EXPERIMENTS ON THE EFFECT OF VARYING THE AREA OF SCREW PROPELLERS.*

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The most extended and undoubtedly the most reliable experiments on propellers of which we have the data were those made by Mr. R. E. Froude, and reported on in 1886.† In these experiments, diameter, speed of advance, and area, both in amount and distribution or shape, were kept constant. The investigation then covered the ground involved in the variation of the other features as noted above, viz., pitch or pitch ratio, and slip or revolutions. The investigation of the influence due to gradual variation in the area was not one of the fundamental purposes of these experiments, and the information relating to this point was restricted to the results arising from a reduction in the number of blades from 4 to 3 or 2, their shape and size remaining the same throughout.

In the experiments to be hereafter described, an additional variable element—that of the amount of area—is to be introduced. In these experiments, therefore, diameter, speed of advance, and shape of blade as well as number of blades are kept constant; while amount of blade area, pitch or pitch ratio, and revolutions or slip, are subject to variation.

The essential feature of the present investigation is therefore the relation of the amount of area to the performance as a whole.

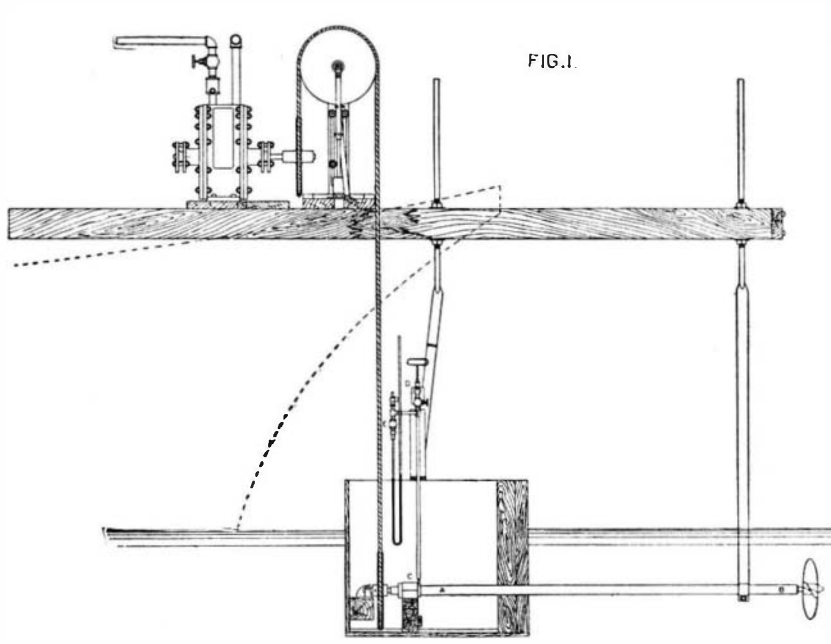
APPARATUS AND MATERIEL.—The experiments here reported were made on propellers of the following dimensions:

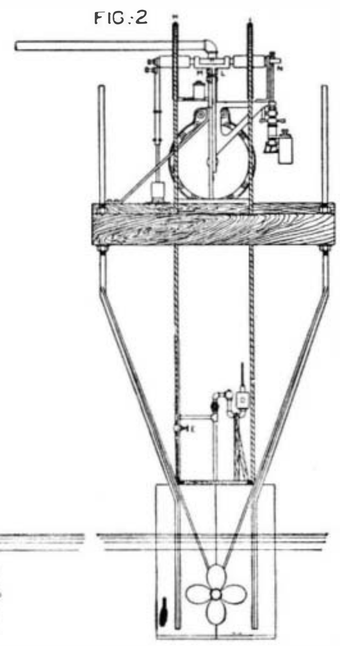
Reference No.	Diameter.	Pitch.	Area ratio.	Max. width of blade ÷ radius.	No. of blades.
2	1'	1' 3	0 18	0 2	4
3	"	"	0 27	0·3	"
4	"	"	0·36	0·4	"
5	"	"	0·45	0·5	"
6	"	"	0·54	0·6	"
7	"	"	0·63	0·7	"
8	"	"	0·72	0·8	"

The number of the propeller and its pitch ratio serve to identify it, the number corresponding to maximum width ratio and to area ratio, as seen by comparing the 1st, 4th, and 5th columns.

