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FLAT PLATE, STRAIGHT-FRAMED HULLS

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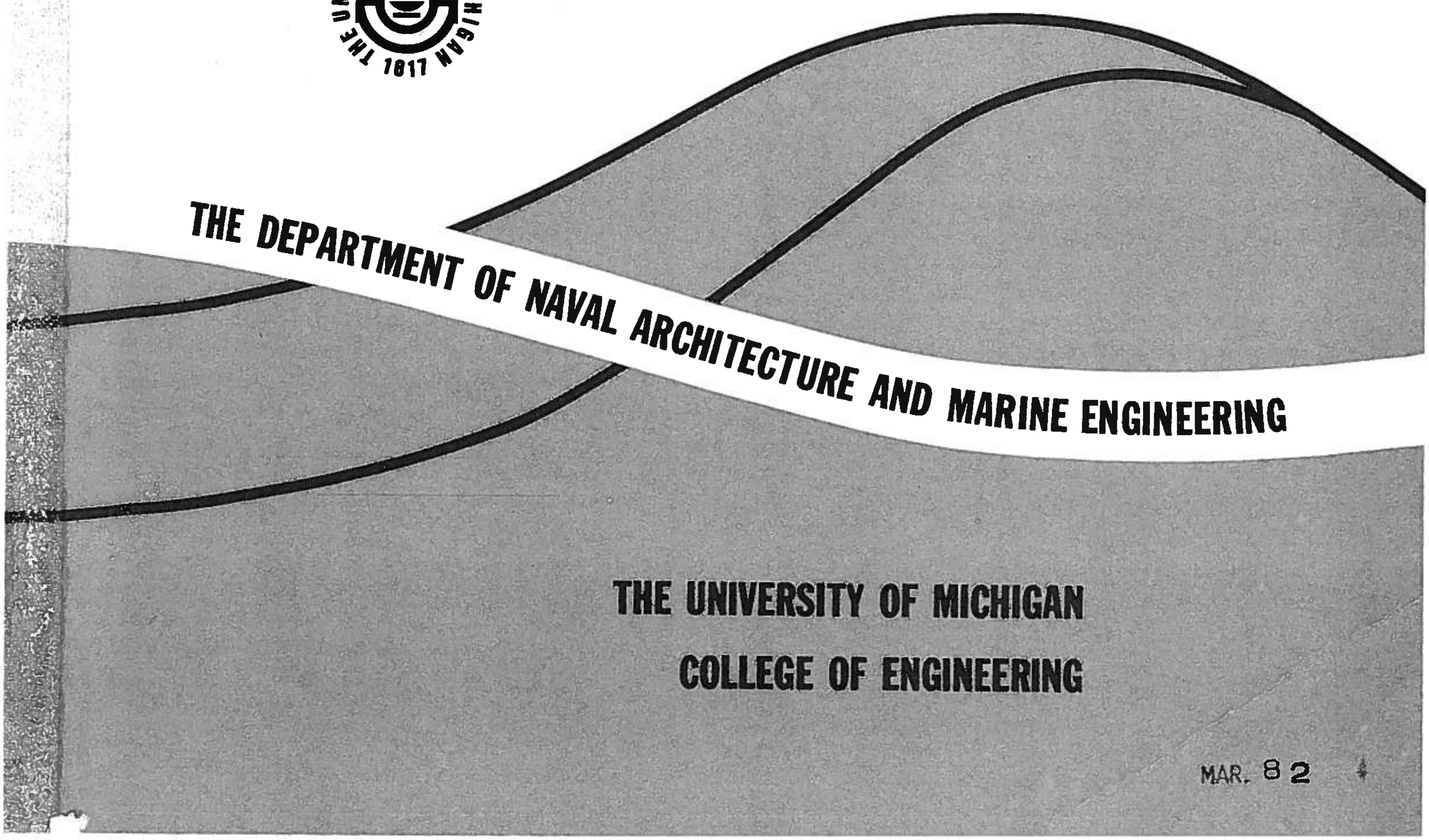

THE DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

FLAT PLATE, STRAIGHT-FRAMED HULLS
(a study of the concept, its development, application, and economic feasibility)

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ACKNOWLEDGEMENTS

I must first thank the respective workers and authors of the studies,which provided the thought impetus and the encouragement for writing this report. I also wish to thank Professor R. B. Couch, who supervised the study; Kim von Blohn, who had done a serious economic feasibility study in a previous report (21); and Professor C. Gallin, who through K. von Blohn had provided valuable reports. Thanks are due to Ferial Arnas who did a trying and tiresome editing of the paper; to Mrs. Dawn Mulder who did an excellent typing job; to Professors H. Benford and T. F. Ogilvie who have made valuable suggestions; and to all the friends who have encouraged and helped in many ways.

Tezal Arnas

Knowledge is a process of the development of the idea rather than a compilation of experiences.

Anonymous

ABSTRACT

The report was prepared in fulfillment of NA 591 Advanced Reading and Seminar in Naval Architecture under the supervision of Professor Richard B. Couch.

The report can be thought of in two major parts. The first part is the history and outcome of extensive studies made of the flat plate straight-framed hulls in the past fifty five years. The second is an economic feasibility review of the concept in today's highly advanced shipbuilding industry.

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TABLE OF FIGURES

NOMENCLATURE

B	Beam in Feet
BHP	Brake Horsepower
CB	Block Coefficient
CM	Midship-Section Coefficient
DWL	Design Waterline in Feet
EHP	Effective Horsepower
EMB	Experimental Model Basin
HP	Horsepower
HSVA	Hamburg Model Basin
IHI	Ishikawajima-Harima Heavy Industries Co. Ltd. of Japan
LBP	Length Between Perpendiculars in Feet
LCB	Longitudinal Center of Buoyancy
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LWL	Load Waterline in Feet
NSRDC	Naval Ship Research and Development Center
OBO	Ore Bulk Oil Carrier
SHP	Shaft Horsepower
SNAME	Society of Naval Architects and Marine Engineering
T	Draft in Feet
UM	The University of Michigan
USCG	The United States Coast Guard
V	Velocity in Knots
Δ	Displacement in Tons
฿	Baseline
℄	Centerline
⊗	Midship

INTRODUCTION

The development of straight-frame hulls has shown that, in comparison to conventional hull forms, favorable results in resistance, propulsion, and sea-keeping can be obtained. Nonetheless, there is need for a better understanding of the submerged portions of the hull lines.

The use of flat plate surfaces appears to have started as early as the American Civil War. For example, the "Ninety-Day" gunboats had flat bottoms. Now, following fifty six years of experimental studies of straight-framed hull forms, we have "Jag-Dev."*

The research and development that has taken place through the years is investigated in the following pages. This history is important since it lays base for understanding further studies and for evaluating their results.

Some deductions as to the economics of the flat plate ships were also sought. I did not go into a detailed study of economics, for it would merely have changed the objective of this paper. I also did not get into the concept of developable surfaces, believing that this too would have been a project in its own right.

This paper is a compilation of the thoughts and ideas that developed through the years of experimental work. It is not my intent to praise the concept but merely to give some insight into what has been done.

Various illustrations and plots are included so as to provide the reader with visual aids to comprehension.

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*Jag-Dev: A cargo ship of the Pioneer class built by Blohm and Voss of Germany for the Great Eastern Shipping Co. Ltd. of Bombay, India.

EARLIER STUDIES

The Allied shipyards* of the World War I lacked the ability to meet the anti-submarine naval demands made on them. In view of the inflationary war-time economy, an automation of shipyards was needed to meet this demand, within the technological limitations of a wartime industry. A system was required which would utilize:

a) Unskilled labor and labor unaccustomed to shipbuilding.
b) A simple construction which would avail itself of such labor, and
c) A supply of prefabricated parts from various sources.

This need provided the impetus for a search to simplify merchant ship construction.(3)**

McEntee and the Studies at EMB

Naval Constructor W. McEntee studied three conventional hull forms. He did a comparative analysis of propulsive efficiency in the conventional and simplified hull forms. Model tests were done at EMB, and the results were impressive in favor of the simplified hull forms when they were presented at the annual SNAME meeting (1917).

McEntee's emphasis was basically on perpendicular plain surfaces. Where curvature was unavoidable, such

---

* Primarily the shipyards of UK and USA

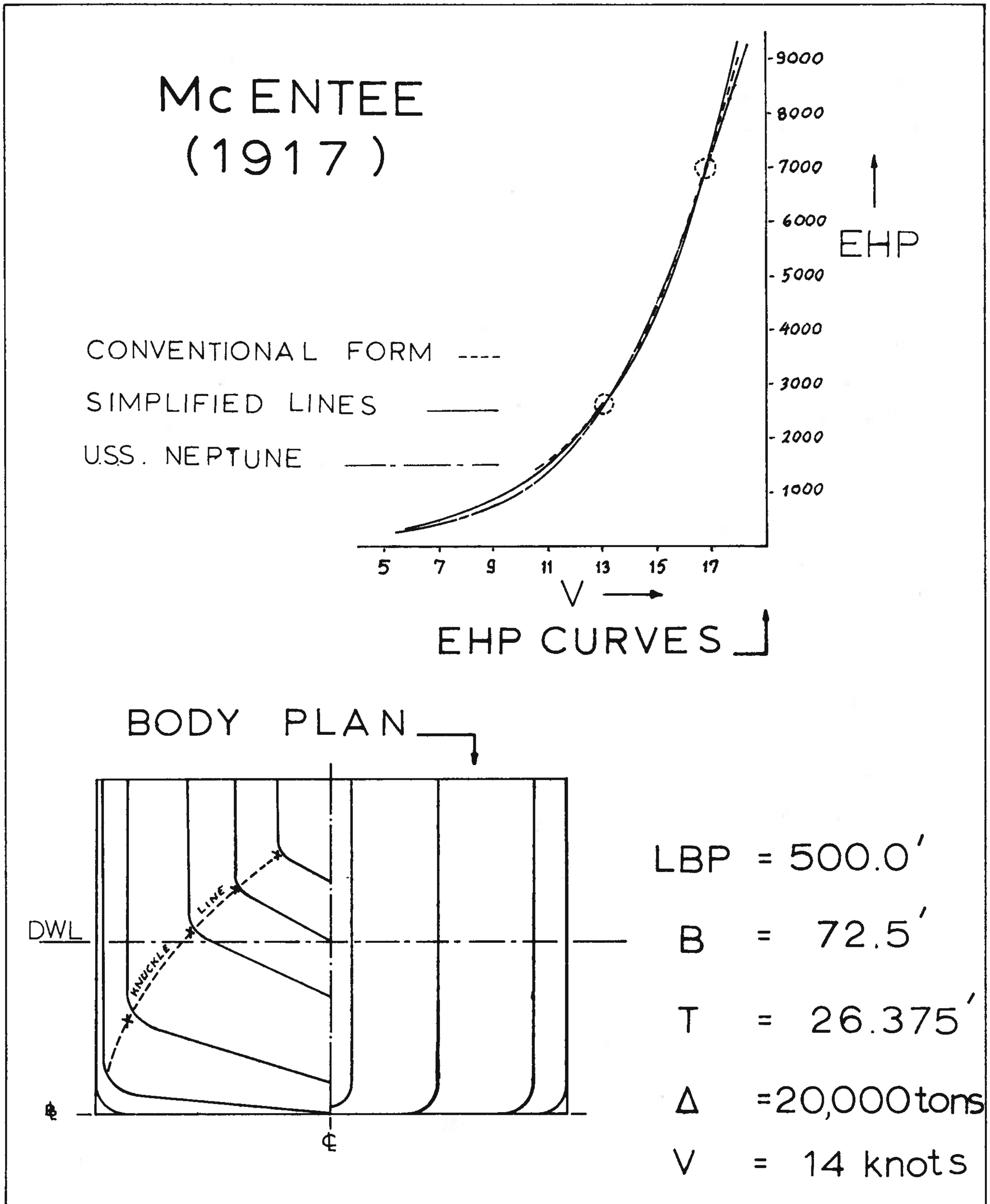
** Numbers in brackets designate references at end of paper.

as at the bilge, a circle was made use of, and any use of double curvature was minimized. The parallel middle body was extended as far as was possible without any major increase in the resistance.

