The Bulbous Bow—A Glimpse of Its Past and Present Status

TAKAO INUI

Dr. Eng.
Professor, The University of Tokyo

Bulbs on Parade

Recently the number of ships which have bulbous bows has been increasing markedly. As a result, today, in contrast to the past, a ship which has a bulb is normal, and the one with a "normal" bow which has no bulb is rather exceptional. Thus, what was once a "normal" is now an "abnormal" bow.

Another thing which is conspicuous is the fact that there are a variety of bulbous bows with different shapes and sizes depending on the ships to which they are adopted. Just by looking at journals at hand for a few minutes, one can pick out a variety of bulbs as shown in Table 1, and Photos 1—7, which were used for the ships inaugurated in Japan in the past six months between March and September in 1965. In Table 1, seven ships are divided into two groups, with five and two ships each. The ships in the first group have full hull forms and those in the second group are fine. The bulbs shown in Photo 1 and Photo 6 are those which are usually called conventional bulbs and have shapes and sizes not very different from the pre-war bulbous bows. However, the bulbs in the first group become larger as one proceeds from Photo 2 to 3 and 4. At the same time, the forward projection from F.P. also increases. The last example of this group shown in Photo 5 has characteristics considerably different from those shown in Photos 1—4. Namely, the latter has a large swelling part near the bottom rather than near the water line, but the former have the shape of the swelling part, which is nearly uniform draughtwise. If one uses the terminology in hydrodynamics, a hull which has the sharpended normal form without a bulb is represented by *sources* or *doublets* which are continously distributed in the longitudinal direction, whereas the swelling part of a bulb is reprensented by the *sources* or *doublets* which are concentrated lengthwise. If there is almost no necking-down between the bulb and the main hull, one calls the former a bulb which is mainly *sources,* whereas if the necking-down is large, one calls it a bulb which is mainly *doublets.* The bulbs in Photos 1—4 are three dimensional bulbs and have the varying strength of the concentrated *sources* and *doublets* draughtwise, whereas the bulb in Photo 5 is a two dimensional bulb which has a uniform distribution of the *sources* and *doublets* draughtwise. In this sense, the bulb in Photo 5 is usually called a *cylindrical bow.*

Photo 6 shows, as we stated previously, a conventional bulb. But the main hull form has been carefully improved, although the details of it can not be seen in the picture. The bulb with a somewhat strange shape which is shown in Photo 7 is quite different from that of Photo 6 in size and shape although it belongs to a high-speed cargo liner just as the bulb in Photo 6 does.

It is natural for the following question to arise here. It may be natural that the bulbs for the ships of different groups may have different sizes and shapes because of the difference in the condition such as the Froude number (or speed-length ratio) for the designed speed and so on under which the ships have to be designed. What is the reason, however, for the large variety

Table 1. Ships With Various Types of Bulbous Bows Built in Japan, Launched During March/Sept. 1965

Name of Ships	Kind of Ships	Ship Owners	Shipyards	Date of Launching	Reference
KOZARA	Bulk-Carrier	Jugoslavenska Oceanska Plovidba (Jugoslavia)	Kure, Kure Shipb.	Aug. 1965	Photo 1.
FUSHU MARU	Ore-Carrier	NYK Line (Japan)	Hiroshima, Mitsubishi	Sept. 1965	Photo 2.
MOBIL JAPAN	Tanker	Socony Mobil Oil Co., Inc. (U.S.A.)	Tamano, Mitsui	March 1965	Photo 3.
JAPAN ROSE	Tanker	Japan Line, Ltd. (Japan)	Tokyo 2nd., IHI	July 1965	Photo 4.
SHOZAN MARU	Bulk-Carrier	Showa Shipping Co., Ltd. (Japan)	Tsurumi, Nippon Kokan	Sept. 1965	Photo 5.
YAMAGUCHI MARU	Cargo-Liner	NYK Line (Japan)	Nagasaki, Mitsubishi	May 1965	Photo 6.
STRAAT FUTAMI	Cargo-Liner	Royal Inter Ocean Lines (Netherlands)	Sakurajima, Hitachi	March 1965	Photo 7.

