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THE DEVELOPMENT OF SHIP MODEL TESTING SINCE 1900

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(The Development of Ship Model Testing since 1900, with Particular Regard to the German Model Laboratories and the Twenty-fifth Anniversary of the Hamburg Model Basin)

by

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INTRODUCTION

The fact that an establishment such as the Hamburg Model Basin has existed for twenty-five years may well be sufficient reason to outline the development of ship model testing since 1900. But such an ambitious undertaking would hardly be justified were it not for the development during this period of ideas which in general significance reach far beyond the particular phenomena of model testing and are indicative of the trend of the mental attitude of civilized humanity in general.

Great men of genius, like Leonardo da Vinci, had laid out the path of transition from mere enjoyment of nature to observation and ultimate control of natural phenomena. Following this course, the development of experimental research in shipbuilding since the beginning of this century passed from the observation of natural phenomena to that control which is the consequence of science.

The first step was the establishment of laboratories based on the laws formulated by nature study, in which to gain empirical data for full-scale structures by measurement of series of models, i.e., by observation on a reduced scale, or experiment.

From these laws of nature, the conditions most advantageous for certain results are now calculated in advance, and their suitability for various practical working conditions, not yet susceptible to theoretical treatment, is investigated in model tests.

This development of model testing and full-scale comparisons during the past decade was given practical impetus by increasingly close competition in the shipping industry.

No longer than 15 years ago, no shipowner would consider a suggested improvement that promised less than 10 per cent increase in efficiency, but today we strive for improvements of 1 to 2 per cent.

We shall now outline roughly the course of development of model testing as it applied, for example, to shipbuilding research and tools, as well as to the more important product, the shaping of ships and propellers.

Shipbuilding research based on model tests became possible only after it had been demonstrated by natural laws that there is mechanical similarity between phenomena in the model and those in the prototype. Mechanical phenomena in ship testing have to do essentially with three material properties, namely: inertia, gravity, and viscosity of the fluid. Corresponding to these are three laws of similarity, viz., Newton's first Law, Froude's Law and Reynolds' Law.

When William Froude, in the 1870's, discovered the law of similitude for phenomena in which gravity is the predominant factor, for example the formation of waves by ships, he discovered one of the essential principles of hydrodynamics for comparing model tests with actual ship conditions.

The second principle, the comparability of phenomena involving viscosity, by means of Reynolds' Law, could be made to agree with the first principle if there existed a fluid for model testing, the viscosity of which would be correspondingly lower than that of water. Since this is not generally the case, it was necessary to make an empirical correction for the difference in viscosity effects in ship and model. The development of model testing and test methods is chiefly due to a growing knowledge of viscosity phenomena and viscosity effects, and of how to make allowance for them, as well as how to calculate them by progressively improved theoretical methods.

Froude's Law, which states that model phenomena and ship phenomena are comparable when the velocities are to each other as the square root of the reduction scale, is therefore the basis of model tests in shipbuilding, unless phenomena are involved which are due predominantly to viscosity.

The size of the first models, which had a length of only 3 to 4 meters (9.8 to 13.1 feet), was determined in ignorance of the viscosity effects on such small models. They were small, partly because of the ease of building them, and partly to avoid the necessity for building excessively large model basins. The cross section of the basin had to be at least 200 times that of the model to eliminate wall effects, and the length of the basin had to be about 25 to 30 times that of the model to allow a constant speed over a sufficiently long run for the measurement of resistance.

THE MODEL BASINS

At the end of the nineteenth century England was foremost in the construction of model basins in all major maritime countries. The first model basin in Germany was established at Uebigau, followed by others at Bremerhaven and Berlin.

According to the plan proposed by William Froude the models were towed by a carriage, and as the width of the basins increased this carriage grew more and more cumbersome. Wellenkampf, 25 years later, reverted to the method used 170 years earlier by Borda, d'Alembert, Condorcet, and Bossut, in which the model was towed by a cable attached to a falling weight. A satisfactory adaptation of this method was developed by Wellenkampf in a dock at Kiel.

Now the width of the basin could be increased as desired, and its length decreased owing to the elimination of the carriage.

This towing method possessed the additional advantage of lowering the cost of model basins. As a result, it was, after 1905, adopted at several basins, for example by the German Navy at Lichtenrade, the Government Technical Schools in Hamburg, in Tokio and in Leningrad, as well as in several shipbuilding centers throughout the world.

