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THE HYDROFOIL BOAT

(Das Tragflügelboot)

by

Dipl.-Ing. K. Büller

[redacted]

Translated by E.N. Labouvie, Ph. D.

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ABSTRACT

This report gives a short summary of the development of the hydrofoil boat during the past 50 years. The limitations of size, the power required, and the stability of these high-speed boats are discussed.

THE HYDROFOIL BOAT

Although work has been going forward on the development of the hydrofoil boat for more than fifty years and although a number of such boats of the most diverse types and sizes have been constructed, the general public is not very familiar with this type of high-speed craft. However, the state of research and technology as well as the test results obtained with hydrofoil boats built thus far have enabled us for years to utilize hydrofoil boats which are of considerable size and are safe to operate in ship traffic. The technical and economic interest presently being shown in these boats justifies the assumption that the hydrofoil boat will soon develop into a familiar means of transportation in high-speed ship traffic.

The idea of the hydrofoil boat was born toward the turn of the century. The attempt was made to free the ship hull entirely from the effect of the water. This was made possible by installing underwater-hydrofoils which were mounted under the bottom of the craft and connected with the craft by means of supports with the result that at high speed the boat hull is lifted above the water level. Apart from the fact that the resistance of the hull is eliminated, the effect of the waves on the hull is also eliminated almost entirely unless the waves exceed a certain size in relation to the hull of the boat.

We know from press reports and patent specifications that Count de Lambert demonstrated a steamboat on the Seine River in 1891 which was equipped with hydrofoil-like devices. The hydrofoils were supposed to lift the craft and thus to reduce the resistance. It is clear that in this case there was no thought of raising the boat out of the water entirely. Actually operational and fully emerged hydrofoil boats were first built by the Italians Forlanini (1906) and Crocco. These boats had displacements of 1.5 tons and obtained speeds of 38–50 knots at an engine output of approximately 75 hp. However, these first promising results did not produce a usable hydrofoil boat. This may have been due to the fact that the Italians had the intention of using the underwater-hydrofoils to replace the floats of seaplanes, thus guiding all further experiments in this direction. In addition, there were also unsolved stability and cavitation problems, apart from the fact that the state of technology was not yet sufficiently far developed. Even today, the danger of cavitation sets speed limits for the hydrofoil boat which cannot be exceeded even with the most favorable hydrofoil profiles. This limit lies at approximately 60 to 65 knots.

In the twenties, the attempt was made to overcome the stability difficulties in a seaway by combining hydrofoils with planing surfaces. The resulting hydrofoil boats exhibited the shortcomings of both types. The speed of these boats was limited by cavitation of the hydrofoils and they were sensitive to wave action, because of the planing surfaces.

The first hydrofoil boats which not only flew but were actually usable were designed by Dr. Tietjens and Baron von Schertel before the last war. Outwardly, the boats of these engineers differ by the fact that with those of Dr. Tietjens the entire weight is concentrated

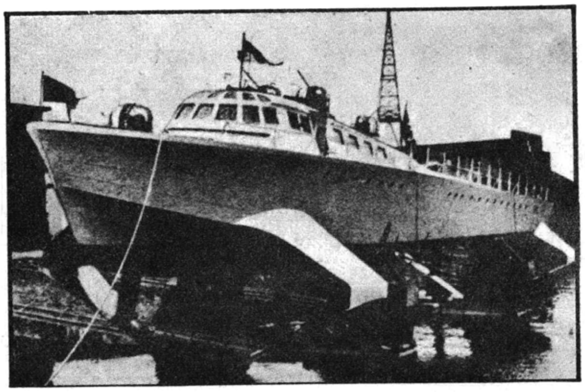

Figure 1 – 80-Ton Hydrofoil Boat, Schertel-Sachsenberg System

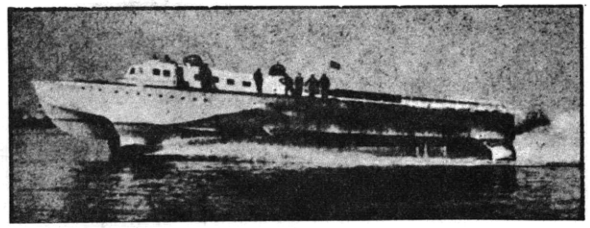

Figure 2 – 80-Ton Hydrofoil Boat Riding on Foils

on one arched hydrofoil while the stern foil merely acts as an elevator. The hydrofoil boats built according to the Schertel system are equipped with two foils which are for the most part arranged in a V-shape with the bow foil carrying 50–75 percent of the weight of the boat. The largest boat constructed according to the Tietjens system had a displacement of 17 tons. The firm Sachsenberg Bros., Inc., built a large number of hydrofoil boats according to the Schertel system, the largest of these having a displacement of 80 tons (Figures 1–2). Thanks to this company, all problems of the hydrofoil boat were thoroughly investigated and tested under the direction of Professor G. Weinblum who was assisted in this work by a large and highly qualified staff of specialists in this field.