The elements directly to be measured in any given experiment on one of the propellers are as follows:

The power absorbed, the thrust developed, the revolutions, the speed of advance in undisturbed water.





APPARATUS FOR DETERMINING THE INFLUENCE OF SURFACE ON THE PERFORMANCE OF SCREW PROPELLERS.

The facilities of an experimental tank not being available, it was decided to mount the necessary apparatus on the bow of a small steamboat, the propeller to be tested projecting forward into undisturbed water, and the boat serving as a carriage whereby any desired speed of advance may be obtained.

ARRANGEMENT OF PROPELLER SHAFT AND FITTINGS.—The arrangement of the propeller and shaft is shown in Fig. 1. A B is a pipe surrounding the shaft proper, and provided at its forward end with a ball-bearing. This pipe, at the rear end, passes through the stem of the auxiliary box or false bow, as shown, and is connected with a watertight joint to the forward end of the thrust dynamometer, C. The water has free entrance to the pipe through the forward ball-bearing, and as far aft as the forward end of the dynamometer, C. The shaft proper is coupled to the brass plunger rod of the dynamometer, and the fit between this rod and the dynamometer end is so perfect that no water can leak through.

THRUST DYNAMOMETER.—This dynamometer consists of a plunger and oil cylinder. They are accurately fitted by grinding and lapping, with a difference of somewhat less than 0·001 inch in diameter. This difference is sufficient to insure perfect freedom of movement, and the presence of a definite layer of oil between the plunger and the walls of the cylinder. The plunger and rod are in one piece, and the forward end of the latter is coupled to the shaft as noted above. The after end projects to the rear and carries the driving sheave, and is also fitted with a screw for attaching a counting device. This rod passes through a solid bearing at each end of the cylinder, and is fitted by grinding and lapping, as with the plunger. In the forward end of the cylinder is a pipe leading to the mercury gage for measuring the pressure. In the after end is an opening giving free escape for such oil as may leak past the plunger. As indicated above, a small leakage was desired in order to insure complete lubrication of all moving parts, and in use the cylinder thus becomes filled with oil on both sides of the plunger, the slight amount lost being made up by a pump connected with the pressure gage, to be described later.

The propellers are run at a number of revolutions somewhat greater than would correspond to the speed of the boat, thus giving a sternward acceleration to the water acted on, and a forward reaction. This gives rise to a pull on the shaft, and the oil on the forward side of the plunger then furnishes a ready means for the transmission of the pressure to the mercury column, where it is measured. The fundamentally important point of the dynamometer is that, when the plunger is revolving, all longitudinal friction is eliminated, and the delicacy for the measure of the forces involved becomes very great.

