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“An Experimental Determination of the Effect of Varying the Angle of Incidence on the Position of the Centre of Pressure of a Curved Plate Moving through Water.”

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THESE experiments determining the positions of the centre of pressure were made with a plate, 75 inches long, $17\frac{3}{4}$ inches wide, and $\frac{1}{2}$ inch thick. The plate was bent in the arc of a circle so that its camber was 1 in 27, the $17\frac{3}{4}$ -inch side being the chord of the arc. The aspect ratio is thus $4\frac{1}{4}$ to 1.

Figs. 1.

METHOD OF ATTACHING PLATE.

The plate was attached to a stream-line body by means of three hinges, along a line 4 inches from the leading edge of the plate, and its movement was controlled by two spring-loaded rods attached at points 12 inches behind the line of the hinges (Figs. 1). These rods were fitted with stops which limited the range over which the angle

of incidence could vary. The body and plate were towed from a high-speed craft whose speed was determined in each experiment by careful timing of runs up and down a measured mile. The maximum speed attained during the trials was 45 feet per second or slightly over 30 miles per hour.

The positions of the centre of pressure for flat plates have been determined by the French engineer Mr. Joessel and by Mr. R. E. Froude (Table I).

TABLE I.

Angle of Incidence (in Degrees).	Centre of Pressure from Leading Edge in Terms of Width.			
<i>Joessel's Experiments.</i>				
4	0.2187	Plate 12 inches long by 16 inches wide. Speed 1 metre per second.		
10	0.250			
17	0.2812			
90	0.500			
<i>Froude's Experiments.</i>				
Aspect Ratio.				
	$\frac{1}{2}$	1	2	Area of plate in all cases 36 square inches. Speeds from $2\frac{1}{2}$ to 5 feet per second.
0	0.193	0.209	0.223	
5	0.230	0.219	0.226	
10	0.260	0.240	0.247	
15	0.285	0.275	0.308	

Fig. 2 shows the results for curved plates in air obtained by Eiffel and Prandtl. These plates had a camber of 1 in 25 and an aspect ratio of 4 to 1, and were thus somewhat similar to the plate used in the following experiments. It was hoped that results of the same nature might be obtained, but owing probably to the proximity of the relatively large stream-line body, the results obtained in these experiments were very different from those anticipated. *Fig. 2* shows these curves plotted with the results in air for comparison.

It will be seen from Froude's figures that for an aspect ratio of 2 to 1 very little variation of the position of the centre of pressure occurs for small angles of incidence and this variation decreases for increasing values of the aspect ratio. As will be seen, similar results were obtained in the experiments carried out by the Author.

The first experiments consisted of determining the pull of the plate at various fixed angles of incidence. The pull was measured by means of a large spring weighing-machine which was carefully calibrated in a testing-machine, both before and after each day's work, and which was never found to vary appreciably on any one day. The pull was determined at speeds of as nearly 10, 15 and 20 knots as possible. The pulls at exactly 10, 15 and 20 knots were deduced from these observed pulls by assuming that the pull varies

Fig. 2.

CURVED PLATES IN AIR.

as the square of the speed, an assumption sufficiently true not to introduce any appreciable error over a short range of speed (Table II).

From the figures in Table II, Table III is derived, giving the pulls at various speeds up to 26 knots.

A series of runs was then made with the plate free to move under the control of the springs. These springs were of a stiffness requiring a load of 100 lbs. to compress each spring 1 inch.

From the observed pulls and speeds thus obtained it is possible, with the help of the data in Table III, to determine the position of the centre of pressure at various angles of incidence with fair accuracy.

TABLE II.

Angle of Incidence (in Degrees).	Pull of Plane.		
	Speed.		
	10 knots.	15 knots.	20 knots.
	Cwt.	Cwt.	Cwt.
0	11	24	43
2	13	30	53
4	$16\frac{1}{2}$	$36\frac{1}{2}$	65
6	$19\frac{1}{2}$	$42\frac{1}{2}$	75
8	$20\frac{1}{2}$	45	80
10	$20\frac{1}{2}$	..	..
12	$20\frac{1}{4}$	..	..

TABLE III.

