in design affecting the lightship can be included, such as machinery arrangement, degree of outfit etc and no estimate of displacement based on the design deadweight is required. The method is simply summarized below:

Quantity estimated	**Assumed range of L**		
	$\mathbf{L_1}$	$\mathbf{L_2}$	$\mathbf{L_3}$
B	B_1	B_2	B_3
T	T_1	T_2	T_3
(D)	D_1	D_2	D_3
$\mathbf{C_B}$	C_{B1}	C_{B2}	C_{B3}
$\Delta = \rho LBTC_B$	Δ_1	Δ_2	Δ_3
$\Delta_{Ext} \approx 1.005\Delta$	$\Delta_{Ext\ 1}$	$\Delta_{Ext\ 2}$	$\Delta_{Ext\ 3}$
Machinery mass	M_1	M_2	M_3
Outfit mass	O_1	O_2	O_3
Steel mass	S_1	S_2	S_3
Lightship = M+O+S	Ls_1	Ls_2	Ls_3
Deadweight = $\Delta_{Ext} - Lightship$	Dwt_1	Dwt_2	Dwt_3



Other dimensions based on solution for L_D, check deadweight and iterate as necessary.

The **Watson (1975)** approach utilises the dimensional ratios to provide a cubic equation in terms of L.

$$\Delta = \rho(1.005)C_B L^3 (B/L)(B/L \cdot D/B \cdot T/D) \text{ and hence } L = \left(\frac{\Delta (L/B)^2 (B/D)}{\rho(1.005)C_B (T/D)} \right)^{1/3}$$

Appropriate estimates of the dimensional rations can then be used and the equation solved by making a first estimate of C_B and iterating. However this method requires the need to determine the design Δ based on the required deadweight. This then relies on an appropriate estimate of K_D.

Similarly, for capacity carrier design, there was the capacity carrier design diagram approach that enabled a systematic approach to investigating the relationship between total hull capacity as a function of cubic numeral (*LBD*) for a range of $C_B^{'}$ and in turn with respect to the required C_B to meet the design speed. This diagram is useful means of describing the problem but relatively complex to construct. **Watson** proposes a simpler approach analogous to the deadweight approach by converting the capacity equation into again a cubic equation in terms of *L*.

$$L = \left(\frac{\nabla_H (L/B)^2 (B/D)}{C_B^{'}} \right)^{1/3}$$

This required use of the same approximate approach to relate C_B and $C_B^{'}$.

$$C_B^{'} = C_B + (1 - C_B)\frac{(0.8D - T)}{3T}$$

1.4 Useful Empirical Relationships for Length, Block Coefficient and *LCB*

1.4.1 Introduction

The following is a collection of useful empirical relationships for length, block coefficient and *LCB* position. Some of these relationships do not represent contemporary practice but are included for historical reference.

1.4.2 Length

Ayre: $\frac{L}{\nabla^{1/3}} = 3.33 + 1.67\frac{V}{\sqrt{L}}$

Posdunine corrected using Wageningen towing tank results: $L = C\left(\frac{V}{V+2}\right)^2 \nabla^{1/3}$ where typically $C = 7.25$ and $V_{trial} = 15.5 - 18.5$ knots.

N.B. Van Lameran suggests $V_{trial} = V_{service} + 1$ knot and Troost that $V_{trial} = V_{service}\sqrt[4]{1.25}$.

Volker's statistics for dry cargo and container ships ($\frac{L}{\nabla^{1/3}} - 0.5$ for coasters and $\frac{L}{\nabla^{1/3}} - 1.5$ for trawlers): $\frac{L}{\nabla^{1/3}} = 3.5 + 4.5\frac{V}{\sqrt{g\nabla^{1/3}}}$

Schneekluth's formula for 'length involving lowest production cost' for ships of $\Delta \geq 1000$ tonnes and $0.16 \leq V/\sqrt{gL} \leq 0.32$: $L_{bp} = \Delta^{0.3}V^{0.3}3.2\left(\frac{C_B + 0.5}{(0.145/(V/\sqrt{gL}) + 0.5)}\right)$

