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Experiments on the Flow Past a Rotating Cylinder

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Communicated by Professor J. D. Cormack

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PART 1.

THE FLOW OUTSIDE THE BOUNDARY LAYER.

In 1925 the writer made a series of measurements of the direction and velocity of the air throughout the field about a rotating cylinder. The resulting velocity contours and streamlines were published at the time*, but later the data were worked up to give the distribution of vorticity throughout the field. This was found by graphically differentiating the components of the velocity. Fig. 1 shows the observed air directions and Fig. 2 the vorticity values.

The results of calculating the circulation round various contours in this field is shown in Fig. 3. It is seen that there is no very marked change in the circulation outside a contour of about twice the area of the cylinder section. It will also be seen that there is no circulation in the wake as a whole. The upper part contains positive vorticity and the lower an equal amount of (more concentrated) negative. This is in accordance with Prandtl's idea that a state of balance has been attained in the production of positive and negative eddying above and below. The circulation corresponding to the actual lift on this cylinder is about 16 ft./sec. The discrepancy is only apparent as the larger figure obtained in Fig. 3 refers to the centre section, where the lift is 15–20 per cent. greater than the mean as measured on the balance (*see* R. & M. 1082).

As these experiments gave no information regarding the conditions close to the surface of the cylinder, a series of measurements in the boundary layer was made in 1927. These experiments are described in Parts 2 and 3.

PART 2.

EXPERIMENTS ON THE BOUNDARY LAYER OF A CYLINDER ROTATING IN STILL AIR.

The apparatus used in this experiment was that prepared to investigate the boundary layer on a rotating cylinder in an air current (Part 3) and hence the cylinder used ($4\frac{1}{2}$ in. diameter) was

* "The Aerodynamics of the Rotating Cylinder." Institution of Engineers and Shipbuilders in Scotland. 1925.

mounted in the 2 ft. wind channel. Measurements close to the surface could not be made at the higher rotational speeds due to vibration troubles. A preliminary experiment gave the values shown in Table 1. These were obtained by a pitot and static tube mounted 8 mm. apart so as to be the same distance (n) from the surface and to be approximately parallel to the tangent. The pitot tube was of glass 0·63 mm. outside diameter and the static tube was aluminium tube flattened till the minor axis of the section (placed normal to the surface) was about 0·5 mm.

The results are shown plotted in Fig. 4. It will be noticed that the velocities at corresponding distances are relatively lower at the higher rotational speeds. In other words, the boundary layer is thicker at low speeds.

The weakness in the above method of measurement lies in obtaining the static pressure. In measurements of velocity in the boundary layer on a stationary surface it is justifiable to assume the static pressure constant along the normal. As the surface is approached, the velocity falls so that even if the curvature is appreciable the centrifugal pressure remains small. When dealing with the surface layer on a rotating cylinder the static pressure gradient along the normal due to centrifugal force may require consideration, since the velocities near the surface are high. Thus the exact position of the static tube may be important and probably it should be curved so as to be parallel to the surface.

To get over these difficulties and to get an idea of the magnitude of the changes in pressure due to centrifugal force, it was decided to measure the total head only and to calculate the static pressure. This pressure was assumed to be below atmospheric pressure by the centrifugal pressure of the circulating air outside the point considered and so (reckoning atmospheric pressure zero) at radius r_1 it is given by

$$p = -\varrho \int_{r_1}^{\alpha} \frac{v^2}{r}\, dr \quad \cdots \quad (1)$$

This expression contains v the quantity sought, thus introducing a difficulty which can be circumvented either by (a) a step-by-step integration, or (b) taking an assumed velocity distribution to calculate the static pressure and revising the calculation when the velocity has been obtained. Method (b) was used outside 5 mm. from the surface. From 5 mm. inwards the following step-by-step method was used :—

At radius r_1 let the total head be H_1 lbs./sq. ft. and the pressure be p_1. At radius $r_2 = r_1 - \delta r$ let these quantities be H_2 and $p_2 = p_1 - \delta p$. Then by Bernoulli's equation we have

$$v_2^2 = \frac{2}{\varrho}(H_2 - p_2) \quad \cdots \quad (2)$$

and from the centrifugal effect

$$\delta p \doteqdot \varrho\left(\frac{v_1^2}{r_1}+\frac{v_2^2}{r_2}\right)\frac{\delta r}{2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Hence

$$v_2^2 = \frac{2}{\varrho}\left\{H_2 - p_1 + \frac{\varrho}{2}\left(\frac{v_1^2}{r_1}+\frac{v_2^2}{r_2}\right)\delta r\right\}$$

or

$$v_2^2\left(1-\frac{\delta r}{r_2}\right) = \frac{2}{\varrho}(H_2 - p_1) + \frac{v_1^2}{r_1}\delta r \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Thus, if the velocity and pressure are known at any section and the distribution of total head has been measured, the velocity at a section just inside is found from (4) and the pressure from (2). These give the information necessary for the next " step ".

Table 2 shows the results of total head measurements made with a small glass tube (diameter 0·36 mm.) the rotational speed of the cylinder being 820 r.p.m. A graphical integration of (1) using the velocity measurements in Table 1 gave the pressure at $n = 5$ mm. as being $-0{\cdot}0089$ lbs. per sq. ft.

The results of the step-by-step calculation from $n = 5$ mm. to the surface are given in Table 3. It is evident that the pressure gradient, though small, is appreciable.

The velocities are dotted on to Fig. 4 along with those found using the somewhat crude pitot and static tubes.

A knowledge of the torque necessary to rotate the cylinder would enable the eddy viscosity to be found from the velocity gradient. The cylinder used in the present experiment being too heavy for the balance used previously for torque experiments this could not be obtained directly. In R. & M. 1018 the writer gave the results of some torque experiments on cylinders and spheres. Using the formula and values given there the torque required to rotate the cylinder of the present experiment at 820 r.p.m. is about $5{\cdot}4 \times 10^{-4}$ ft. lbs. per ft. length of cylinder.
Evidently*

$$Q = \text{torque} = 2\pi\bar{\mu} l r^3 \frac{d\,(q/r)}{dr}$$

where

$\bar{\mu}$ = coefficient of eddy viscosity
l = length of cylinder.

Taking $d\,(q/r)/dr$ from a plot of the values found in Table 3, the following values of $\bar{\mu}$ were obtained :—

n (mm.)	0·1	0·2	0·4	0·7	1·0	2·0	4·0
$\bar{\mu} \times 10^6$ slugs/ft. sec.	0·40	0·38	0·74	1·8	2·9	6·2	22

* Lamb, Hydrodynamics. 5 edn., p. 556.

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These values are plotted in Fig. 6. The accepted value of the coefficient of viscosity for air at the temperature of the experiments is about $\mu = 0{\cdot}38 \times 10^{-6}$ slugs per ft. second. Thus, close to the cylinder $\overline{\mu}$ is approximately equal to μ showing that turbulence is probably absent.

