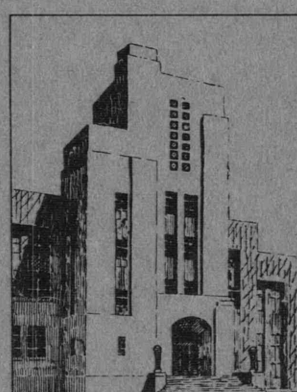
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

THE DELINEATION OF SURFACE LINES OF FLOW AND WAVE PROFILES AT THE DAVID TAYLOR MODEL BASIN

BY LT. J.F. HUTCHINSON, USNR



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REPORT 535

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PERSONNEL

The new procedure involving the use of hydrogen sulfide and white lead paint was developed and perfected at the U.S. Experimental Model Basin by Captain (then Commander) E.L. Gayhart, USN, about 1933.

The report was written by Lieutenant J.F. Hutchinson, USNR.

THE DELINEATION OF SURFACE LINES OF FLOW AND WAVE PROFILES AT THE DAVID TAYLOR MODEL BASIN

ABSTRACT

The method of taking surface lines of flow on towing models and of marking wave profiles on the models at the David Taylor Model Basin is described, the reasons for using these methods are explained, and examples of the results are given, including the manner of interpreting the test results.

INTRODUCTION

All model basin establishments have, in the course of their testing work, developed methods of more or less automatically delineating the streamlines on or near the surface of a model while the model is traveling through the water.

Some use streaks of wet paint, applied along the girth of transverse sections. When the water flows by any section, it drags some of the wet paint along the surface. The direction and length of the paint streak serves as an indication of the direction and velocity of the water at that point.

Other establishments use small metal flags attached to shafts projecting through the model, with angle indicators on the inside. This procedure is designed to afford an indication of the average direction of water in the depth of boundary layer covered by the width of the flag, instead of the direction at the surface of the model only. This method, assuming that it gives the correct results, has merit in that it determines the average flow in a layer of water surrounding the model. For example, when a test is made to determine the proper position for a pair of bilge keels, which may extend well out from the side of the vessel, this method is intended to give the best direction of flow for the whole depth of the keels.

The present method of delineating lines of flow at the David Taylor Model Basin is basically the same as that developed some 40 years ago and described by Taylor in the first edition of "The Speed and Power of Ships," published in 1910 but differs from it in some important details.

The new method of taking lines of flow is definitely superior to the old method, in that it gives uniformly good results, and the flow lines are much more definite, both as to position and as to character. In the old method, the mixture of sesquichloride of iron and glue with which the model surface was painted often washed off during the first run, and gave spotty results. The marks obtained were wide and as a rule none too clearly defined. In the new method a hydrogen sulfide solution is ejected and carried over areas covered with white lead paint.

GENERAL CONSIDERATIONS

Taking the lines of flow directly on the surface of a model, as has been the practice at the U.S. Experimental Model Basin and the David Taylor Model Basin for many years, has frequently been criticized on the ground that the information it gives is restricted to a thin layer of water alongside the hull. It is, as stated previously, to obtain information on the behavior of the water in the boundary layer as a whole that the use of vanes or flags projecting from the model has become standard in other model basins.

The following reasons are advanced for continuing the present practice at the Taylor Model Basin:

a. It is simple, rapid, and inexpensive. Although the model must be removed from the carriage and lifted out of the water after every 2 or 3 streamlines are taken, for reasons to be explained later, the whole area of the underwater body can be covered in a 4-hour test.

b. The model experiments in which cylindrical pitot tubes were used to explore the flow in and beyond the boundary layer, although limited to one model in America and one in Germany, both indicate that the direction of flow is more or less uniform throughout the thickness of the boundary layer, with the possible exception of areas near obstructions such as shafts, struts, and bossings.