The measurement of the pressure is by means of an

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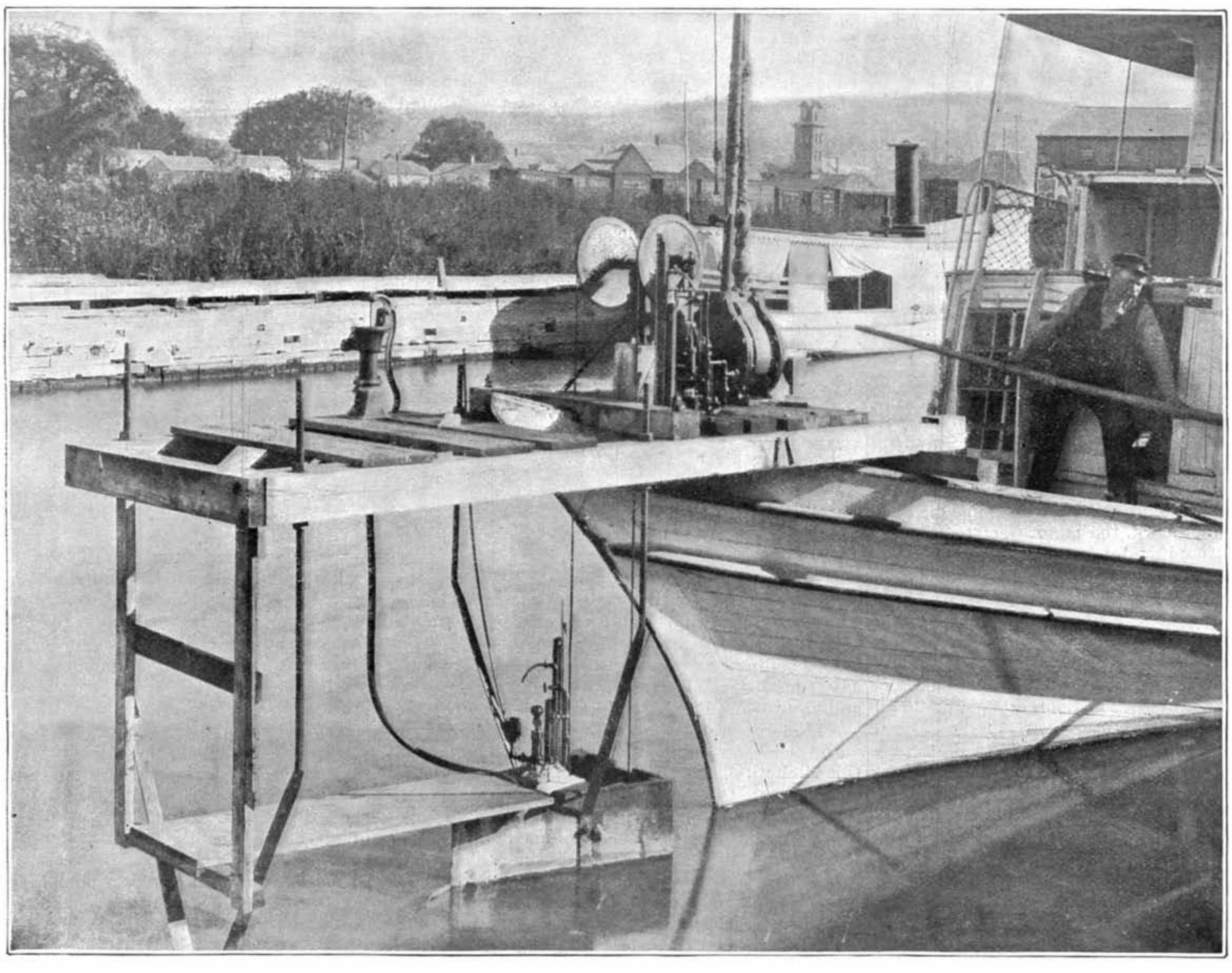
† Transactions Institute of Naval Architects, vol. xxvii, p. 250.



THE EXPERIMENTAL APPARATUS MOUNTED AT BOW OF STEAM LAUNCH.

open mercury manometer, as shown in Fig. 1. The stop valve, E, is for the purpose of damping any tendency in the column toward vibration due to periodic fluctuations in the pressure measured. The performance of the thrust dynamometer and pressure manometer was exceedingly satisfactory, and, I believe, leaves little to be desired as to delicacy, accuracy, steadiness, readiness of calibration, and general reliability. The manometer as used in these experiments was not self-registering, but was read by an observer at intervals of a few seconds throughout the run. This gave a very satisfactory value for the mean, but required, of course, the services of an extra observer.