From $n = 0{\cdot}4$ mm. outwards it appears that the turbulence increases steadily throughout the region explored.

PART 3.

EXPERIMENTS ON THE BOUNDARY LAYER OF A CYLINDER ROTATING IN AN AIR CURRENT.

As yet, there is no satisfactory theory giving the lift experienced by a rotating cylinder in an air stream. There seems, however, to be general agreement that the circulation is affected largely by the eddies generated on the surface. It was accordingly decided to explore the surface layer. The cylinder used was of brass, $4\frac{1}{2}$ ins. diameter. The channel speed throughout was kept at about 8 ft. per sec. and the rotational speed at 820 r.p.m., giving a ratio

$$(\text{Surface Speed})/(\text{Wind Speed}) = 2$$

The low rotational speed was adopted to avoid vibration troubles. To obtain uniformity with previous experiments, the above ratio was chosen, and this fixed the channel speed.

The method adopted was to measure the total head and the static pressure separately, i.e. at different times. The pitot tube was of glass $0{\cdot}45 \times 0{\cdot}36$ mm. external measurements at the end. The total head was compared with the pressure in a hole in the channel wall some distance upwind. The pressure in this hole was afterwards compared with the pressure on the front generator of the cylinder (when stationary) and the total heads recorded in Table 4 and plotted in Figs. 7, 8 and 9 are referred to this front generator pressure H_0. The same remarks apply to the static pressure, so that the recorded pressure would be zero at a point of zero velocity if there were no loss of head.

The apparatus used was identical with that employed for the investigation of the boundary layer on a stationary cylinder described in Part 2. A correction (Δ H) to the observed total head has been applied to allow for the fact that at low speeds a small pitot reads high. The amount of this correction (*see* Table 4) may not be reliable, but errors from this source can hardly affect the general results.

Measurements of total head and static pressure were made along lines normal to the surface at $\theta = 0°$, 20°, 40°, 60°, 80°, 90°, 100°, 120°, 160°, 200°, 240°, 280° and 320° where θ is measured from the up-wind direction. On the sections at $\theta = 240°$, 280° and 320° at a short distance from the surface, the velocity changes sign being no longer in the same direction as the velocity of the cylinder surface. This necessitated exploring these sections with the pitot tube in both directions. The results for the tube facing the reverse velocity are given in Table 6 and will be found plotted with the others in Figs. 7, 8 and 9. At the point on the sections where the two directions give the same pressure, the static pressure should also have an identical value, unless the reversal of the tube causes a change in the flow. The agreement is as good as can be expected at $\theta = 280°$, and $\theta = 320°$, while at $\theta = 240°$ exploration with the tube in its normal position has not been carried far enough.

With the above exception, no attempt has been made to make the tube face the air direction beyond placing it parallel with the tangent to the surface and this should be kept in mind when examining the curves of velocity obtained.

A preliminary estimate of the velocity having been made at each point on every section, the corrections to the total head were obtained and applied (*see* Table 4). The corrected values are shown in Figs. 7, 8 and 9, along with the static pressure. The finally adopted velocities are given in Table 7, and are shown plotted in Fig. 10. It is seen that in most cases the velocity tends to approach the circumferential velocity of the cylinder as the surface is approached. Fig. 11 shows contours of constant velocity throughout the region explored, the figure being distorted by enlarging the boundary layer in order to show the latter more clearly. In a previous paper* the writer showed contours of velocity round a rotating cylinder at the same ratio of circumferential speed to wind speed, namely, 2, but in that case the apparatus used could not be brought nearer the surface than about 0·7 radius. Fig. 12 has been constructed by combining the results of the two experiments. There is still an annular region not covered by either experiment. The contours have been dotted through this region. A few isolated readings indicated that these dotted contours are approximately correct, but further experiment is required to complete this region.

The velocity curves in Fig. 10 were integrated and the integral curves used to plot the streamlines shown in Fig. 13.

From the fundamental equations of steady flow we have

$$\begin{aligned} 2\,\varrho\,u\,\zeta &= -\frac{\partial}{\partial y}\left(p + \frac{1}{2}\varrho\,v^2 + \frac{1}{2}\varrho\,u^2\right) + 2\mu\frac{\partial\zeta}{\partial x} \\ &= -\frac{\partial \mathrm{H}}{\partial y} + 2\,\mu\frac{\partial\zeta}{\partial x} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (5) \end{aligned}$$

In the present experiment, taking x along the surface and taking the normal value of μ for air, $2\,\mu\,\partial\,\zeta/\partial x$ was found to be negligible compared to $\partial \mathrm{H}/\partial y$ so that if the flow close to the surface can be represented by (5) the vorticity is given by

$$-\frac{1}{2\,\varrho u}\;\frac{\partial\,\mathrm{H}}{\partial y}.$$

* loc. cit.

The numerical results obtained by this expression are given in Table 8, and shown as contours in Fig. 14, the sign adopted being shown on the latter diagram. In Part 2, it appears that for a cylinder rotating in still air, the effective coefficient of viscosity increases rapidly with the distance from the surface, so that it is possible that in the present case the last term in (5) may become appreciable. For this reason, the results obtained for the vorticity are not above suspicion.

It is interesting to compare the static pressure close to the surface as obtained by the small static tube with that obtained by a different method in R. & M. 1082.* This comparison is shown in Fig. 15. Unfortunately, different cylinder diameters were used in the two experiments. The influence of the channel walls will, of course, depend on the cylinder diameter, and possibly explains the differences between the two curves.

The writer has elsewhere shown that the circulation round a contour enclosing a rotating cylinder some distance from the surface corresponds with the observed lift. Fig. 16 shows how in the present experiment the circulation decreases rapidly in the first millimeter from the surface and thereafter more slowly as it approaches the value corresponding to the lift.

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* R. & M. 1082.—The pressures round a cylinder rotating in an air current.

TABLE 1.

Velocities near a Cylinder rotating in still air as determined by Pitot and Static Tubes.

Diameter of Cylinder = 114 mm. R = 57 mm.

Distance from surface n mm.	100 n/R %	q/v = Speed at Pitot / Surface Speed. 410 r.p.m.	820 r.p.m.	1,230 r.p.m	2,060 r.p.m
0·44	0·76	0·80	0·72	0·67	
0·70	1·22	0·58	0·51	0·51	
0·97	1·7	0·48	0·41	0·40	
1·20	2·1	0·44	0·40	0·38	
1·82	3·2	0·38	0·33	0·31	
2·46	4·3		0·31	0·28	
3·70	6·5		0·26	0·25	
4·80	8·5		0·26	0·21	0·20
7·40	12·9	0·28	0·19	0·17	0·16
9·90	17·3		0·20		0·14
20·00	35·0		0·18		0·10
28·00	50·0		0·15		0·08

TABLE 2.