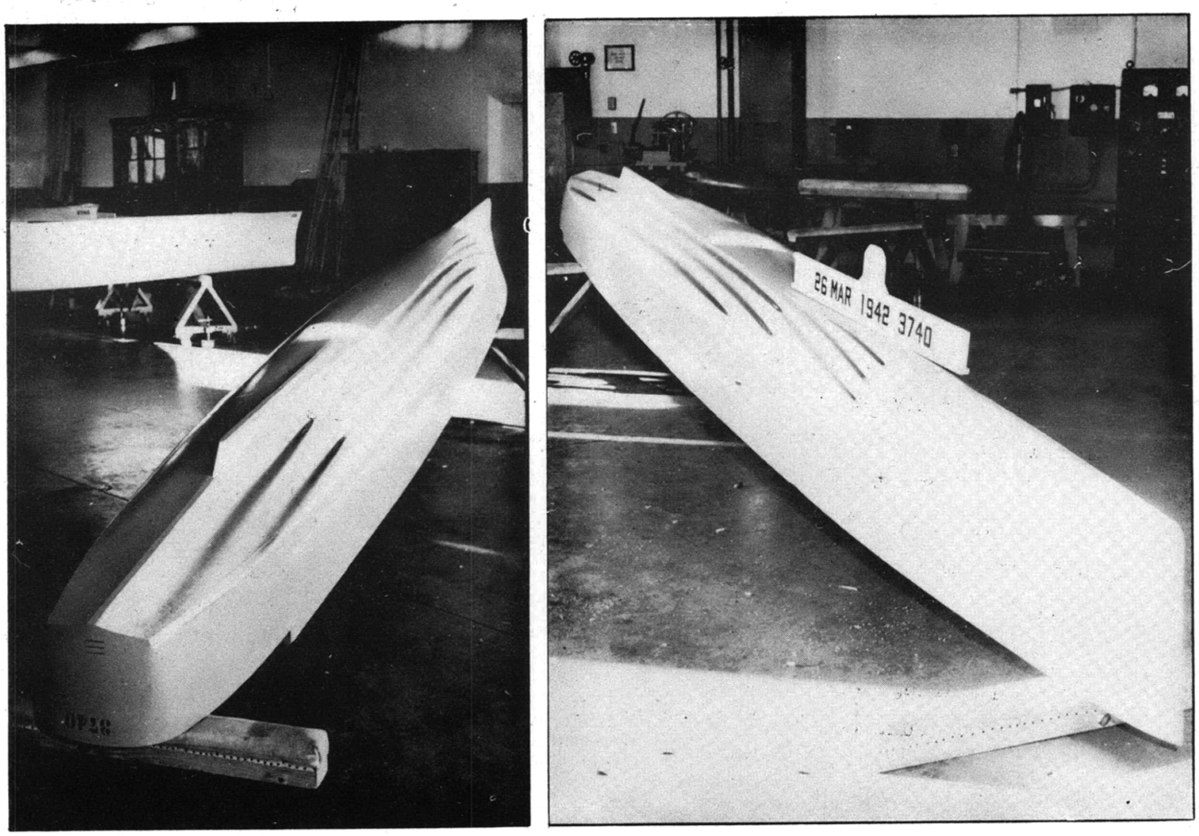

Figure 1 - Examples of Good Streamlines, Excellently Delineated

The small variation in the width of the streamlines forward indicates uniform flow; the gradual widening of the two streamlines on the stern indicates a slower motion of the water, caused by the forward component of motion due to friction in the boundary layer.

c. The nature of the flow is indicated much more definitely by surface streamlines, as explained subsequently, than it would be by vanes; the latter give only the direction, or at most, an indication that the direction is not particularly definite.

d. No area or region of flow, found unsatisfactory on full scale, has been overlooked in a model study when the surface of the model has been adequately covered with surface streamline marks.

The wave profile on a model is formed by one particular set of streamlines on the surface of the model, those at the surface of the water.

Because gravity effects are simulated by towing the model at the corresponding speed,* the geometrical shape of the wave profile around the model is reproduced in the ship.

TEST PROCEDURE

A towing model upon which surface lines of flow are to be taken is first painted with a "dead flat" white lead paint; this is applied over the standard enamel surface. The painted area is limited, as a rule, to one side of the model only, and to the region where it is desired to observe the nature of the flow.