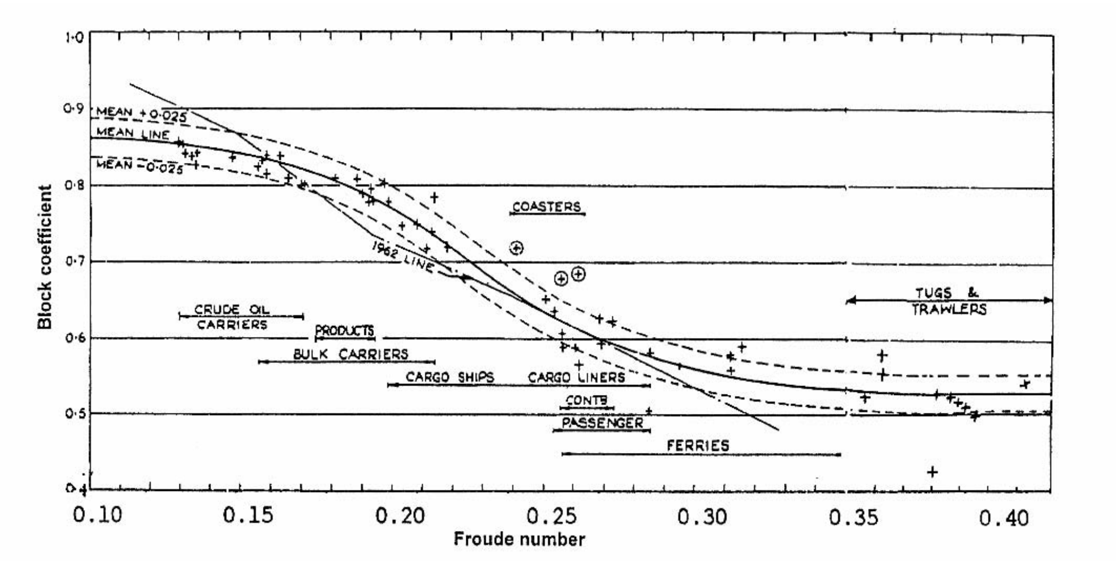
1.4.3 Block Coefficient, C_B

Alexander formula: $C_B = K - 0.5V/\sqrt{L}$ where $K = 1.03$ for high speed ships to 1.12 for slow speed ships.

Alexander due to **Ayre**: $C_B = C - 1.68V/\sqrt{gL}$ where $C = 1.08$ for single-screw, 1.09 for twin screw. $C = 1.06$ is often used for contemporary designs.

Telfer: $C_B = 1 - 1.26(B/L)\frac{V}{\sqrt{gL}}$

Troost: $\dfrac{V}{\sqrt{gL}} = 0.32 - 0.276C_P$ and $\dfrac{V}{\sqrt{gL}} = 0.328 - 0.276C_P$ for single screw and twin screw respectively.



Townsin: $C_B = 0.7 + \dfrac{1}{8}\tan^{-1}\dfrac{(23 - 100V/\sqrt{gL})}{4}$ (from figure above)

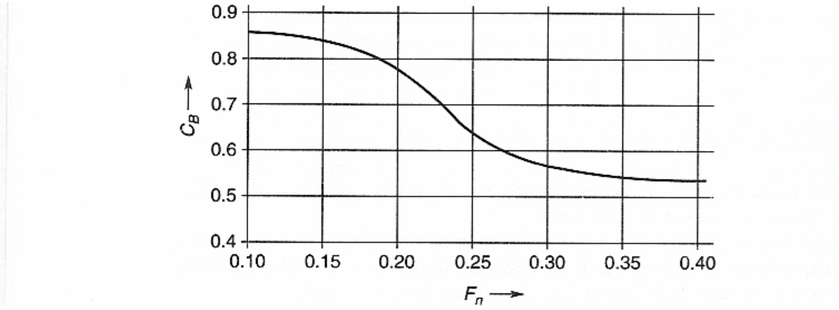
Schneekluth for $0.48 \le C_B \le 0.85$ and $0.14 \le V/\sqrt{gL} \le 0.32$. If $V/\sqrt{gL} \ge 0.3$ then $V/\sqrt{gL} = 0.3$ is used:

$$C_B = \frac{0.14}{V/\sqrt{gL}}\frac{L/B + 20}{26} \quad \text{and} \quad C_B = \frac{0.23}{(V/\sqrt{gL})^{2/3}}\frac{L/B + 20}{26}$$

Schneekluth / Jensen for modern Japanese hulls for $0.15 \le V/\sqrt{gL} \le 0.32$:

$$C_B = -4.22 + 27.8\sqrt{\frac{V}{\sqrt{gL}}} - 39.1\frac{V}{\sqrt{gL}} + 46.6\left(\frac{V}{\sqrt{gL}}\right)^3$$

Jensen



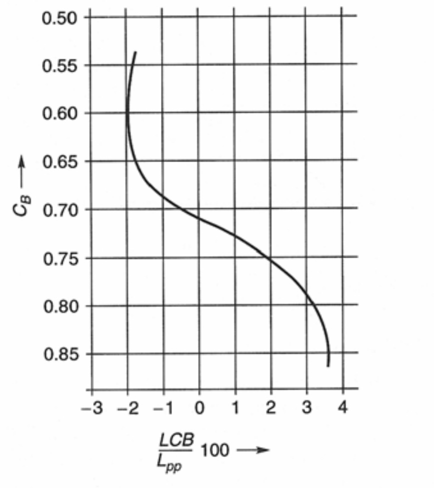
1.4.4 *LCB* Position

BMT standard line; $LCB = 20(C_B - 0.675)$ %L (+*ve* forward 'midships)