Total Head near a Cylinder rotating in Still Air at 820 *r.p.m.*

n = Distance of Tube from Surface (mm.).

H = Total Head (lbs. per sq. ft.).

n	H	n	H
0·18	0·191	1·12	0·040
0·28	0·160	1·50	0·029
0·32	0·118	2·30	0·019
0·38	0·106	3·47	0·012
0·48	0·073	6·15	0·010
0·54	0·064	7·80	0·007
0·66	0·058		
0·93	0·043		

TABLE 3.

Details of Calculation of Static Pressure and Velocity near Cylinder from the Observations of Total Head.

n (mm.)	5–4.	4–3.	3–2.	2–1·5.	1·5–1.	1–0·7.	0·7–0·4.	0·4–0·2.	0·2–0·1.	0·1–0.
r_1 ft. ..	0·20410	0·20085	0·19760	0·19485	0·19272	0·19109	0·19010	0·18911	0·18844	0·18810
δr ft. ..	0·00325	0·00325	0·00325	0·00163	0·00163	0·00099	0·00099	0·00066	0·00033	0·00033
q_1 ft./sec. ..	3·99	4·16	4·43	5·12	5·77	6·65	7·58	9·35	13·0	14·93
p_1 lbs./sq.ft.	—0·0089	—0·0095	—0·0102	—0·0111	—0·0117	—0·0125	—0·0132	—0·0139	—0·015	—0·015
H_2 lbs./sq.ft.	0·011	0·013	0·020	0·028	0·040	0·055	0·090	0·185	0·250?	
q_2 ft./sec. ..	4·16	4·43	5·12	5·77	6·65	7·58	9·35	12·96	14·93	16·3
p_2 lbs./sq.ft.	—0·0095	—0·0102	—0·0111	—0·0117	—0·0125	—0·0132	—0·0139	—0·015	—0·015	—0·016

TABLE 4.

Measurements of Total Head.

n = Distance from Surface to centre of tube.
H = Total Head at small pitot.
H_0 = Total Head in free stream.
ΔH = Correction for small pitot.

θ = 0°				θ = 20°			
n mm.	Observed $H-H_0$ lb./sq. ft.	ΔH	$H-H_0$ lb. per sq. ft.	n	Observed $H-H_0$	ΔH	$H-H_0$
0·18	+0·166	0·006	0·160	0·18	0·127	0·002	0·125
0·32	0·100	0·009	0·091	0·32	0·089	0·003	0·086
0·46	0·065	0·009	0·056	0·46	0·066	0·005	0·061
0·60	0·046	0·009	0·037	0·60	0·047	0·005	0·042
0·75	0·033	0·009	0·046	0·75	0·031	0·006	0·025
1·17	0·014	0·009	0·005	0·89	0·019	0·007	0·012
1·6	0·008	0·008	0·000	1·17	0·015	0·008	+0·007
2·3	0·002	0·001	0·001	1·6	0·004	0·009	—0·005
3·0	0·001	0·000	0·001	2·3	0·006	0·009	—0·003
4·4	0·001	0·000	0·001	3·0	0·001	0·009	—0·008
5·8	0·001	0·000	0·001	4·4	0·003	0·009	—0·006
θ = 40°				**θ = 60°**			
n	Observed $H-H_0$	ΔH	$H-H_0$	n	Observed $H-H_0$	ΔH	$H-H_0$
0·18	0·052	0·001	0·051	0·18	—0·053	0	—0·053
0·28	0·049	0·001	0·048	0·28	—0·028	0	—0·028
0·38	0·044	0·001	0·043	0·38	+0·003	0	+0·003
0·59	0·029	0·001	0·028	0·59	0·022	0	0·022
0·79	0·016	0·001	0·015	0·79	0·022	0	0·022
0·99	0·017	0·001	0·016	0·99	0·023	0	0·023
1·40	0·007	0·001	0·006	1·40	0·019	0	0·019
1·8	0·007	0·001	0·006	2·2	0·015	0	0·015
2·2	0·011	0·001	+0·010	3·2	0·008	0	0·008
4·1	0·000	0·001	—0·001	4·3	0·006	0	0·006
6·3	0·005	0·002	+0·003	6·3	0·006	0	0·006
θ = 80°				**θ = 90°**			
0·18	—0·141	0	—0·141	0·18	—0·100	0·001	—0·101
0·28	—0·087	0	—0·087	0·28	—0·083	0	—0·083
0·38	—0·052	0	—0·052	0·38	—0·055	0	—0·055
0·59	—0·012	0	—0·012	0·59	—0·025	0	—0·025
0·79	+0·002	0	+0·002	0·79	—0·005	0	—0·005
1·20	0·009	0	0·009	1·00	—0·002	0	—0·002
2·2	0·005	0	0·005	1·4	+0·001	0	+0·001
4·3	0·004	0	0·004	1·8	+0·003	0	+0·003
6·3	0·005	0	0·005	2·2	—0·001	0	—0·001
				4·3	—0·003	0	—0·003