Angle of Incidence (in Degrees).	Pull of Plane (in Cwt.).													
	Speed (in Knots).													
	10	14	15	16	17	18	19	20	21	23	23	24	25	26
0	11	..	..	..	..	..	$38\frac{3}{4}$	43	48	52	57	62	68	74
2	13	..	..	..	$38\frac{1}{4}$	43	$47\frac{3}{4}$	53	$57\frac{1}{4}$	64	70	$76\frac{1}{2}$	..	..
4	$16\frac{1}{2}$	..	$36\frac{1}{2}$	$41\frac{1}{2}$	47	$52\frac{1}{2}$	$58\frac{1}{2}$	65	$71\frac{1}{2}$	$78\frac{1}{2}$	..	..	..	..
6	$19\frac{1}{2}$	$36\frac{3}{4}$	$42\frac{1}{2}$	48	54	$60\frac{3}{4}$	$67\frac{1}{2}$	75	..	..	..	..	..	..
8	$20\frac{1}{2}$	39	45	$51\frac{1}{4}$	$57\frac{3}{4}$	65	72	80	..	..	..	..	..	..

Let P be the pull of the plate in pounds at any known speed V knots, and let x inches be the distance of the centre of pressure abaft the line of the hinges. Let S lbs. be the pull of the two control rods acting at a distance of 12 inches from the line of the hinges. Then

$$P \times x = S \times 12.$$

Now the speed and pull being known (see *Fig. 3*) it is possible by interpolation in Table III to determine the angle of incidence for any given pull and speed. From this angle, S can be deduced as follows:—The springs were given an initial compression of 3 inches

when the angle of incidence was 8° . Each 1° decrease in the angle of incidence puts on a further 0.21 inch compression, and so S is easily obtained for any angle between 8° and 0° , the limiting values of the angle of incidence in the tests. Thus, for example, if the angle of incidence is 6° , $S = 200 \times 3 + 200(8 - 6) \times 0.21 = 684$ lbs. Thus all the terms in the above equation are known except x , which may be determined. The distance of the centre of pressure from the leading edge of the plate is $x + 4\frac{3}{4}$ inches.

Fig. 3 shows the curve obtained with the plate able to move under the control of the springs. From this and from Table III, values of x are determined for various values of the angle of incidence. The distances from the leading edge of the plate to the various centres of pressure are obtained as above, and from these results the curves in Fig. 4 are plotted, from which Table IV is derived

It will be seen from *Fig. 4* that the centre of pressure is nearest the leading edge of the plate when the angle of incidence is about $5\frac{1}{2}^\circ$, and that, for all angles of incidence likely to be used with such a combination of plate and body, the position of the centre of pressure does not move far from a point one-third of the width of the plate from the leading edge.

In Table II it will be seen that the range of incidence angle is from 12° to 0° at 10 knots. It is interesting to note that no increase in pull is obtained by making the angle of incidence greater than 8° . Though this does not hold good at higher speeds, the Author has no figures available to prove it.

TABLE IV.

Angle of Incidence (in Degrees).	Distance from Leading Edge of Plane to Centre of Pressure.	Distance from Leading Edge of Plane to Centre of Pressure as Percentage of Width.
	Inches.	
8	6·4	36·05
7	6·345	35·75
6	6·155	34·65
5	6·13	34·55
4	6·23	35·20
3	6·36	35·80
2	6·49	36·55
1	6·62	37·3
0	6·75	38·0

It is also of interest to note that, in *Fig. 3*, at one part of the curve the pull is actually decreasing as the speed is increasing. The change of incidence angle occurs gradually and not suddenly as it would do if the centre of pressure had moved as it does for plates in air as shown in *Fig. 2*.

To sum up, it may be said that with small angles of incidence below 10° , the position of the centre of pressure lies between 33 and 38 per cent. of the width of the plate from the leading edge, and that any variation of its position with varying angle of incidence within these limits may be neglected without introducing any serious error.

The experiments described are believed to give reasonably accurate results, but the conditions under which they were carried out were such as to prevent strictly accurate results being obtained. It was not possible in conducting these tests to determine the effect of varying speed on the position of the centre of pressure, but this is believed not to be large.

The Paper is accompanied by two sheets of diagrams, from which the Figures in the text have been prepared.