NORMAND's NUMBER FOR MERCHANT SHIPS

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Summary

Normand's Number is defined as the factor N by which any change in weight is to be multiplied, in order to give the change in displacement.

Normand's Number has been calculated for about 200 merchant ships of various types and capacities, and the results are given in diagrams of Normand's Number as functions of the displacement and the ratio displacement/deadweight.

The use of Normand's Number in preliminary design ought to be greatly extended as the Number will only vary with size of ship for most types of merchant ships. Passenger ships, however, require a few more parameters, e.g. speed, route and number of passengers. The material has been too limited for a complete determination of the variation for passenger ships.

When a new design is based on a parent vessel, the diagrams can be applied to determine Normand's Number, and hence the new displacement can be obtained with good accuracy.

Introduction

Various methods are used in determining the displacement and principal dimensions of a preliminary design for a merchant ship, e.g.:

1. The principal dimensions are first assumed and then modified by a process of trial and error.
2. The displacement of the preliminary design is determined from the ratio Dw/Δ of similar ships, or by means of diagrams.
3. The displacement and the principal dimensions of the preliminary design are determined by the use of a parent vessel as near to the type and size of the preliminary design as possible.
4. The dimensions of the preliminary design are determined from mathematical expressions.

Of the above methods, No. 3 is probably most generally used in merchant shipyards. This method often necessitates the determination of the effect of changes in weights (such as weight of steel, equipment, engine, or Dw) on the displacement. It is obvious that any weight change, e.g. an addition to the equipment of the ship, causes a primary change in displacement which in turn causes secondary changes in the weights of steel, equipment, and engine. Therefore, the difference between the initial displacement and the displacement of the new preliminary design must be considerably greater than the increase in weight which the preliminary design is to carry. The coefficient by which the change in weight is to be multiplied in order to give the corresponding change in displacement is here indicated by N (or Normand's Number).

Historical review

In a publication in 1885 [6] [7] J. A. Normand states: «The plus or minus difference of displacement must be equal to the plus or minus difference of weights, as calculated for the vessel chosen as type, multiplied by a coefficient K which can be exactly determined». As far as it has been possible to ascertain, this was the first time the problem had been raised as a subject for discussion.

Later on, W. Hovgaard [2] continued this work and gave an expression for the factor K:

$$N = \frac{W}{W - \Sigma\, r\, w}$$

$$= \frac{W}{W - w_1 - {}^1/_3 w_3 - {}^2/_3(w_2 + w_4 + w_5)}$$

where $W = w_1 + w_2 + w_3 + w_4 + w_5 + w_6 =$ displacement

w_1 = weights varying in direct proportion to the displacement

w_2, w_4, w_5 = weight groups varying in direct proportion to the displacement raised to the $^2/_3$ power

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w_3 = weights varying according to the displacement raised to the $^1/_3$ power

w_6 = weights which are not integral parts of the ship and which are hence independent of changes in the principal dimensions and displacement

r = the power to which the displacement occurs in the weight equation.

The splitting up of the displacement into the weight groups w_1 to w_6 has been adapted by Hovgaard as applicable to warships and this system was subsequently modified by H. H. W. Keith [3]. G. C. Manning [3] [4] has developed the following weight equation for merchant ships

$$\Delta = w_a + w_b + w_c + w_d + w_e$$

where Δ = displacement

w_a = weight of hull, hull fittings, equipment, outfit, crew and effects

w_b = weight of propelling machinery

w_c = weight of fuel

w_d = weight of water and stores

w_e = paying deadweight, permanent ballast and margin

w_a is proportional to Δ, w_b and w_c are proportional to $\Delta^{2/3}$ and w_d and w_e are independent of changes in displacement.

Manning developed the following coefficient R for merchant ships:

$$R = \frac{\Delta}{\Delta - w_a - {}^2/_3(w_b + w_c)}$$

where R is the ratio between the increase in displacement and the increase in the weight group concerned caused by increase in the independent variables. In [3] Manning states: «The weight equation has been relatively little used by experienced designers. Most of them prefer the direct approach, using the trial and error method. The author feels that the weight equation could be used to good advantage in actual design work to a much greater extent than has been customary. The fact of the matter is that the weight equation shows too clearly the cost of an increase in any weight group, provided the other factors are held constant».