TRANSMISSION DYNAMOMETER.—For the transmission dynamometer the arrangement shown in Figs. 1 and 2 was used, constituting a special form of rope dynamometer. The ropes, F and G, lead from the driving sheave on the after end of the propeller shaft, the former being the tight and the latter the loose side. These pass over sheaves, H and I, and then around the sheave on the motor shaft. These sheaves are all of the same diameter, in the present case 15 inches. The sheaves, H and I, are mounted with ball bearings on a shaft, K, which is carried by a block, L M, the latter being connected to the base by a pair of thin steel plates or springs. This is the well known Emery support or substitute for a knife edge, and for slight movements is almost perfectly frictionless, at the same time affording rigidity in the directions desired.

The sheaves, H and I, and their shaft thus form a balanced rocking system or lever pivoted in the middle, and therefore without deflection so long as the tension on the two sides of the rope is the same. When running, however, the difference between the tensions on the tight and loose sides will determine a moment which will tend to throw this arm down. This motion is prevented by a strut connected with the arm, N, by a spherical joint, and resting on the bottom of an inverted steam engine indicator piston. The compression of the indicator spring is then used to measure the moment, and thence, knowing the revolutions, the power transmitted is immediately known. The indicator drum was given continuous and uniform motion in one direction only, by connecting it through a cord with the main drum of the Weaver recorder.

MOTOR.—For driving the propellers a small rotary engine was used as indicated in the figures. This gave a nearly uniform turning moment and proved itself very satisfactory for the purpose in view.

RECORDS OF REVOLUTIONS, TIME AND DISTANCE.—All records relating to revolutions, time and speed were recorded on a Weaver time and speed recorder, which, it will be remembered, consists essentially of a modified Morse register with a number of pens under electrical control.

THE COURSE.—For the course a distance of 1,000 feet was measured off on a railroad tangent running close to the east shore of Cayuga Lake, where the beach is bluff and deep water extends close to the shore. A similar course was also laid off on a straight reach of the "Inlet," a channel about 100 feet wide leading from the lake to the city. Most of the work was done on the outer course, the Inlet course being used only when the water on the lake was too rough for regular work outside. The observations relating to the ranges were made by an observer holding a circuit breaker in his hand, which was closed opposite each range, thus furnishing ten series of distances of 100 feet each.

THE PROPELLERS are of brass, four bladed as shown, and the blades are of elliptical contour when developed, with maximum widths as shown by the table above. For making the propellers a wooden pattern was first prepared for No. 8. This propeller being cast, the pattern was reduced in blade width and thickness, and No. 7 was next cast, and so on down to No. 2, but one original pattern being thus required for the entire series.

MODE OF CONDUCTING AN EXPERIMENT.—For the determination of a single point or item of the final data two single runs were made, one north and one south.

The boat being brought on the course some distance from the first range mark, the motor was started, and the revolutions were brought by tachometer to the desired point. The speed of the boat at the same time was brought to the constant value, and as the boat neared the range marks the counting and recording mechanism was thrown into operation. The indications of the mercury column on the thrust dynamometer were read and recorded at intervals of a few seconds while on the course. The fluctuations were in all cases slow and gentle, and usually from ten to fifteen readings were sufficient to give a closely accurate average of the indications. In the meantime the range observer closed his circuit on passing each range, and the other records were automatically recorded.

The data thus taken consisted of the following:

An indicator card from the power dynamometer.

A column of readings from the thrust dynamometer.

A strip of paper with dots giving time revolution and range marks.

CALIBRATION.—For the purpose of standardization, the apparatus was erected in the laboratory and operated as nearly as possible under the conditions of use. The power dynamometer was standardized by means of a Prony brake applied on a wheel located on the end of the shaft instead of the propeller. The thrust dynamometer was standardized by applying known thrusts by means of a right angle triangle having a knife edge bearing. The calibrations were made at various speeds and a large amount of data was taken as the basis of these important determinations. The calibration of the power dynamometer was also determined by measurements and the known theory of its action.