Of the three models that were tested, an oil fuel barge and a 400 foot freighter showed a resistance gain of at most two percent, while, interestingly enough, the 500 foot cargo vessel showed some improvement over the conventional design. In this instance the conventional form was better up to 13 knots. Then in the range up to 17 knots the simplified version showed an approximate seven percent savings in resistance at 15 knots. See figure 1.

McEntee's conclusion is that, from the standpoint of resistance, the simplified lines could give propulsive efficiency results that were as good as or better than the conventional designs'.

Figure 1 also shows a schematic of the simplified lines of the body plan of a 500 foot cargo vessel which showed a savings in resistance over the parent hull lines.



LBP = 500.0'

B = 72.5'

T = 26.375'

Δ = 20,000 tons

V = 14 knots

500' CARGO VESSEL OF SIMPLIFIED LINES

REF (4)

FIG 1

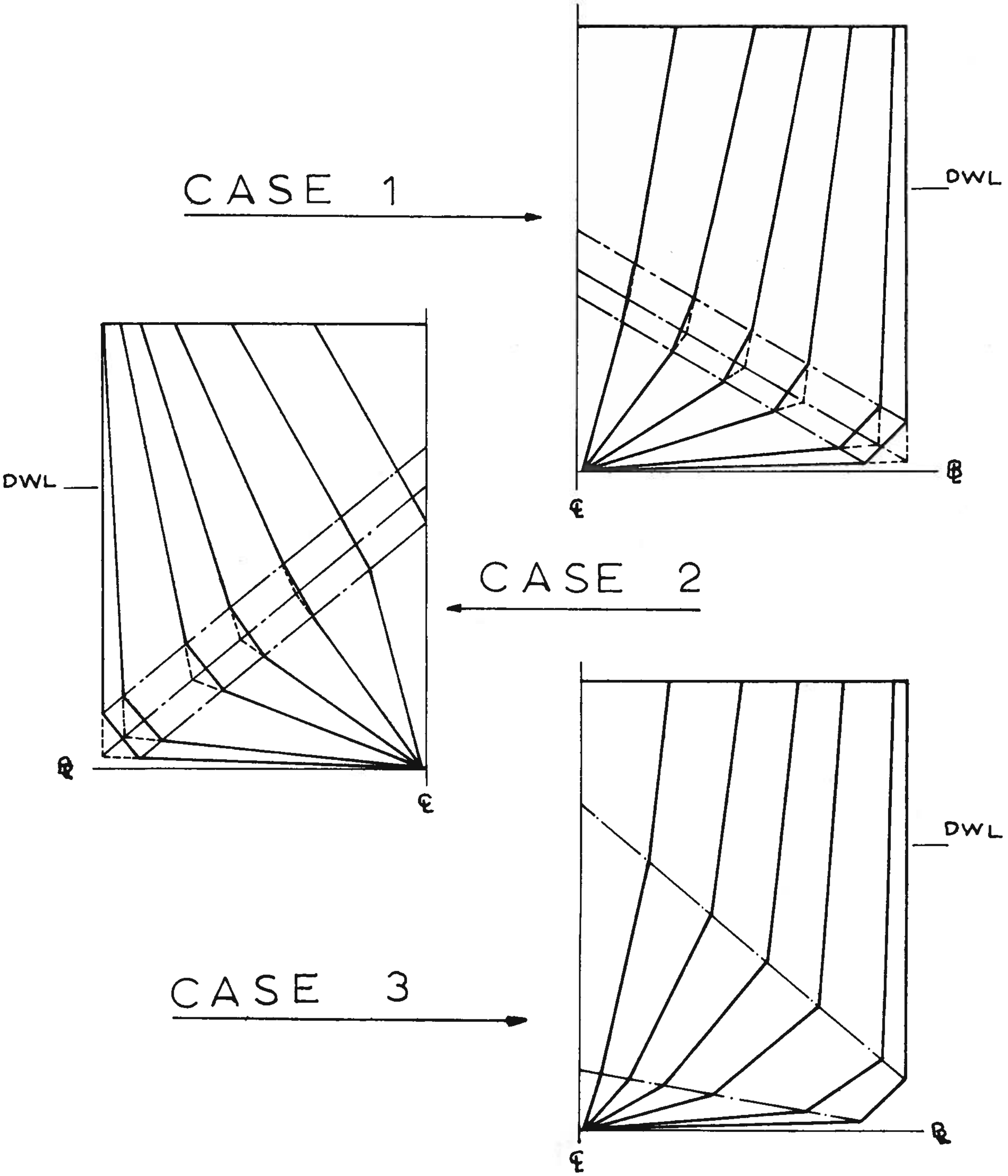
Sadler and the Studies at the UM

At the time McEntee presented his paper, the University of Michigan's model tank basin was busy undertaking tests of a more courageous design. Professor Sadler and a visiting Professor from Tokyo, Mr. Yamamoto, had done away with the circular bilge, using perfectly straight lines. There were no double curvature at all. An interesting result of their study showed that less resistance could be attained with the models tested compared to some of the then current conventional designs.

The object of the tests was to determine the difference in resistance that existed between the shipshape form and that of the straight frame hull. There were no attempts made to develop the best possible form. The ranges of block coefficients of the tested models were between 0.6 and 0.8.

Results of the tests showed that the shipshape form was the best, and among the straight-frame models those with a steeper slope to the bilge diagonal gave better results. See figure 2 cases 1 and 2. The resistance increased due to the lack of conformity with the proper stream line flow. Figure 2 case 3 shows a half body sketch of this particular model. From the point of view of resistance, a curved diagonal line in the body plan was suggested. A compromise was achieved, from the horsepower (EHP) standpoint, by combining the increase in resistance of a conventional hull using bilge keels and that of a straight frame hull with its square corner.

SADLER & YAMAMOTO
(1918)



REF (2)

FIG 2

D'Eyncourt and Graham and the Studies in England

Sir E. D'Eyncourt and T. Graham worked towards a simplification of Merchant ship construction from 1917 to 1919. Their first studies were done on angular bilge ships. Later, the chamfered bilge showed an equal ease of construction and hence was adopted.

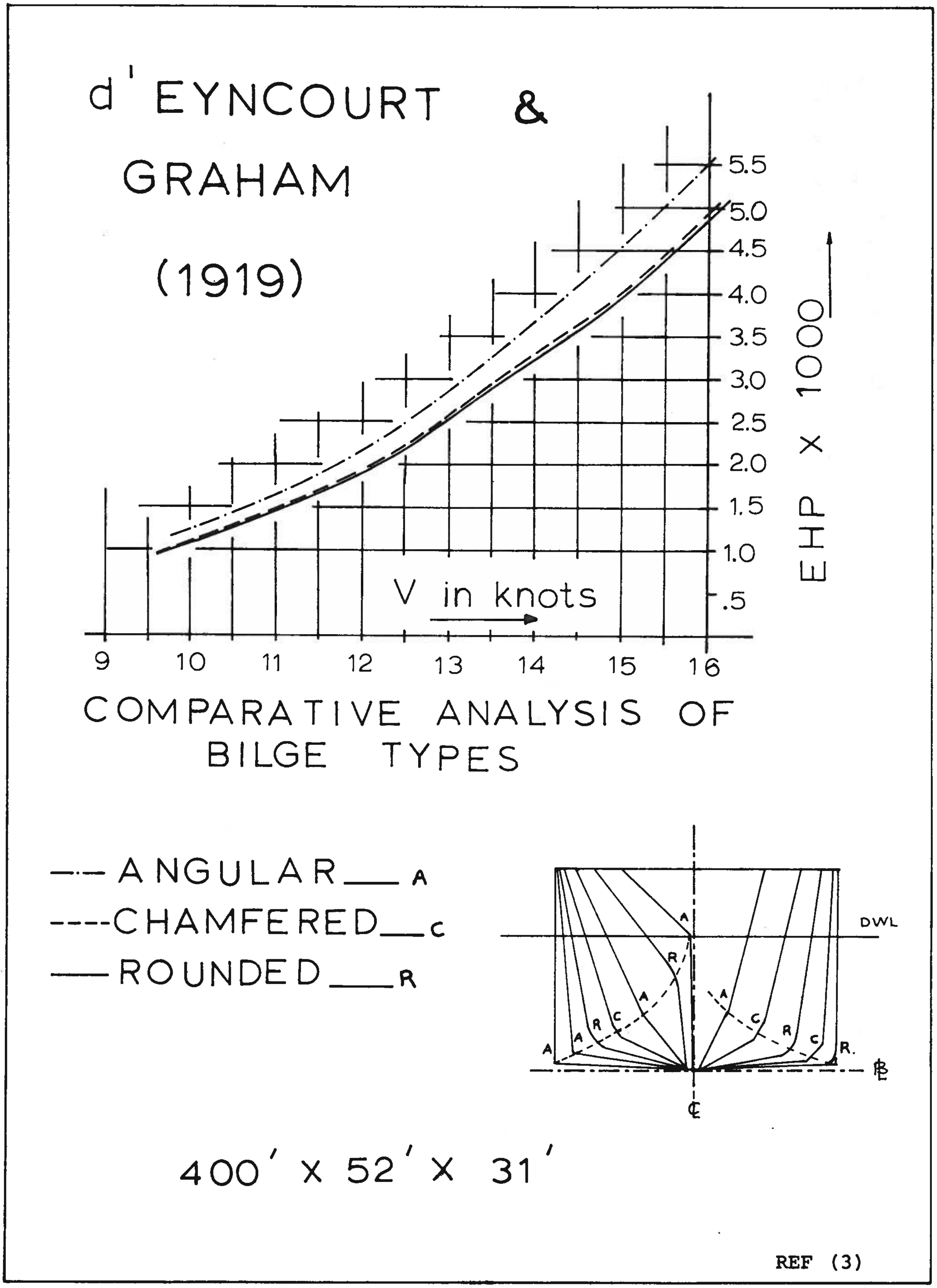
The chine line gradually rose up toward the aft section of the hull, depending upon the shape and the speed of the vessel. The alignment of this chine line seemed to have considerable influence upon the resistance and powering requirements of the eleven models that have been tested. The run of the hull was more important than the entrance. In other words, a return to the blunt-fore-end in association with a fine after-end appeared, within limits, to be the directing principle towards an efficient form. References to the allocation of buoyancy were made because of the significance they bear in relation to the design of single screw straight-frame vessels.

A study was also made in order to define the limits of a straight-frame vessel's speed. Two types of ships were tested:

a) Intermediate vessels of up to 16 knots.

b) High-power war vessels of up to 40 knots.

The results were in good agreement with the conventional hull form below twenty knots. However, from 20 to 40 knots the resistance increased from two percent to six percent, respectively, at full speed due to the angular bilge formation. This gain in resistance was thought to be due primarily to the unsuitable adjustment of the chine line, and also to the vertical allocation of buoyancy since models were kept at the same prismatic curves.