The data of this research work have been in the possession of the Allies since 1945 and now these data are also to be made available to the German public through the medium of several publications. The previously constructed boats were either lost as a result of war damage or else they were taken abroad by the occupying powers. The Russians, in particular, showed a keen interest in the hydrofoil boats and they ordered a large hydrofoil boat to be built for the Baltic Fleet according to the designs of the engineers of the Sachsenberg Shipyard who had remained in Dessau-Rosslau.

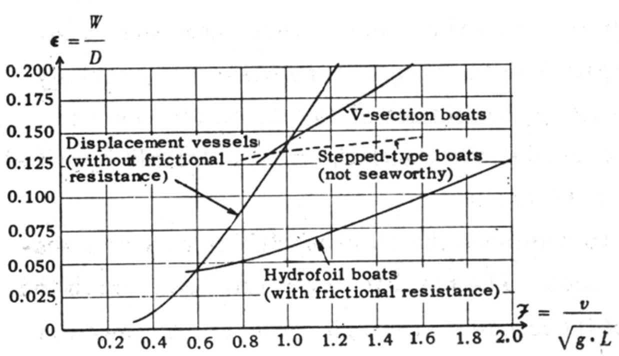

Figure 3 – Optimum Values of the Glide Ratio of Various Types of High-Speed Boats

(According to v. Schertel)

A comparison of the planing numbers (or glide ratios) of various types of boats (Figure 3) indicates that from the resistance standpoint the hydrofoil boat is superior to other types of ships even in the range of small Froude numbers starting from 0.8, quite apart from the fact that it exhibits very good performance characteristics in a seaway. In connection with this diagram it must be borne in mind, however, that in this case we are dealing with optimum values of the planing numbers and that we have learned from experience that these may easily be exceeded on account of minor faults of construction, especially in the case of hydrofoil boats. If we assume reasonably constructed hydrofoil boats, however, it may be said that from the standpoint of economical operation the latter are far superior to other types of craft in the speed range of 35 to 70 knots and at Froude numbers exceeding 0.8. Among ships of equal size and speed, the hydrofoil boat may yield power savings of up to 50 percent in comparison to other types of high-speed boats.

From the Froude number may be determined the maximum size up to which the hydrofoil boat still exhibits advantages compared to other types of craft. This maximum size is obtained if a speed limit of approximately 60 knots is taken as the practical maximum. In that case, we obtain vessels of approximately 2000 tons. Although for structural and other reasons this size cannot be attained at present, it nevertheless indicates that a wide field of activity still lies open.

The principal objections raised in regard to the hydrofoil boat concern its stability and seaworthiness. Experience gained thus far indicates that the hydrofoil boat can be given almost any desired rolling stability and that the boats built thus far were too stable rather than the opposite. In evaluating the rolling stability of a hydrofoil boat, we may, in general, make use of the simple method used in shipbuilding. For the initial stability we may use the metacentric height and for the trend of the heeled stability we may use the righting arm curve as a criterion. The static forces acting in the case of a ship are substituted by dynamic forces which may be conceived as being in a state of static equilibrium.

It is not known, in general, that longitudinal stability of hydrofoil boats is harder to achieve than rolling stability since the hydrofoil boat may be trimmed by only a few degrees if the hull is not to pierce the water surface. This sensitivity is based on the fact that the angle of attack of the hydrofoils is small and that at high speeds only a minor change in the angle of attack is permissible for reasons of cavitation. Moreover, the change of trim produces an increase in resistance which leads to a decrease in speed which in turn causes a deeper immersion of the craft.

It is necessary to know the lift coefficients of the hydrofoil profiles to be used before the hydrofoils can be calculated and constructed. It must be borne in mind, moreover, that these values are a function of the aspect ratio and the dihedral angle of the hydrofoils. The calculation of this dependency is based on the investigations of Wagner, Sottorf, and Muttray.

The trimming of the boats by a change or movement of weights may be offset by adjusting the hydrofoils or the elevator. Other familiar devices are flaps which are installed on the bow foil and which are not only used to produce a stabilizing effect, but also to support the boats when they go into a turn.