More recently H. Witte [8] has determined the coefficient R for many different types of warships. E. C. M. Danckward [1] and L. M. Nogid [5] must also be mentioned.

Nomenclature

Many different letters have been used for the coefficient in the course of time, amongst them K, N or R and the names Normand, Hovgaard, and Keith are also associated with it.

Since Normand treated the problem before Hovgaard and Keith, the designation Normand's Number (N) is preferred here.

Mathematical basis

The equation for displacement can be written in the following way:

$$\Delta = P_a + P_b + P_c + \ldots + P_k + \ldots + P_n \quad \ldots (1)$$

where the P's are weights. When Δ is changed this will cause one or more of the P's to be altered. Each of the P's can be expressed as a function of the displacement raised to some power k, i.e.:

$$P_k = p_k \cdot \Delta^k \quad \ldots\ldots (2)$$

where k can assume completely arbitrary values.

It is desirable to determine the change in displacement Δ when an arbitrary term P_i is changed.

By differentiation of (1) with respect to Δ the following is obtained:

$$1 = \frac{\partial P_a}{\partial \Delta} + \frac{\partial P_b}{\partial \Delta} + \frac{\partial P_c}{\partial \Delta} + \ldots + \frac{\partial P_i}{\partial \Delta} + \ldots + \frac{\partial P_k}{\partial \Delta} + \ldots + \frac{\partial P_n}{\partial \Delta} \quad \ldots\ldots (3)$$

For each term the following relation can be established:

$$\frac{\partial P_k}{\partial \Delta} = \Delta^k \frac{\partial p_k}{\partial \Delta} + k p_k \Delta^{k-1} = \frac{P_k}{p_k}\frac{\partial p_k}{\partial \Delta} + k\frac{P_k}{\Delta} \quad \ldots (4)$$

As only p_i is changed, the following will be obtained from (3) and (4):

$$1 - \sum_a^n k\frac{P_k}{\Delta} = \frac{P_i}{p_i}\frac{\partial p_i}{\partial \Delta} \quad \ldots\ldots (5)$$

Ignoring the influence of the change of displacement on P_i the additional weight coefficient will then be:

$$N = \frac{\partial \Delta}{P_i \dfrac{\partial p_i}{p_i}} = \frac{\Delta}{\Delta - \sum_a^n k P_k} \quad \ldots\ldots (6)$$

If the weight marked i is changed by x tons the displacement will consequently be changed by N x tons, other things being equal.

Normand's number for merchant ships

As mentioned in the introduction it is often valuable to know Normand's Number during the first stages of a design in order to determine the preliminary displacement. A study has therefore been made of the variation of Normand's Number with type and size of ship.

Data of displacement, deadweight, weight of steel, equipment, and engine were obtainable for about 200 ships, mainly from publications of different kinds.