Schneekluth (for Japanese designs); $LCB = 8.80 - 38.9\dfrac{V}{\sqrt{gL}}$ %L (+*ve* forward 'midships)

Schneekluth (for tankers and bulkers); $LCB = -0.135 + 0.194C_P$ %L (+*ve* forward 'midships)

Jensen



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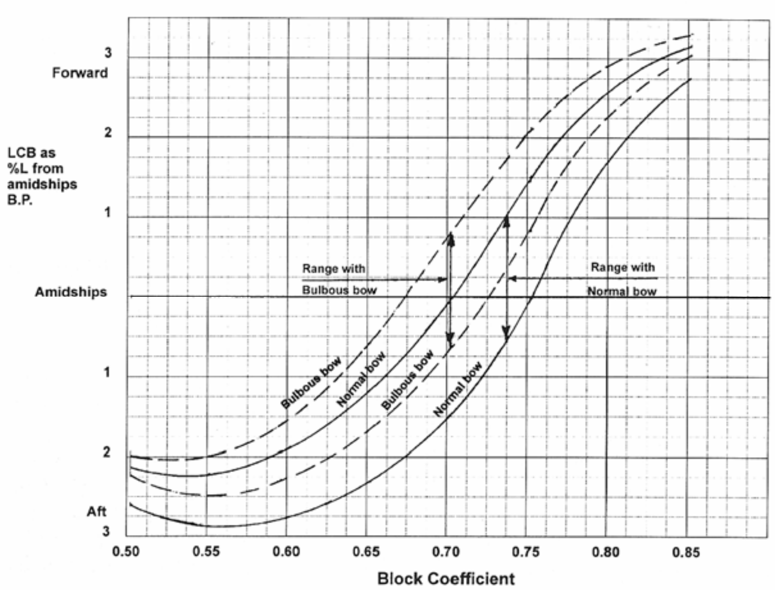
Watson



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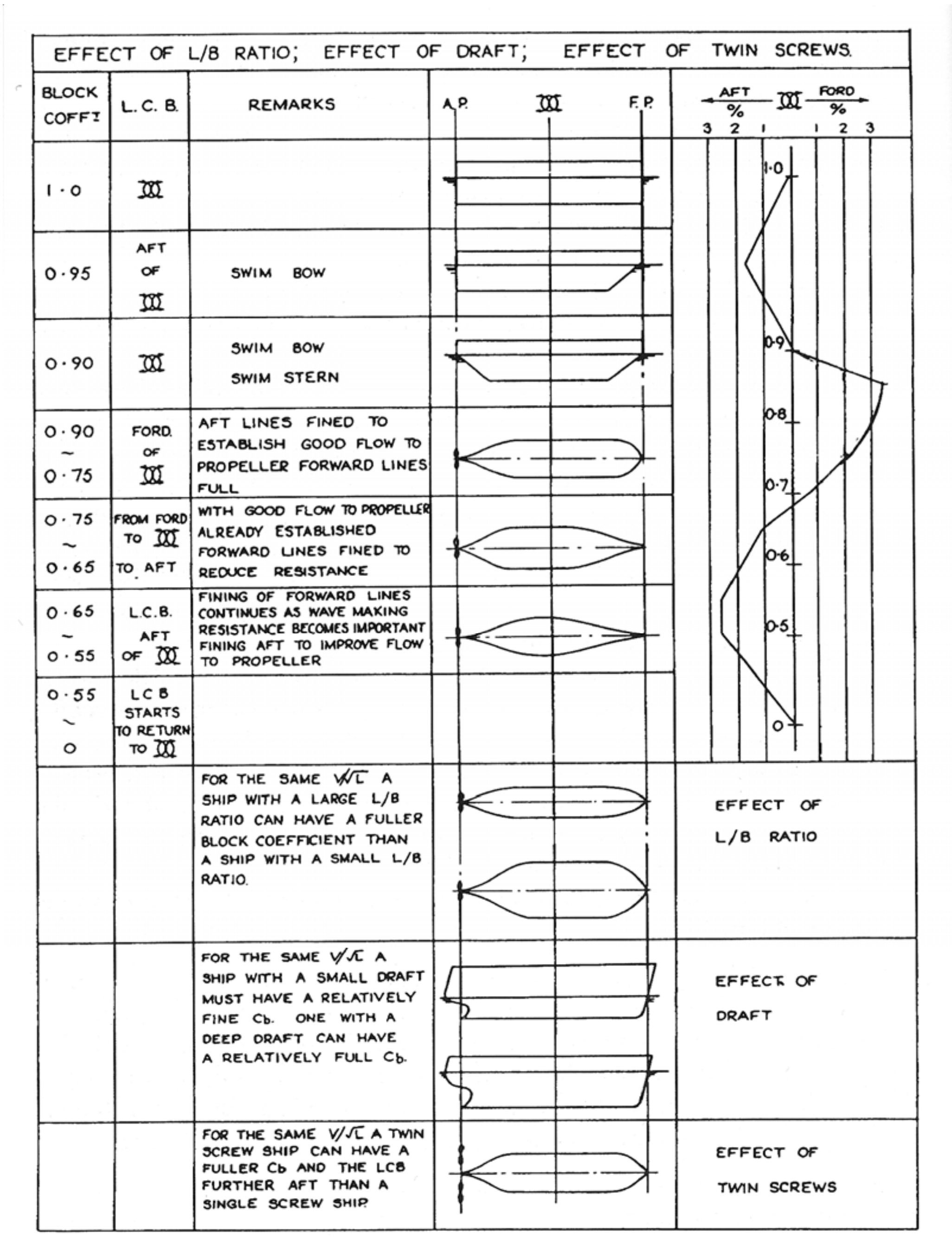
1.4.5 Summary of relationship between C_B and LCB