COMPARATIVE ANALYSIS OF BILGE TYPES

FIG 3

In conclusion, cargo vessels of speeds up to 11 knots gained two to three percent in resistance with angular bilges. This was negligible compared to bilge keels on conventional hulls. With chamfered bilges, satisfactory results of up to 11 knots and a gain of one to two percent in resistance for intermediate vessels up to 16 knots was obtained. See Figure 3. In these the chine should have a distinctly rising contour at both ends of the ship.

Note: In Figure 3 a schematic body plan shows the variety of bilge configurations in a mixed form. A comparative analysis of bilge types is shown in a graph of EHP vs V.

RATIONAL AND SYSTEMATIC STUDIES

Johnson's Study, 1964

In 1922 Zeyss in Germany had done some studies of straight frame hulls. However, it was not until 1964 that a series of systematic tests with a rational approach was conducted on straight frame hulls.

In 1919 Sadler's conclusion was that the conventional hulls were better but that the straight frame hulls could be constructed to be equivalent in performance. Johnson's study picked up from this point...

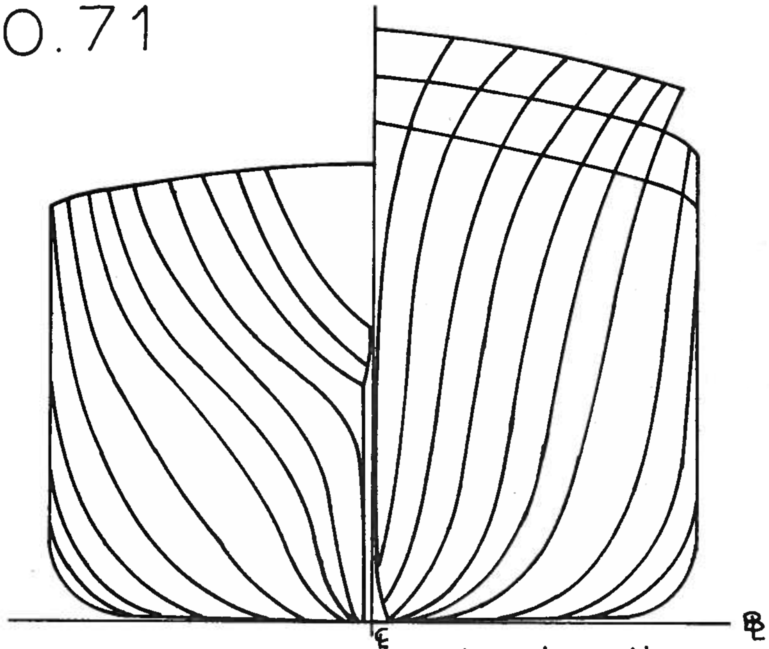
The leading idea was to construct a ship with a conventional form, determine the streamline flow, and then develop a hull with straight frames keeping the general characteristics close to the original prototype. The sectional area curves were kept practically the same with little deviations from the original. The LCB position was within the minimum resistance region for the conventional hull forms. The test results concluded with the fact that there could not have been much of a gain from using a larger number of knuckles in order to make the knuckle lines follow more truly the stream lines. Hence, on the average, there were two to three knuckles per station with the exception of one in which there were four knuckle points.

The tests involved two different hull configurations, those of $C_b = 0.71$ and $C_b = 0.82$.

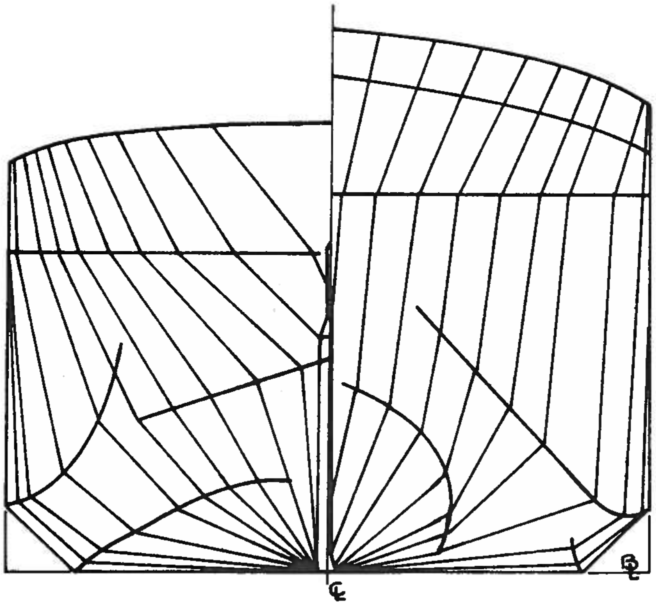
Johnson also made use of simply bent frames. One of the drawbacks in the 0.82 designs was that if the plates in the forebody could be twisted thereby

JOHNSON - I
(1964)

$C_b = 0.71$



parent hull



simplified

REF (4)

FIG 4

letting the knuckle line bend upwards instead of merely rolled, a better flow and less resistance would have been arrived at. His 0.71 series were different than those of 0.82 not only because of factors which influence the design of a full ship but also because of a different stern design which resulted in vortices forming due to the abrupt change of flow from the bottom to the side. A deadwood arrangement eliminated this, but still it was not as good as the 0.71 series.

It was apparent from Johnson's study that with increasing simplification of the form, the improvements attained slowly disappeared. Johnson also made the assumption that for seakeeping, the straight-framed hulls (V-formed sections) would be beneficial due to greater damping compared to conventional hulls (U-formed sections). Thus the best ship form would be a compromise, combining the advantages of the straight-frame hull's seakeeping, with the conventional hull's propulsive efficiency.

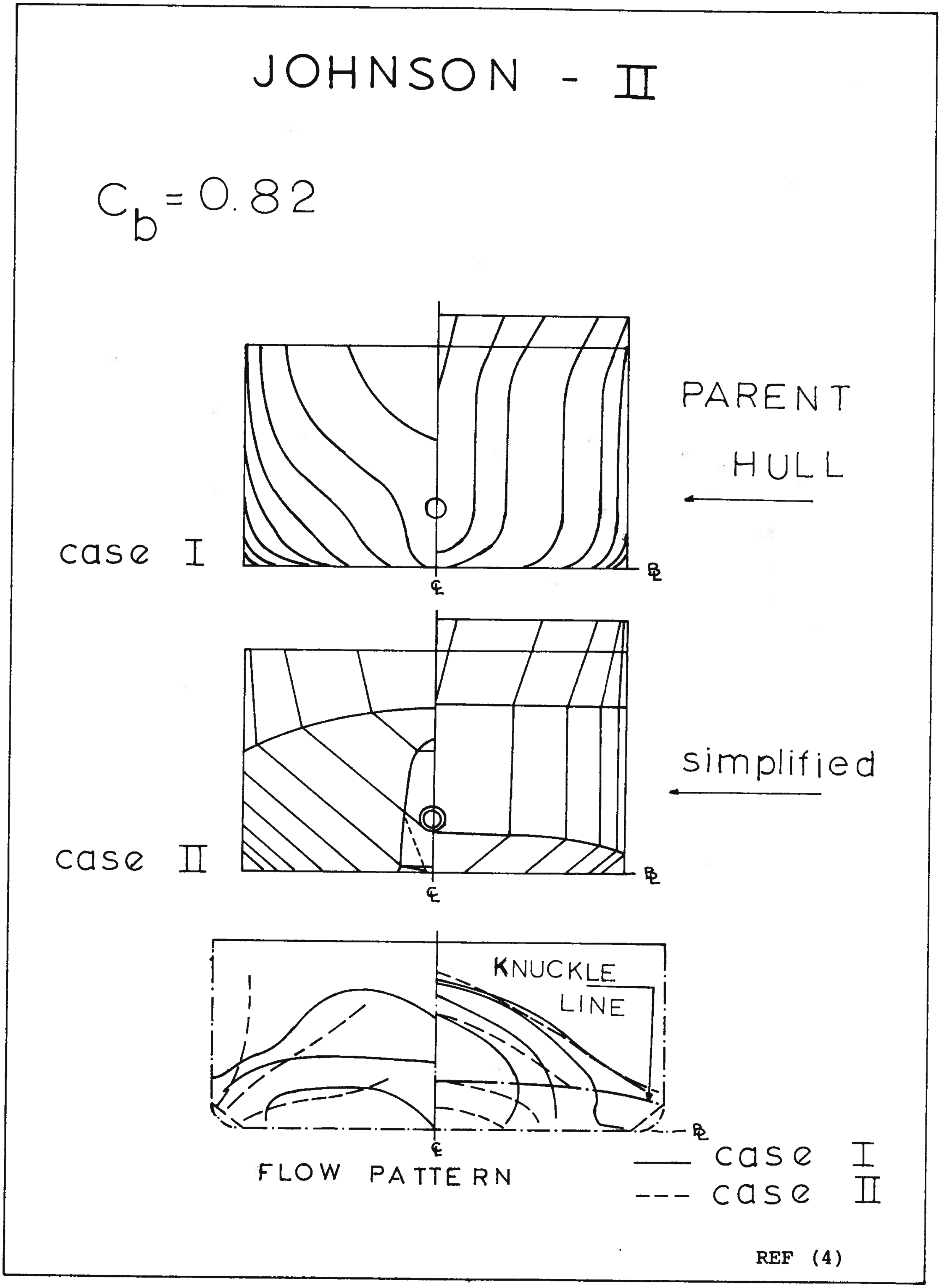

JOHNSON - II
$C_b = 0.82$
PARENT
HULL
case I
℄
BL
simplified
case II
℄
BL
KNUCKLE
LINE
℄
BL
FLOW PATTERN
—— case I
--- case II
REF (4)

FIG 5

The PIONEER Concept

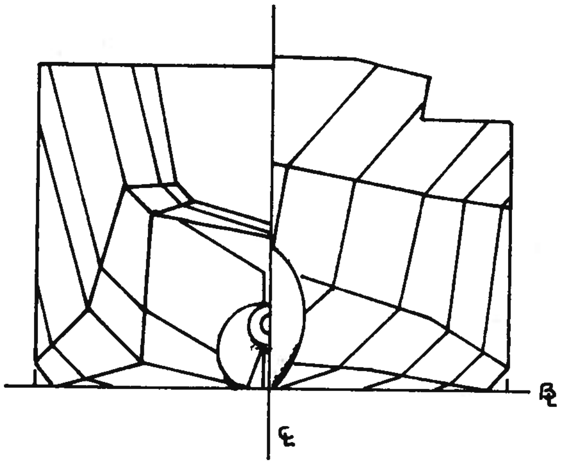
Johnson's study provided the basis for a whole new concept of shipbuilding. It was indicated that straight frame ships could be built to have similar hydrodynamic and seakeeping properties as those of conventional hull form. The problem now was in the application of the concept and whether such an idea could be profitable and any quicker in today's highly specialized industry. A whole new system of shipbuilding needed to be devised. The PIONEER concept entered the scene here.

Importance was given not only to resistance, propulsive and seakeeping properites but also to outfitting, equipment and interior furnishings. In order to attain a significant economical gain in the building and operating cost, the ease of construction needed to be made applicable to every detail which goes into shipbuilding.