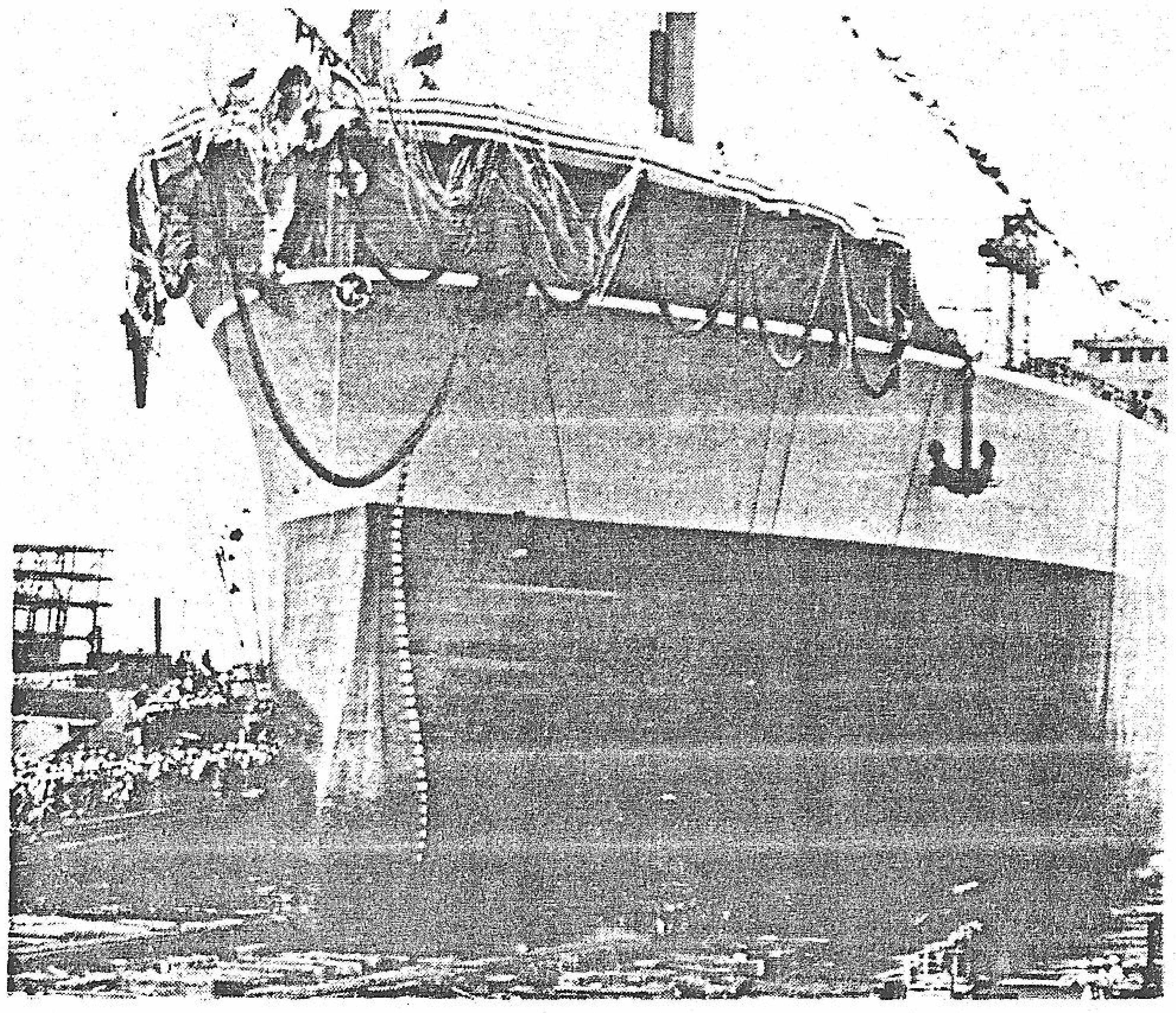


Photo 1. "Kozara" Bulk-Carrier

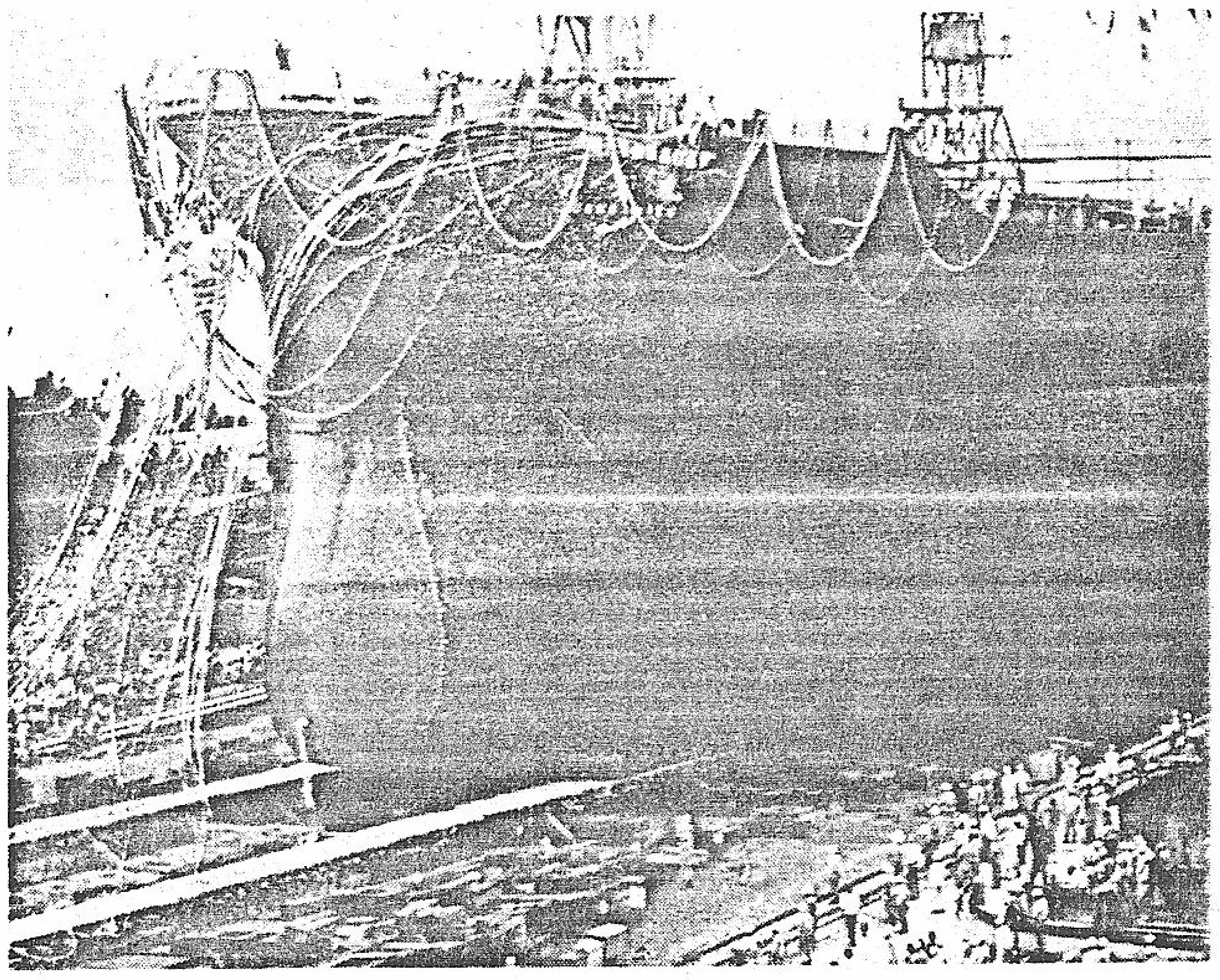


Photo 2. "Fushu Maru" Ore-Carrier

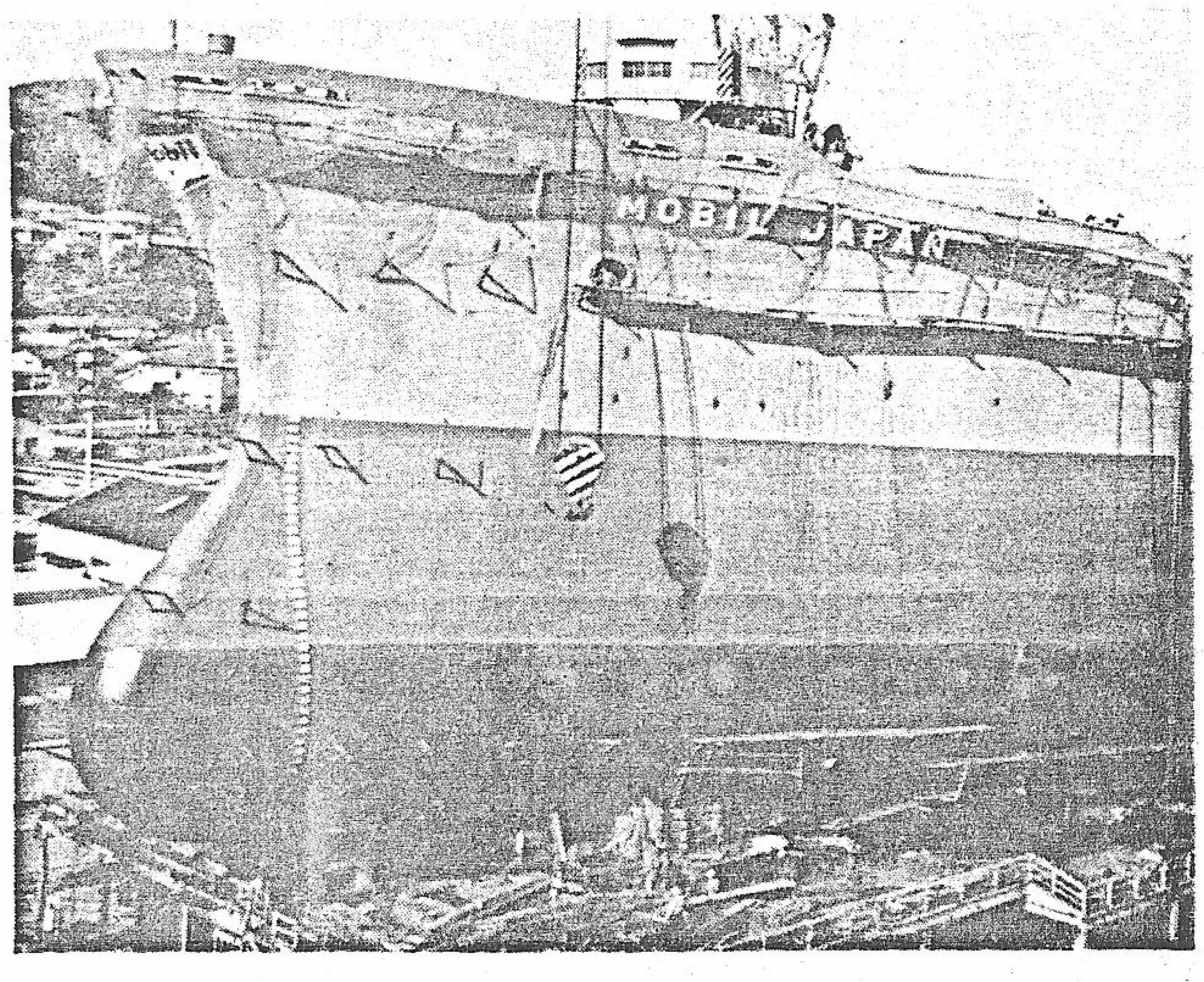


Photo 3. "Mobil Japan" Tanker

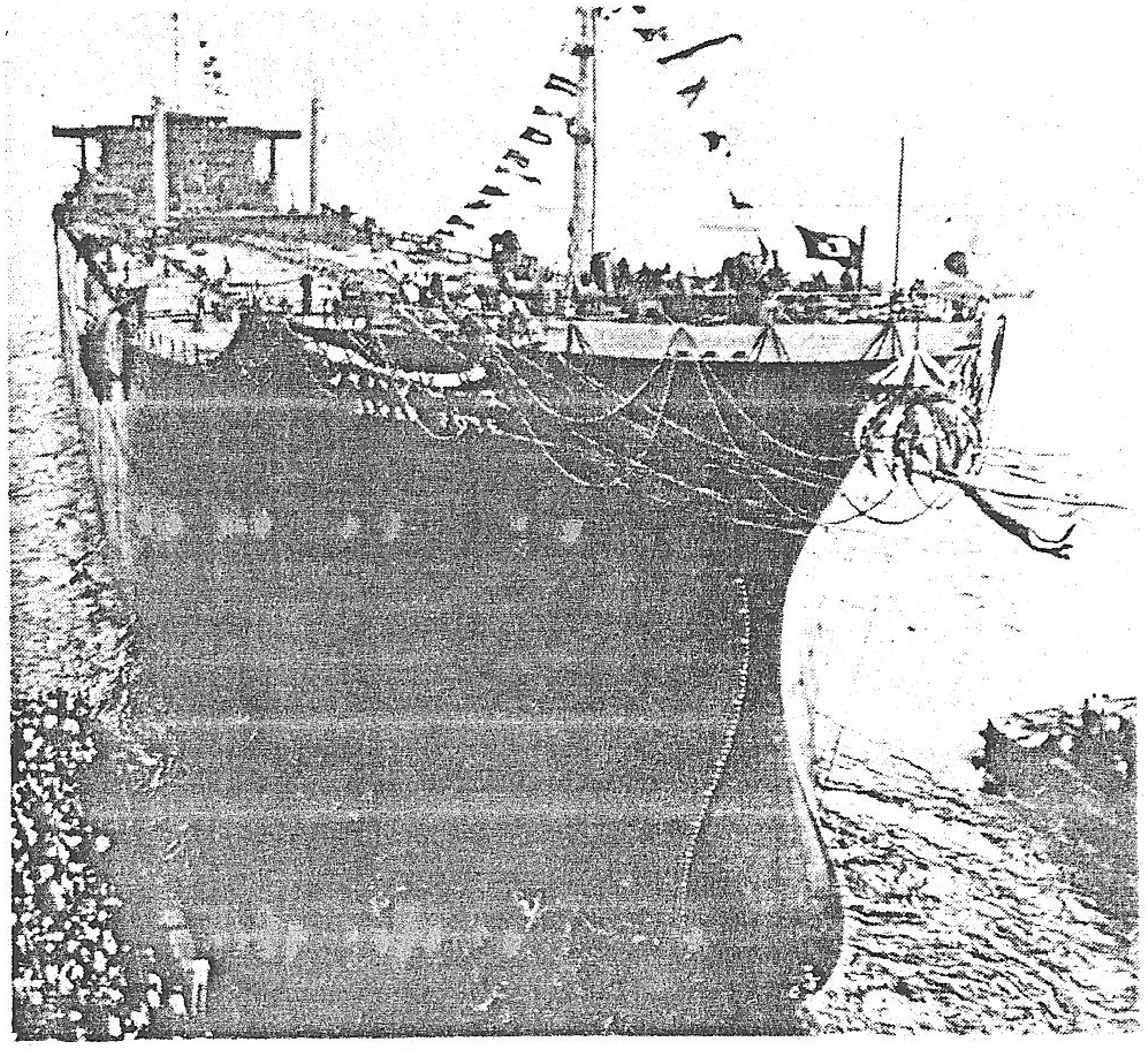


Photo 4. "Japan Rose" Tanker

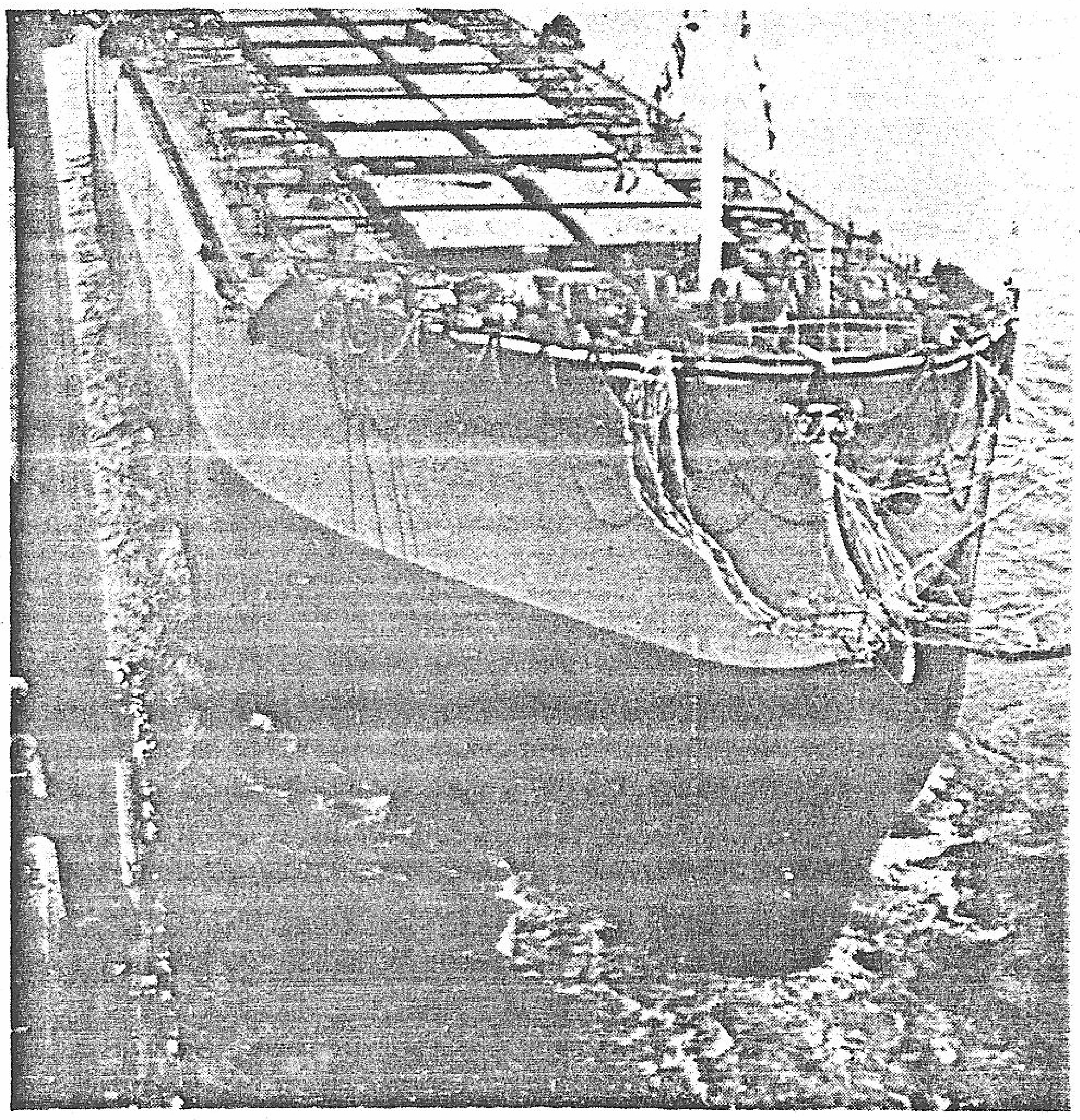


Photo 5. "Shozan Maru" Bulk-Carrier

of bulbs even for the ships in the same group in the above examples?

This question is not as easy to answer as it appears although it is a naive question even a layman might ask. In fact, it is the central problem of ship hydrodynamics today. As a matter of fact, the history and the progress of ideas in ship hydrodynamics can most clearly be seen in the thoughts on the bulbous bow. In the present article, the author intends to take up the problem of bulbs as an introduction to the wider problem of changes in thinking on ship hydrodynamics or on the scientific methodology in general because the latter is believed to be more important than the problem of the bulb itself. It is, however, extremely difficult to accomplish the task within these limited pages, especially without using the