The white lead paint is taken from the bottom of the can, where the paint is thick, in the form of a paste, and where the percentage content of linseed oil is low. This paint is then mixed with turpentine, approximately 2 parts of paint to 1 part of turpentine by volume. The resulting mixture is quite thin, and, with the addition of a small amount of drier, will set up properly in about 8 hours.

It has been found possible, when time was limited, to put the model in the water and to take streamlines with the paint still wet.

At the leading edges of the areas on the model where the lines of flow are to be observed, holes about 1/4 inch in diameter are drilled completely through the wood hull, boring from the outside. A snugly fitting copper tube is driven into the hole from the outside until the outer end is flush and a rubber tube is attached to the copper tube on the inside. On the inner end of the rubber tube a funnel is attached.

The model is then placed in the water and secured to the carriage in the normal manner. After the towing carriage and model reach the desired speed, a concentrated solution of hydrogen sulfide in water is poured into the funnel and ejected through the hole. As it flows aft in the boundary layer of water, it combines with the lead in the paint to form lead sulfide.** This compound turns black, leaving

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* This refers to the standard procedure in ship model testing.

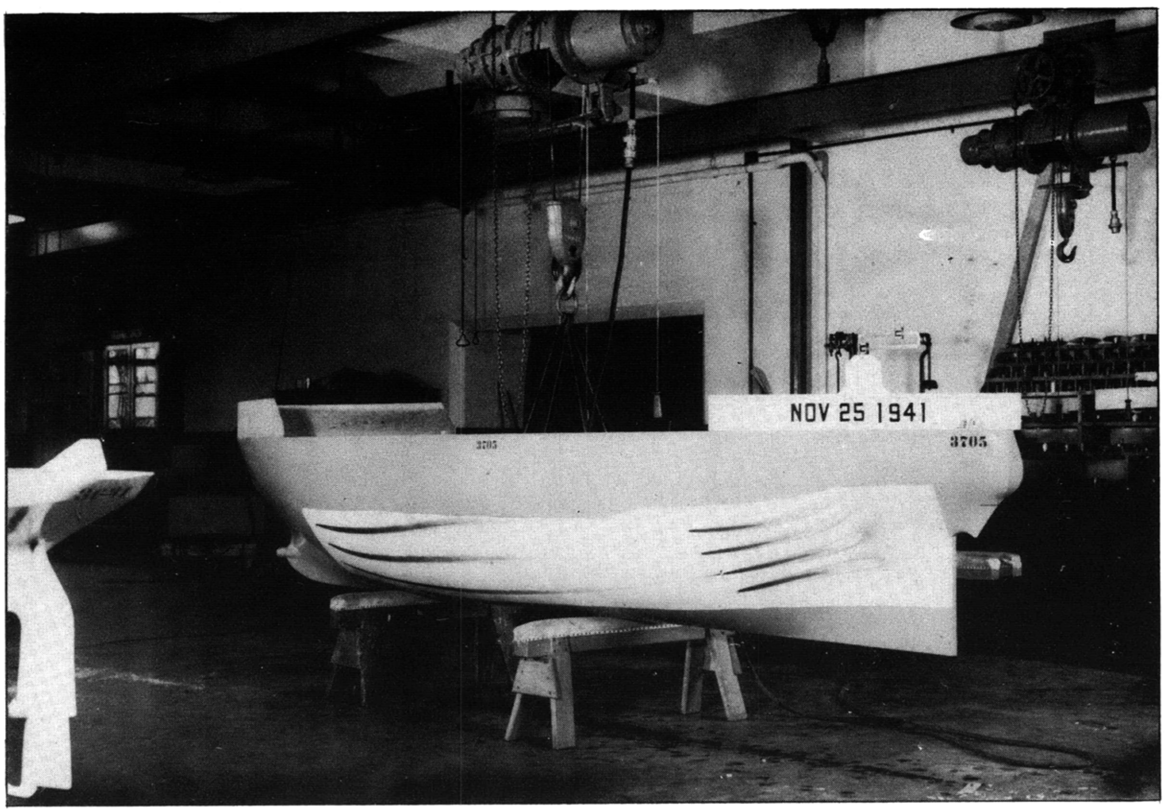
** See the Appendix.

the lines of flow clearly marked on the white surface of the model by a streak or smear extending aft from each hole. The model is then taken out of the water and the boundaries and the centerline of the discolored area are marked, for convenience in lifting their positions from the model and for transferring them to a drawing after the entire test has been completed.