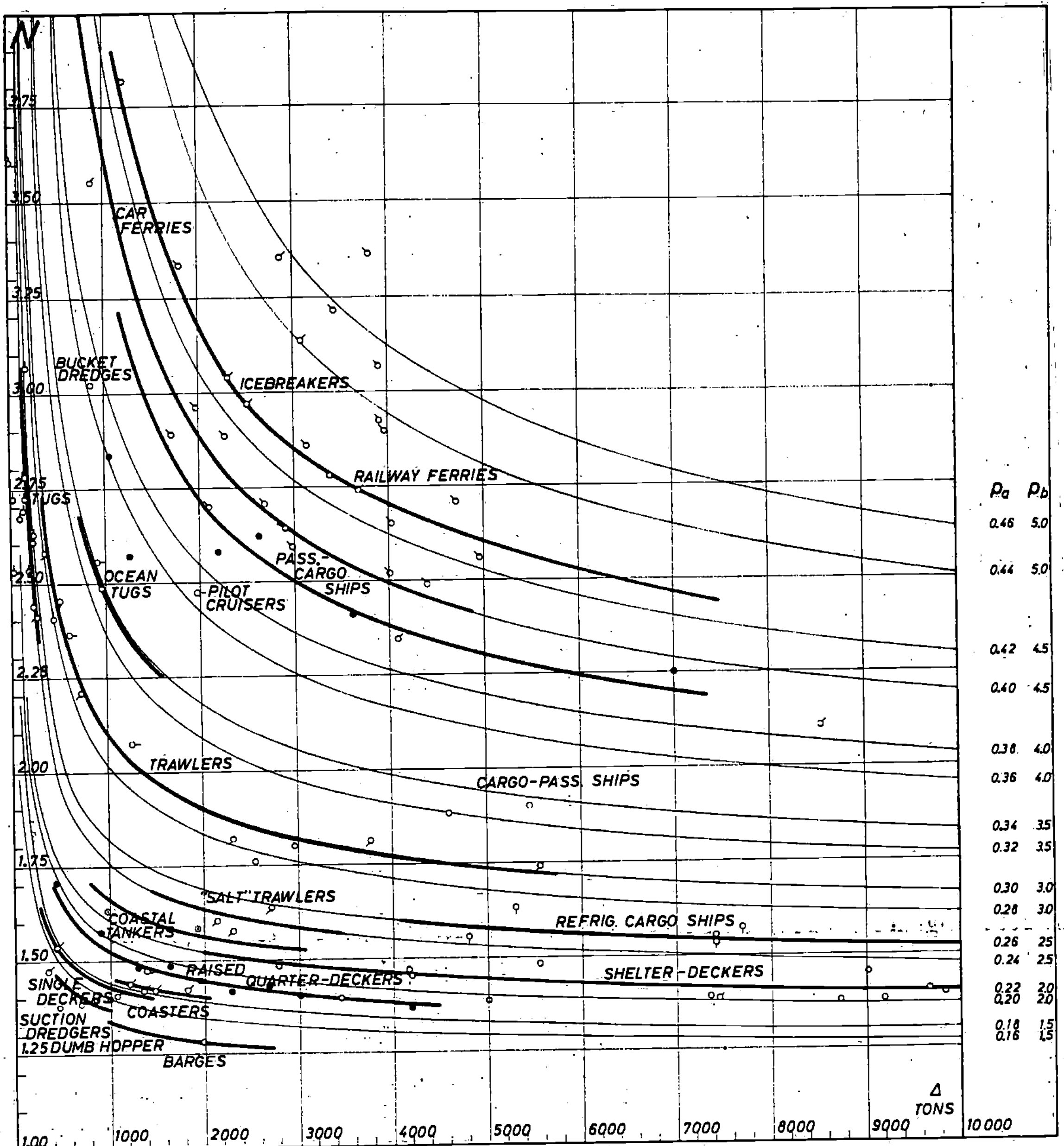

Fig. 1. Normand's Number for small and moderate sized merchant ships.

Based on these data, Normand's Number has been calculated on the basis of the following assumptions:

1) The weight of steel (S) is proportional to the displacement Δ.
2) $^3/_5$ of the weight of the equipment (E) varies proportionally to $\Delta^{2/3}$, $^1/_5$ proportionally to $\Delta^{1/3}$ and $^1/_5$ is independent of the displacement.
3) $^3/_5$ of the engine weight (M) (consisting of all the machinery between the engine room bulkheads plus the propeller) varies proportionally to $\Delta^{2/3}$ and $^2/_5$ of the engine weight is independent of the displacement.
4) Deadweight (Dw): The weight of fuel oil varies proportionally to $\Delta^{2/3}$ and the remaining deadweight is independent of the displacement.

Where the quantity of fuel oil has not been known the weight is estimated to be equal to $^3/_5$ of the engine weight.