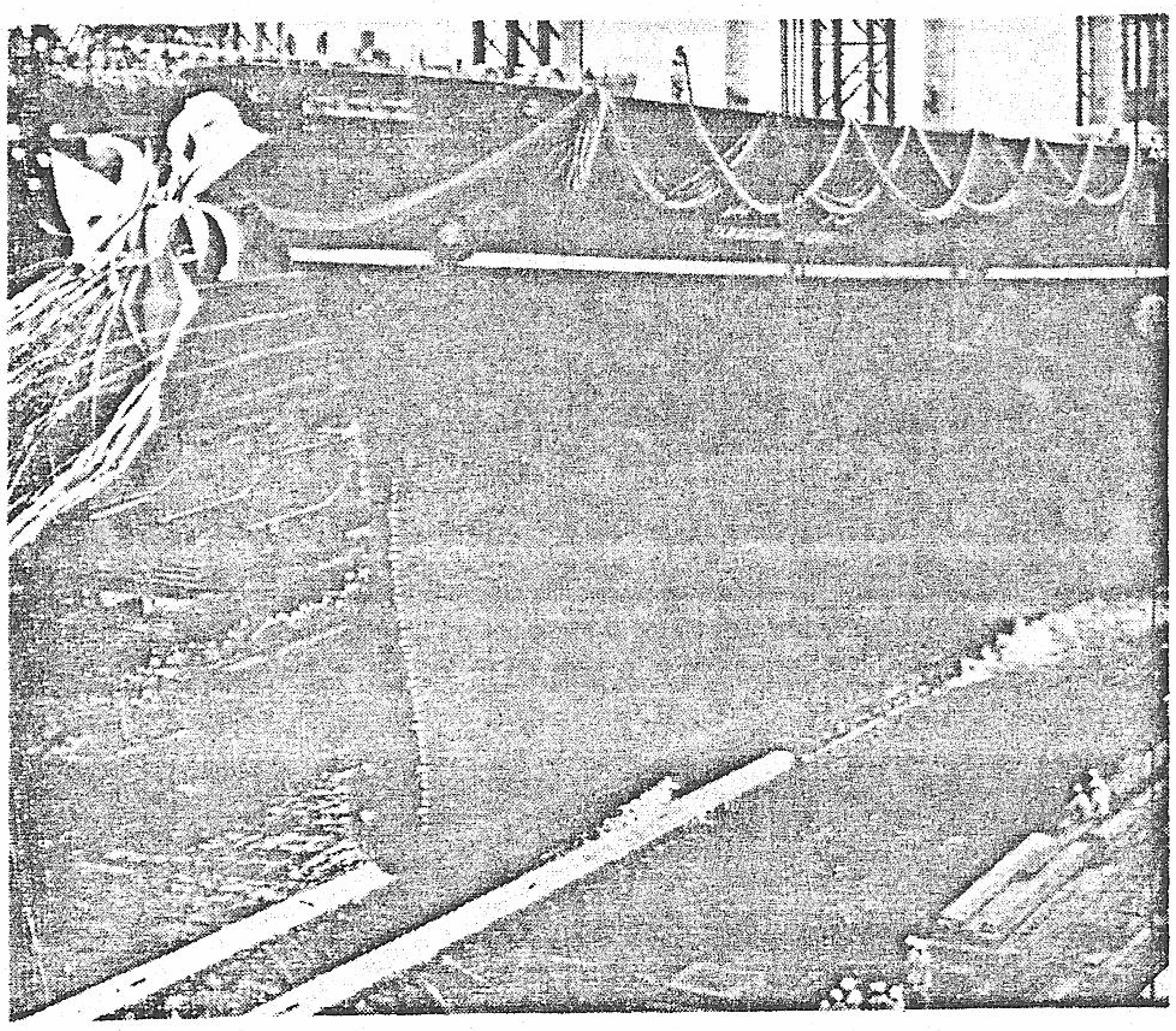


Photo 6. "Yamaguchi Maru" Cargo Liner

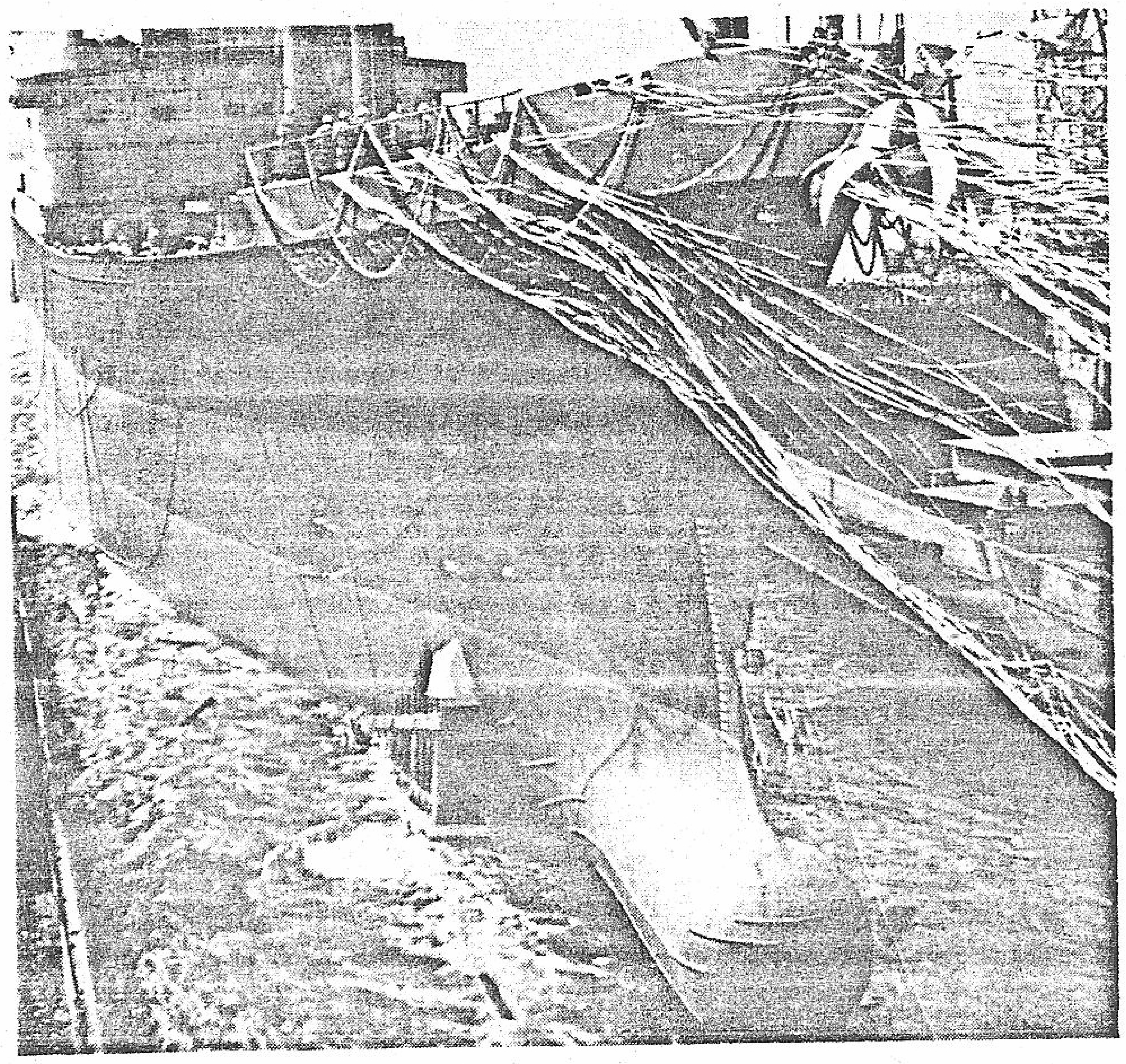


Photo 7. "Straat Futami" Cargo Liner

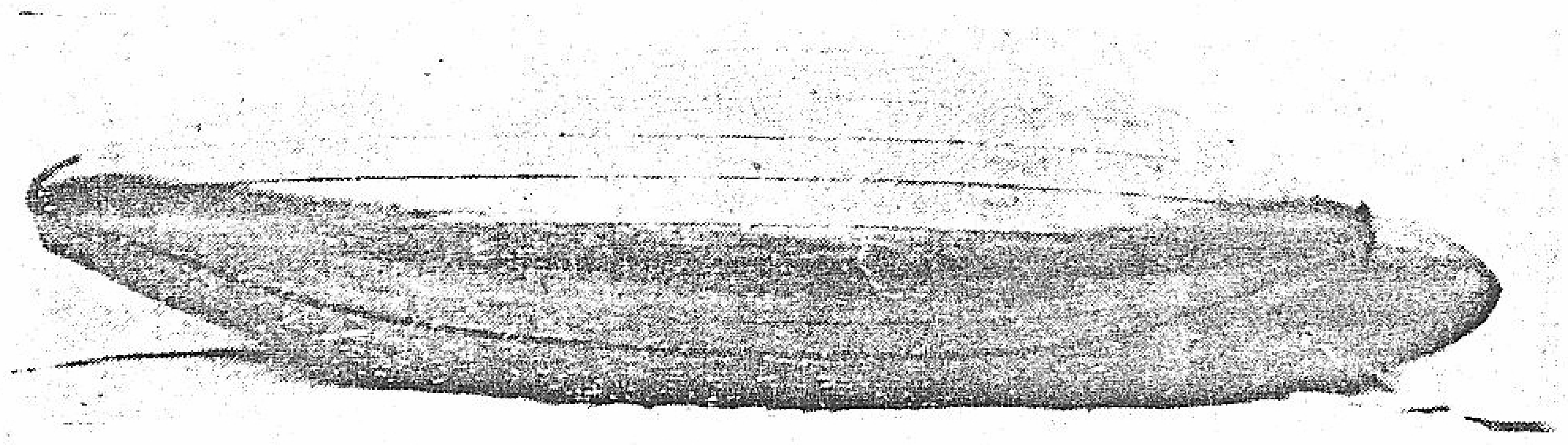
tools of mathematics. We shall, therefore, look at the history of the bulbous bow in general to see how it has been studied tank-experimentally and then see how the theory has been used and what role it has been playing in the study of the problem. It is because the understanding of these subjects is essential for the understanding of the changes which have taken place in these few years in ship hull form designs. These changes are the most important point on which the present article is focussed. Because of the reason stated above, however, we restrict ourselves to sketching only the rough outlines of them, deferring the discussion of the details to the next opportunity.

Historical Sketch of the Bulbous Bow

The idea of the bulbous bow has something diagonally opposite to the normal sense and intuition of ordinary, men. If one wants to decrease the resistance, particularly the wave resistance of ships, he would consider first to sharpen the ends of ships. In this seuse, an attempt to make the ends blunt may be a fantastic idea indeed. To make clear when such thought was conceived and by whom it was in troduced in shipbuilding is a very interesting thing. The author has tried to know in vain. There is, however, a short description in the books written by D.W. Taylor (1) and H.E. Saunders (2) that this bulbous bow probably originated from the ram bow provided in the old warships such as the "Victory", the flagship embarked by Admiral Nelson in the Battle of Trafalgar.

This ram bow was not originally equipped to decrease the resistance of ships, but to crash through the sides of the opponent ships with, like a horn of an ox, in the midst of the melee that was caused by the limited range of weak guns of those days. As technology of guns advanced, the original merit of the ram bow became doubtful. Unexpectedly, however, the ram bow was found by chance to be useful sometimes for reducing resistance of ships, and it was definitely proved later by accurate measurements of the resistance through model tests on completion of experimental tanks. In this connection, an interesting story is found in the paper of R.W.L. Gawn (3) (1941).

Swan



Raven

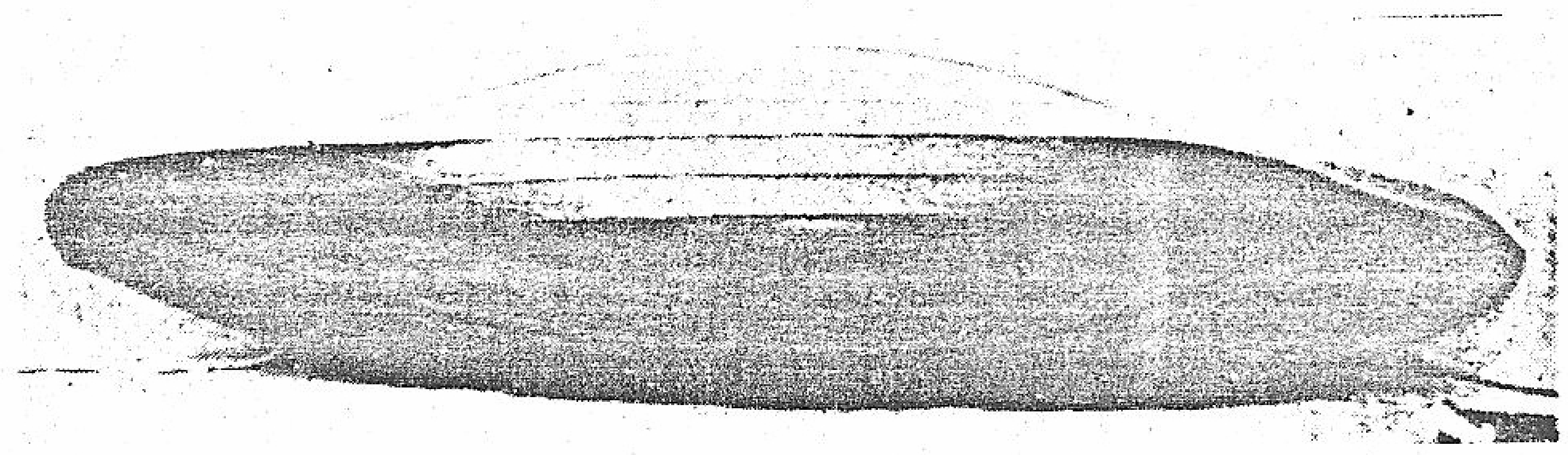


Photo 8. Models "Swan" and "Raven"
(Reference (3) and Photo. 5)