TABLE 4—*continued.*

$\theta = 100°$				$\theta = 120°$			
n mm.	Observed $H - H_0$	$\triangle H$	$H - H_0$ lb. per sq. ft.	*n* mm.	Observed $H - H_0$	$\triangle H$	$H - H_0$
0·18	—0·088	0·001	—0·089	0·18	—0·097	0·010	—0·107
0·28	—0·083	0·001	—0·084	0·20	—0·088	0·010	—0·098
0·38	—0·082	0·001	—0·083	0·28	—0·085	0·010	—0·095
0·59	—0·052	0	—0·032	0·48	—0·080	0·010	—0·090
0·79	—0·012	0	—0·012	0·56	—0·060	0·009	—0·069
1·20	0·000	0	0·000	0·93	—0·035	0·006	—0·041
1·6	+0·003	0	+0·003	1·47	—0·017	0·005	—0·022
2·0	+0·003	0	+0·003	2·4	—0·017	0·001	—0·018
2·4	+0·001	0	+0·001	4·2	—0·020	0	—0·020
3·0	—0·001	0	—0·001	6·0	—0·021	0	—0·021
$\theta = 160°$				$\theta = 200°$			
n	Observed $H - H_0$	$\triangle H$	$H - H_0$	*n*	Observed $H - H_0$	$\triangle H$	$H - H_0$
0·18	+0·076	0·008	+0·068	0·18	+0·138	0·004	+0·134
0·27	+0·025	0·010	+0·015	0·25	+0·102	0·006	0·096
0·36	—0·015	0·009	—0·024	0·32	+0·082	0·009	0·073
0·54	—0·051	0·009	—0·060	0·46	+0·027	0·010	+0·017
0·73	—0·064	0·009	—0·073	0·60	—0·009	0·010	—0·019
1·09	—0·067	0·008	—0·075	0·82	—0·031	0·003	—0·039
1·99	—0·052	0·009	—0·061	1·6	—0·067	0·002	—0·069
3·8	—0·009	0·010	—0·019	3·0	—0·074	0·002	—0·076
5·6	+0·003	0·010	—0·007	4·4	—0·074	0·002	—0·076
7·4	+0·004	0·010	—0·006	5·8	—0·076	0·002	—0·078
$\theta = 240°$				$\theta = 280°$			
0·18	+0·096	0·007	+0·089	0·18	+0·095	0·009	+0·086
0·31	+0·058	0·010	+0·048	0·31	+0·049	0·010	+0·039
0·43	+0·032	0·010	+0·022	0·43	+0·025	0·009	+0·016
0·56	+0·011	0·010	+0·001	0·56	+0·019	0·009	+0·010
0·68	—0·011	0·009	—0·020	0·81	—0·028	0·008	—0·020
0·94	—0·033	0·008	—0·041	1·19	—0·042	0·005	—0·047
1·32	—0·041	0·007	—0·048	1·44	—0·053	0·004	—0·057
1·94	—0·053	0·006	—0·059	1·82	—0·051	0·004	—0·055
				2·4	—0·049	0·003	—0·052
				3·1	—0·054	0·002	—0·056
$\theta = 320°$							
0·18	0·172	0·007	0·165				
0·32	0·114	0·010	0·104				
0·43	0·059	0·009	0·050				
0·56	0·026	0·008	0·018				
0·68	+0·008	0·005	+0·003				
0·94	—0·009	0	—0·009				
1·32	—0·012	0	—0·012				
2·6	—0·015	0	—0·015				

TABLE 5.

Observations of Static Pressure near a Rotating Cylinder in an air stream.

$V = 8$ ft. per sec. Surface velocity $= v = 16$ ft. per sec.

θ	n mm.	Static Pressure $p - H_0$ lb. sq. ft.
0°	0·47	—0·036
	2·4	—0·037
	4·2	—0·036
	6·0	—0·033
20°	0·47	—0·145
	3·3	—0·128
	6·1	—0·115
40°	0·47	—0·295
	1·40	—0·289
	4·2	—0·267
	7·9	—0·236
60°	0·47	—0·436
	1·40	—0·424
	4·2	—0·397
	7·9	—0·357
80°	0·47	—0·483
	1·40	—0·449
	2·4	—0·477
	3·3	—0·494
	5·1	—0·474
	7·0	—0·455
90°	0·47	—0·405
	1·40	—0·375
	2·4	—0·404
	3·3	—0·468
	4·2	—0·502
	5·1	—0·483
	6·0	—0·474
	7·9	—0·456
100°	0·47	—0·383
	1·40	—0·339
	2·4	—0·396
	3·3	—0·430
	4·2	—0·481
	5·1	—0·487
	7·9	—0·453

θ	n mm.	Static Pressure $p - H_0$ lb./sq. ft.
120°	0·47	—0·204
	1·40	—0·219
	2·4	—0·263
	3·3	—0·341
	4·2	—0·395
	5·1	—0·420
	7·5	—0·390
160°	0·47	—0·101
	1·40	—0·119
	4·2	—0·128
	7·9	—0·132
200°	0·47	—0·080
	1·40	—0·075
	4·2	—0·073
	7·9	—0·077
240°	0·47	—0·081
	0·75	—0·080
	1·17	—0·079
	1·88	—0·081
	3·3	—0·078
	4·7	—0·080
	7·5	—0·079
280°	0·47	—0·053
	1·17	—0·057
	4·7	—0·057
	8·9	—0·054
320°	0·47	—0·004
	3·3	—0·006
	7·5	—0·008

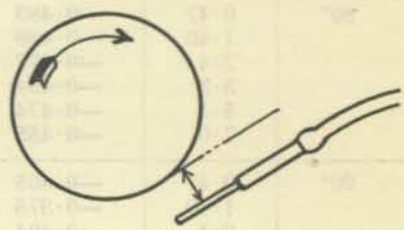
TABLE 6.

Total Head.

Tube Reversed.

$\theta = 240°$				$\theta = 280°$			
n mm.	Observed $H - H_0$	$\triangle H$	$H - H_0$ lb. per sq. ft.	n	Observed $H - H_0$	$\triangle H$	$H - H_0$
0·39	—0·087	0	—0·087	0·46	—0·064	0	—0·064
1·17	—0·084	0	—0·084	0·75	—0·065	0	—0·065
1·6	—0·085	0	—0·085	1·6	—0·064	0	—0·064
2·3	—0·078	0	—0·078	3·0	—0·061	0	—0·061
3·0	—0·082	0	—0·082	4·4	—0·062	0	—0·062
4·4	—0·076	0·000	—0·076	5·8	—0·041	0·000	—0·041
5·8	—0·075	0·002	—0·077	7·4	—0·019	0·001	—0·019
7·4	—0·076	0·002	—0·078	10·1	—0·005	0·003	—0·005

$\theta = 320°$			
0·39	—0·009	0	—0·009
0·89	—0·007	0	—0·007
1·17	—0·008	0	—0·008
1·6	+0·002	0·002	0·000
2·3	+0·001	0·004	—0·003
3·0	+0·008	0·004	+0·004
4·4	+0·004	0·004	0·000
5·8	+0·004	0·004	0·000
7·4	0·000	0·003	—0·003



Reversed Tube.

TABLE 7.

Velocity near Rotating Cylinder in an Air Stream.

n = distance from surface (mm.).
Velocities are given in ft. per sec.

θ \ n	0·2	0·5	1·0	2·0	3·0	4·0	6·0
0°	12·3	8·6	6·3	5·8	5·8	5·8	5·5
20°	14·9	13·0	11·6	10·7	10·3	10·1	9·6
40°	17·1	16·7	16·1	15·7	15·5	15·1	14·7
60°	18·1	19·5	19·4	19·1	18·8	18·3	17·9
80°	18·2	19·5	19·4	19·9	20·6	20·4	19·9
90°	16·9	17·6	17·6	18·1	19·4	20·4	19·9
100°	16·4	16·4	16·8	17·8	18·8	19·8	—
120°	9·6	10·8	11·9	13·8	15·9	17·6	18·1
160°	11·3	6·9	5·7	7·3	8·8	9·8	10·2
200°	13·1	8·6	4·7	2·0	1·8	1·3	+ 1·6
240°	11·5	8·9	5·6	4·1	—	—	—
280°	10·1	7·4	4·5	+ 1·7	+ 1·7	0	− 4·0
320°	11·6	5·1	0	− 2·0	− 2·2	− 2·5	− 2·5

TABLE 8.