EFFECT OF L/B RATIO; EFFECT OF DRAFT; EFFECT OF TWIN SCREWS.				
BLOCK COFFT	L. C. B.	REMARKS	A.P. ⊗ F.P.	← AFT % ⊗ FORD % → 3 2 1 1 2 3
1 · 0	⊗			1·0
0 · 95	AFT OF ⊗	SWIM BOW		
0 · 90	⊗	SWIM BOW SWIM STERN		0·9
0 · 90 ~ 0 · 75	FORD. OF ⊗	AFT LINES FINED TO ESTABLISH GOOD FLOW TO PROPELLER FORWARD LINES FULL		0·8 0·7
0 · 75 ~ 0 · 65	FROM FORD TO ⊗ TO AFT	WITH GOOD FLOW TO PROPELLER ALREADY ESTABLISHED FORWARD LINES FINED TO REDUCE RESISTANCE		0·6
0 · 65 ~ 0 · 55	L.C.B. AFT OF ⊗	FINING OF FORWARD LINES CONTINUES AS WAVE MAKING RESISTANCE BECOMES IMPORTANT FINING AFT TO IMPROVE FLOW TO PROPELLER		0·5
0 · 55 ~ 0	LCB STARTS TO RETURN TO ⊗			0
		FOR THE SAME $V/\sqrt{L}$ A SHIP WITH A LARGE L/B RATIO CAN HAVE A FULLER BLOCK COEFFICIENT THAN A SHIP WITH A SMALL L/B RATIO.		EFFECT OF L/B RATIO
		FOR THE SAME $V/\sqrt{L}$ A SHIP WITH A SMALL DRAFT MUST HAVE A RELATIVELY FINE Cb. ONE WITH A DEEP DRAFT CAN HAVE A RELATIVELY FULL Cb.		EFFECT OF DRAFT
		FOR THE SAME $V/\sqrt{L}$ A TWIN SCREW SHIP CAN HAVE A FULLER Cb AND THE LCB FURTHER AFT THAN A SINGLE SCREW SHIP		EFFECT OF TWIN SCREWS

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1.5 Dimensional Ratios and Form

1.5.1 Introduction

Summary of the fundamental influence of basic dimensional and form relationships:

L/B – Resistance, propulsion, hull construction costs and methods, directional stability.

L/D – Longitudinal strength and stability.

T/D – Freeboard and hull volume.

B/T – Stability and resistance.

B/D – Stability; $KG = f(D)$, $KM = f(B)$

$C_B - f(F_N)$, dangers of too full a form resulting in penalty on resistance first cost and operational costs. Higher L/B facilitates higher C_B.

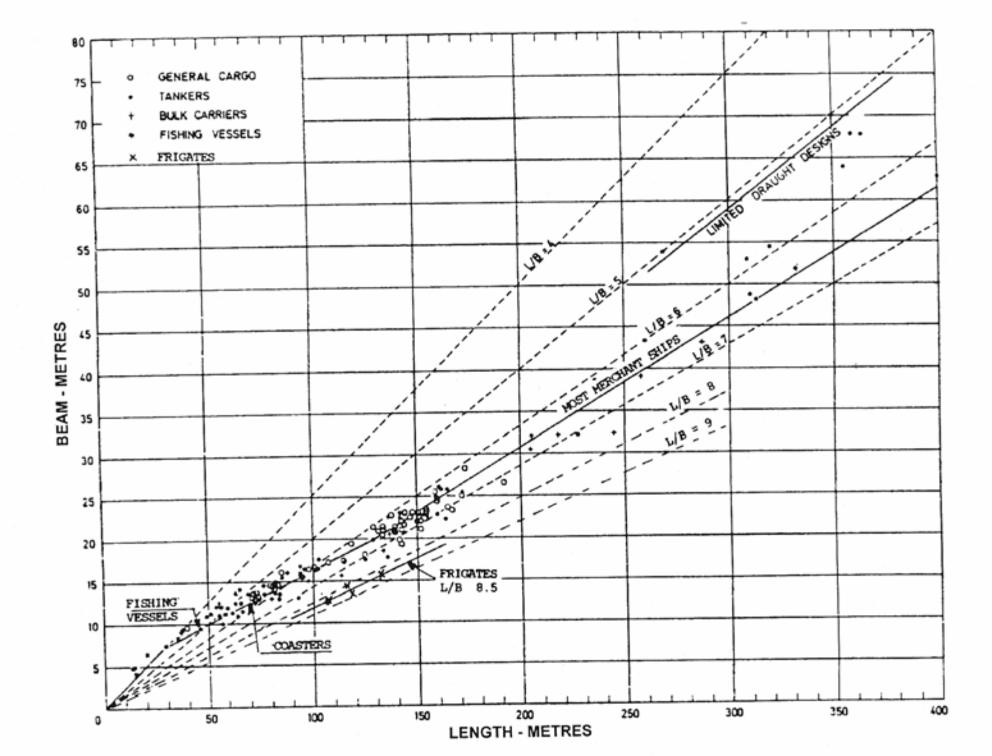
LCB – Optimum position for given dimensions and fullness dictated by LCG, trim and powering requirements.