William Froude himself conducted a field test for a comparison of the bulbous and normal forms in a creek in the River Dart near Dartmouth Harbour in 1867, four years before completion of the first tank of Torquay (1871). In the picture of Photo 8, the model "Swan" the upper, has a blunt-ended bow like a bulb, while the model "Raven", the lower, presents the sharp-ended normal form. In this test, W. Froude also confirmed feasibility of the "law of similitude" called after his name by exercising tests of geosim series models varying $L=12$, 6, 3 feet. Fig. 1 is the result of the field test with $L=12$ ft model. Model A shows *Raven* type and model B *Swan* type. Compared to the sharp-ended *Raven* type, the *Swan* type of blunt bow end shows a little higher value of resistance in low speed, but a considerable reduction resulted in a higher speed range above 375 ft/min. W. Froude was deeply concerned about the results of this test. On completion of the first tank at Torguay, he immediately renewed the models of both types and conducted again the tests with incomparably

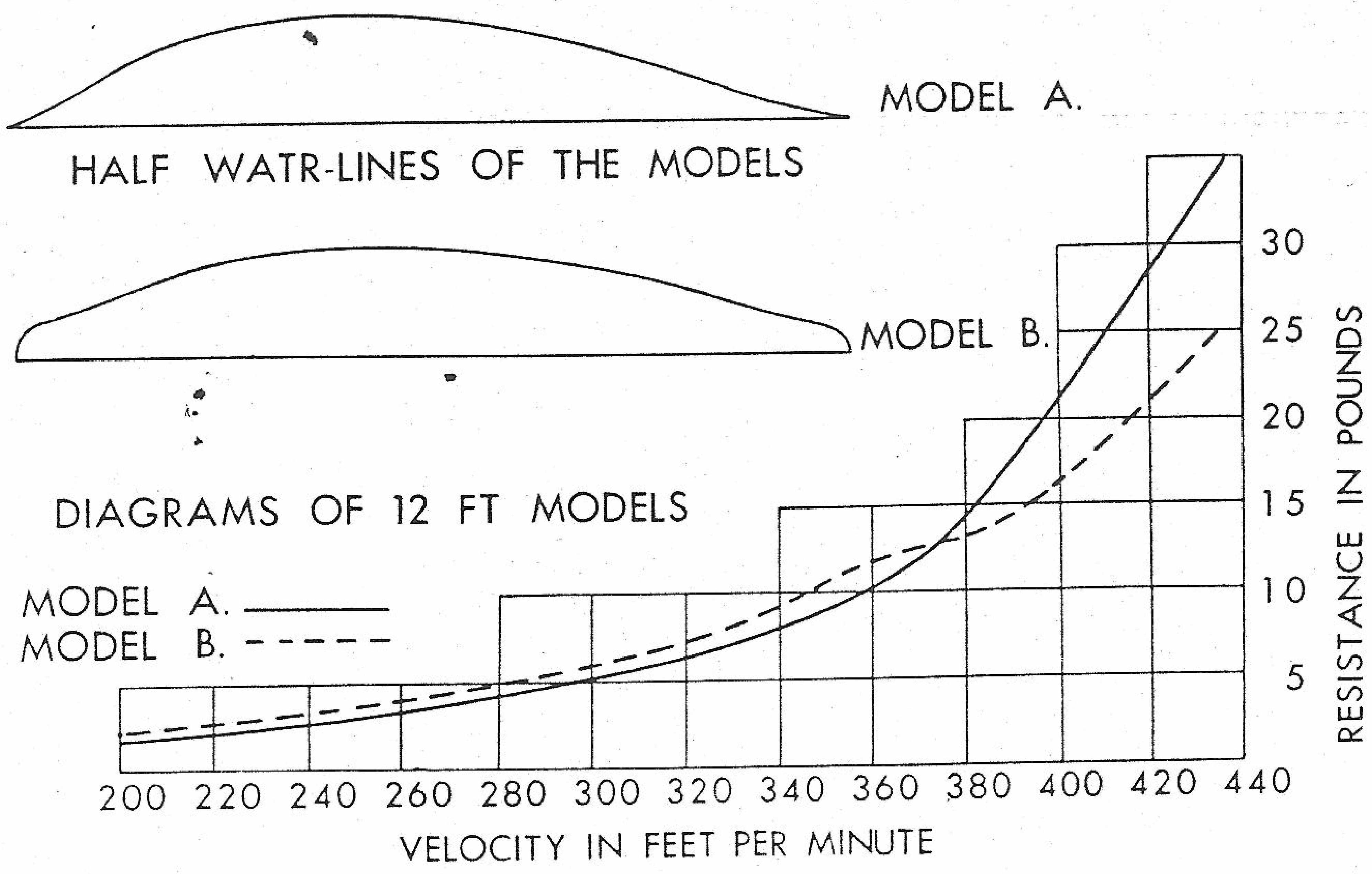


Fig. 1. Model Test Results on "Swan and "Raven" [Reference (3) and Photo. 6]

higher accuracy than the first field tests. In is interesting that he attained the result of same tendency in the whole.

In early days, the British Navy ventured to adopt the bulbous bow based on the results of this and successive tests. According to the paper of H.E. Saunders,(4) the U.S. Navy has conducted repeatedly the tests with ram bow models, since the first Washington tank was constructed in 1900. This led to the present concept of the bulbous bow, and the studies have been made by the staff including D.W. Taylor. The results of the experiments in the initial stage were applied to the U.S. battleship "Delaware" constructed in 1907 and attained an epoch-making success in its speed, and the height of bow wave was observed much lower than that of the existing hull forms.

In designing, however, guide rule has not been established enough to be applied in general. So, the designers, in individual cases, had to rely upon their own experiences and intuition. Naturally, on the other hand, with such success made as "Delaware", there should have been disgraceful failures in which not only the expected decrease in resistence was obtained, but reversely the resistance increased.

These situations, however, were remarkably improved in 1921, when large-scaled bulb-series tests were performed in the tanks of the U.S. Navy on 43 models in total with A and B types of parent forms and the results were published in the book written by Taylor. This is the noted bulbous form of Taylor regarding f—t chart. The features of two types of parent forms can be expressed as per Table-2 by the symbols used by Taylor. A is a fine form such as fast passenger vessels or battle cruisers while B is a full form such as battleships. General commercial ships other than passenger vessels are more closely allied to B than A. Fig. 2 shows an example of chart for B-series, speed length ratio $V/\sqrt{L}=0.805$ ($F=0.2397$). In the Figure, ordinates show f, and abscissae t are as shown in Fig. 3. It may be considered that f represents a relative size of bulb and t presents its approximate position. The maximum value of f adopted in the bulb series equals to $f=0.16$ in A-series, and f max$=0.20$ in B-series. As for t, its positive value can only be considered. The negative of $t(<0)$ was only the case with one out of 43 models. That is, there was only ($f=0.20$, $t=-0.40$) in B-series. According to Taylor's expression, the form of bulb is "roughly of triangular section with its base at the keel level and its apex at the load water line".

Table 2. Eggert Taylor's Bulb-Series

Series	A	B
Number of models	20	23
L (ft)	20	20
B/L	0.1142	0.1616
B/H	3.35	3.20
l ($=C_P$)	0.60	0.65
C_m	0.92	0.99
$\dfrac{\Delta}{\left(\dfrac{L}{000}\right)^3}$	60	150

The contours in Fig. 2 is Rr/Δ or the siduary resistance Rr/Δ per displacement Δ (in ton) and is closely allied in general to the tendency of the theoretical curve in Fig. A-2 concerning the simple wave-making interference between two sinusezidal wave systems to be shown later in Appendix. Putting aside further detailed comparison with theoretical curve, let us follow the figures of the empirical curve in Fig. 2. When noticed at the change in Rr/Δ that varies with the increase in t, along the datum line of $f=0$ in the figure, t (optimum) for $f=0$ is given as $t=0.35$. However, by adopting $f=0$ or a bulb it is possible to reduce further Rr/Δ value. For this speed, the bulb of ($t=0$, $f=0.07$) is optimum, and it is noted that Rr/Δ is reduced further by 13 per cent as compared with the minimum value of Rr/Δ for ($f=0$), without bulb. Accurately speaking, in examining the range of reduction in f (optimum), t (optimum) and Rr/Δ due to Froude number, En or $V/\sqrt{L}$, Fig. 4 can be obtained in B-series. This tells that there is no considerable change in t (optimum), but f (optimum) makes