This corresponds to a displacement equation:

$$\Delta = p_a\Delta + p_b\Delta^{2/3} + p_c\Delta^{1/3} + p_d\Delta^0 \quad \ldots\ldots (7)$$

which gives the following Normand's Number:

$$N = \frac{\Delta}{\Delta - p_a\,\Delta - {}^2/_3\, p_b\Delta^{2/3} - {}^1/_3\, p_c\Delta^{1/3}} = \frac{\Delta}{\Delta - P_a - {}^2/_3\, P_b - {}^1/_3\, P_c} \quad \ldots\ldots (8)$$

The results of the investigation are given in the diagrams Fig. 1 and Fig. 2, the first diagram applying to ships with a displacement of less than 10,000 tons (1,016 kg) and the second to ships with a displacement of up to 100,000 tons.

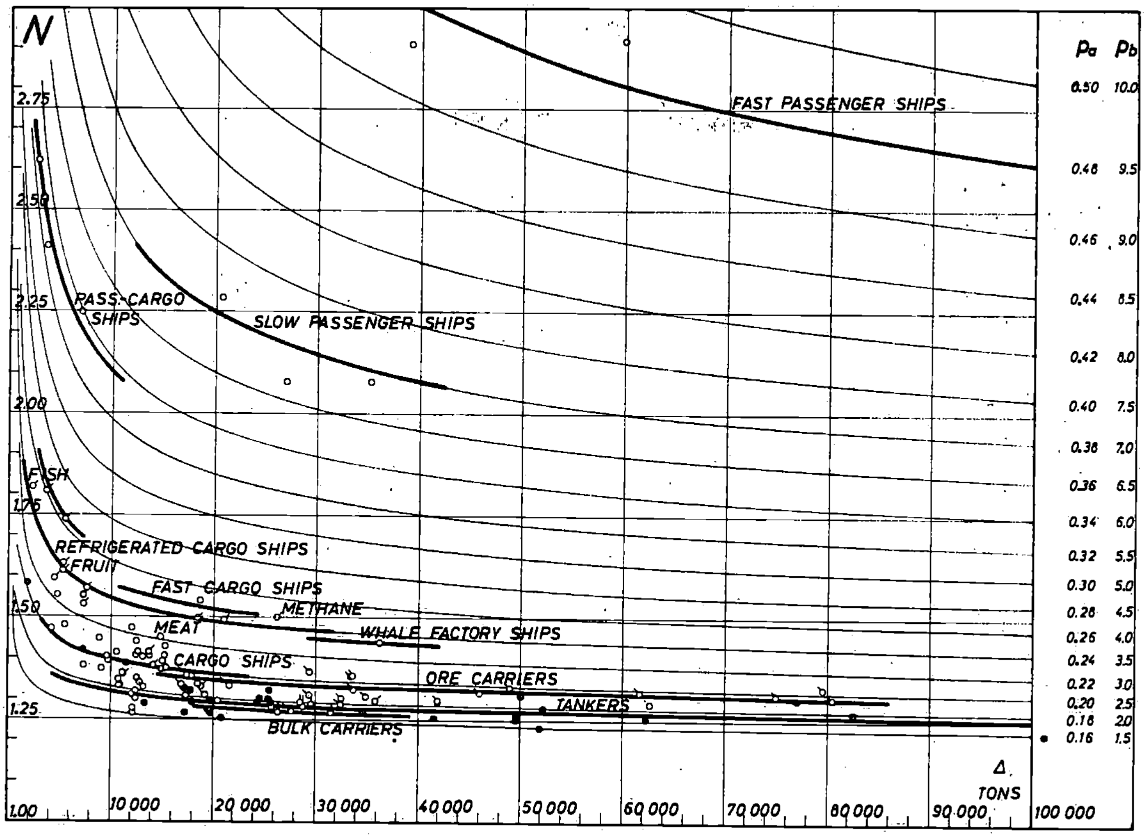

Fig. 2. Normand's Number for large merchant ships.

Both diagrams have displacement as abscissa and Normand's Number as ordinate.