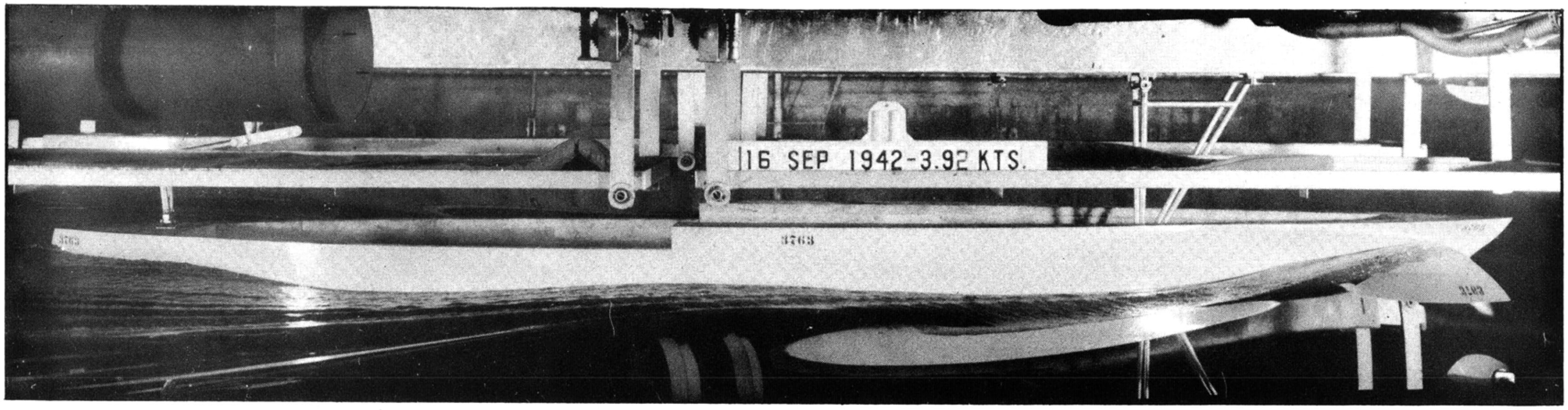
At a point where the discoloration becomes too indefinite, the line of flow may be continued by drilling another ejection hole and tracing a new line by the same method.

As a rule, 2 or 3 streamlines can be taken on each run, dependent upon the number of men in the operating crew. The length of a streamline from the ejection hole usually varies from 2 to 4 feet, but it may extend to 5 feet. By adding new holes the lines of flow can be extended to cover an area of almost any length desired.