For current needs, however, this method was found to be impractical because it was not sufficiently adaptable for the various requirements of modern model testing. The runs in these basins were usually too short, as they were limited by the length of towing cable. Thus it was difficult to obtain constant resistance data because of the formation of eddies along the afterbody due to inertia.

Then in 1911, shortly before the World War, when large, fast steamships with four propellers, and large fighting ships were built, it became evident that existing model basins were no longer adequate in size. Moreover, towing by cable did not lend itself readily to the development of other methods of predicting ship performance, such as self-propulsion.

There were two alternatives: building larger model basins or the use of large, self-propelled models.

The second method, that of building large self-propelled models from 12 to 15 meters (39.37 to 49.21 feet) in length, was adopted by the German, Italian, and English navies in designing their large, fast ships. However, the lack of torsion meters of reliable design, and adverse meteorological influences, made this method unsatisfactory at first. Variations in data exceeded considerably even the degree of accuracy of 5 per cent which at that time was still considered adequate.

The first method, that of building larger model basins, was adopted in 1913 by the Hamburg Government, which built the Hamburg Model Basin, under the initiative and energetic direction of Hermann Blohm and Otto Schlick.* This method was found to be the more practical and reliable of the two, particularly since it did not preclude the use of large, self-propelled models, and it made possible for the first time the conduct of tests free of meteorological influences.

The model basins at Teddington and Vienna, built at the same time as the Hamburg Basin, were smaller. Soon after these two tanks were constructed, basins of the same size were built in Tokio, Rome, Wageningen and Drontheim, most of them according to Dr. Gebers' designs for the Vienna Basin.

Developments during the past 25 years have shown that these single-basin plants are not sufficiently adaptable, that their range of usefulness is too restricted, and that they are too short for maximum speeds.

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* The original HSVA was built, 25 years ago, as a result of a memorandum by Dr. Foerster.

Therefore the HSVA decided 10 years ago to erect a number of separate basins, each for a specific purpose. A shallow basin for inland-shipping research was built, with provisions for representing a current in the shallow water channel, as well as a basin for high speeds, such as is required for testing airplane floats. These basins were built with the aid of the Society of Friends and Patrons of the HSVA. A cavitation tunnel was erected, with funds supplied by the Notgemeinschaft. With funds from the Öffa, a maneuvering basin was constructed, so that tests can now be carried out in five tanks simultaneously, thus assuring the highest technical and economic efficiency.

This development of a combination of a large basin for 10-meter (32.8-foot) models with auxiliary basins represents the ultimate step in the design of model testing establishments. On this Hamburg pattern are being built and will be built all the latest model basins in Leningrad, Washington (Carderock), and St. Nazaire.