1.5.2 *L/B* Ratio

Once an initial solution for length is determined then L/B ratio is then useful to determine beam. L/B ratio has steadily reduced in order to reduce ship first cost, for merchant vessels values of 7.6 were typical. This has implications for the required block coefficient in that it has to be reduced to compensate and also with respect to propulsion due to the influence on wake fraction with the necessity to consider flow into the propeller carefully. Typical values of L/B ratio are:

- $L/B = 6.5$ for $L > 130$m;
- $L/B = 4.0 + 0.025(L-30)$ for $30 \leq L \leq 130$;
- $L/B = 4.0$ for $L \leq 30$;
- Most recently, for reefers, containerships and bulk carriers $L/B \approx 6.25$ due to first cost implications.
- For draught limited vessels where there is necessity to maximize displaced and/or internal volume once the limits on draft, length, block coefficient are reached the beam increases with a corresponding reduction in L/B ratio. This is the case with ULCCs (deadweight > 350 000 tonnes) where $L/B \approx 5.5$.

- Other extremes of L/B ratio are: Great lakes bulk carrier $L/B \approx 9.5$; Ice breakers $L/B \approx 4.0$; Frigates $L/B \approx 8.5$; Aircraft Carriers $L/B \approx 7.0$



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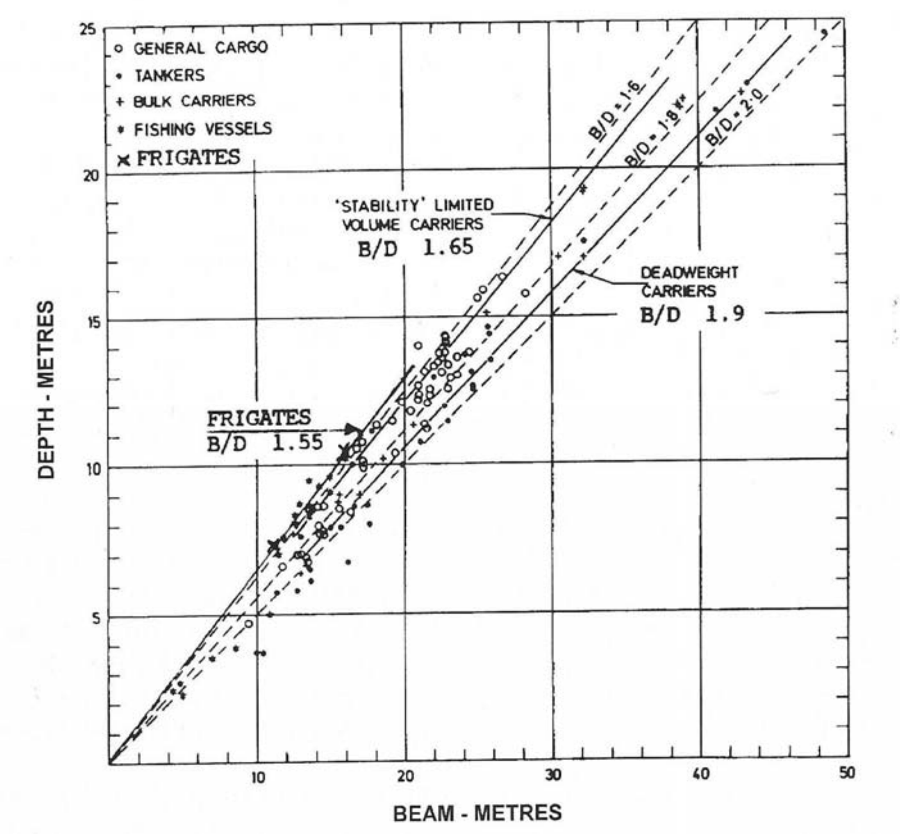
1.5.3 *B/D* Ratio