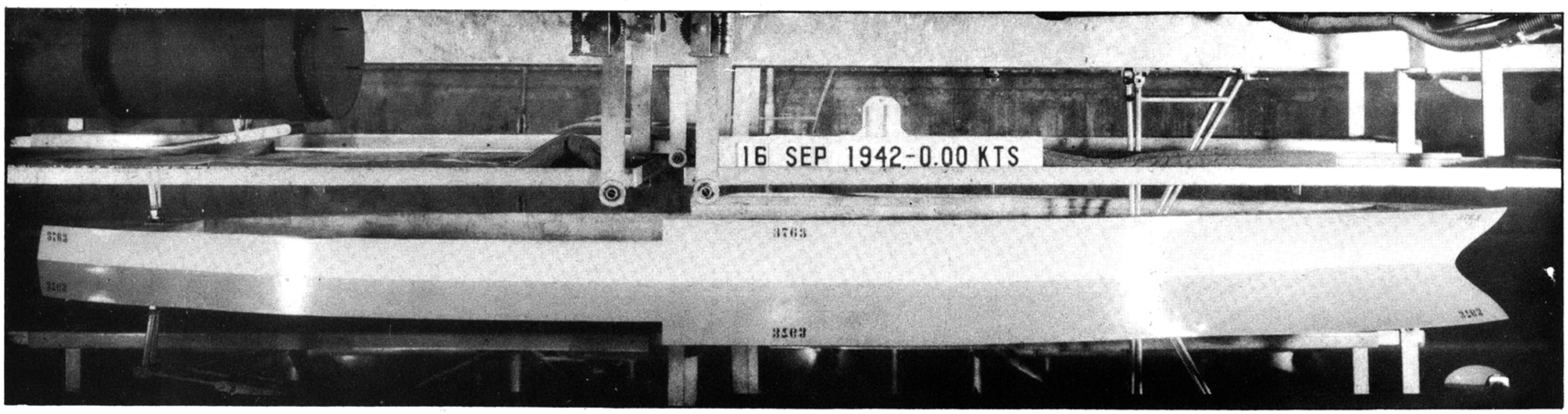
When all the desired lines of flow have been obtained, the model is taken out of the water and the marks are photographed. The photography must be done shortly after the completion of the tests, as the lines will fade out considerably in a day or two, unless the original mark was unusually dark and heavy.



This is the model of an icebreaker, with one propeller at the bow, to the left in the photograph, and two propellers (not shown) at the stern, to the right in the photograph. The four streamlines in the afterbody indicate definite separation of flow from the hull and possible eddying under the stern. The streamlines high up on the side of a ship generally parallel the wave profile.



This photograph shows the wave profile and part of the wave pattern around the model as it is towed under the carriage. The change in trim forward and aft can be determined qualitatively by the position of the deck at the bow and stern relative to the platforms under the carriage frame, or it can be observed on a special trim indicator, not shown here. The number on the model, the date, and the model speed furnish the necessary identification.



One photograph is always taken of the model at rest, to serve as a reference.
When the photographs are finished and ready for forwarding, the ship displacements and speeds are marked on them.

Figure 3 - Standard Set of Wave Profile Photographs

The wave profile along the side of the model is taken in two ways:

1. By photographing it with a special camera mounted on the carriage abreast the model when the latter is running at the desired speed.

2. By marking it along the side of the model with a scriber or other suitable instrument. The point of the scriber is applied to the surface of the model just at the waterline, while the model is running at the desired speed, pushed in to make an indentation in the surface, then drawn sharply upward to make a scratch locating the indentation. A long spline is applied to the model surface after the model is taken out of the water, a fair line scribed on the model through the marked points, and this line transferred to a drawing.

To accompany the photograph mentioned in 1, a second photograph is always made with the model at rest under the carriage; see Figure 3.

TEST RESULTS

When the surface streamlines and the wave profile are picked off the model and transferred to the body plan of the vessel, a diagram of the lines of flow and the wave profile is the result, as shown in Figures 4 and 5.