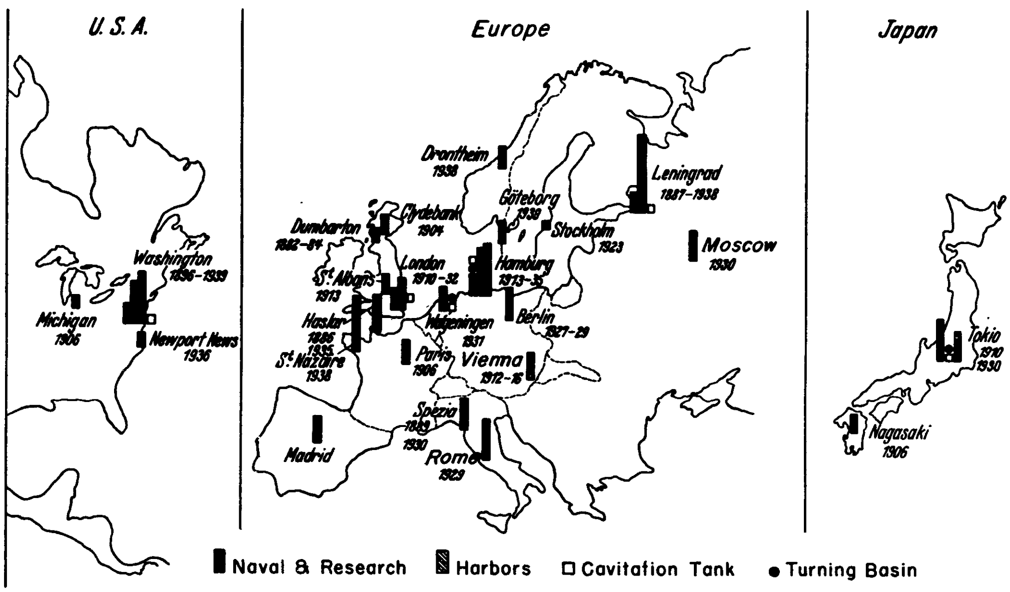

Figure 1. - Experimental Model Basins

Cavitation tanks patterned after that of Dr. Lerbs have been built from Hamburg plans in Leningrad and Tokio, and one is under construction at Wageningen. Figure 1 gives the number, date of building, and location of the existing model basins of the world. (Translator's Note: - Although the figure shows the small model basin at Newport News, dated 1936, it omits the small model basin of the Stevens Institute of Technology at Hoboken, New Jersey, and the seaplane basins at Ottawa, Canada, and at Langley Field, Virginia. No mention is made of the variable pressure water tunnel at Washington, built before the Hamburg tunnel.)

TEST METHODS

The development of tools, instruments and test methods proceeded hand in hand with the development of laboratories and model basins.

Ship models are built of paraffine or of wood. These methods were so simple and so nearly perfect from the start that no further development was necessary. On such models provision was made to measure both ship resistance and propeller performance.

Model resistance is measured in two ways:

1. The pull is measured at a constant carriage speed either by balance scale, tension spring, or the deflection of a pendulum.

2. The speed attained with a falling weight at a constant pull is measured.

The first method, in which the model is towed by a carriage, requires perfectly level rails, uniform wheel friction and constant voltage to permit maintenance of constant speed.

The second method is suitable for resistance tests in waves, because the ship is propelled with constant power and is deflected from its course by the waves, which by this method can be reliably recorded. The development lies in the variety and adaptability of the various methods.

W. Froude made use of a specially designed ball-valve steam engine with rope drive for operating his carriage. Later, storage batteries and direct current were used with a Ward-Leonard transmission. In modern practice sufficient constancy is obtained by converting alternating to direct current.

The performance of an open-water propeller is determined, now as then, by a dynamometer by which the propeller's pull is measured. This method was suggested by Froude and was perfected by Gebers.

Thrust is usually measured by a balance scale; torque is measured by dynamometer readings (Washington and Teddington), by tooth pressure (Gebers), or by spring elasticity, as it is now done at Hamburg, Tokio, and Leningrad, after experiments with the first two methods.

It was customary for years to reproduce wake and thrust deduction effects by a combination of the model towed by a carriage with a propeller pulling on a dynamometer in such a way that the propeller was brought close up to the model from the outside. Until 1915 this method was used universally at Uebigau, Bremerhaven and Berlin, as well as elsewhere.

As director of the Uebigau Basin, the writer had occasion, as early as 1910, to carry out the propeller model tests for Russian twin-screw vessels with propeller tunnels, and for the quadruple-screw S.S. IMPERATOR. Even at that early date the need for the development of a means of self-propulsion was recognized.

The first apparatus for self-propulsion of models with automatic recording of thrust and torque was constructed in 1913 for the writer, on his own initiative, by Maihak, Ltd., in Hamburg, and ordered in the same year by Russia. It was delivered after the war as a quadruple-screw apparatus, with a sensitivity of 1 gram thrust. Although offered to the HSVA in 1917 it was not accepted, so that this basin was not equipped with the writer's apparatus until five years later.

Working concurrently, Dr. Gebers developed a self-propulsion apparatus in 1915 for the Vienna Basin, which is now used in many other basins. This is true also of the Wellenkamp method developed in 1917 by Ministerialrat Schlichting and Dr. Schmidt.

Self-propulsion devices must be simple mechanically and easy to operate, small, light, and above all adaptable and easy to alter. The chief requisite, however, is minimum friction in the shaft bearings between the propeller and the torsion meter because this is the sole source of test inaccuracies. This means that there should be as few bearings as possible. Consequently the Hamburg apparatus has only two bearings in which there is friction, while those used by all other basins have at least twice as many sources of friction.