Vorticity near Rotating Cylinder in an Air Stream.

As given by :— $\zeta = -\frac{\partial H}{\partial n} \quad 2\varrho q$

θ \ n	0·2	0·5	1·0	2·0	4·0	6·0
0°	−2500	−1300	−350	− 50	0	
20°	−1300	− 850	−180	− 20	0	
40°	− 60	− 260	− 60	− 20	− 5	0
60°	+1000	+ 250	− 10	− 20	− 4	0
80°	+1900	− 600	+ 50	− 10	0	0
90°	+ 650	+ 580	+ 35	− 4	− 13	
100°	+ 320	+ 970	+110	− 8	− 10	
120°	+ 350	+ 620	+320	0	− 7	− 7
160°	−2600	−1600	+ 60	+180	+150	0
200°	−1600	−1700	−800	−200	0	0
240°	−1400	−1200	−460	−200	—	—
280°	−1500	−1250	−800	− 55		
320°	−2500	−2500	−750	0	0	+70

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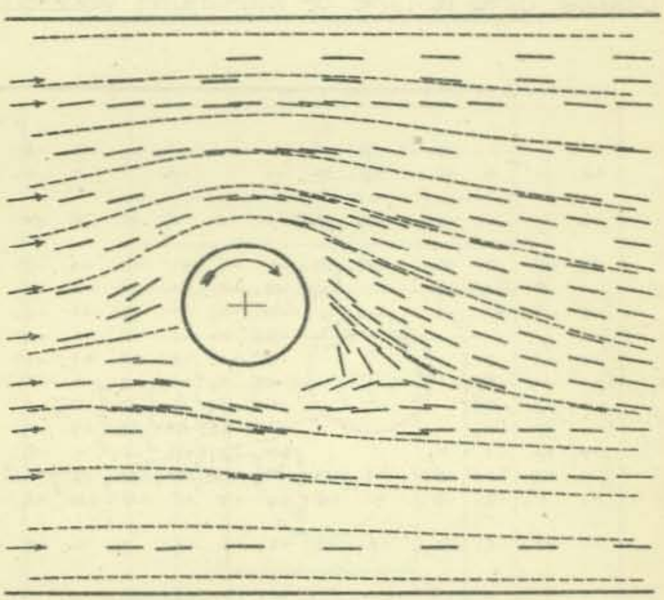
Fig. 1.

Experiments on Flow past a Rotating Cylinder.

Short Full Lines show the Observed Air Direction at their Mid-point.

Peripheral Speed ÷ Mean Tunnel Speed = 2



P.4483, 85/6003, 2/14, 775, 10/31.

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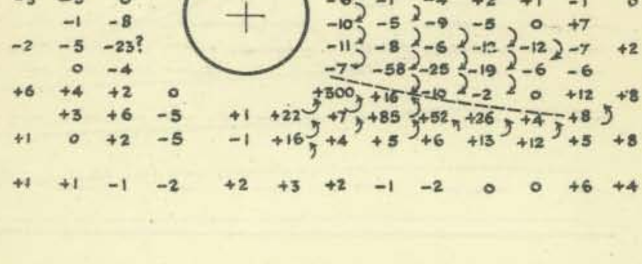
FIG. 2.

EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

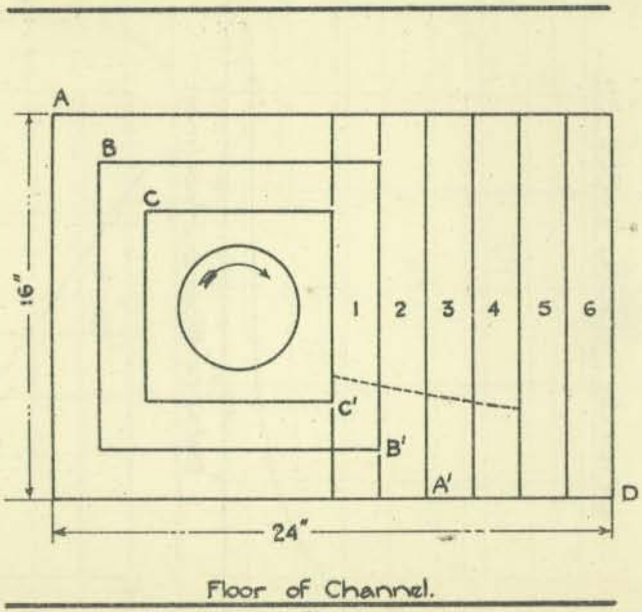
Values of the Vorticity $\delta v/\delta x - \delta u/\delta y$ deduced from the Observed Velocities.

Dotted Line is Line of Minimum Velocity.



Experiments on Flow past a Rotating Cylinder.

Circulations for Various Rectangles as deduced from the Observed Velocities.



Area	Circulation Ft²/sec.
Square CC'	− 19·0
" BB'	− 19·2
" AA'	− 19·9
Strip 1	− 0·2
" 2	+ 0·2
" 3	0
" 4	− 0·1
" 5	+ 0·1
" 6	− 0·4
Rectangle AD	− 19·5
Upper Part of Strip 1	+ 1·6
Lower " " " 1	− 1·8
Upper " " " 2	+ 1·3
Lower " " " 2	− 1·1
Upper " " " 3	+ 0·9
Lower " " " 3	− 0·9

The dotted line is line of minimum velocity.
The tabulated values of the circulation are uncertain to ± 0·2

FIG. 3.

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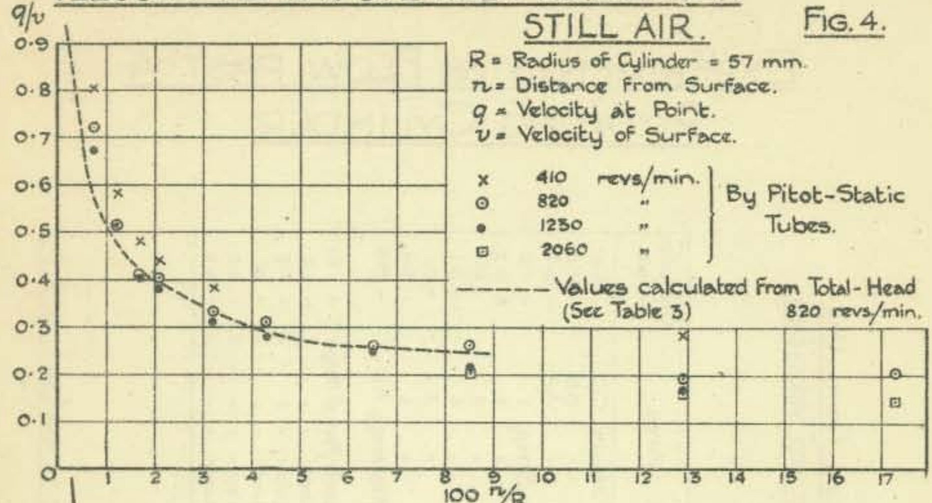
EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

FIGS. 4-6.