In both diagrams a family of curves for

$$N = \frac{\Delta}{\Delta - p_a \Delta - {}^2/_3\, p_b \Delta^{2/3} - {}^1/_3\, p_c \Delta^{1/3}} \quad \dots (9)$$

is included so that a particular curve corresponds to constant values of p_a, p_b, and p_c. The values of p_a and p_b are given to the right of the diagrams. In all cases p_c has the value of 7.5, as the influence of this coefficient is insignificant. Due to the marked difference of the weight distribution in small and large ships, the best solution proved to be the use of two sets of values for p_a and p_b.

Various ship types are indicated in the diagrams, and faired, average curves have been drawn through the plotted values as heavy lines. It will be noticed that for certain types of ships the scatter is very small. This is particularly so for ship types in which speed, construction and equipment do not vary much, as — for example — is the case for tankers. For dry cargo ships the scatter is greater. In the case of slow ships and ships with very little equipment, Normand's Number will be a little above 1.3, whereas for ships having a high speed and a lot of equipment, including cold stores, it will become 1.5—1.6. The latter value particularly applies to the recent American vessels of 20 knots.

If a closed shelter decker is sailing as an open shelter decker Normand's Number rises by 0.04—0.08, the lowest figure applying to the largest ships. However, for coasters the difference can be still greater (~ 0.3).

For a tanker with a displacement of 100,000 tons a change of 10 % in the displacement will involve a variation in Normand's Number of about 2 %. On the other hand, for a passenger-cargo ship with a displacement of 5,000 tons, a change of 10 % in the displacement will result in a 4 % change of Normand's Number, that is, twice the figure applied to the large tankers. In other words the error in the change of displacement will be almost negligible even for quite considerable weight changes, and will generally be less than the uncertainty in the final determination of the weight of the ship.

Most of the smaller Scandinavian passenger ships carry a certain amount of cargo in addition to passengers. In contrast large passenger ships carry very little cargo and consequently have a comparatively smaller deadweight. As the speed of the passenger ships and the quantity of oil carried are also extremely dependent on the route on which they sail, Normand's Number will show a much greater variation within this type of ship. On account of the rather limited available data it has not been possible to fix the influence on Normand's

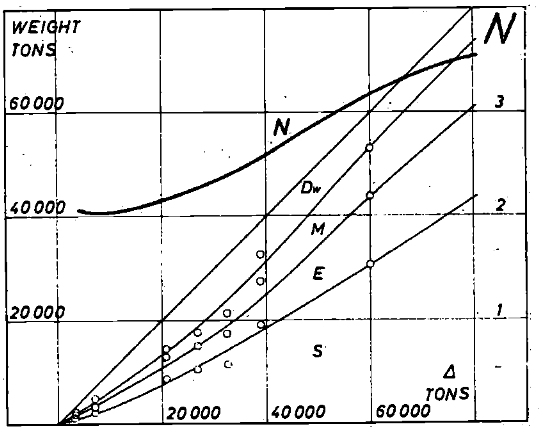

Fig. 3. Weight distribution and Normand's Number for passenger ships (S, E, and M varied gradually with Δ).

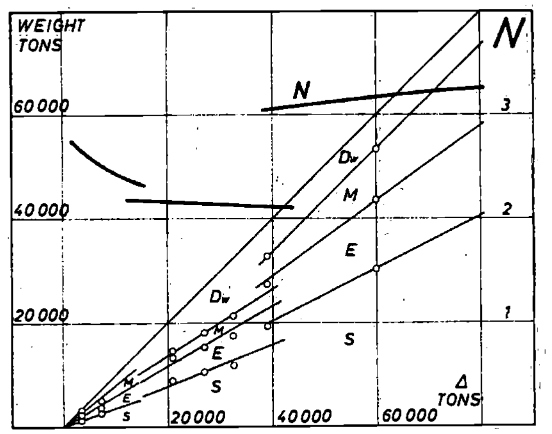

Fig. 4. Weight distribution and Normand's Number for passenger ships (S, E, and M varied by steps).

Number of parameters other than type and size of ship.

Figs. 3 and 4 give an idea of the uncertainty in the determination of Normand's Number for passenger ships. Both figures show weight and Normand's Number as functions of the displacement.