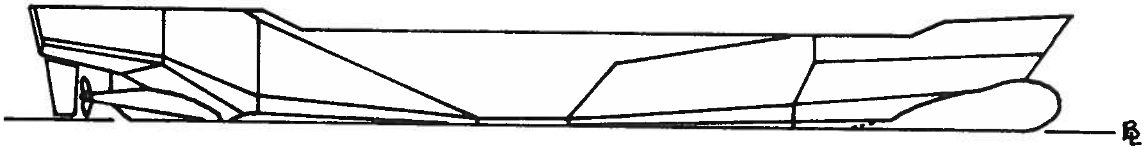
The demand for the lowest resistance and the demand for the most favourable propulsive efficiency lead to two different hull configurations. A hull form with less resistance could require more power than that of a higher resistance hull form. Therefore, self propulsion tests were made to achieve a better understanding of both the resistance and the overall propulsive efficiency.

Streamline tests with wet paint were carried out and the knuckles were so arranged as to follow the flow lines. Systematic model tests were carried out at different draft, trim and load waterlines. The improved form took shape with a large cone and wedges. This apparently became the parent hull which Blohm & Voss named "The Basic Pioneer."

BLOHM & VOSS "PIONEER"
(1967)



body plan



profile

435.2′ × 74.8′ × 23′

$C_b = 0.603$, $\Delta = 13180$ LTSW , V= 20k.

REF (5f)

FIG 6

The immersion of the bulbous bow and the transom stern played a decisive role in assessing the influence of these on the resistance. Two types of stern designs were tested: the basic Pioneer's normal stern and the broader stern for more deck and under deck area. The broader stern had less favourable propulsive efficiency - it required a modification of the submerged part of the afterbody lines.

Blohm & Voss also came up with a containership design to meet the fast and low block vessels. The speed range was set between 18 and 21 knots, and the $C_b = 0.60$. Tests with this new design led to what Blohm & Voss called "The New Container Pioneer", a modified version of the old container pioneer. A $C_m = 0.993$ corresponding to a $C_b = 0.60$ was too large for the container pioneer. The new container pioneer was developed by various bulb and wedge formations as well as considering the loading and unloading stability of the vessel. This had the combination of a normal stern and low tuck which gave the best results. See Figure 6. Figure 7 illustrates the results of the tests conducted by NSRDC. The rounded form was built to container pioneer characteristics for resistance and propulsion performance comparison.

JAG-DEV, the first Pioneer ship built showed better trial results in operation than those determined through model tank tests. An advantage of 0.6 knots over the model tests was obtained in ship trials of the Pioneer.

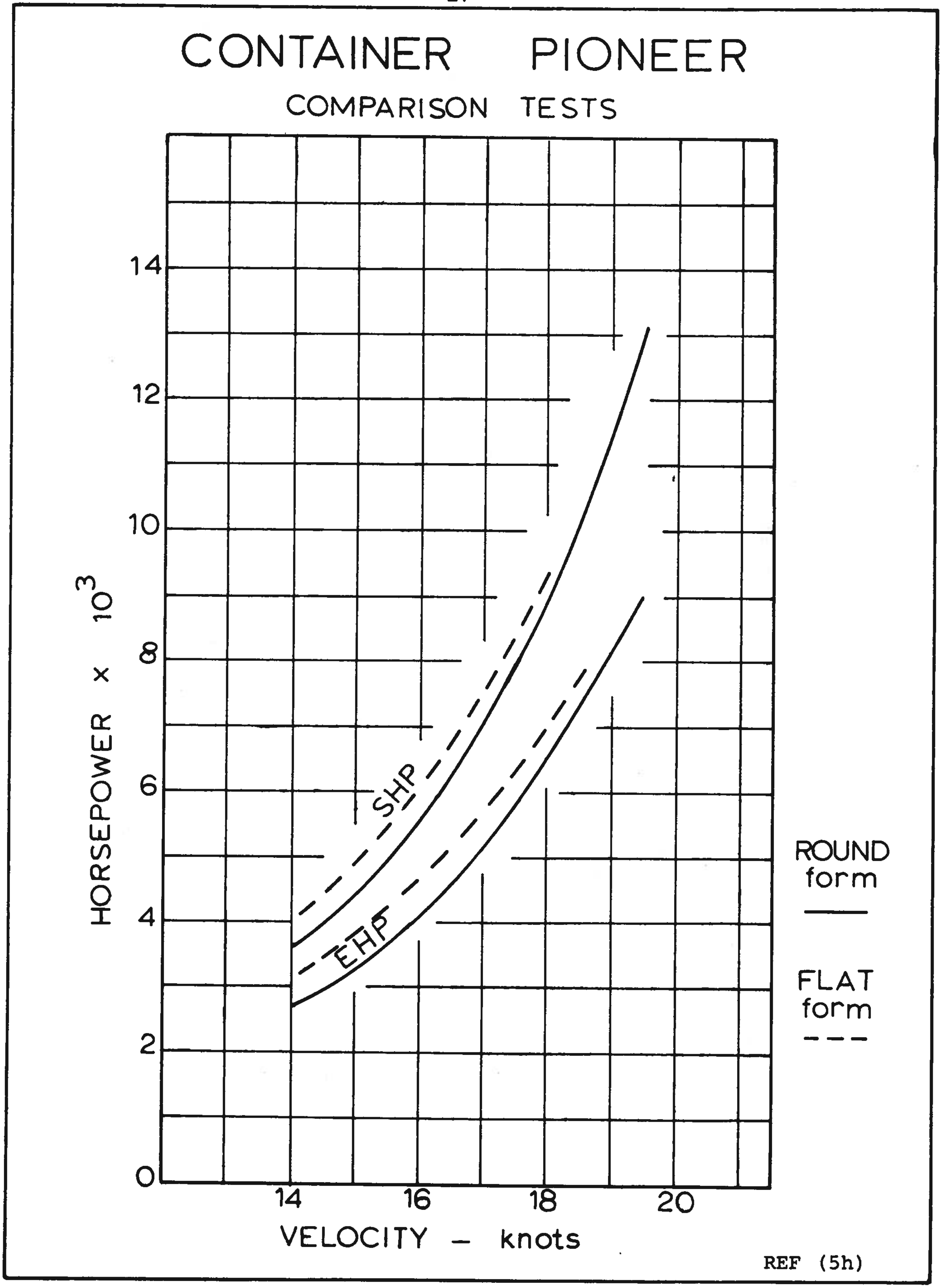

CONTAINER PIONEER
COMPARISON TESTS
HORSEPOWER x 10^3
0
2
4
6
8
10
12
14
VELOCITY – knots
14
16
18
20
SHP
EHP
ROUND form
FLAT form
REF (5h)

FIG 7

OTHERS

Pacer Class

The U.S. Maritime Department of Commerce sponsored research to develop a commercial cargo ship of simplified hull form. PD-133 Pacer Class was the outcome (10).

The parent model was of a conventional U form with a four percent bulb. As the figure 7 illustrates, the model has a double chine form having coefficients identical to the parent. At full load draft the double chine hull averaged a two and a half percent higher resistance than the parent hull over normal operating conditions of 15 to 20 knots. An addition of a bulb did not improve the resistance properties! There was some cross flow observed in the streamline tests. Hence a restudy of chine locations was needed.

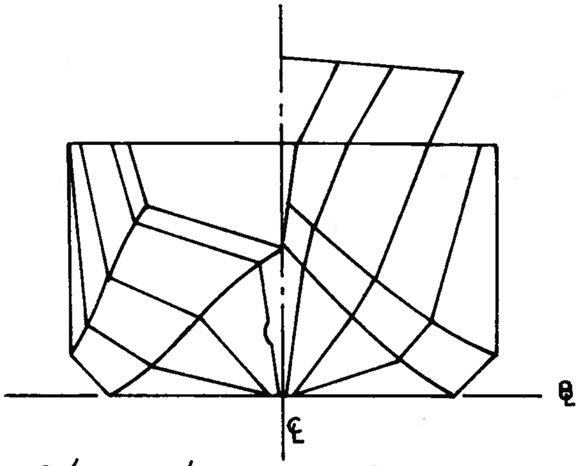
Helical Ship

As seen in Figure 7, Helical ship is a patented form consisting of flat plates. These are plates with a curvature in a single plane and rectangular sections with the exception of the bow and stern under-water portions which are helical in shape (10).

Merely a geometrical interpretation of a ship's body, a model built to Mariner proportions, showed a twenty percent (in EHP) resistance increase when compared to the Mariner parent. It claimed cheaper fabrication as well as improved cargo storage due to its box shape.

PACER CLASS

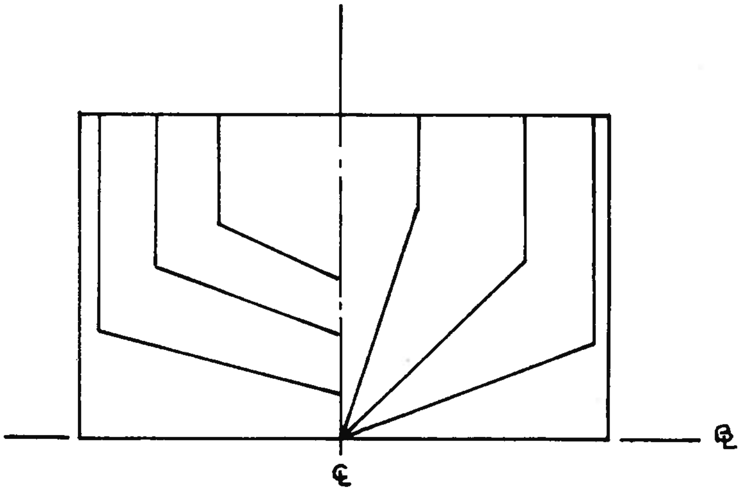
(1969)



535′ × 78′ × 27′ $\Delta = 19{,}380$ LTSW

$C_b = 0.601$ V = 20 k.

HELICAL SHIP



REF (10)

FIG 8

Icebreakers and the Fitting of the Flat Plate to the Hull Form

Icebreakers, mainly due to their operational environment and purpose, make use of thick high-tensile steel plates with double curvature. Because of the sharp curvatures that exist with icebreaker designs the plates may not be easily workable. Since there can be no savings in hull material, for icebreakers need to be over-designed in structures to meet their design characteristics, the only savings then lead to the reduction of man-hours in construction. Ferris (7) suggests that the fitting of the flat plating to the form of the ship, can be achieved by modifying the lines of the icebreaker and by rearranging the strakes of plating. He suggests to use narrower plates when rearranging the strakes in some places to improve workability. This however must be weighed against the cost of additional welding.

In shipyard practice a fair amount of lengthwise bending can be done without difficulty and some twist can be attained by the application of small forces. A much more difficult process is to produce a bulge in the middle of a plate. The difficulty, it seems, of making any sort of deformation increases in thickness of the plate.

A savings in man-hours will bring down the cost of construction. However, as Rear Admiral E. Thiele of USCG points out in the discussion of the paper, we cannot tolerate going to full flat plate application in icebreaker designs. The main reason for this is that an icebreaker must have a very good rolling capability merely to break loose in heavy ice during ramming operations. What appears to be an advantage in seakeeping on polyhedral ships becomes a disadvantage in this case since seakeeping is of secondary effect over that of icebreaking in icebreaker designs.

Straight-Framed Tanker

Basic resistance tests were undertaken at the University of Michigan Ship Hydrodynamics Lab by E. Snyder for a sponsored project on a straight-framed tanker. Conventional bow versus a spoon bow and other bow variations were tested.

Even though not very much is said in the report it appears that the design of the tanker was achieved through simple application of straight-line approximation over that of the curved hull form. The results were not favourable from the EHP standpoint. See Figure 9.

The spoon bow showed the lowest resistance over the speed range of 16 to 18 knots in both the full load and ballast condition. However, no comparison of a typical tanker bearing similar principal characteristics is mentioned.