B/D ratio has a major impact on transverse stability since principally $KG = f(D)$, $KM = f(B)$ remembering that $GM = KM – KG$. Stability limited capacity designs tend to have lower values of B/D ratio than deadweight carriers. Higher values result from the requirement for greater stability; due to deck cargo and handling gear; reduced machinery weight increasing the lightship KG; and finer form resulting in lower KM for a given B. Conversely lower values of B/D result from minimum or no handling gear or deck cargo accompanied by light superstructure, a lower profile in terms of shear and camber; and a fuller form providing greater KM. Generally stability limited capacity designs $B/D \approx 1.65$ and deadweight carriers $B/D \approx 1.90$. Care should be taken suggesting a B/D ratio less than 1.55. Typical values are:

- Bulk carriers $B/D \approx 1.88$;
- Reefers and containerships $B/D \approx 1.7$;
- Tankers $B/D \approx 1.91$ but for VLCC/ ULCC up to $B/D \approx 2.5$ due to increased beam;

- Frigates (general) $B/D \approx 1.55$.



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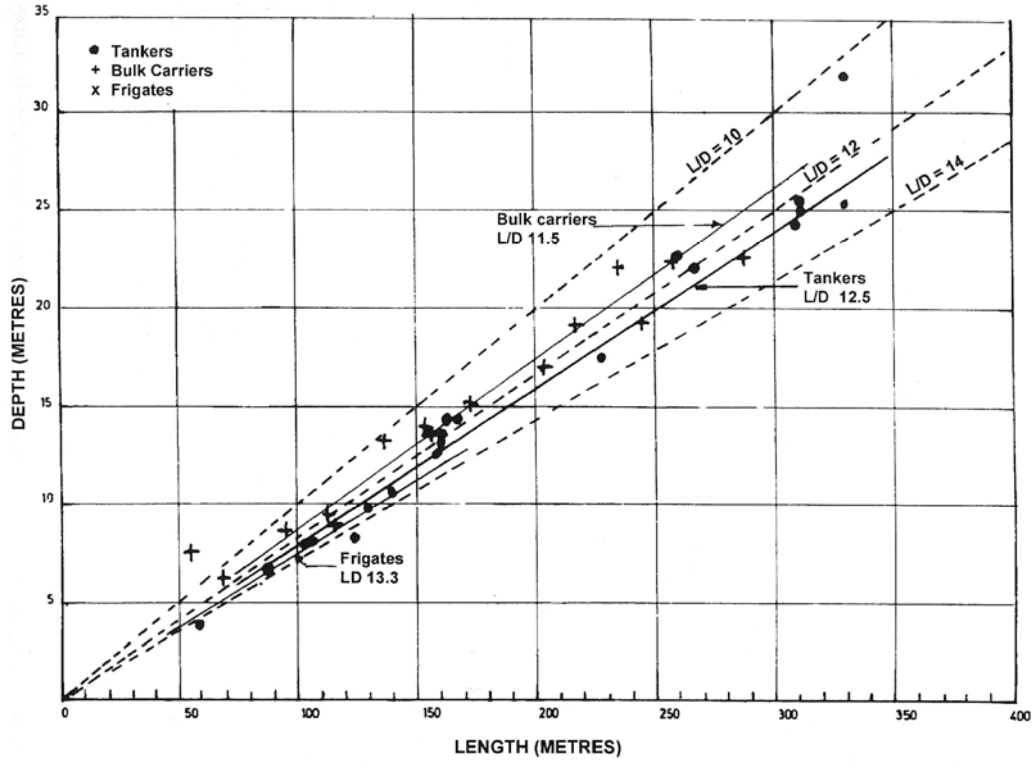
1.5.4 *L/D* Ratio

The next logical ratio to consider is L/D ratio which is a key consideration in longitudinal strength in terms of longitudinal bending moment and resulting hull deflection. Given that stability is likely to be in excess of the statutory minimum this tends not to drive depth it is longitudinal strength that governs L/D ratio. Classification societies require special consideration for vessels of $L/D > 15$. In longer vessesl, such as VLCCs, where higher tensile steel is used it is desirable to keep L/D ratio down to limit hull girder deflection. Where longitudinal strength is not so significant, such as Great Lake bulk carriers where wave induced bending is less significant than in ocean going service then L/D ratios can be as high as 20. More typical values of L/D ratio, for a range of ship types are:

- Bulk carriers $L/D \approx 11.75$;

- Reefers and containerships $L/D \approx 10.6$;
- Tankers $L/D \approx 10.50$;
- Frigates (generally) $L/D \approx 13.3$.