To the specifications determining the performance characteristics of a hydrofoil boat, there must be added not only the conditions of the rolling and longitudinal stability, but also those of directional stability and maneuverability. In waterways with heavy traffic, the high speed of the hydrofoil boats can only be utilized if these boats can be made to respond quickly to rudder deflections and if good maneuverability and adequate directional stability

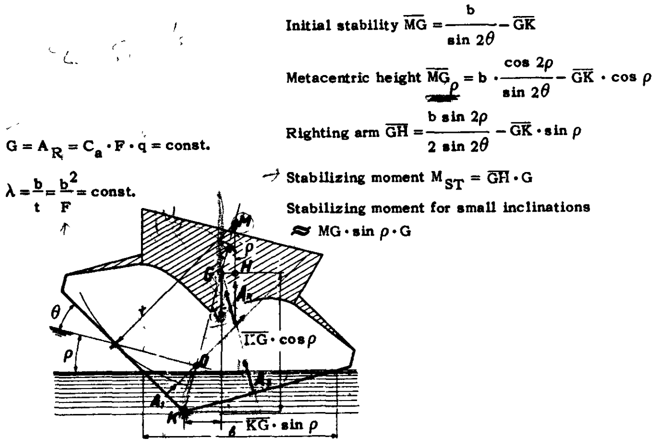

Figure 4 – Static Rolling Stability at Constant Lift Distribution Over the Width of Immersion b

(Without effect of the water surface)

can be achieved. As is the case with an ordinary ship, these qualities cannot all be achieved to an optimum degree at the same time; they must be adapted to the craft's intended use in each case.

Generally speaking, the maneuvering qualities of a hydrofoil boat depend on the distribution of the lateral plane, i.e., on the arrangement of the foils and of the rudder with respect to the center of gravity. Due to the small lateral plane a sideslip of the boat is caused by the centrifugal force when the rudder is deflected. This sideslip produces an unsymmetrical inflow against the sides of the foils and thereby, in contrast to ordinary ships, an inward heel during the turn. This inclination, approaching the position of the apparent perpendicular as it may be observed in the case of an airplane, is regarded as very pleasant and as desirable from the standpoint of structural statics as well.

Although on account of the danger from cavitation it is necessary to make the profiles of the hydrofoils as thin as possible, it is found on the other hand that strength considerations call for opposite requirements. In general, the profiles used have a thickness-chord ratio ranging from 0.05 to 0.1. In order to enable the reader to form an idea of the dimensions of a hydrofoil, we shall furnish the following data for a boat with a displacement of 80 tons. Width of the bow foil, 33 ft; chord of the middle part, 3.3 ft; and thickness in this region, approximately 3 in.

Since the hull underway is supported at two fixed points, different stresses are applied to the hull than in the case of ordinary high-speed boats. However, it must also be borne in mind that even in a normal floating position the hydrofoil boats may be exposed to the seaway and that accordingly the hull must satisfy these conditions as well.

The additional weight of the hydrofoils is partially offset by a special lightweight construction of the hull. In the case of boats already constructed weight coefficients of 2.5 lb/ft^3 (steel construction) have been obtained. Larger boats were built in light metal. The hydrofoil boat of 9.5-ton displacement just completed in Switzerland is built of wood. This boat has a length of 45/47 ft, carries 32 passengers, and attains a speed of 46 knots with 450 hp. When riding on hydrofoils, the draft amounts to 2.5 ft in the at-rest position and when the foils are retracted the draft is 4 ft.

The interest which the Swiss people take in hydrofoil boats is motivated purely by considerations of traffic requirements and economic operation. It has been observed for a long time that the ship traffic no longer satisfies the requirements of making fast connections and that passengers in increasing numbers turn to land vehicles although the latter have to make considerable detours which adds to the expense of their operation. However, even land vehicles face certain limitations inasmuch as even now the shore roads no longer permit any further increase in their traffic load. Such conditions, incidentally, are not only typical of Switzerland, but are found to exist all over the world. In all such cases where it is a question of establishing the shortest express connection by water between two or several places and where the distances are too short to make the use of airplanes profitable, the hydrofoil boat is predestined to fill this gap. For this reason, the hydrofoil boat will in many places become a natural means of high-speed communication on the water such as the airplane has already become in the air.

In the discussion following this lecture Professor Dr. Eng. Weinblum pointed out with considerable emphasis that the hydrofoil boat must still be regarded as a ship. There are two types of ships: 1. Displacement and 2. Planing and hydrofoil boats. Any modern ship theory will have to deal with both types. The main objection raised against the usefulness of hydrofoil boats is that their performance is not yet satisfactory in a following sea. Numerous test runs have shown that in comparison to planing boats hydrofoil boats have the advantage that they are far less sensitive to wave action, especially head seas. In order to insure adequate safety when moving in a following sea, it will be necessary to investigate this problem even more thoroughly. Unfortunately, the development of these boats was not an altogether systematic one. The example set by aeronautics appeared to be the ideal to pursue, but it could not be attained because of the manifold difficulties which arose, especially during the war. Professor Dr. Eng. Horn emphasized that no complete analogy exists between the hydrofoil boat and the displacement craft as far as stability is concerned. When dealing with the stability of the hydrofoil boats it must be borne in mind that the lift is not distributed uniformly over the foils. There also occurs a lateral force at the height of the metacenter. Thereby each inclination is accompanied by a lateral deviation and there occurs, moreover, an additional moment which may have the effect either of increasing or reducing the stability.

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2. Hydrofoil boats – Seaworthiness
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