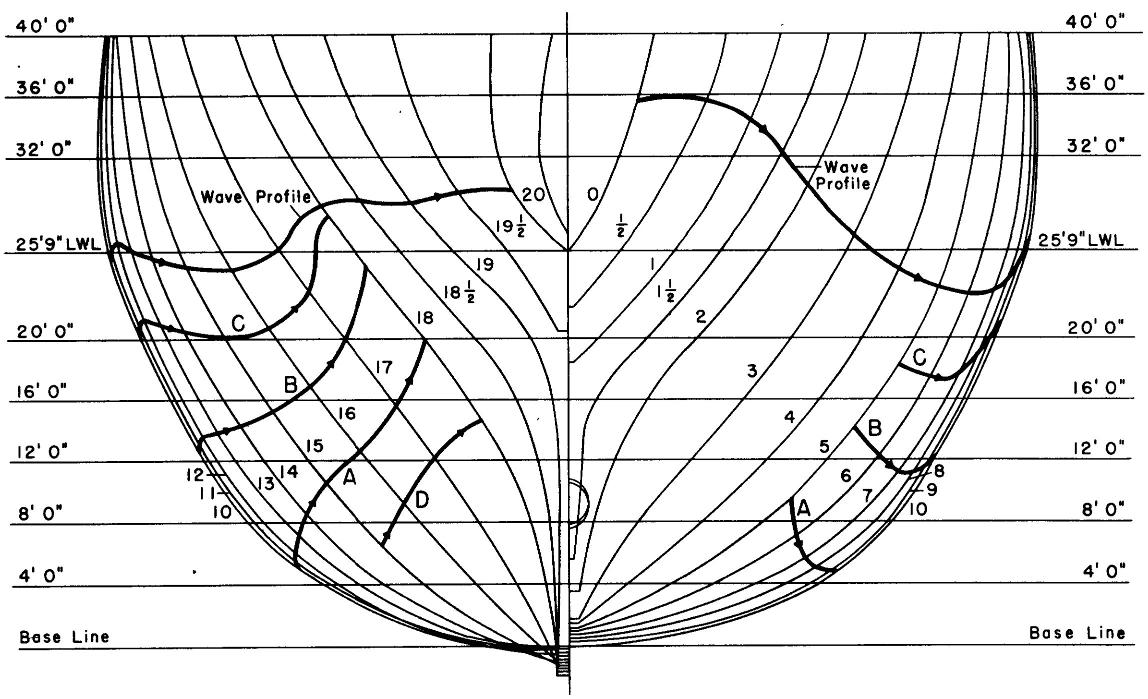


Figure 4 - Lines of Flow and Wave Profile as Derived from a Model Test

This is the plotted result of the lines of flow shown in Figure 2 on page 4. The forebody is at the right and the afterbody at the left.