VELOCITY NEAR A CYLINDER ROTATING IN STILL AIR.

FIG. 4.



Observations of Total Head near a Cylinder rotating in Still Air.

FIG. 5.

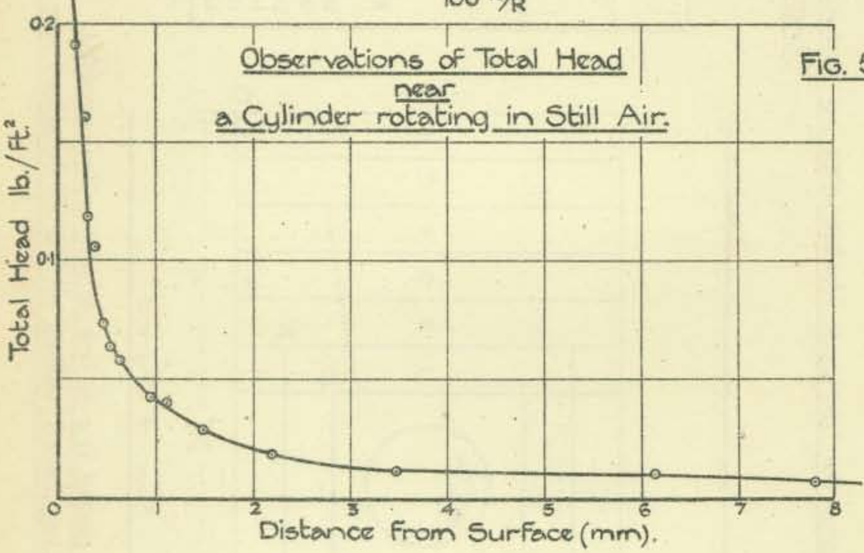
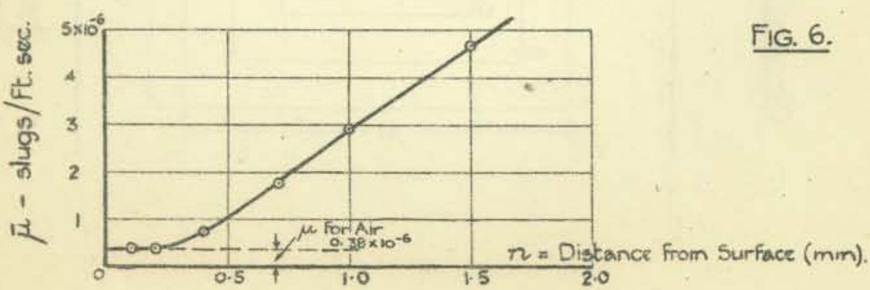


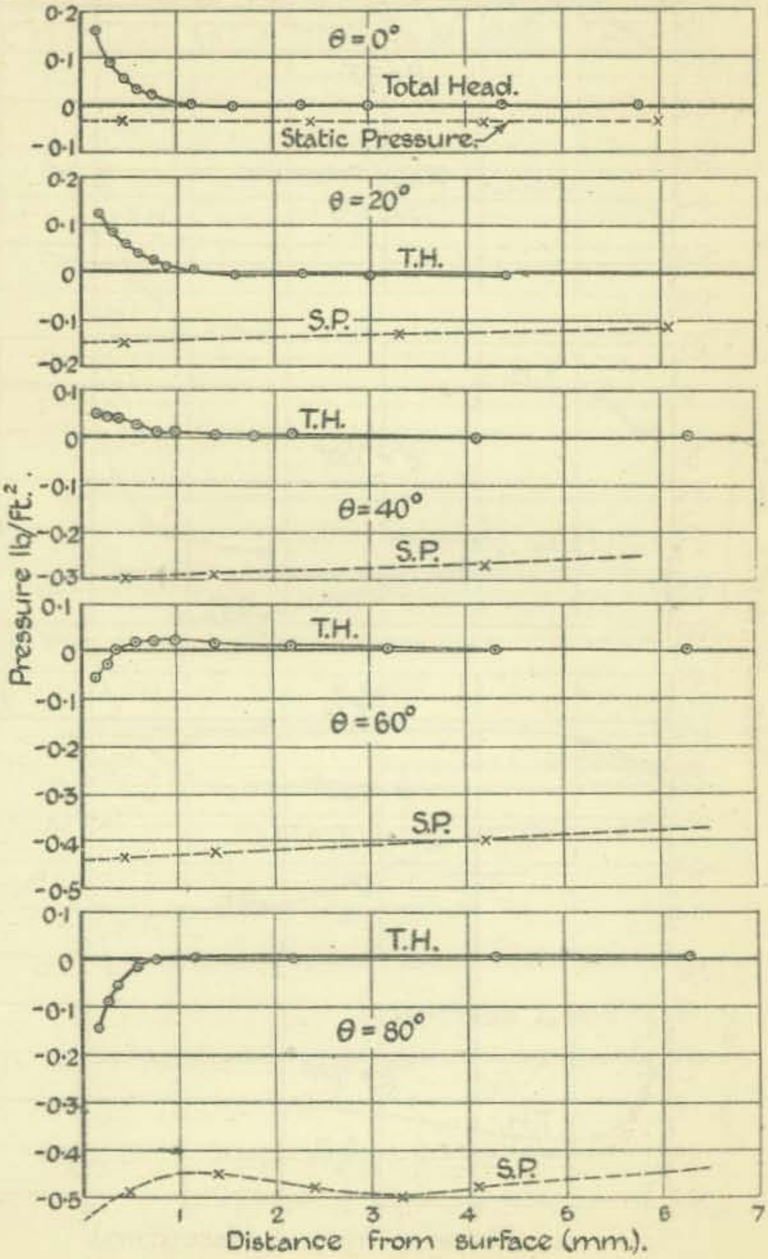
FIG. 6.



Experiments on Flow past a Rotating Cylinder.

Fig. 7.

Total Head and Static Pressure near a Cylinder Rotating in an Air Stream.