In Fig. 3 it is assumed that the weight distribution for the different groups varies gradually from small passenger ships to large ones, whereas in Fig. 4 the variation is assumed to take place in three steps, as follows: first smaller passenger ships, then larger and comparatively slow ships and finally very large ships. A rather substantial difference between the variation of Normand's Number with displacement in the two cases will be observed.

Influence of the Dw/Δ ratio and quantity of fuel

The equation for displacement can be written

$$\Delta = S + E + M + Dw \quad \ldots\ldots \quad (10)$$

where S, E, and M are weight of steel, equipment and machinery, respectively, and Dw the deadweight. Using the conditions from the preceding section the following will be obtained:

$$N = \frac{\Delta}{\Delta - p_a\Delta - {}^2/_3\, p_b\Delta^{2/3} - {}^1/_3\, p_c\Delta^{1/3}}$$

$$= \frac{\Delta}{\Delta - P_a - {}^2/_3\, P_b - {}^1/_3\, P_c}$$

$$\sim \frac{\Delta}{\Delta - S - {}^2/_3\,(0.6\,E + 1.2\,M) - {}^1/_3\; 0.2\,E}$$

$$\sim \frac{\Delta}{\Delta - S - 0.47\,E - 0.8\,M}$$

$$= \frac{\Delta}{Dw + 0.53\,E + 0.2\,M} \quad \ldots\ldots \quad (11)$$

From this term it is clearly seen that more than anything else the ratio Dw/Δ determines Normand's Number. Therefore in the diagram shown in Fig. 5 Normand's Number has been depicted as a function of the Δ/Dw ratio. A parabola having the line N = Δ/Dw as tangent is drawn through the plotted points. It will be seen that the majority of the points are on the curve or very close to it, only in cases of very large Δ/Dw ratios is there a marked scatter. In a broad sense it can be said that in this area ships with a comparatively small bunker capacity will be found below the curve and ships carrying a comparatively large quantity of fuel above the curve.

A ship with a displacement of 21,000 tons, a deadweight of 14,000 tons, and a bunker capacity of 4,000 tons, may have a Normand's Number of 1.70. If the same ship had only 2,000 tons of fuel oil, Normand's Number would only be 1.54. A further reduction to 1,000 tons bunker capacity will result in a Normand's Number of 1.47.

Normand's Number will also be changed by the consumption of oil. If the ship has 4,000 tons of oil on board on departure and 0 tons on arrival, Normands Number will have varied from 1.70 to 1.55.

Faulty allotment of weight groups

The example for the ship of 21,000 tons in the preceding section shows that if 1,000 tons are moved from the weight group, varying according to $\Delta^{2/3}$, to the weight group which is independent of changes in displacement, Normand's Number will fall by about 0.08.

If 1,000 tons are moved from the weight group where the variation is proportional to Δ to the group where there is a proportionality to $\Delta^{2/3}$ Normand's Number will fall by about 0.04.