But self-propelled models, no matter how ideal may be their similarity to their prototypes, are defective, in that pressure conditions are dissimilar for the propellers in the range where there is danger of cavitation, i.e., danger of vaporization, to which water is exposed as the speed of the propeller increases.

The final stage in the development of means for studying propeller performance, therefore, is the water tunnel, built to the specifications of Dr. Lerbs, in order to permit measurement of propeller performance under pressures reduced to correspond to those of the prototype, and in general to allow observation of the effect of changes in form and pressure on vaporization.

In the course of development, a series of new and improved methods and devices was evolved for propeller and turning-circle tests. It would lead too far afield to describe the various devices. It is sufficient to state that the development was further advanced in this direction by the construction of special maneuvering basins.

Special development occurred also in the investigation of inland shipping. This is particularly important to Europe where an extensive and divergent network of shallow inland waterways requires the designing of economic ship forms and the easy regulation of traffic. Thus the German basins are provided with adjustable bottoms, and the HSVA has a special flow arrangement to permit measurement of the effects of river currents.

Research recently instituted on the movements of ships in waves necessitated the construction of wave-makers, as well as of instruments for measuring vibrations, accelerations and stability.

As far as propulsion research is concerned, we may regard the development of model basins and test instruments, i.e., the tools, as completed, since they permit making the required tests with an accuracy of 1 to 2 per cent. Greater accuracy is still extraordinarily difficult to achieve for various reasons, and it is considered costly and unnecessary.

THE TEST DATA

Several questions now arise: "What has been accomplished in the course of time with these basins and methods?" "What progress has been made in the development of their objects of research, the form of the ship, the design of the propeller, and the efficiency of propulsion?"

In this respect three epochs are plainly distinguishable, proceeding simultaneously with, and parallel to the three structural epochs of the model basins, i.e., the epochs of "what occurs", "how it occurs", and "why it occurs."

The first era, that of "what occurs", was a time purely of contemplation of nature and of measurement of forces according to the principles of gathering a systematic mass of statistics. It lasted until about the turn of the century. In many branches it still persists.

The problems of this epoch were solved for the first time in the earlier experimental basins.

The systematic propeller tests of R. E. Froude with models of 100-millimeter (3.93-inch) diameter; of Dr. K. Schaffran with 120-millimeter (4.72-inch) propellers, and of D. W. Taylor with 300-millimeter (12-inch) propellers, are well known. Comparison of these test data with one another and with trial data of ship propellers showed good agreement within the limits of accuracy required at that time.

Series tests were also carried out with ship forms of all possible types. Especially well known are the extensive ship form series tests published in 1910 by D. W. Taylor, which have established a reliable basis for choosing the most suitable ship dimensions.

The effectiveness of these systematic propeller and ship form tests for dimensioning propellers and ships was demonstrated by their usefulness in shipbuilding at the turn of the century. This is also shown by the trend toward building new model basins which began about that time.

The second epoch began when questions arose concerning the nature of the phenomena and when efforts were made to understand the physical mechanism of flow phenomena, i.e., to learn "how it occurs."

This second stage was characterized in propeller research by three methods:

1. The optical method, by which Flamm took motion pictures of propeller models operating in a glass tunnel. He thus discovered for the first

time the mechanism of boss and tip eddies in his photographs and showed them to his colleagues of the Schiffbautechnische Gesellschaft.

2. The pressure test method by which Gebers in Berlin was first to show the velocity distribution in the propeller race by means of pitot tubes.

3. The chemical method by which the writer, in the Dresden Model Basin, identified and recorded the streamline curves ahead of, abreast of, and behind the propeller, with running propeller models. This procedure has again been adopted by Gutsche as a promising method for the analysis of flow phenomena.

In the realm of ship form research this period experienced similar applications:

1. The optical method was first ingeniously applied by Ahlborn to record photographically the eddy mechanics, and the lines of force in the flow about variously shaped bodies.

2. The pressure test method had long been used in the construction of pumps and turbines, and for several years has also been the well known means in model testing for obtaining information on the velocity distribution in the vicinity of a ship.

3. The chemical method was first applied by D. W. Taylor to record the course of streamlines on the surface of ship forms. Today it is an everyday means, at least in the Hamburg Basin, of tracing streamlines on ship forms, and it furnishes the desired information as to the "how" of flow. A mechanical method is used in England, in which small, rigid, hinged flow-vanes project from the ship form into the stream, which then swings them into its own direction.