Fig. 2. Typical *f*-*t* Chort

Location and Personnel

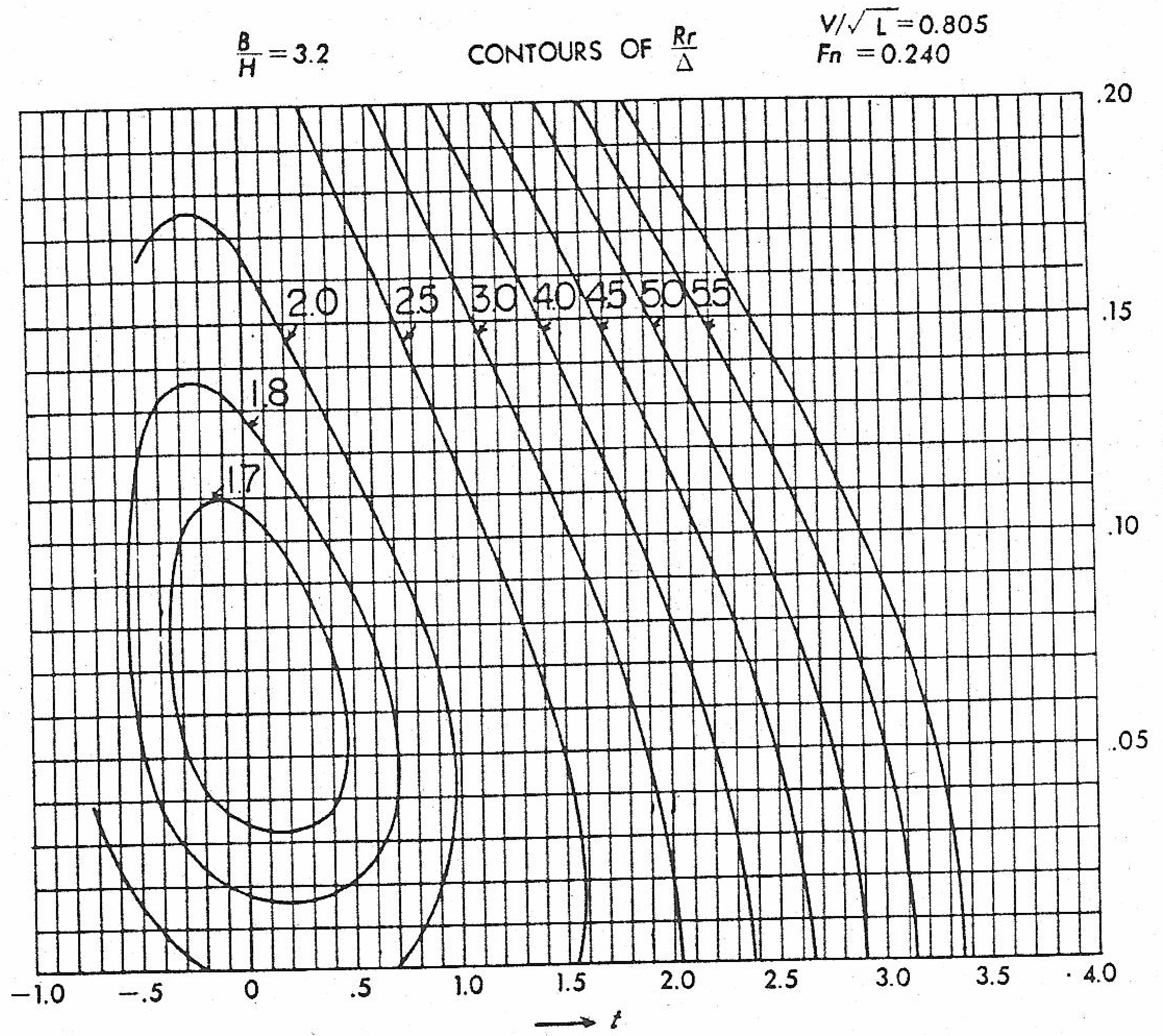


Fig. 3. Diagram Illustrating Definition of *f* and *t*

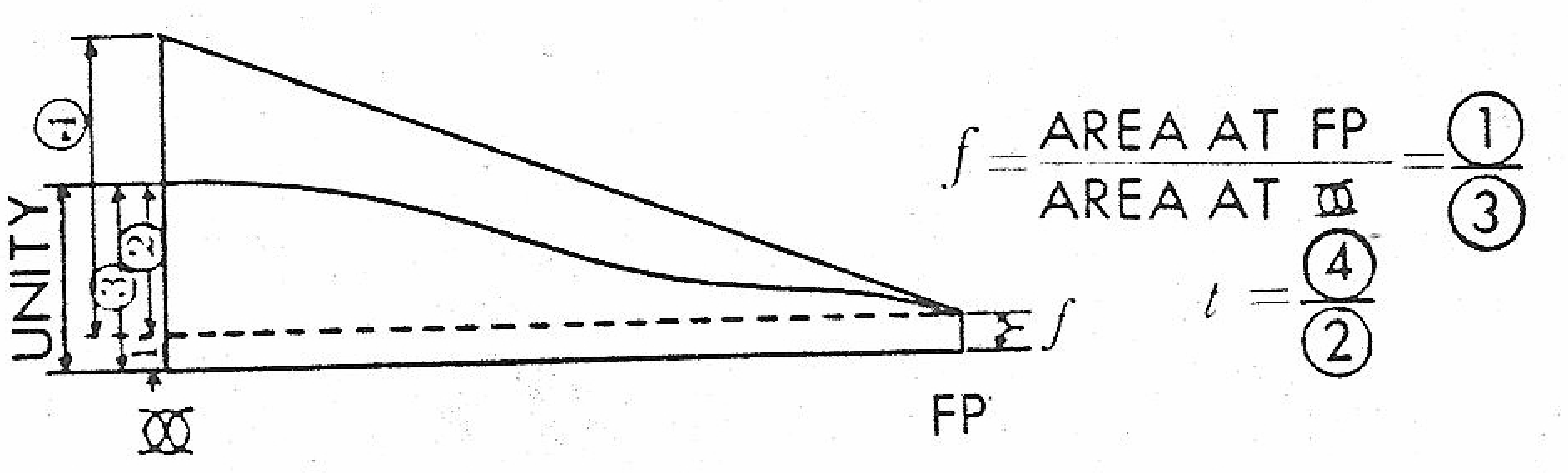
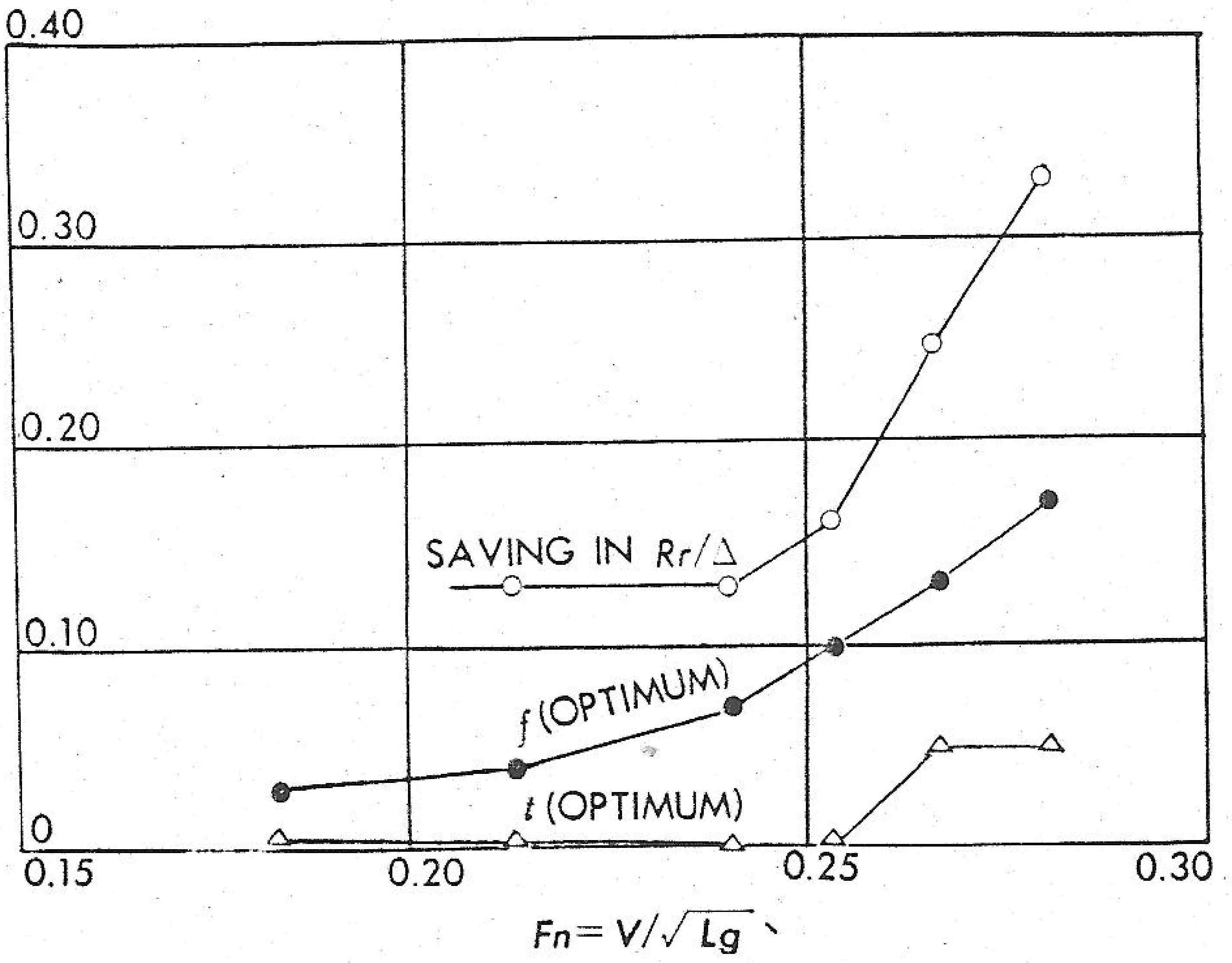


Fig. 4. Results with Series B (Eggert-Taylor)



rapid increase with increasing *Fn* together with the amount of reduction in Rr/Δ. In this connection, comparison with theory is interesting, but it will be explained later, and the description is given here about the further results of the tank tests exercised since with the bulbous bow.