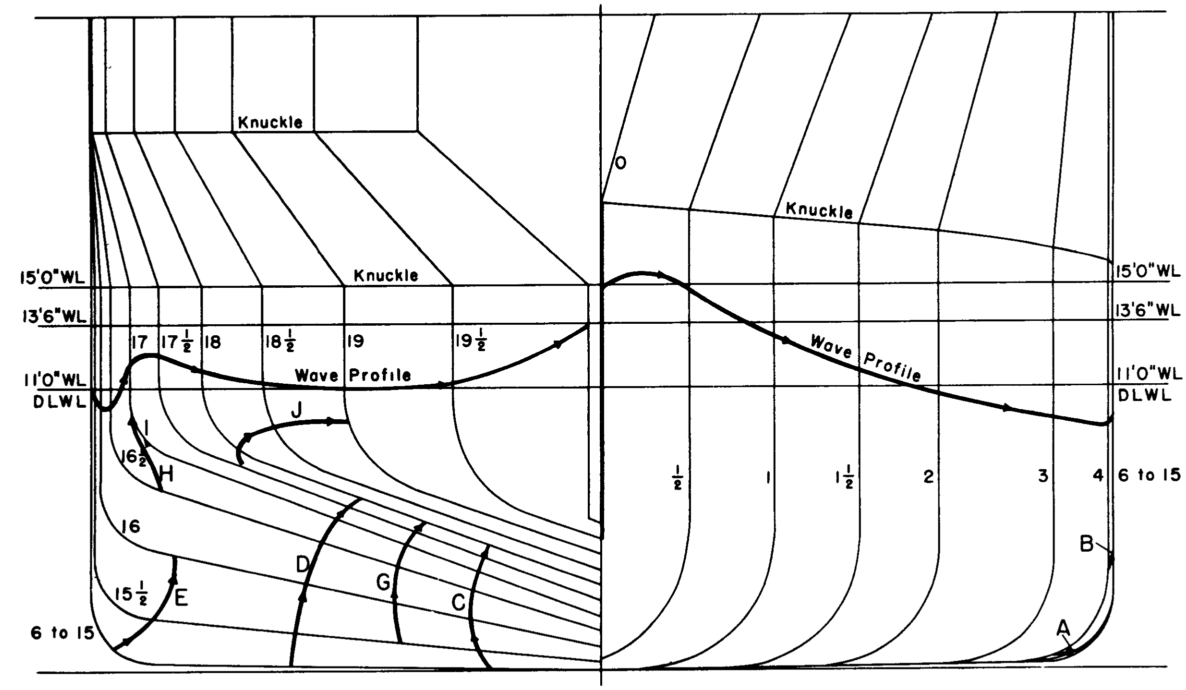


Figure 5 - Body Plan Showing Lines of Flow and Wave Profile on a Model

Each set of lines of flow and wave profile corresponds of course to only one speed; these features vary with speed, especially the wave profile. These results are for the model shown in Figure 6 on page 8.

INTERPRETATION OF RESULTS

A careful study of the streamlines on the model will afford a fund of information not only as to the direction of flow, but concerning the nature of the flow. A long, narrow line indicates high velocity; a short, wide and smeary line indicates low velocity; a sudden breaking off of the line indicates separation from the surface of the model; and an irregular line or an area with diagonal tails indicates eddying along the model.

Examination of Figures 2 and 6 will show streamlines of this kind. A schematic diagram to show the various types is given in Figure 7.