REDUCTION OF OBSERVATIONS.—The data obtained as previously described was reduced as follows:

The mean ordinate of the indicator card was determined, and from the calibration data the corresponding power was immediately known. Similarly the mean altitude of the mercury column was determined, and by the calibration data the corresponding thrusts were found. The revolutions per minute, and per 100 feet for the entire course, as well as the speed per minute, were then determined by counting from the strip of tape used in recording the revolutions.

The two sets of results north and south corresponding to a given determination were then averaged and the results thus found were accepted as a series of values of speed revolutions, thrust and power, mutually corresponding the one to the others. This constituted the original reduced data. It became necessary, in order to put the data into form for plotting or investigation, to reduce it to constancy of some one feature. The data was first reduced to constancy of speed, the slip in each case being unchanged.

A correction was also introduced at this point to allow for such slight departures from the standard pitch ratio of 1·3 as existed in the propellers as actually used.

The data was next reduced to constancy of revolution, the slip in each case remaining the same.

DISCUSSION OF RESULTS.—In all cases the slip for zero thrust was specially determined by a set of runs in which, at constant speed, the revolutions were so controlled as to give no thrust. In all cases, except for No. 2, the slip at which this occurs is seen to be negative, and the thrust at zero slip is positive. This result is well known in a general way, but the present experiments, so far as the author is aware, are the first published in which the point has been made the subject of quantitative determination. The explanation of the apparent anomaly is found in the influence due to the thickness of the blade. Independent experiments show, for a body of cross section like a propeller blade near the root, that due to the stream line distribution about such a body, the resultant force, when the direction of relative motion is parallel to the plane face, is directed from the plane face inward, or at least in such a direction as to give a forward component in the case of a propeller thus moving. It is not, therefore, until a negative slip is reached with a more pronounced pressure on the back that this forward component is overcome and a zero thrust obtained. It is also notable that this effect seems to be the less pronounced the narrower the blade, so that for No. 2 a zero thrust was found at nearly zero slip.

The general or average ratios between the thrusts of 2, 3 and 4 bladed propellers given as the result of Froude's experiments are 0·65, 0·865 and 1·00 for areas in the ratios 0·50, 0·75 and 1·00. The corresponding ratios here found for the particular pitch ratio 1·3 with four blades and area ratios 0·18, 0·27 and 0·36, or with areas the same as those for 2, 3 and 4 bladed propellers, are found to vary somewhat with the slip, as shown by the following table:

Slip.	Ratios of Thrusts for Area Ratios.		
	0·18	0·27	0·36
0·10	0·43	0·78	1·00
0·15	0·51	0·80	1·00
0·20	0·56	0·82	1·00
0·25	0·60	0·83	1·00
0·30	0·63	0·85	1·00
0·35	0·65	0·86	1·00
0·40	0·66	0·87	1·00

We come next to the efficiency curves. These are of great interest and highly suggestive. Taking true slips within the usual working range of 0·20 to 0·30, corresponding to apparent slips of, let us say, 0·10 to 0·20, the efficiency increases with the decrease of area, and vice versa. For low values of the true slip, however, the reverse is the case and efficiency increases with the increase of area. For a slip of about 0·20 with this pitch ratio, efficiency seems to be nearly independent of area. Or, viewed from another standpoint, a propeller of small area is comparatively inefficient at low slips, and does not reach its maximum efficiency until a high value of the slip is reached. This maximum value is, however, higher than that reached by propellers of more area. Vice versa, a propeller of large area reaches its maximum efficiency at a lower value of the slip than for less area, and such maximum is less than that for the propeller of the smaller area. Again, the variation of maximum efficiency for variation of area ratio from 0·18 to 0·72 is only about 5 per cent, so that variation of area ratio within this range has comparatively slight influence on the efficiency.

The maximum efficiencies herein determined are slightly less than the value 69 per cent given by Froude for 4 blades and area ratio 0·36. The cause of this difference I am at present unable to explain.