The Projected Bulbous Bow of the Japanese Battleship "YAMATO"

Since the experiment of Eggert described previously there has been no such methodical series test of bulbous form on a large scale, but there have been many small-scale or fragmentary experiments such as those by E.M. Bragg[5] (1930). There is also the unpublished prewar data for the British ship Queen Mary with fifty-three models and those for the Japanese battleship Yamato. Among these experiments the author is especially interested in the process by which the hull shape of Yamato was designed. As can be seen from the picture of the model shown in Photo 9 (scale=1/200) (this model was constructed by Professor Tagori of the University of Tokyo), the bulb of Yamato is considerably projected forward from F.P. and is clearly different from the bulbs of the Eggert-Taylor type. Following seems to be the process by which it was finally adopted. (The following account is due to Mr. T. Takahashi, now at I.H.I., who participated in the experiment at that time at the Technical Institute of the Navy).

Out of forty-eight models tested for the hull form of Yamato only the last four models had bulbs. The tests were conducted between 1933 and 1937. For the forty-c—k of the British type with $M=L/\nabla^{1/3}$ as the para-four models with the normal bows the ordinary tank tests were made and the results were analyzed referring to meter. Thus, by the summer of 1936 the best form of the normal bow was decided for $L_{PP.}$ = 250m L_{WL} = 253m B_{max}=38.9m, H=10.4m, Δ (standard)=62,315t. V_{max}=27 knots, cruising rang 7,200 sea miles, and main engine power 135,000 SHP (the combination of 2 × 37,500 turbine and 2 × 30,000 diesel). However, the two diesel engines originally planned were replaced by two turbine engines, and the S.H.P. and Δ (standard) were increased from 135,000 to 150,000 and from 62,315t to 69,143t, respectively, due to the increase in the tonnage which was required by the gradual reinforcement of the armament. And yet the principal particulars were not allowed to be changed, only L_{WL} being allowed to be increased by 3m to 256m. For the requirement to maintain the speed and the cruising range, which was imperative from the design point of view, there was no other means than to reduce the resistance by improving the hull form. There were two contradicting opinions at this point. One opinion was that the better hull form should be searched for among the normal bows and the other opinion was that one should give up the normal bow and adopt the bulbous bow. Especially, the late Vice-Admiral Hiraga was the strong advocate of the latter opinion, which was eventually adopted. First, the bulbs of the Eggert-Taylor type which do not have forward projection ($X/L=0$) were tested with $f=0.07$ and 0.16. With these bulbs the reductions of E.H.P. by 8 and 18 per cent, respectively, were obtained at $Vs=27$ knots. Thus, the possibility of reducing E.H.P. became apparent. It was found, however, from the observation of the wave profile along the model side in the tank test for these $X/L=0$ groups of bulbs that the first crest immediately behind F.P. became higher when the bulb was attached. As a result, the splash could even reach the No. 1 turret in a strong wind which could cause some

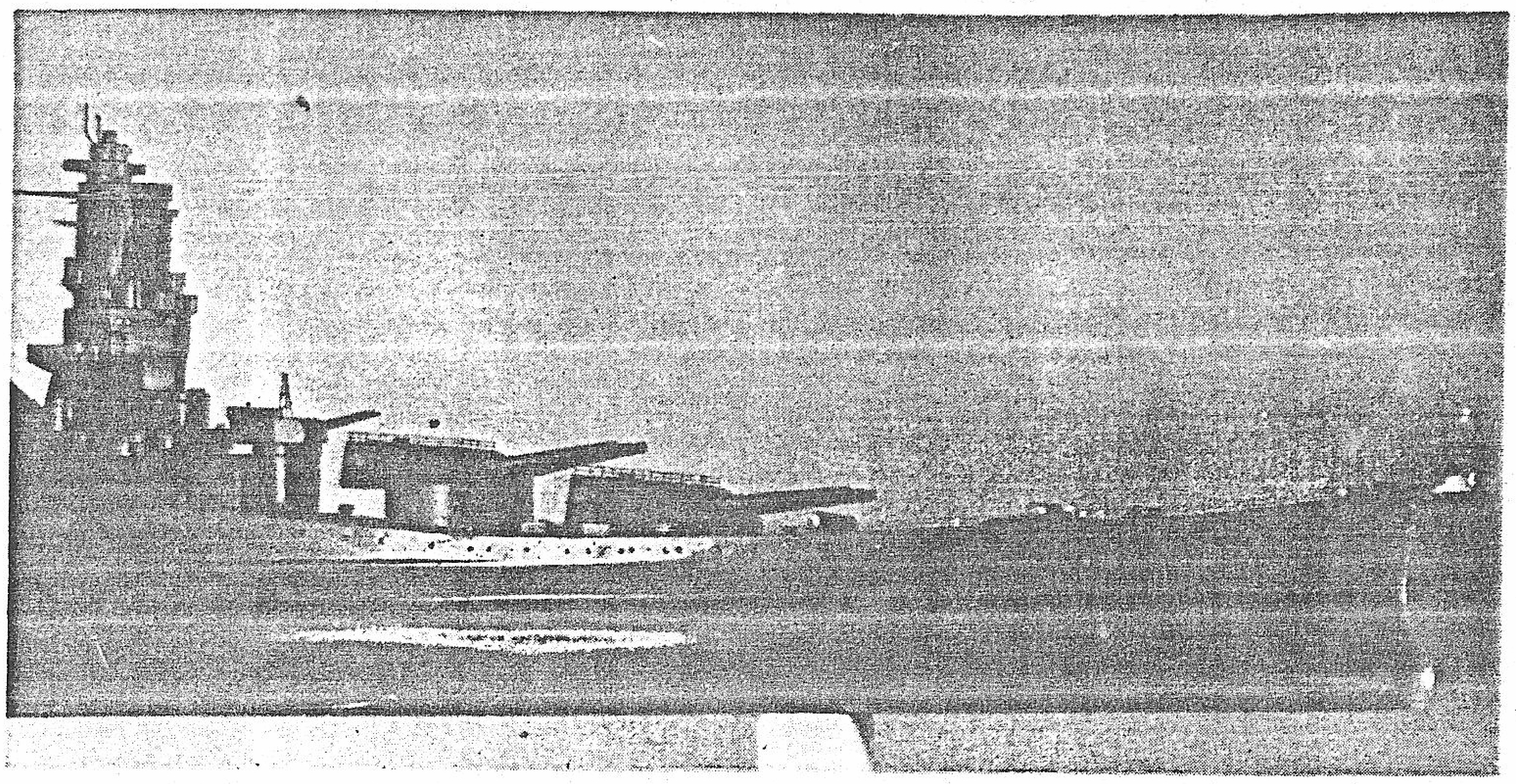
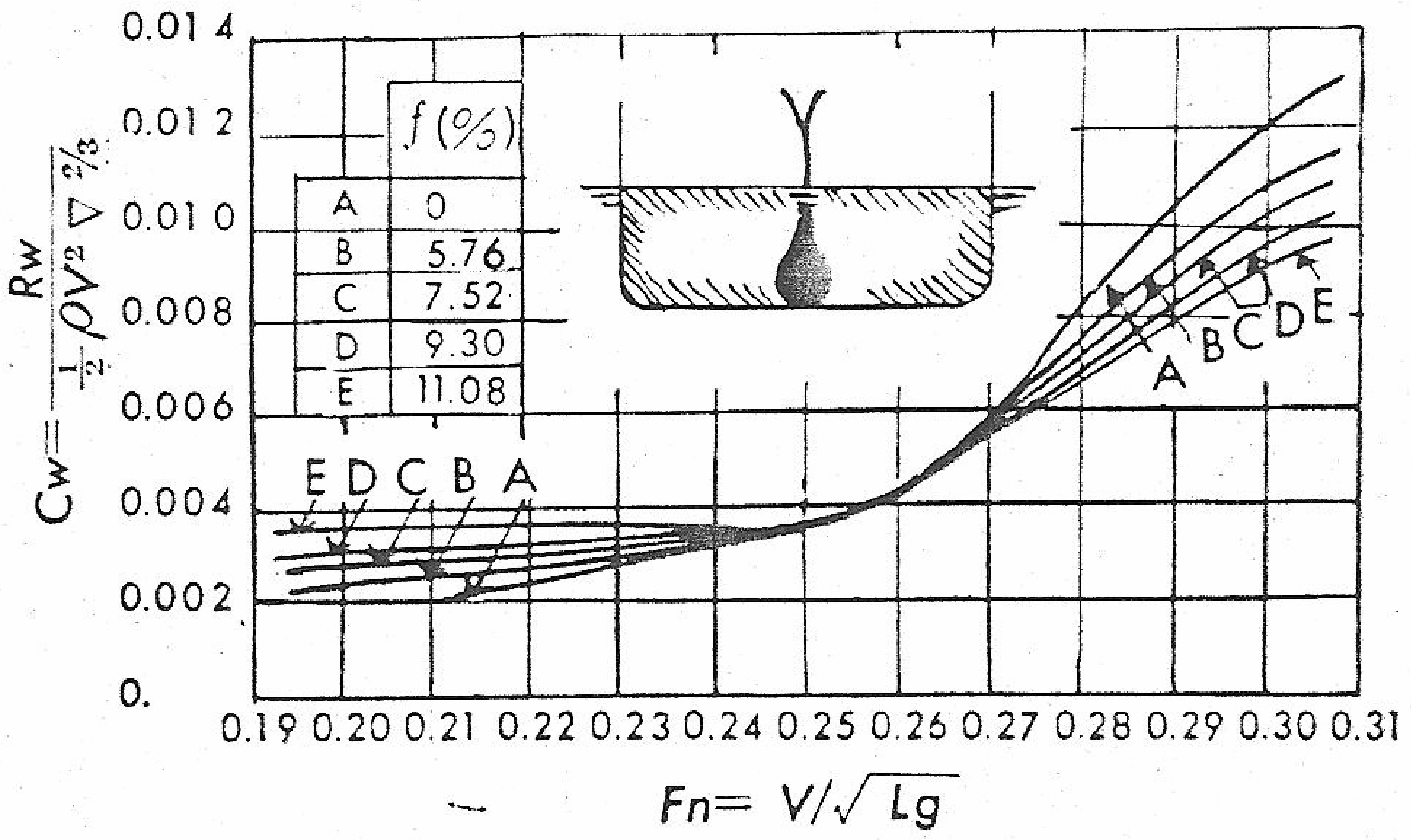