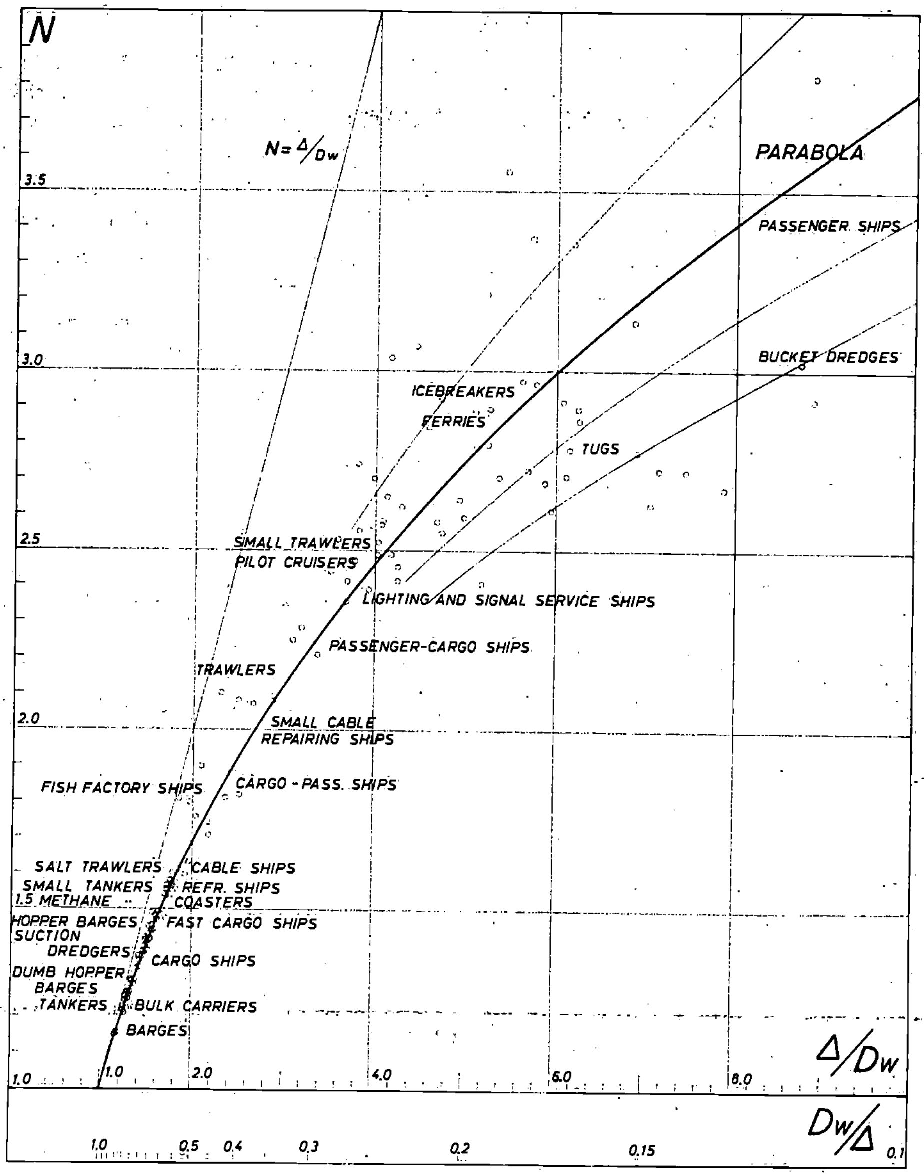

Fig. 5. Normand's Number as a function of the Δ/Dw and Dw/Δ ratio.

In the case of a smaller ship the variations would of course have become greater. As an example it can be mentioned that for an ordinary dry cargo ship with a displacement of 14,000 tons the conditions will be as follows:

1,000 tons changed from Δ to $\Delta^{2/3}$
or from $\Delta^{2/3}$ to $\Delta^{1/3}$
or from $\Delta^{1/3}$ to Δ^{0}

causes a change in N of — 0.05.

From this it will be seen that an incorrect distribution of the displacement among the weight groups will only have comparatively little influence on Normand's Number.

Procedure for the initial determination of displacement for a preliminary design

1) Parent ship to be chosen.
2) Changes in weight to be determined in comparison to parent ship, including changes in weight of engine as a result of different speeds.
3) Normand's Number to be determined for parent ship by using Figs. 1 and 2, possibly in conjunction with Fig. 5.
4) The change in weight is multiplied by Normand's Number, giving the change in displacement.

5) If it is desired to obtain the weight changes in the individual groups, the displacement of the parent ship must first be divided into corresponding weight groups and the individual p_n values determined.

$$\Delta = \sum p_n \Delta^n$$

In the groups where no changes have taken place p_n is unaltered, and the new weight is determined by inserting the new displacement in the terms

$$P_n = p_n \Delta^n$$

Conclusions

As the investigation has proved that Normand's Number only varies with the size of ship for most ship types, it is highly recommended that Normand's Number be used when determining the displacement of a preliminary design. It is not necessary to calculate Normand's Number for the parent ship, as Figs. 1 and 2 in conjunction with Fig. 5 can be used.

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