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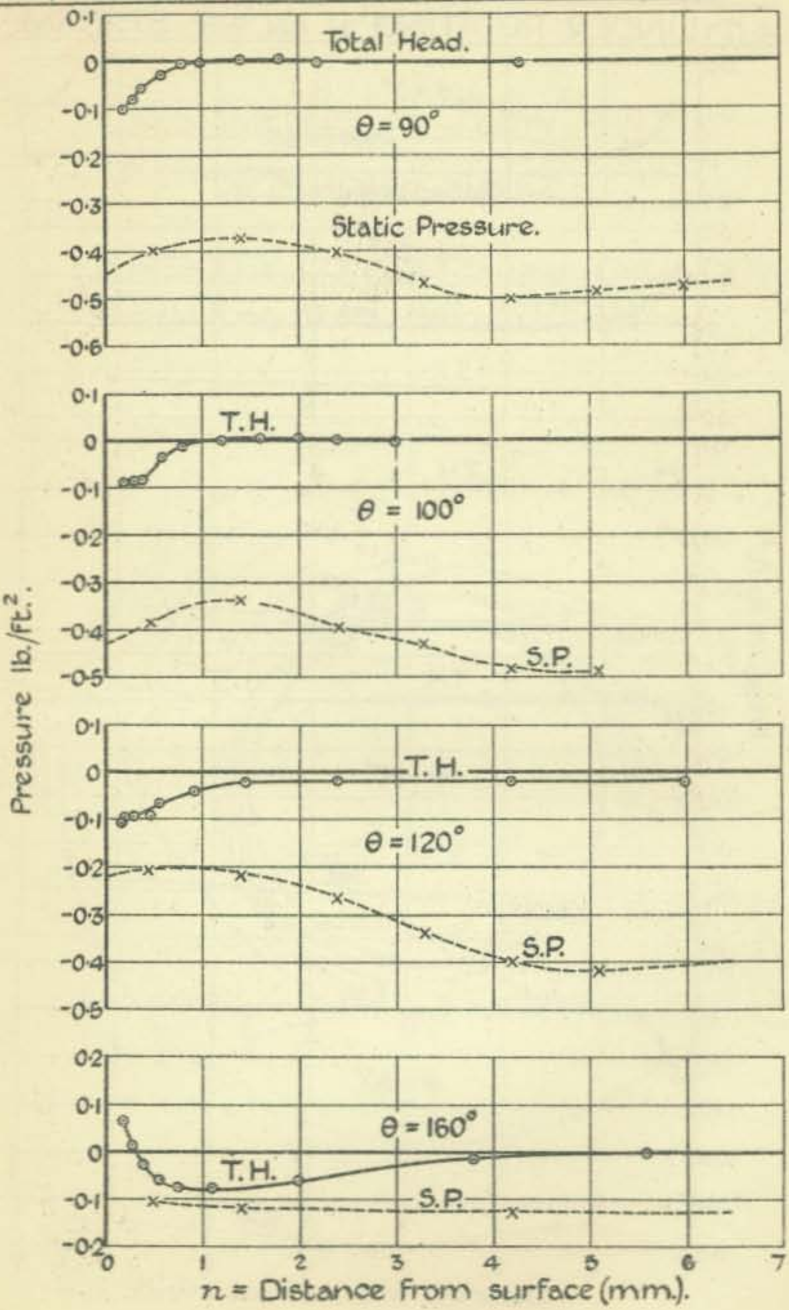
EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

FIG. 8.

TOTAL HEAD AND STATIC PRESSURE NEAR A CYLINDER ROTATING IN AN AIR STREAM.



EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

FIG. 9.

TOTAL HEAD AND STATIC PRESSURE NEAR A CYLINDER ROTATING IN AN AIR STREAM.

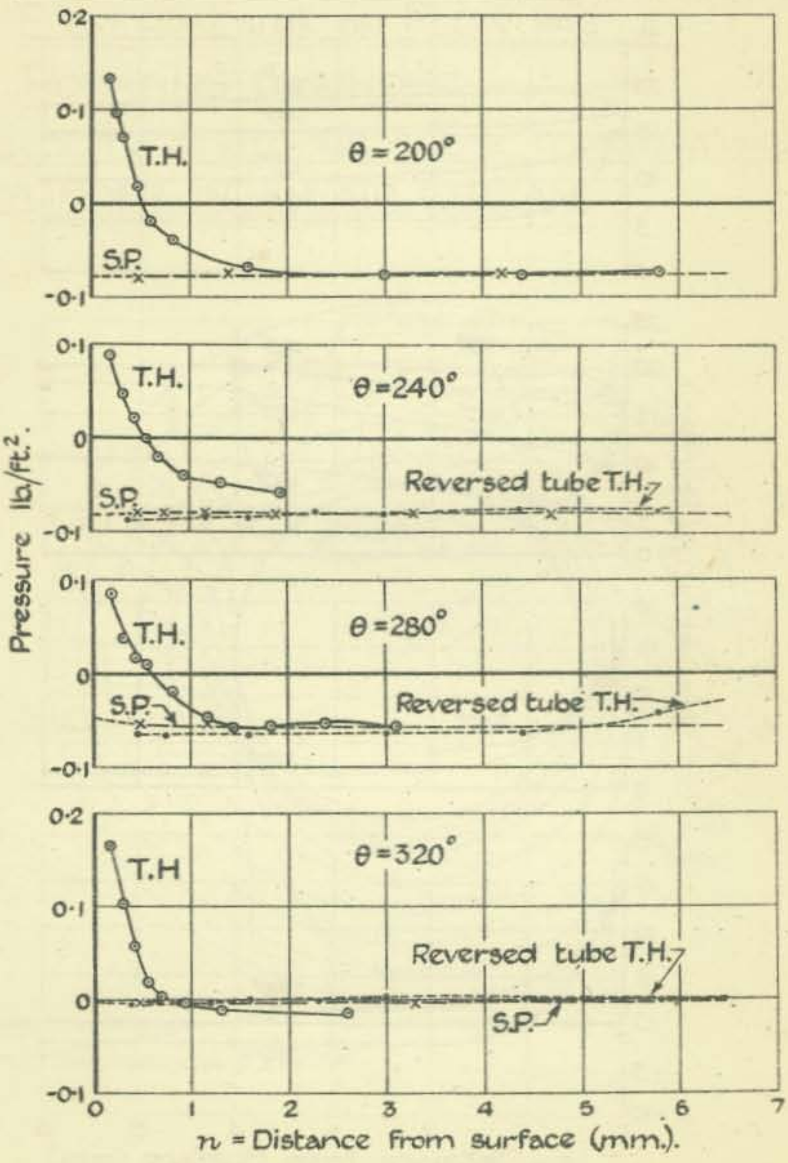


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FIG. 10.

Velocity near a Cylinder rotating in an Air Stream.