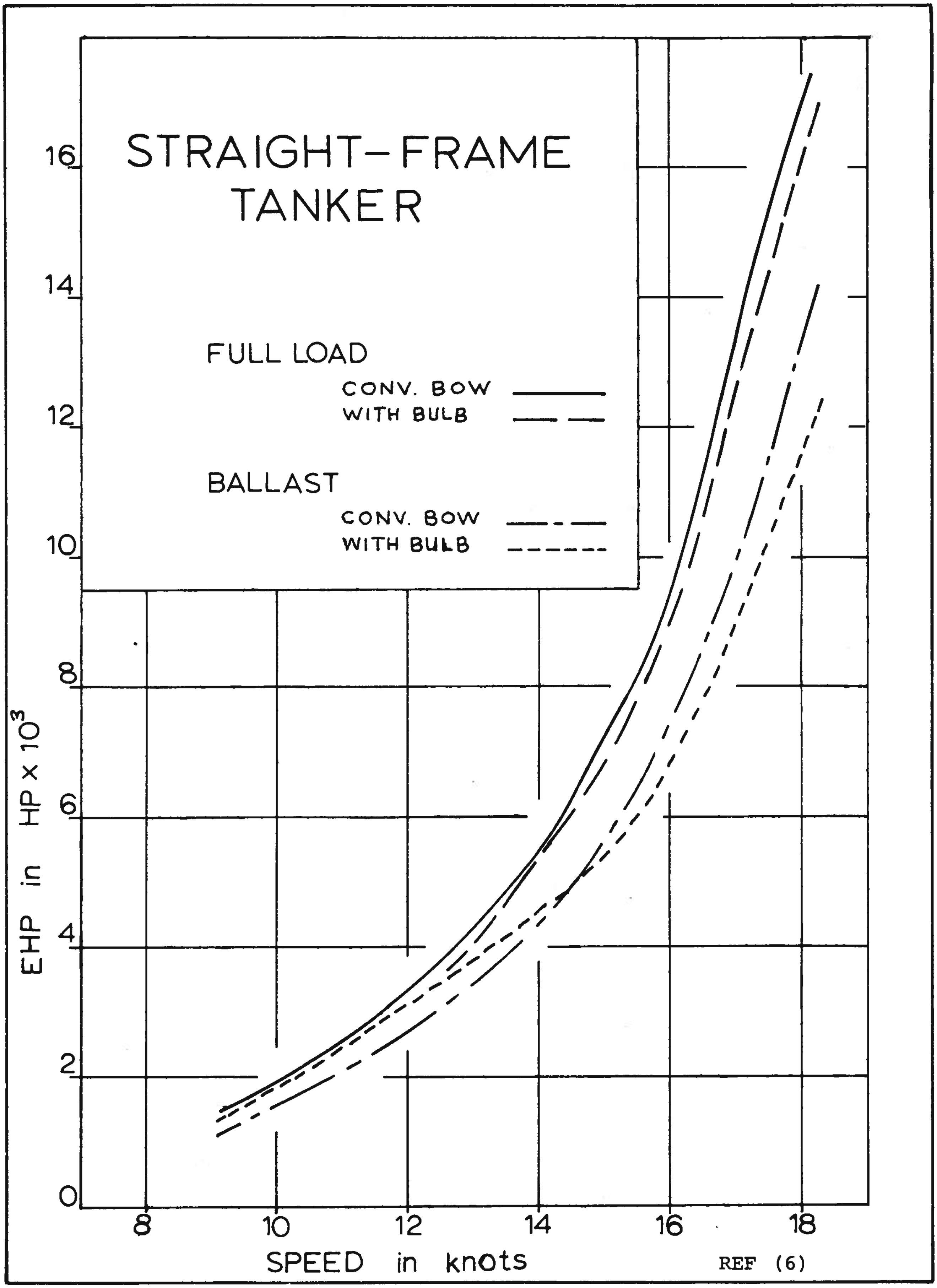
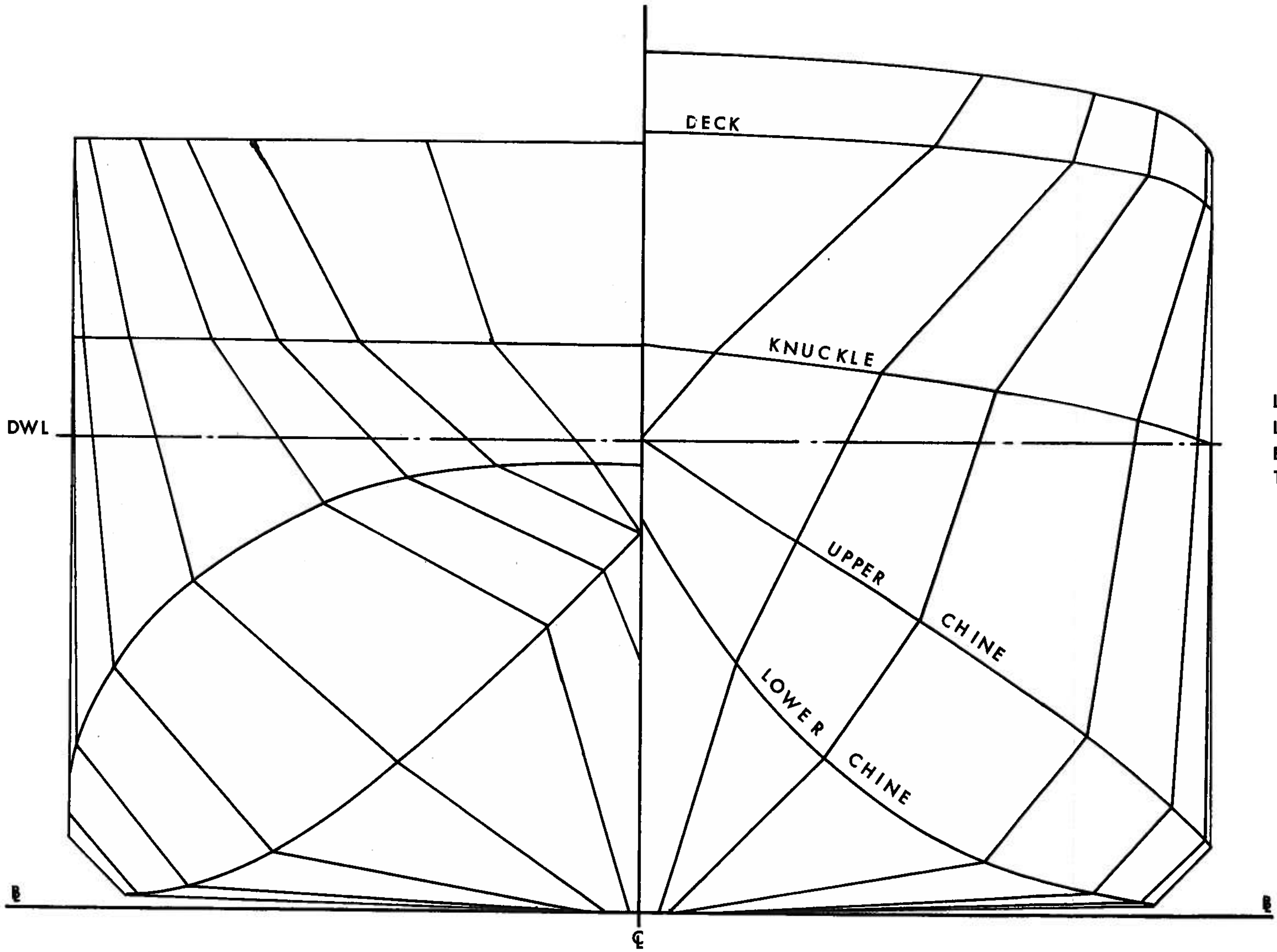

STRAIGHT-FRAME TANKER
FULL LOAD
CONV. BOW
WITH BULB
BALLAST
CONV. BOW
WITH BULB
EHP in HP x 10^3
0
2
4
6
8
10
12
14
16
8
10
12
14
16
18
SPEED in knots
REF (6)

FIG 9



LBP = 630 ft.
LWL = 648 ft.
B = 85 ft.
T = 35 ft.

BODY PLAN of STRAIGHT-FRAME TANKER

REF (6)

FIG 10

THOUGHTS ON A DESIGN APPROACH

The proper manner of developing the hull lines depends completely upon flow analogies and testing. One must select a basis ship bearing a round body plan. Then through model tank testing an understanding of the flow of the submerged body must be attained before one comes up with a polyhedral hull form where the knuckles are supposed to be tangent to the streamline flow. What is important in comparing the curved to that of the flat hull's lines is the sectional area and the LCB location. Too much variation in this respect would lead to an erroneous comparison.

When Blohm & Voss searched for optimum ship parameters and dimensions, they used Schneekluth's method and Gallin's computer aided ship design approach. Schneekluth's method yields the LBP and the C_b of the ship through a systematic variation of the mentioned parameters. The aim of the calculations - regardless of the methods used - should be based upon the cheapest possible ship (the ship with lowest initial cost of building) as well as the most economical ship (the ship that has the lowest operating cost per year).

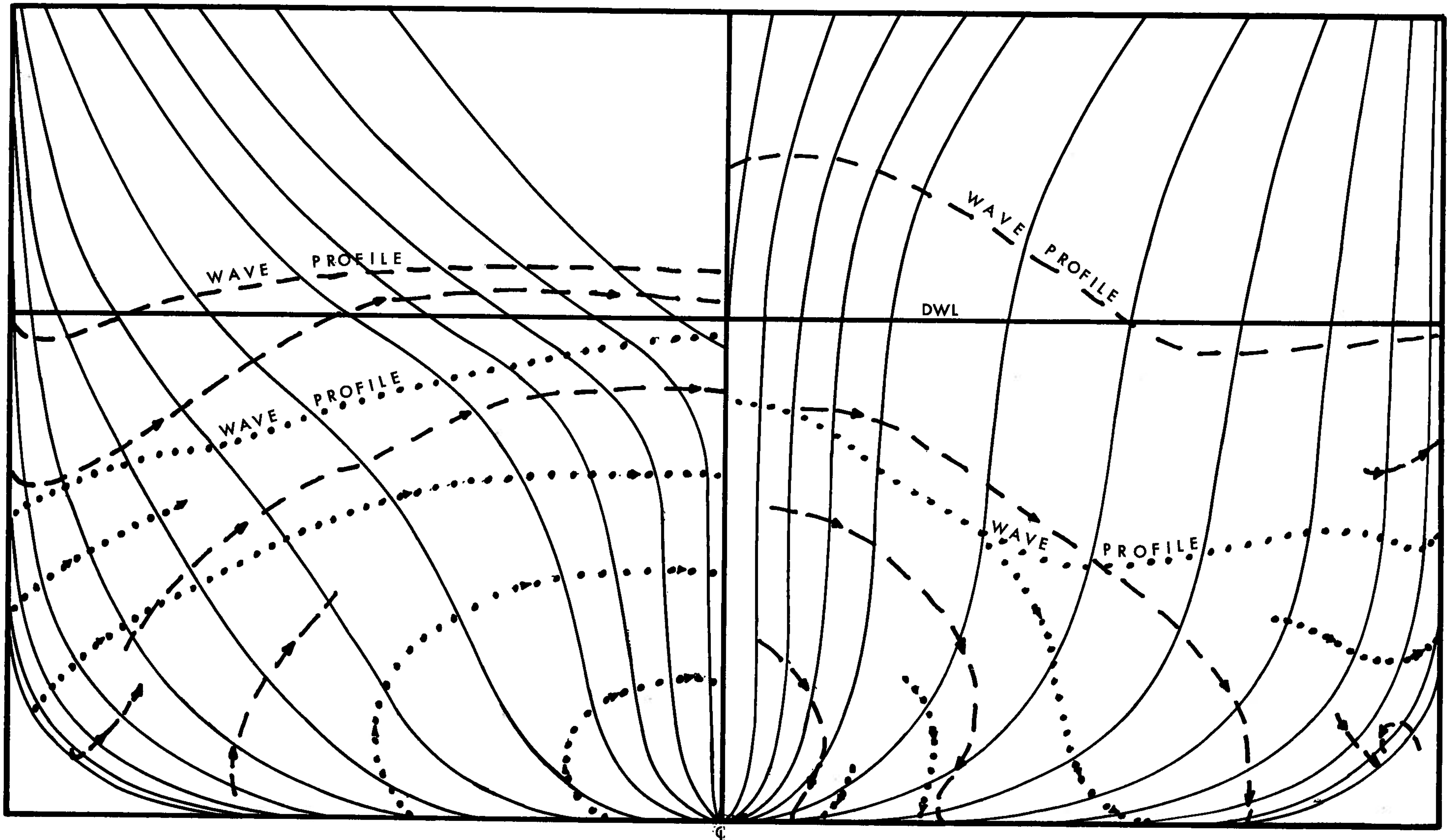
Flow Analogies

Streamline tests with wet paint or by other means are essential because they reveal the flowline pattern. Flowlines must be thoroughly studied before developing the chines for the straight-frame hull.