However, it is necessary not only to learn the effect on flow of the propeller by itself, and of the hull by itself, but more particularly to cover both in interaction, i.e., to discover the so-called thrust-deduction and wake mechanism, and thus be able to control it for the best possible effect.

In order to establish an optimum standard, systematic tests were carried out ten years ago in Hamburg, with completely submerged cylindrical bodies having afterbodies of various fullness, for the determination of so-called thrust-deduction and wake conditions, and efficiency.

For this purpose all the methods discussed in the foregoing are used, especially the pressure-test method, which gives particularly good results in wake research at the Hamburg Basin.

Since, in the case of propellers, the fields of action are cylindrical, wake wheels and wake rings are also used (the former as suggested by the writer and the latter by Van Lammeren), which have the property of mechanically integrating the phenomena in a circular ring.

These research methods and this manner of working during the second period in the development of model testing further increased the achievements of the first epoch, and contributed, above all, to an increase in the reliability of predictions, thereby strengthening the confidence of yards and shipowners in model testing. Consequently there was a clearer definition of the risk of the guaranty period for the construction of new ships and consequently also of design.

In the past 15 years the foregoing methods have effected a material improvement in the propulsive efficiency of the propeller, the ship form and of the two in their interaction. Various estimates give probable average improvements in propulsive efficiency of 15 per cent and 20 per cent. I refrain from making an estimate of the monetary savings involved.

One of the earliest practical successes of this second stage in model testing was the contra-propeller of Wagner and Hass, followed by the designing of wake-adapted propellers, suggested by the HSVA in 1923, which resulted in improvements, especially in single-screw vessels. A new successful advance is the Düsenschraube (mantle propeller) as developed by Kort. (Translator's note: - The latter is, however, by no means a new idea.)

Through suggestions by Maier and Yourkevitch based on flow research, improvements in hull design were effected which have made it possible to surpass Taylor's excellent standard ship form in almost all speed ranges by several per cent. (Translator's note: - Dr. Kempf makes no mention of the fact that American naval architects were exceeding Standard Series model performance for many years before Maier and Yourkevitch were heard of.)

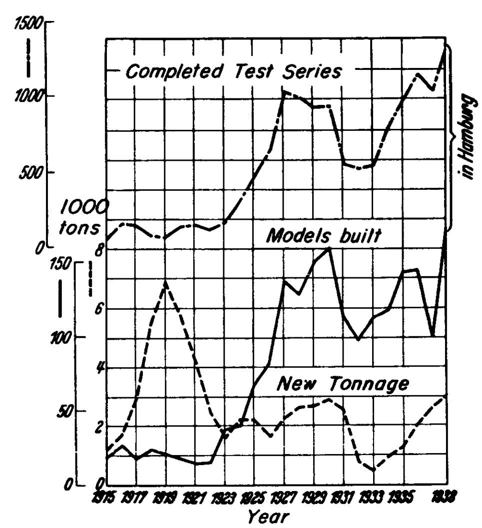

Figure 2

Regarding the interaction of propeller and hull, distinct improvements have been made in the case of single-screw vessels as well as those having multiple propellers, by adopting afterbody shapes which produce the most uniform flow possible. This results in an increase in the efficiency of the propellers, a reduction in the stresses to which they are subject, and a decrease in vibration.

A material aid at this stage in the development of model testing is the variable pressure water tunnel in which, as in Flamm's glass tank, all phenomena can be followed optically and recorded.

The usefulness of tests in water tunnels has been the subject of many recent reports. If further proof is required, it may be found in the fact that several large model basins now actually have such tanks or are installing them; see Figure 1.

In any case, problems which can be solved only in the water tunnel will soon increase materially in number and importance.

The third and final stage in the development of model testing begins with the question "Why does it occur?"

The answer lies in the formulation of theories based on established physical laws, by which the phenomena can be explained and calculated in advance. This final stage had its inception after the World War. With respect to the propeller, it is characterized by extension of the propeller theory by Betz, Glauert, Helmbold, Goldstein, Hogner and Lerbs. With respect to the ship form it is characterized by development of the theory of wave resistance by Havelock, Mitchell, Hogner, Weinblum, and Wigley, and by development of the friction and boundary-layer theory by Prandtl and Von Kármán.