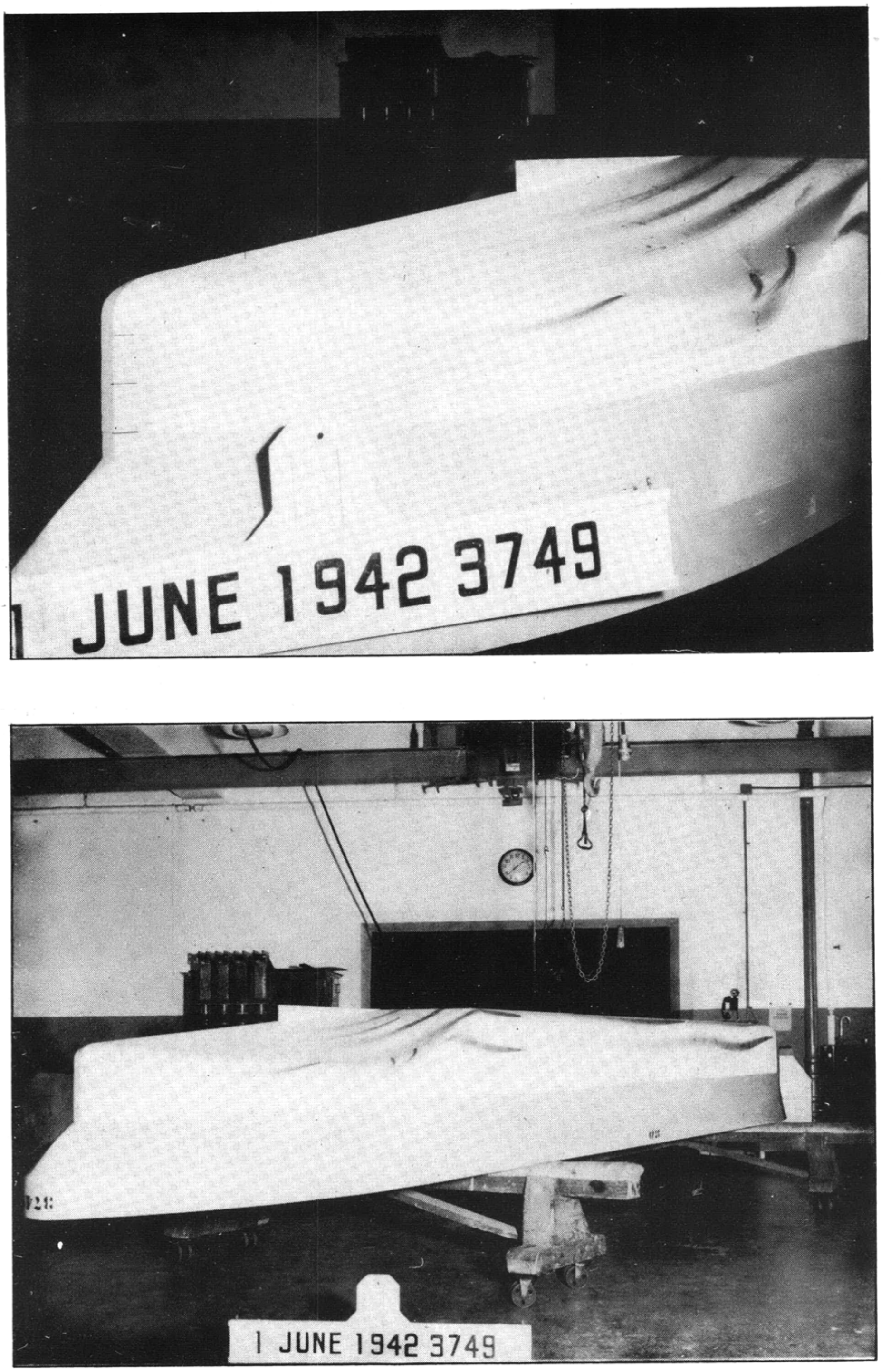


Figure 6 - Irregular Flow as Depicted by Streamlines

Note the manner in which the streamline on the side of the forebody follows the wave profile. The three horizontal lines at the stern are waterline marks, for checking the draft.

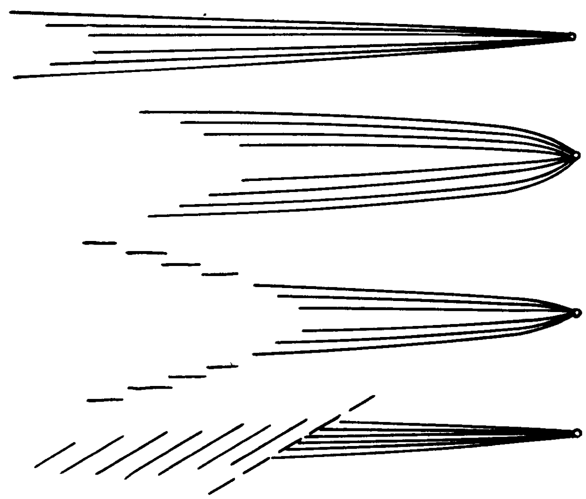


Figure 7 - Schematic Diagram of Four Types of Surface Streamlines

APPENDIX - THE METHOD OF GENERATING HYDROGEN SULFIDE

The hydrogen sulfide is generated in a regular gas generator by pouring hydrochloric acid over lumps of iron sulfide. The gas thus formed is lead through a rubber tube to a bottle of plain water, where it bubbles up through the water and forms the solution used in the tests. The residue and spent acid collect in the bottom of the generator and are disposed of.

The chemical reactions which take place during the process are relatively simple. The hydrochloric acid combines with the iron sulfide as follows:

$$2\ HCl + FeS \longrightarrow H_2S + FeCl_2$$

The H_2S dissolves in water to form a concentrated solution, and the $FeCl_2$, along with spent HCl, collects on the bottom as residue. The solution is allowed to "cook" for about 2 hours, and is then tested for strength by smearing a board painted with lead paint and observing the degree of blackness for the mark obtained.

The H_2S reacts with the lead carbonate in the paint as follows:

$$2H_2S + PbO\cdot PbCO_3 \longrightarrow 2PbS + 2H_2O + CO_2$$

The characteristic black color of lead sulfide (PbS) causes the discoloration along the line of flow.

The H_2S solution as prepared is good for only about a day after it is made up, and therefore must be used shortly after preparation. In addition, the solution must be kept tightly bottled, as the gas evaporates from the water rather rapidly if the container is left open. If the solution is strong and the white lead paint is in good condition, about a pint of H_2S solution is required for each streamline.

The lines can be made darker and more permanent by the addition of about a quarter of a pint of hydrochloric acid per gallon of saturated H_2S solution.