If there be no limit on diameter or revolutions, the conditions likely to give the best efficiency are those of low area ratio and high slip, sufficient size and revolutions being provided, of course, to give the necessary thrust. With electric motors or steam turbines, where the revolutions are naturally high, such a propeller may the more readily be selected, and probably, in such cases, propellers of this character and worked at high values of the slip will be found most efficient.

In conclusion, it may be well to again point out that the data herein contained relates to pitch ratio 1·3, and the conclusions of the present section must be understood strictly as applying to this value of the pitch ratio only.

Electrical News and Notes.

It is stated, says The Medical Record, that telephones are to be placed in the wards of one of the Paris hospitals, within reach of the bedridden patients, so as to enable them to communicate with their friends outside. There will also be an arrangement whereby the telephones may be switched on to a wire connected with a concert hall, so that the performance may be enjoyed by the invalids.

A simple lightning arrester has been employed by Siemens & Halske on an electrical power transmission line leading to the Brussels exhibition. It consists of two rods or bars mounted on insulators and parallel for a portion of their length, where they are close together, while the end portions of the rods diverge, and on account of this shape the device has been termed the "horn" lightning arrester. One of the rods or "horns" is connected to the line or instrument to be protected and the other to the ground.—Revue Industrielle.

A syndicate of New York and Saratoga capitalists has purchased, at a cost of $60,000, the land in the vicinity of Hell Gate Rapids, on the upper Hudson, about seven miles above Glens Falls. The intention is to utilize the great water power at the place for an electrical plant. A dam and power house are to be erected, and with the electricity generated therein a railroad, to be known as the Saratoga Northern, running between Saratoga Springs and South Glens Falls, will be operated. This road will have branches to intermediate places and also to Glens Falls, Sandy Hill and Fort Edward.

The number of periodicals dealing exclusively or largely with electricity amounts to sixty-six. Of these, eighteen are published in France, fourteen in the United States, twelve in Germany, six in England, three in Switzerland, two in Austria, Belgium, Holland, Italy, and Spain, and one in Canada, Japan, and Russia. The oldest electrical paper now in existence is the Annales Télégraphiques, published since 1855 in Paris, France. The second oldest is The Journal of the Telegraph, published since 1868 in Chicago, and the third, the Journal Télégraphique, published since 1869 in Berne, Switzerland.—L'Industrie Electrique.

Budapest, the progressive capital of Hungary, has no longer any horse cars. On December 27, 1897, the transformation of all horse car lines into electric roads was completed. The city has the largest mileage of electric roads of any city in Europe. The total length of the tracks is 119 miles (of which 66 miles are operated by one company); total length operated with underground conductors, 36 miles; number of motor cars, 355; other cars, 58; central stations, 5, with a capacity of 6,500 kilowatts. The entire equipment was completed a full year before the time originally contemplated.—Oesterreichische Monatschrift.

Plans are being made to secure electric power generated by the Housatonic River for the factories of Western Connecticut. James C. Delong, an electrical expert, was in Waterbury several days conferring with local manufacturers, and figuring to what extent the electric power would be used by them. Mr. Delong is the representative of a syndicate of New York capitalists who propose to buy the water privileges of the Housatonic Waterbury Company, which has erected an immense dam across the Housatonic River, about two miles above Shelton, and the big canal that furnishes water power to the Shelton and Birmingham factories. This dam has a fall of twenty-eight feet, and an electric power plant, it is declared, can be erected that could furnish electric power to every factory and electric road in Ansonia, Derby, Shelton, Waterbury, Thomaston, Torrington, Winsted, New Britain, Bristol, Hartford, Berlin, Southington, Meriden and Naugatuck, while if the Naugatuck division of the Consolidated Railroad should be equipped with electricity it could furnish power for that, as well as the Waterbury Traction Company and the other trolley lines of that vicinity. The plans involve an expense of several hundred thousand dollars.