In relation to the mechanism of thrust deduction and wake, this third stage in natural science is marked by the works of Fresenius, Thoma, Telfer, Horn, and Dickmann.

At present, we have reached a stage where we understand the "how" of many branches of model science, and where the solution of the question "why" has also progressed up to certain limits. Many important points, however, such as the breaking off of vortices behind irregularities, and the formation of non-uniform flow along the afterbody in the region of the shaft bossings, are not yet fully understood and require further study.

The development of model science hitherto considered was confined to a study of the steady conditions of models running in calm water. As stated in describing the model basins, model science includes the investigation of and research into irregular phenomena such as occur in steering, starting, stopping, and the movements of ships in waves, as functions of the stability of the ships. In other words, model testing covers all phenomena of motion encountered by an actual ship in operation.

Naturally this entails a considerable extension of the field of research and experiment. Therefore, during the past seven years, the HSVA has made preparations for further development of the various branches of research by establishing special bureaus.

The first was a trial-run section, whose task it is to measure speed and power aboard ships by means of specially designed instruments, thus obtaining reliable data for comparison with model data. This information is useful to shipbuilders and shipowners, as well as to model basins.

The next laboratory was erected in Cuxhaven for fouling research. Here were studied the causes, effects, and means of controlling fouling of bottoms.

Recently a research organization was instituted for the study of stability and vibration, and a strength-testing group was assembled which carries out tests aboard ships in operation and in laboratories, and investigates "how it occurs" in specific instances.

Such research, however comprehensive, costly, time-consuming, and necessary it may be, can never be adequate or exhaustive, because tests are always conducted on single subjects and can not be directly applied to the subject in general.

This great need for comparison can be filled only by mass statistics, which have been found by experience, both here and abroad, to achieve practical results more surely and more cheaply.

In order to collect such mass data on ships, contact was established three years ago with the shipping industry through a central bureau for the collection of ship data, and arrangements were made on more than a hundred German ships to obtain current data on all the dynamic phenomena of the ships.

Model testing would have only a limited value if the reliability of the model data and their applicability to full-scale ships were not assured.

The reliability of model data was checked by comparative tests carried out with the same hull and propeller models in various basins, which showed good agreement.

Through the international cooperation of experimental model basins during the past seven years minimum dimensions of models have been fixed which eliminate discrepancies. This has increased faith in model testing, as demonstrated by the growing number of orders at the HSVA (Figure 2), as well as by the erection of many new model basins (Figure 1).

In order that the science of model testing may attain its ultimate object, the applicability of model data to prototypes within a variation of a few per cent must be assured, and the reliability of results made certain. Under this heading comes the clearing up of all remaining unsolved points, resulting chiefly from lack of understanding of the frictional conditions obtaining in the full-scale ship with respect to skin-roughness of the hull and roughness of propellers. In this respect important progress was made in cooperation with aerodynamics.

Knowledge obtained regarding laminar and turbulent flow shed light upon the multitudinous frictional factors, and special friction tests with movable test plates in ships and long pontoons, such as were carried out by the HSVA 10 years ago, crystallized and confirmed the theory.

The special trials undertaken with the TANNENBERG in 1937 and 1938* are keystones in this course of development. On these trials the data of full-scale propellers and the friction coefficient of the skin were checked exactly and confirmed.

Summing up what has been said in this outline of the development of model testing science, it can be said that the development of basins, instruments and knowledge has reached a stage which assures the reliable determination of the optimum propulsive conditions for full-scale ships.

One task still to be accomplished is the research recently started to insure adequate maneuverability of ships under all operating conditions.

Model testing science will conquer nature only after it has succeeded in attaining a knowledge of natural phenomena by careful and numerous investigations. In addition to all its merits this fact entails a danger of hybridism and exaggeration, from which we can not be preserved by skill, but only by wisdom. Schiller expressed this thought when he said:

"Work is the condition of life, wisdom its aim, and happiness its reward."

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* The TANNENBERG trials were reported by Dr. G. Kempf of the HSVA, in Werft-Reederei-Hafen, 15 June 1939. This report will shortly be available in English as U.S. Experimental Model Basin Translation 91.