Flow patterns differ from ballast to the full-load condition. One must conservatively consider both flow patterns before assessing the knuckle lines on the polyhedral body. The flow pattern for the basis ship in Figure 11 is attained through an understanding of Saunders Hydrodynamics (8) and therefore believed to be well oriented in terms of flow directions.

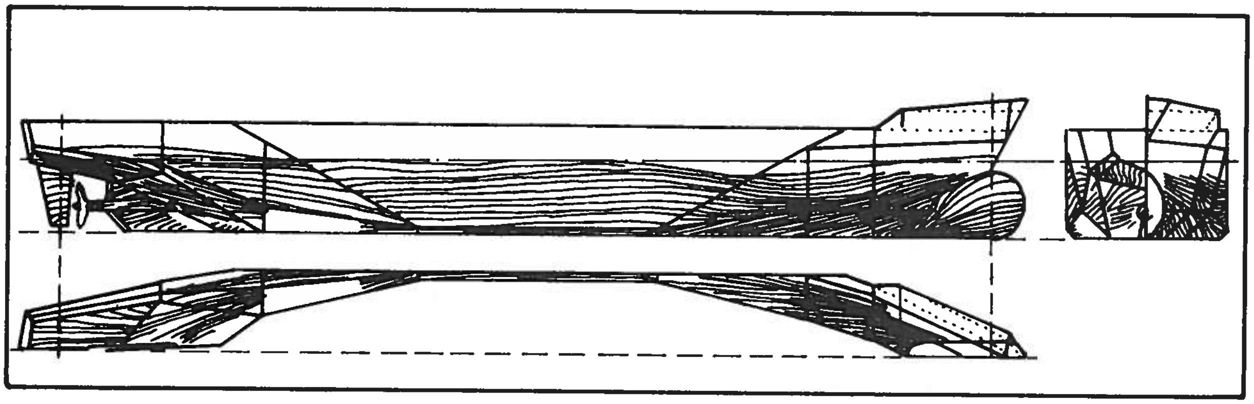
The flow into the propeller is very important. Hence, a drastic change of afterbody underwater lines is needed to keep the same characteristics, including wake and vortices, in the polyhedral hull as in the basis ship. The New Container Pioneer had a stern bulb to overcome this problem. See Figure 12.

Not all knuckles have the same importance in their influence on the flow around the ship. The knuckles and the chine lines must lie tangent to the streamline flow for attaining the smoothest possible flow.

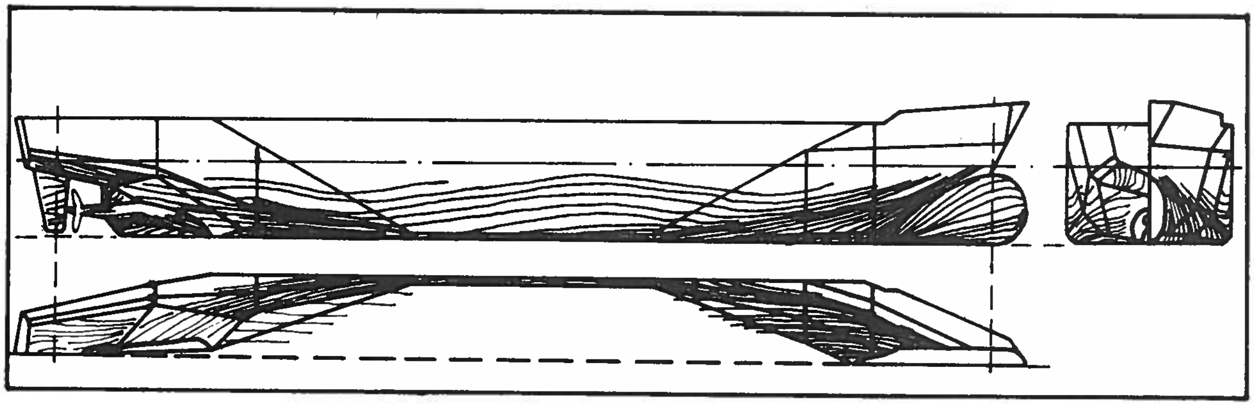


FLOW PATTERNS AROUND THE CURVED HULL FORM

FIG 11



The New Container PIONEER Streamlines



The New Container PIONEER Streamlines with the Added Stern Bulb

FIG 12

REF (5f)

SEAKEEPING

Seakindliness data are incomplete. More extensive research is needed in this field. Extensive rolling tests with and without bilge keel must be done to observe if there need be any bilge keels. D'Eyncourt's study had assumed that the increase of resistance due to chamfered bilge was equivalent to a round bilge with bilge keels. Do we need bilge keels on straight-framed hulls? This must be confirmed with model tank tests. [Cavitation tests, maneuvering tests, along with tests in a waterflow tunnel must be done for improvements on straight-framed hulls. Also, tests in irregular waves are needed to assimilate a full comparison with the curved hull forms.]

However, there are some studies which give a clear insight into the pitch, heave and vertical acceleration of a polyhedral hull which show great promise. The seakeeping tests were carried out in the Hamburg Model Basin (HSVA) for "Container Pioneer" hull forms. Tests were done in regular head seas with five different wave lengths. The The wave lengths being respectively 0.6; 0.8; 1.0; 1.2; and 1.4 of the LBP. The tests also consisted of a study of the propulsion powers and rotary speeds as well as the ship motions at several ship speeds.

The wave lengths used in the tests represent wind velocities in the North Atlantic between 5.5 and 9 Beaufort. In determining the maximum possible speed of the ship in different seaways, the measurements were based, on the available torque of the selected engine.*

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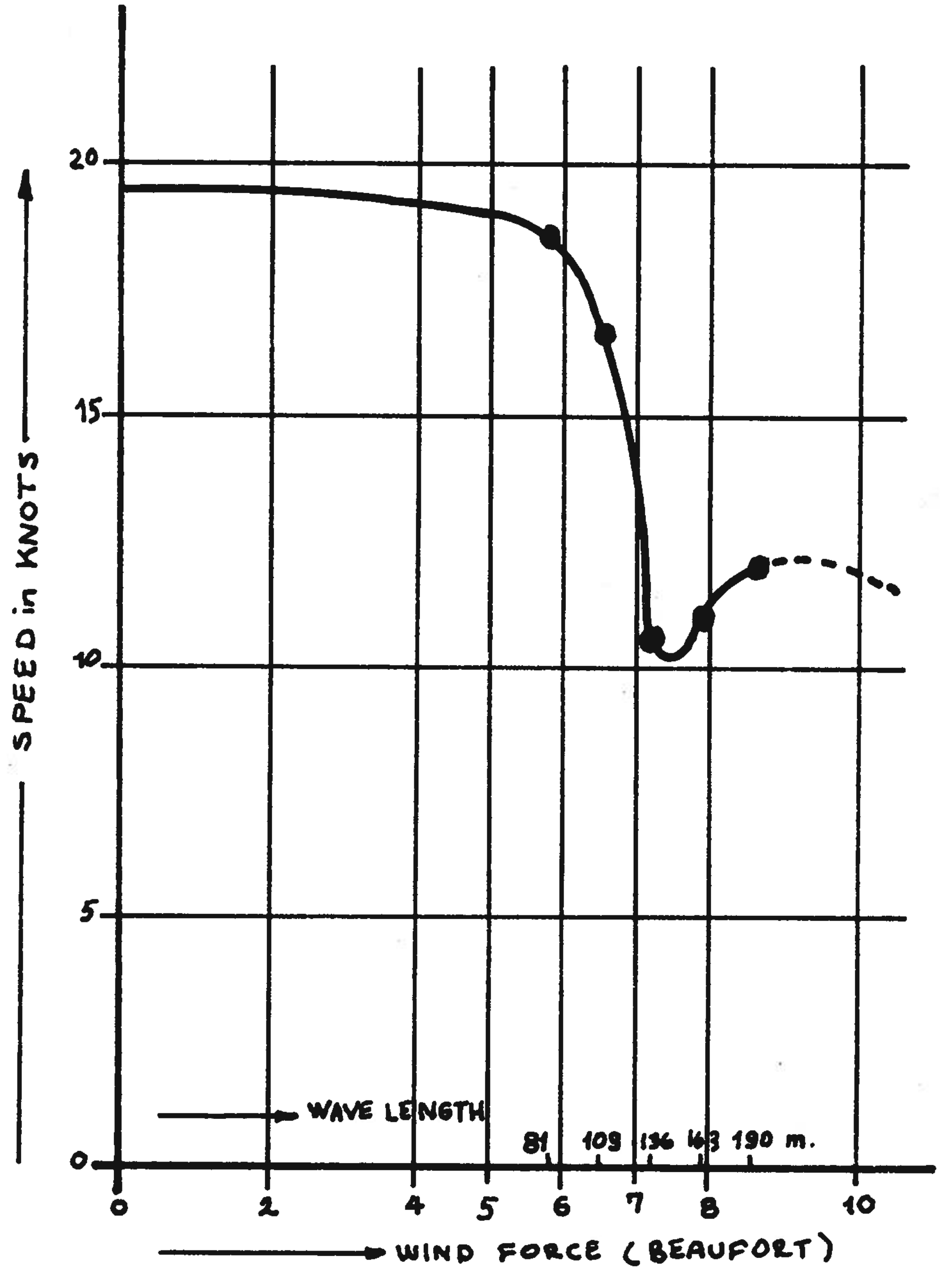
* Pielstick diesel engine type 12PC-2V with a present total rating of 12000 BHP.