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1.5.5 *B/T* Ratio

The principal influences of B/T ratio are on residuary resistance and transverse stability. Care has to be taken to avoid large values that will penalize resistance while too small a value will cause stability problems. In general values of B/T ratio should be within the range:

$$2.25 \le B/T \le 3.75$$

A value of $B/T \approx 3.0$ tends to minimize wetted surface and therefore allows for forms with minimum frictional resistance. This is especially significant for forms at lower Froude number where frictional resistance dominates. For single screw draft limited vessels **Roseman et al. (1994)** give a limit on B/T ratio and **Saunders (1959)** give the solution for minimum wetted surface as, respectively:

- $B/T = 9.625 - 7.5\ C_B$ or

- $B/T = 5.93 - 3.33\ C_M$

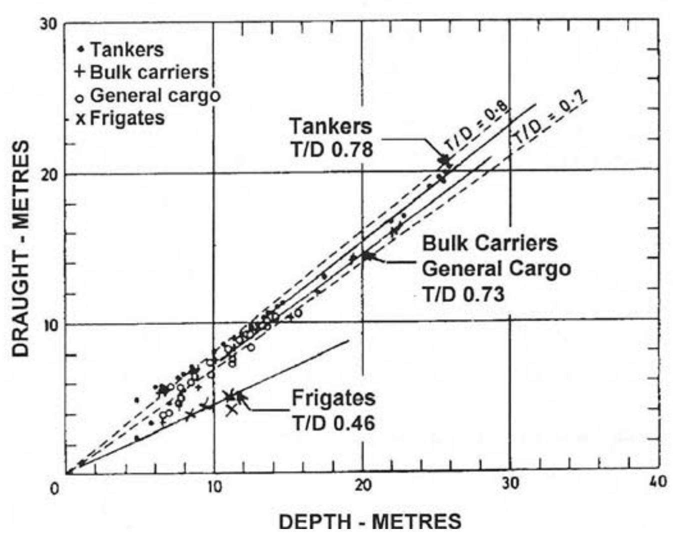
Example values of B/T ratio are:

- Bulk carriers $B/T \approx 2.65$;
- Reefers and containerships $L/D \approx 10.6$;
- Tankers $B/T \approx 2.85$

1.5.6 *T/D* Ratio

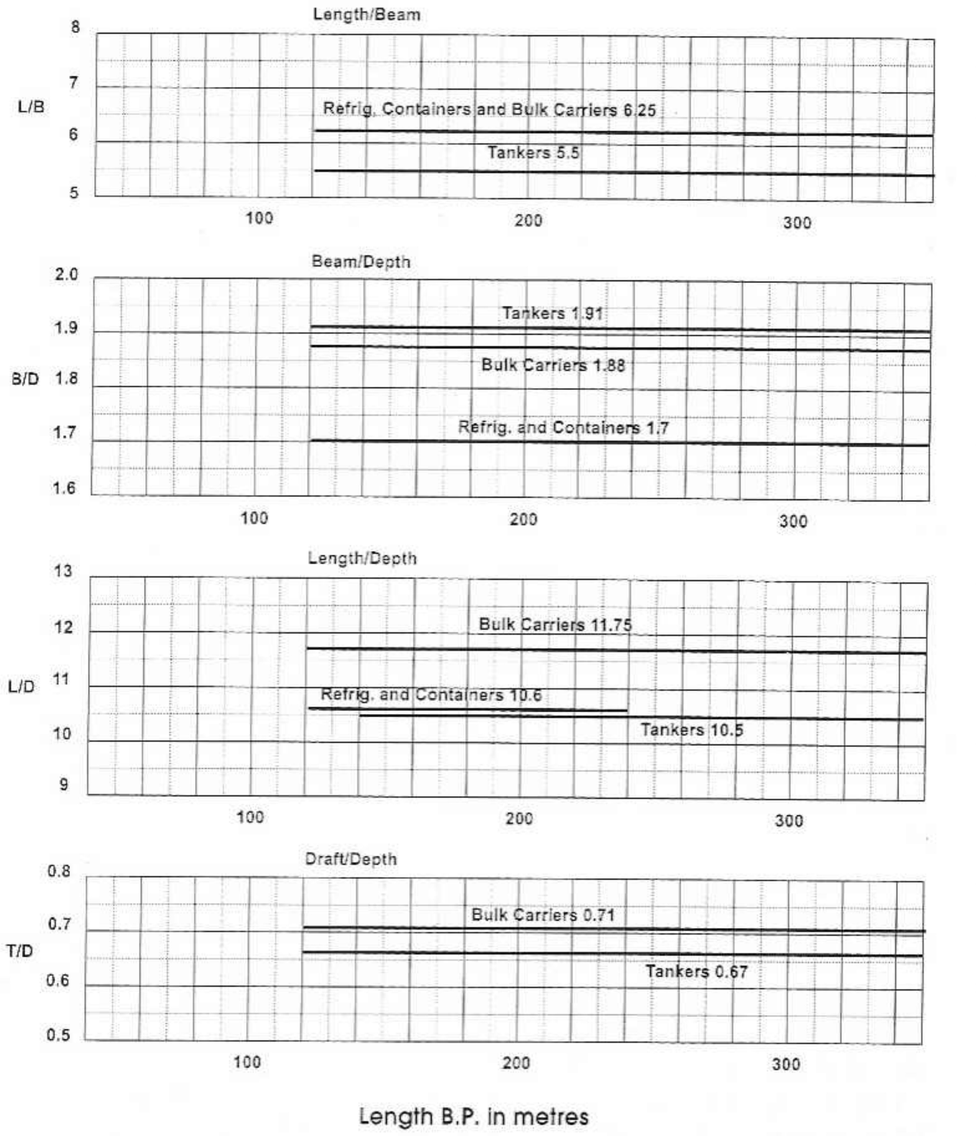
T/D ratio reflects the freeboard requirement for merchant ships. It is useful to suggest typical values but for design purposes any estimate of depth so derived is revised as soon as the freeboard is considered more formally. The absence of shear and extensive superstructure as well as the general increase in size of ships results in contemporary values being slightly lower than past designs. Typical values of T/D ratio, for a range of ship types are:

- Bulk carriers and Reefers $T/D \approx 0.71$;
- Tankers $T/D \approx 0.67$;
- Containerships (generally) $T/D \approx 0.62$
- Warships (generally) $T/D \approx 0.46$



[1]

1.5.7 Summary of Dimensional Ratio Data with respect to Length



[1]

1.6 Influence of Changes in Dimensions and Form

1.6.1 Introduction

It is useful to have a qualitative understanding of the fundamental influences that increasing or reducing principal dimensions and C_B has on the ship design problem. Such understanding can provide the designer with useful understanding and guidance but it is insufficient to suggest improvements to a design on a quantitative basis.

1.6.2 Summary of Influence of Increases in Parameters

Optimisation of main dimensions

	Capital cost		Operational cost
	Hull	Machinery	
Increase L	Most expensive way to increase displacement; increases cost	Reduces power and cost	Reduces fuel consumption and cost
Increase B	Increases cost (but less proportionately than L). Facilitates increase in D by improving stability	Increases power and cost	Increases
Increase D and T	Cheapest dimensions to increase; reduces cost	Reduces power and cost	Reduces
Increase block coefficient	Cheapest way to increase displacement and deadweight	Increases power. Above a certain relationship of F_n to C_b can cause rapid increase in power	Increases

[1]

- Increase L - Note conflict between increased hull production first cost and reduced operational cost and first cost of machinery due to reduced power.
- Increase B – Improved stability through increased KM. Increase in B (and B/T) increases R_T. Also tends to result in higher steel mass and reduced deadweight – displacement ratio.
- Increase T – Constrained by T_{Max}. If T_{Max} reached then likely increase in B with attendant penalty on R_T.

- Increase D – Benefits stability by delaying deck edge immersion and maximum GZ but subject to rise in KG and subsequent reduction in GM. Increase capacity to achieve required hull volume. Implications for freeboard and arrangement. For specific T will reduce deadweight – displacement ratio.

- Increase C_B – Dangers of too full a form resulting in penalty on R_T, first cost and operational costs. Higher L/B facilitates higher C_B.

- *LCB* – Optimum position for given dimensions and fullness dictated by LCG, trim and powering requirements.

1.6.3 Cost Data to Support Relative Cost of Parameters

Incremental changes in total capital costs as percent of original capital cost due to a 1% increase in the parameter

category	percent of total		L		B		D		C b		V k	
	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker
steel	28%	41%	0.47	0.81	0.30	0.43	0.24	0.38	0.11	0.17		
outfit	26%	22%	0.27	0.06	0.27	0.04		0.02		0.01		
machinery	30%	20%	0.29	0.14	0.21	0.11			0.07	0.04	1.01	0.50
misc/ovhd	16%	17%										
total	100%	100%	1.03	1.01	0.78	0.58	0.24	0.40	0.18	0.22	1.01	0.50

Incremental changes in total capital costs as percent of original capital cost due to a 1% increase in the parameter

category	percent of total		L		B		D		C b		V k	
	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker	ore carrier	VLCC tanker
steel	28%	41%	0.47	0.81	0.30	0.43	0.24	0.38	0.11	0.17		
outfit	26%	22%	0.27	0.06	0.27	0.04		0.02		0.01		
machinery	30%	20%	0.29	0.14	0.21	0.11			0.07	0.04	1.01	0.50
misc/ovhd	16%	17%										
total	100%	100%	1.03	1.01	0.78	0.58	0.24	0.40	0.18	0.22	1.01	0.50

[3]

Key References

[1] Watson , D. G. M., ‘Practical Ship Design’, Elsevier, 1998.
[2] Watson , D. G. M., ‘Designing Ships for Fuel Economy’, YARD, 1988.
[3] Fisher, K. W., ‘The Relative Cost of Ship Design Parameters’, Trans RINA, 1973.
[4] Schneekluth, H., and Bertram, V., ‘Ship Design for Efficiency and Economy’, Butterworth Heinemann, 1998.