Photo 9. Model of "Yamato" in Scale 1/200 (with coutecy of Dr. Tagori)

trouble in the operation of the weapon. Therefore, the idea of the bulb with the forward projection was put forward, and the tests were made for the bulbs with $X/L=0.012$ ($X=3$ m) and $X/L=0.020$ ($X=5$ m) with $f=0.07$ in each case* where X is the maximum forward projection of the bulb measured from F.P. The latter bulb ($X=5$ m) was better at the top speed of 27 knots but at the cruising speeds of 16—18 knots the former bulb with $f=0.07$ and $X/L=0.012$ ($X=3$ m) was found to be better, and was, therefore, finally adopted. This was barely before the laying down of the "Yamato" on November 4, 1937. Aside from the problem of resistance, there were problems which were new at that time such as the effect of the extended bulb of this kind on the propulsive efficiency or the self propulsion factors and the problem of the scale effect between the model and the actual ship. But at the official speed trial, 27.5—27.7 knots were obtained, which were more than the designed speed of $Vs=27.3$ knots, and the propulsive efficiency was also good.

The first Japanese merchant vessels which adopted the bulbous bows were the sister boats, KASHIWARA-MARU and IZUMO-MARU, both 27,700 GT, of N.Y.K. Line built in 1939 to 1940. Fig. 5 shows the result of the experiment by Dr. M. Yamagata(7) (1938) which became the basis for designing the bulbs of those ships. The bulbs which were tested in this experiment were those which had no forward projection ($X=0$) and their sizes were $f=0$, 0.0576, 0.0752, 0.0930 and 0.1108 respectively. The experiment was begun with the largest bulb ($f=0.1108$) and then the bulb was scraped to make smaller bulbs mentioned above, while the displacement was kept constant by gradually increasing the draught. As can be seen from the figure the residual resistance was reduced by 25 per cent for $Fn=0.30$ when going from A ($f=0$) to E ($f=0.1108$). It was also shown in this experiment that the curves B to E for the models with the bulb cross at $Fn=0.256$ with the curve A without the bulb and, therefore, the model without the bulb was the best for the speed lower than that value, whereas at the higher speeds the models with the bulbs were better. The reduction of the resistance was simply proportional.

Fig. 5. Effect of Buldbous Bow [Reference (7) and Fig. 64]



H.E. Saunders' Conclusion on the Design Rule of a Bulbous Bow

As has been described in the preceeding paragraph, there have been so many tank tests on the bulbons bow for the warships as well as for the merchant vessels during and after the war in Japan as well as in the other countries that one might think that the principle for designing the bulbous bow has already been established. This, however, is not necessarily true. As the most prominent proof of the above statement, let us quote the following statements from the book by H.E. Saunders, cited previously, on pages 509—510 in §67.6 entitled Design of Bulbous Bow.

"An attempt to reconcile the model-test data of E.F. Eggert, E.M. Bragg and A.F. Lindblad, and to evolve systematic values of the design parameters f_E ($=f$) and t_E ($=t$) from them, *has so far proved unsuccessful.* The

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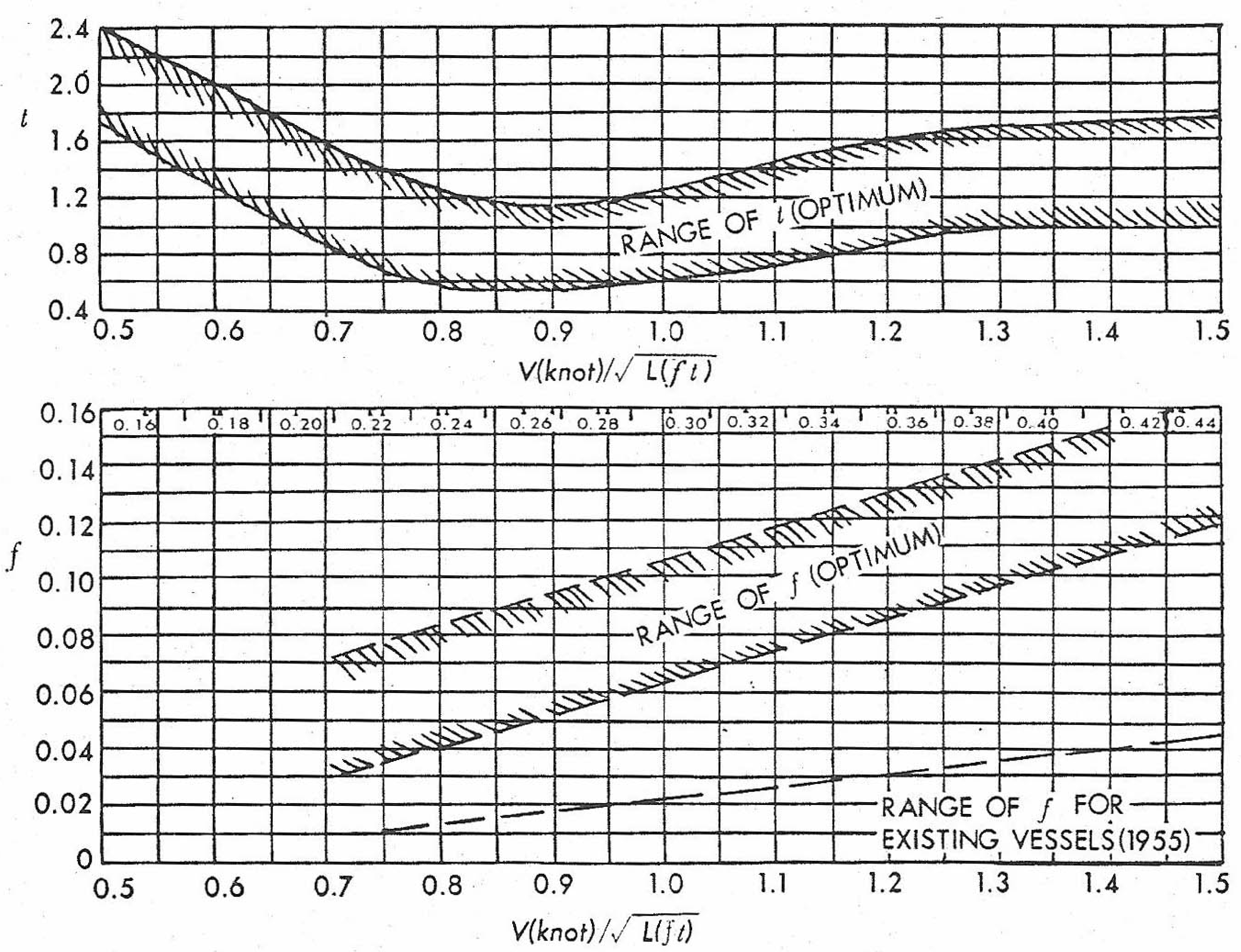
* This kind of bulb with the forward projection from F. P. was tested by the U.S. Navy before the World War II and the effect of reducing the resistance was recognized. It was adopted for the battleships when the Delaware type of 1910s were changed into the Arizona type of 1915s (E. E. Saunders(2), Vol 2, p. 510)

Fig. 6. Design Data for Bulbous Bow
[Reference (2) Vol II Fig. 67D]



design values actually used on a considerable number of vessels whose performance bettered or equaled that of the Taylor Standard Series have been plotted, therefore, on a basis of speed-length quotient. From these plots the tentative design lanes of Fig. 67. D (=Fig. 15) were derived. They indicate, for Tq ($=V/\sqrt{L}$), a lower limit of 0.70, $Fn=0.208$, and a high or limit of 1.50, $Fn=0.447$.

"Those who use them as interim guides *until better rules are developed* should recognize the following shortcomings:

(a) The f_E values do not increase indefinitely with Tq beyond the range of $Tq=1.5$ shown in the diagram. They almost certainly diminish to zero at some upper limit of Tq around 1.9 or 2.0.

(b) The proper value of f_E appears to depend upon Cp and the displacement-length ratio $\Delta/(0.10L)^3$, *but the various model-test data shows conflicting trends*. It is probable that the best value of f_E increases with both Cp and the fatness ratio.

(c) The upper and Lower limits of Cp and fatness ratio for which bulb bows give beneficial results *are not yet determined.*

(d) It is possible that the best values of t_E depend upon factors other than Tq, *but if so no definite trends are yet apparent. Selecting the proper value of* t_E *appears, however, to be less important than using the proper value of* f_E."

In the above quotations the parentheses and the underlines were added by the author for the sake of the reader's convenience or to draw the attention of the reader. Especially, the last part of item (d) is clearly misleading in view of the most recent theory of the bulbous bow. This is a good example of the fact that a purely experimental method, having nothing to do with the theory, can give conclusions with only a limited validity when applied to such a problem as that of the bulbous bow, in which complicated wave-making interference comes into play.

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