MAXIMUM SPEED OF "CONTAINER PIONEER" REF (5f)

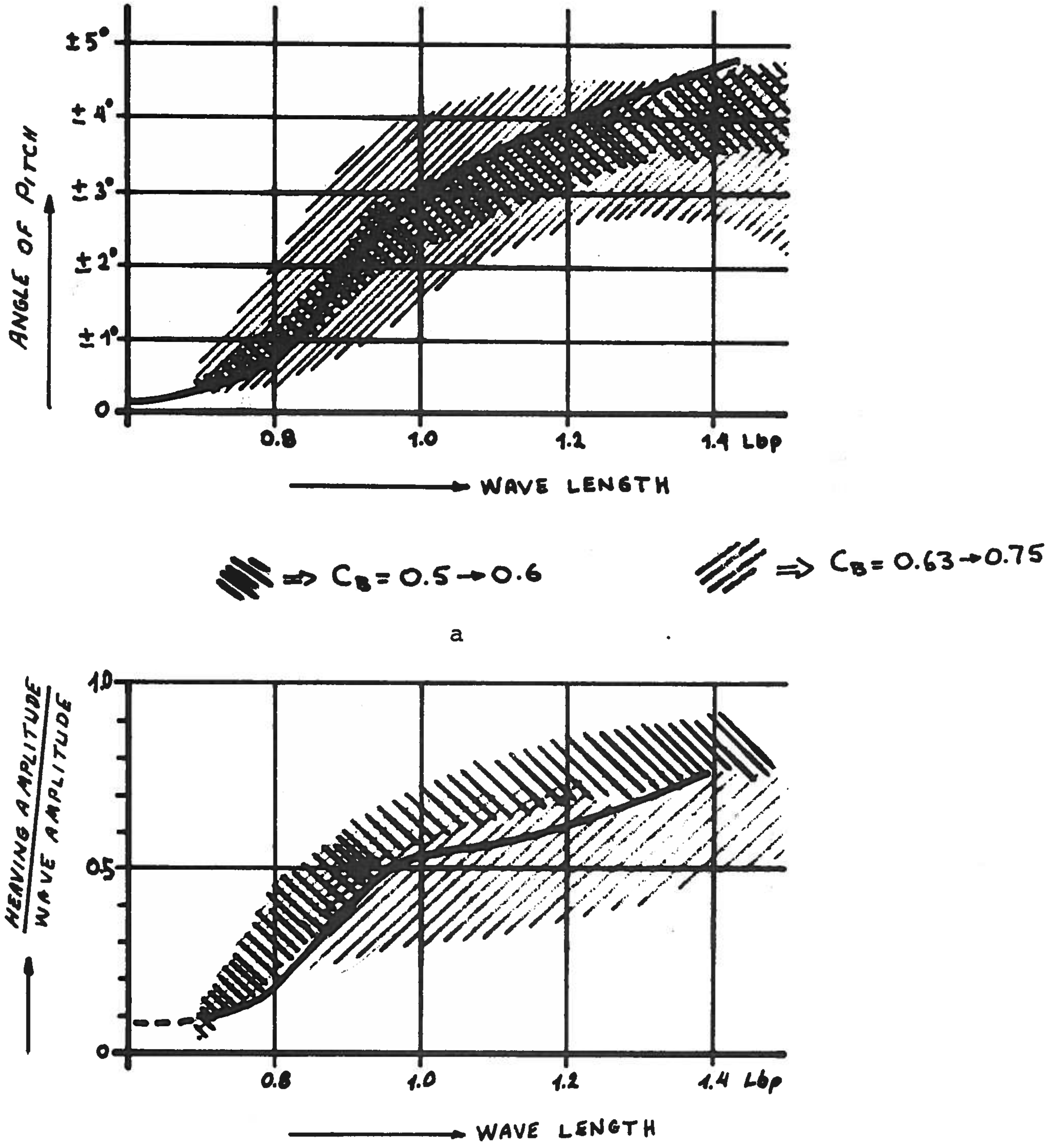
FIG 13

Figure 13 (Maximum Speed in Waves) shows that the calm water speed of approximately 19 knots was maintained up to about Beaufort 5. This is advantageous when meteorological statistics of the North Atlantic are considered. There velocities between 2 and 5 Beaufort occur most frequently during the year.

In the resonance range, (wave length=ship length at about 7 Beaufort) the speed drops a little more sharply (54%) compared with a normal 60-65%. This is due to the damping effect of the edges of the polyhedral hull form. The wind velocity for Beaufort 7 is attained with an annual frequency of 5%, thus being of no serious influence on the service speed of the ship, but offering the advantage of dampened ship motions. A difference of one knot between service and trial speed was attained, which is normal.

Figure 14 (a,b) is plotted as a function of the wave length and the block coefficient, giving pitch angle and heave amplitude. Shaded regions are representative of the motions of other conventional ships measured by HSVA. Plot (a) shows that the pitch angles up to a wave length of 0.1LBP lie in the center of the range, above this they come closer to the upper limit. Plot (b) shows the heave amplitudes which are smaller than the normal throughout the wave range.

Figure 15 shows the vertical acceleration in a seaway as a function of wave length and block coefficient. The vertical acceleration at the forward perpendicular is smaller than that of other ships.



a

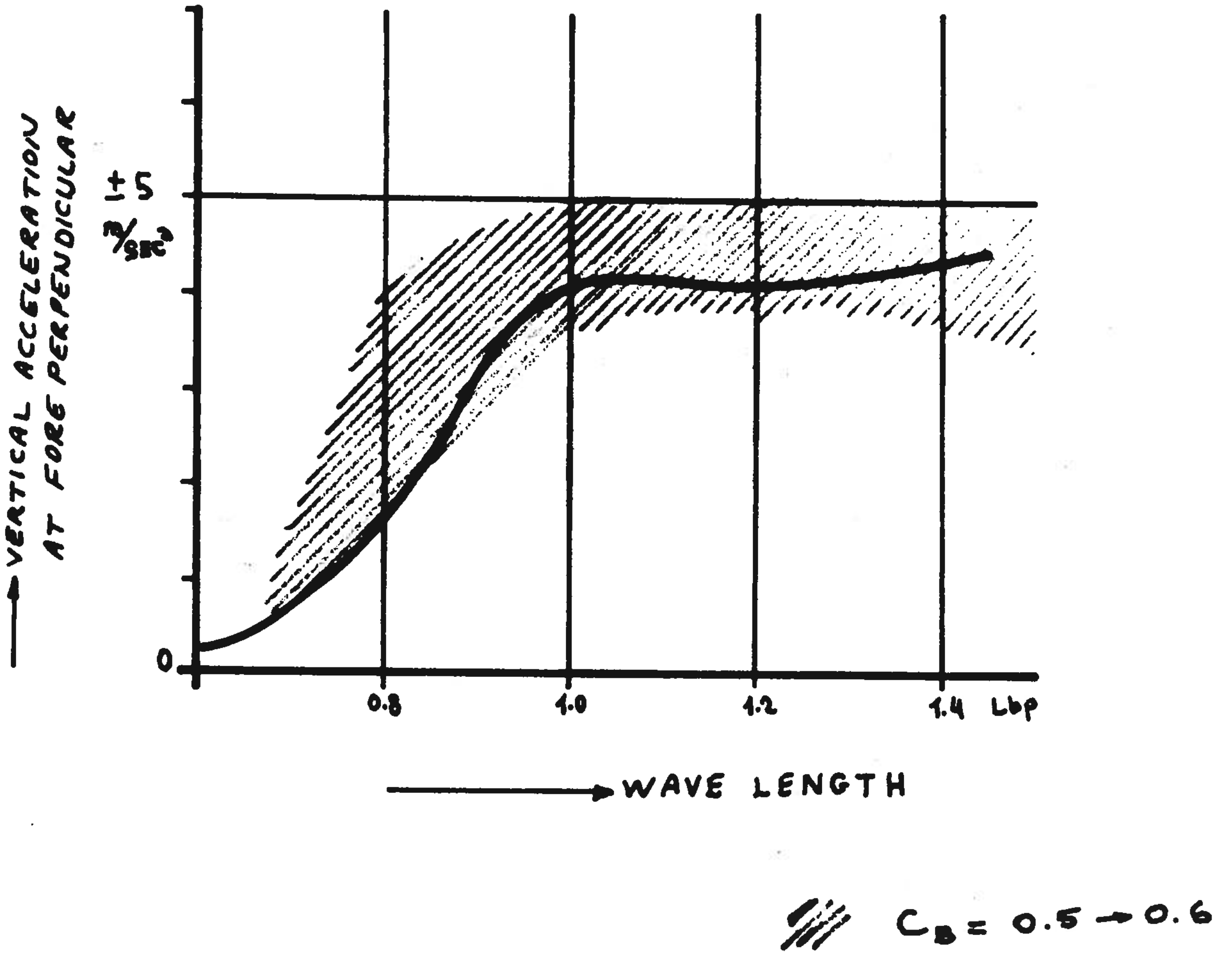
b

PITCH & HEAVE MOTIONS OF THE SHIP IN SEAWAY

REF (5f)

FIG 14

In conclusion: A smooth streamline flow was attained even in waves during the tank tests of the "Container Pioneer." A favourable damping influence on the ship's motions confirm the assumption that Johnson's study made, namely that the edges of the hull form with flat and even surfaces exert a higher damping.



VERTICAL ACCELERATION
IN A SEAWAY

REF (5f)

FIG 15

CONCLUSION

The conclusions that have been derived from this study are:

- Streamline flow analogies are extremely important. Hence model tests must be carried out when searching for simplified ship forms.
- Formation of chine lines - knuckles - is the decisive factor in determining comparable resistance properties. Knuckles must be oriented so that the streamline flow is tangent.
- Chamfered bilge with proper slope is the best choice.
- Chine slopes must be greater for better resistance properties.
- Correct configuration of after body lines is very important. A good choice of transom stern must be made, also the under-water lines must be so formed that a proper flow into the propeller is achieved.
- Model propulsion tests are needed.
- Sectional area and LCB locations must not differ greatly, if the simplified version is developed from a basis conventional hull form.
- Productivity in building must be considered not only in the hull but in superstructures, deck arrangements, etc. In other words, the ship must be treated as a system made up of modules for faster and efficient building.

WHAT REMAINS TO BE STUDIED FOR IMPROVING STRAIGHT-FRAMED DESIGNS

- A better understanding of submerged afterbody.
- Effects of various types of bulbs.
- Effects of lengthening the parallel middle body.
- Lower bound of fine hull forms (such as $C_b = 0.60$).
- Defining an upper and lower bound of LBP. Flexibility of length changes.
- Upper and lower boundaries of efficient operation such as speed limits (max-min).
- An analysis of wake distribution and vortices to improve designs.
- Applicability of the concept to other types of hull forms and comparative analysis with conventional designs. (eg. Lash ships, fishing vessels, roro ships, passenger vessels, warships, barges, and small craft).
- A comparative analysis of straight-framed designs to an accepted series hull form.
- A study of developing series of straight-frame ships.
- More experiments on seakindliness.
- Computer application of straight-framed designs to a standardization of hull form.

A LOOK AT THE ECONOMIC ASPECTS AND SOME SUGGESTIONS

The cost of fabrication increases from the standpoint of workability of the individual shell plates of a ship. This increase can be visualized if we make the following breakdown:

i) Surface so nearly flat that no forming operation is needed prior to erection.
ii) Plate needs to be rolled in the direction of its length.
iii) Plate needs to be rolled in the direction of its length.
iv) Plate needs to be heated and pressed to form.

The cost of fabrication increases from i) to iv). This is most economical when the greatest possible number of plates are in categories i) and ii). (7)

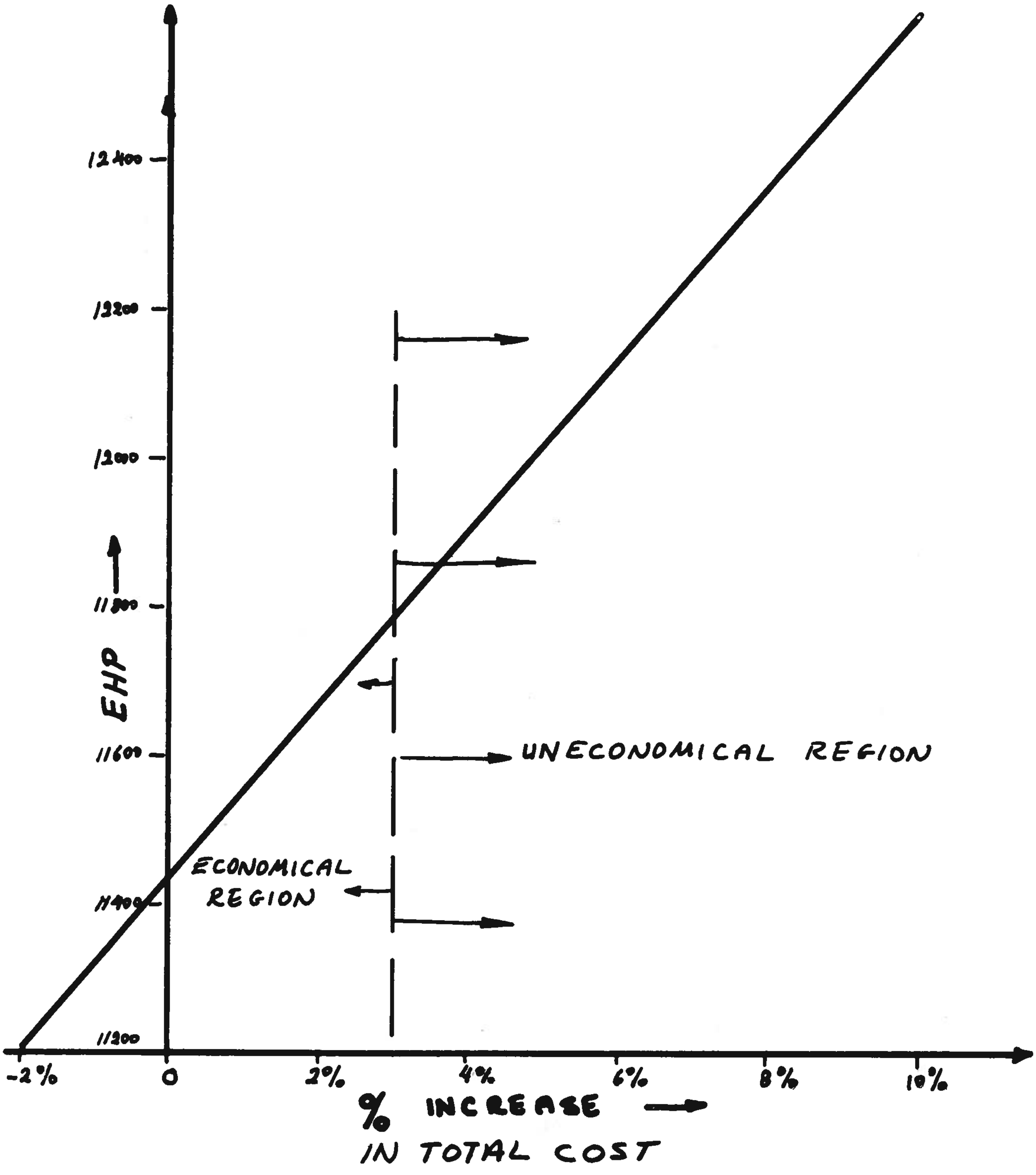
A breakeven point is necessary between the future operational costs (primarily fuel costs, and then overhaul, repair etc.) and the cost of hull construction. The hull construction amounts to 25% of the total for a typical container/general cargo type ship. The cost breakdown of a typical ship is as follows. (10,11)

SUBJECT	% OF TOTAL COST
HULL	25%
OUTFIT	12%
ACCOMODATIONS	3%
PROPULSION	20%
AUXILIARY MACHINERY	11%
DECK MACHINERY	7%
ELECTRONIC OUTFIT	9%
MISCELLANEOUS	13%
	100%

A 25% hull construction savings for a polyhedral hull would only influence the total cost by 5.2%.

PROCESS	% MAN HOURS OF HULL CONSTRUCTION
ROLLING & PRESSING	1.6%
FLANGE & SHAPE	0.5%
LAYOUT	2.1%
FURNACE	1.0%
Total	5.2%

As reference 11 states this is a small marginal saving and will hardly even off with an increase in the SHP of the ship. If we select a tradeoff point for a feasible construction area for building polyhedral hulls, with an increase in resistance of 3% based upon experimental data, we would have figure 16.



FOR STRAIGHT-FRAMED HULL

FIG 16

It is clear that in order to break through and justify the building of flat plate straight-frame hulls one must take a different approach to the study than merely relating figures based upon today's shipbuilding industry in the U.S.

We must isolate two approaches for two states:

1) Industrially-complex state.
2) A semi-developed or an underdeveloped state.

We must also look into the present available automation techniques - such as N/C flame cutting, automatic welding - and the present and projected tendencies in shipbuilding output.

The latter will be the decisive principle underlying the future buildings of ships. What type of ships do we need or rather what is the industry investing in and what will it invest in? In the case of the automated production we should look into the means of series cost reduction through multiple ship production. Since little economic data of man hours and costs could be attained from today's industry, my approach will be that of a hypothetical suggestion.

The State of the Art

Reference 12 claims that the market for the fully cellular container ship has reached the saturation point. It projects a sharp falloff of tonnage for delivery in 1973 after a successful high output in 1972. At the present time it seems that there will be a need for more smaller multipurpose ships.

The orders for general cargo ships are decreasing. Oil tankers at the moment seem to have leveled off approximately at an output of ten million gross tons. However, the orders for OBO ships and specialized carriers (such as LNG, LPG) reflect a certain popularity. We should here also include the growing interest in tug-barge combinations.

The article also projects that 1971 would have been the peak year with the production leveling off thereafter. In a recent interview (13) D.D. Strohmeier, president of SNAME suggests several points that have been ignored. A growing supportive merchant marine is in need to back up the sea power of the U.S. for defense purposes amongst others. Also another interesting point is that the 80 strategic materials which are vital to the U.S., mostly come by sea transportation. Our expectation then is that more shipbuilding is to take place.

Industrially-complex States

"...because of the increasing competition between the shipbuilders as well as between the shipyards, and because of the very difficult economical situation of the German shipbuilding industry, it has become necessary to keep the cost of the building and operation of ships as low as possible. In the past few years one of the most important features resulting from striving after efficiency...is the use of flat-surface shaped ships." (5h)

Whence the Pioneer concept was put into application by Blohm & Voss. It was clear that an additional 3% savings in hull construction was needed to pay off the economical feasibility of the concept. In a similar manner U.S. shipbuilding needs a breakthrough.

I can only predict that a series multiple production is needed. (20,17) A series cost reduction can be achieved in two ways. The first is to consider the entire hull as a repeating process. The second is to divide the hull into as many identical parts as possible and to regard these as series produced parts. Fabricating ships concerned with building bridges have used this concept of repeating units. With these flat units or those with minimal curvature, they have been able to highly automate their welding and handling operations. In modular steel deck bridges, 75% of the welding is done automatically. In 1970 the General Dynamics Quincy Yard operated on 40% automatic welding.

With the present day advancement in welding techniques and their automation, as well as numerical control operations employing computers, savings in building should be obtained. This is so provided that the turn-around time and output becomes compatible and competitive with foreign yards. In Japan a 200,000 DWT tanker could be delivered in three months. (13) However, since most able foreign yards are booked till 1975 and an understanding of the importance of shipbuilding in this country is realized by the government we should expect more national efforts and encouragement being centered around "building at home." Avoiding political jargon, the feasible way out seems to be in reorganization and up-to-date equipping of certain facilities within the yard itself.

In terms of economics, a shipyard using old facilities with good building ways and not much capital to invest in new facilities might subcontract their subsections to fabricating ships. Bethlehem Steel Sparrows Point Yard has taken this approach in utilizing a "New Panel and Blast-paint Ship." Considering that a tanker has 60% flat plate sections and a container/cargo ship some 20%, considerable savings could be achieved. To implement such a saving, some suggestions are:

- Series Cost Reduction
  Due to the repetitive nature of the work the operation falls into a low cost position in a learning curve.
- Ease of Flow
  Mechanized flow throughout the shop eliminates much of the routine handling, which even in well laid out fabricating shops adds 25 - 30% to their hourly costs.
- Maximum Utilization of Automatic Welding
  Plates joined together by welding on both sides without a need to turn them over. Stiffeners can be automatically fitted into place and several at a time may be welded.

— <u>Automatic Plate and Stiffener Setting</u>
A mechanical procedure which eliminates the chipping and grinding of tack welds.

— <u>Precision Burning</u>
Automatic burning machines can be highly utilized with the flat work, and edges may be cut to precision before subassembly, eliminating waste and fitting problems.

— <u>Computer Applications to Layout of Ship Equipment</u>
Example: the analyzer-draft system (ADS) developed by IHI of Japan. (14) Other control and computer applications to ship design and building must be sought.

— <u>Weather Factor</u>
Work done inside improves working conditions resulting in fewer lost days. Ref. (20b) claims a 30% increase in productivity due to it.

Hence, with the above approach, most optimistically, we should be able to save an additional 15.1% as compared to the earlier 5.2% savings on hull construction.

Burning	3%	Fabrication Subtotal
Chipping & Grinding	0.9%	
Straightening	0.7%	
Burning	1.6%	Preassembly
Chipping and Grinding	1.1%	
Chipping and Grinding	5.8%	Way Work
Straightening	2.0%	
Total	15.1%	

However, this may still not say very much. The important point is to employ highly automated methods in good balance with human factors engineering. This should improve output regardless of its application to the type of hull form.

Secondly, we must think in modules. A complete modular construction should bring savings in multiple ship production. Forebody, aftbody, parallel middle body, superstructure and deck arrangement could be thought of as modules. Separate treatment of each unit with a similar breakdown of modules within, each being built independently of each other, would not only create the necessary material flow but create the necessary series production as well. Various applications of the thought have been universal and good results have been achieved. However, an application of a systematic layout planning should assist any new investments in future shipyards.

Semi-developed and Underdeveloped States:

The low cost of labor abroad at first seems attractive. However, one must consider the efficiency of unskilled labor, the high cost of importing material goods, and the risk in investments. The low cost of labor may not pay very highly whether it be a curved hull form or that of a polyhedral one. But the initial cost of investment could be lowered by buying less machinery, and investing more on automated production.

When one considers the market American builders have lost to foreign yards, due to the high first cost of building at home, it will be obvious that new ways of bringing capital must be sought. There is also the problem of foreign navies,dependent on the U.S., which are becoming reluctant to buy American warships.

CONCLUDING REMARKS

> In 1917 Professor Sadler (1) said: "...the shipbuilding and ship designing profession is apt to be somewhat conservative, and perhaps rightly so, in connection with the shape of ships, particularly when we take into account all the factors involved, and it seems to take somewhat of a cataclysm, such as is occurring at the present time, to make us change some of our preconceived ideas on ship's form."

This could very well be applicable today. Even though the conditions are different, the present difficulty in today's shipbuilding is basically the same: that there is a need for growth in the merchant fleet. One way is to go for the simplified hull forms, similar to what the Germans have attempted. This paper, I hope, has been clear enough in reciting the previous studies on this subject. I have also tried to give a perspective for future shipbuilding regardless of the shape of the hull form. I believe we could learn from the previous studies, even if we didn't contemplate plunging into full application of the concept of flat plate straight-framed hulls.

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