Tunnel Velocity = 8 Ft./sec. Cylinder Diam. = $4\frac{1}{2}$ in.
Surface Velocity = 16 Ft./sec. = 114 mm

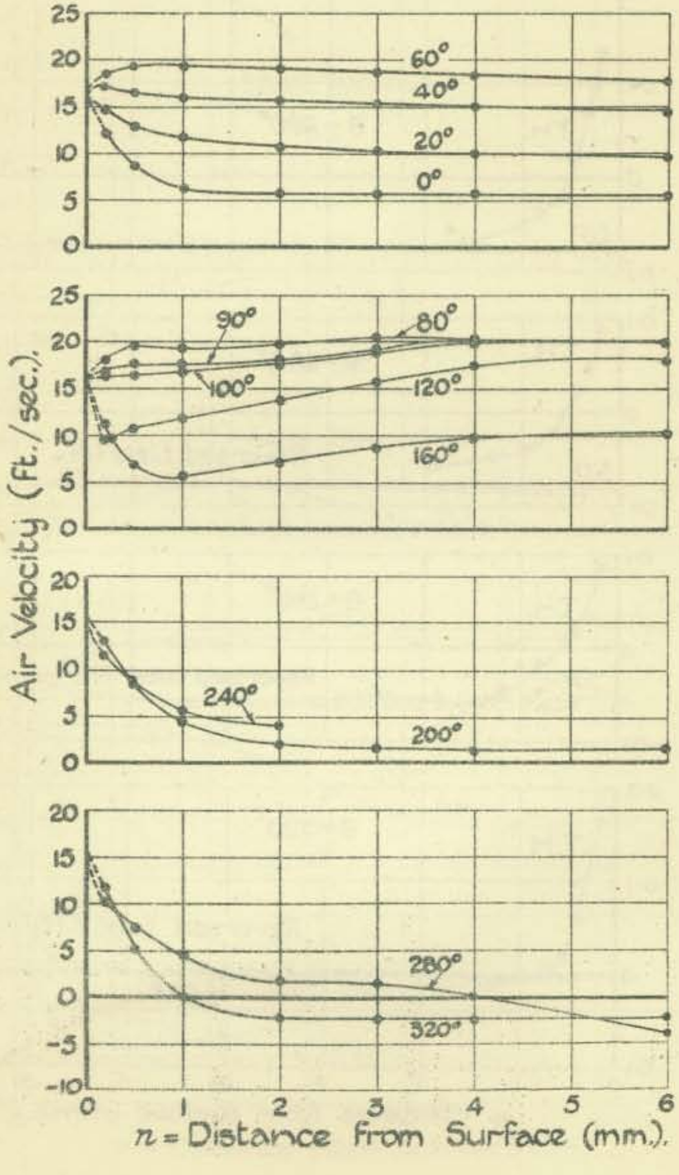

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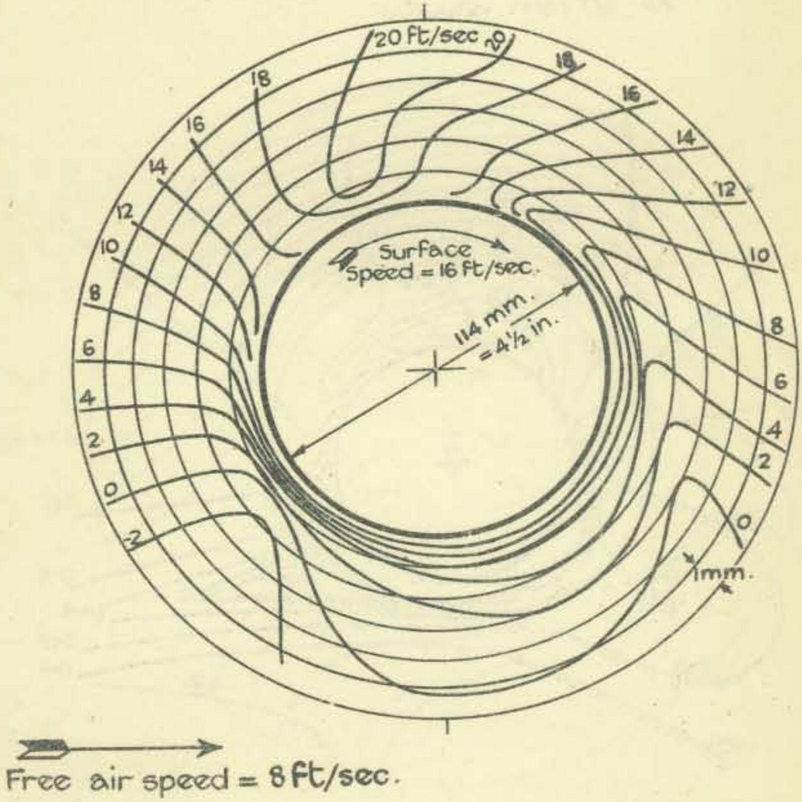
FIG.11.

EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

VELOCITY CONTOURS CLOSE TO ROTATING CYLINDER IN AN AIR STREAM.



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EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

FIG. 12.

SKETCH SHOWING DISTRIBUTION OF VELOCITY IN THE NEIGHBOURHOOD OF A CYLINDER ROTATING IN AN AIR STREAM.

$\frac{\text{Circumferential speed of cylinder.}}{\text{Air stream velocity.}} = 2$

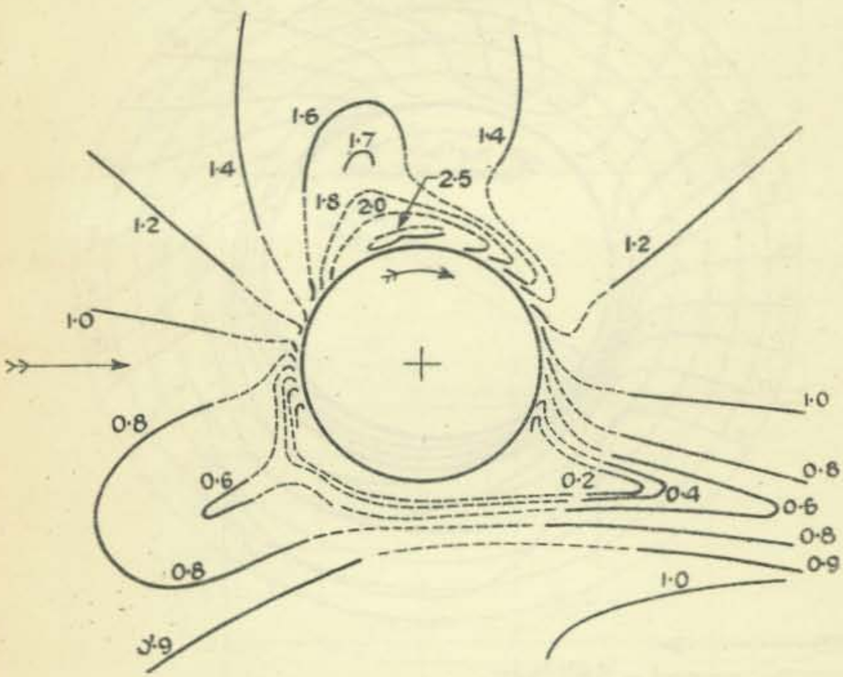

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FIG.13.

EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

APPROXIMATE STREAMLINES CLOSE TO CYLINDER ROTATING IN AN AIR STREAM.

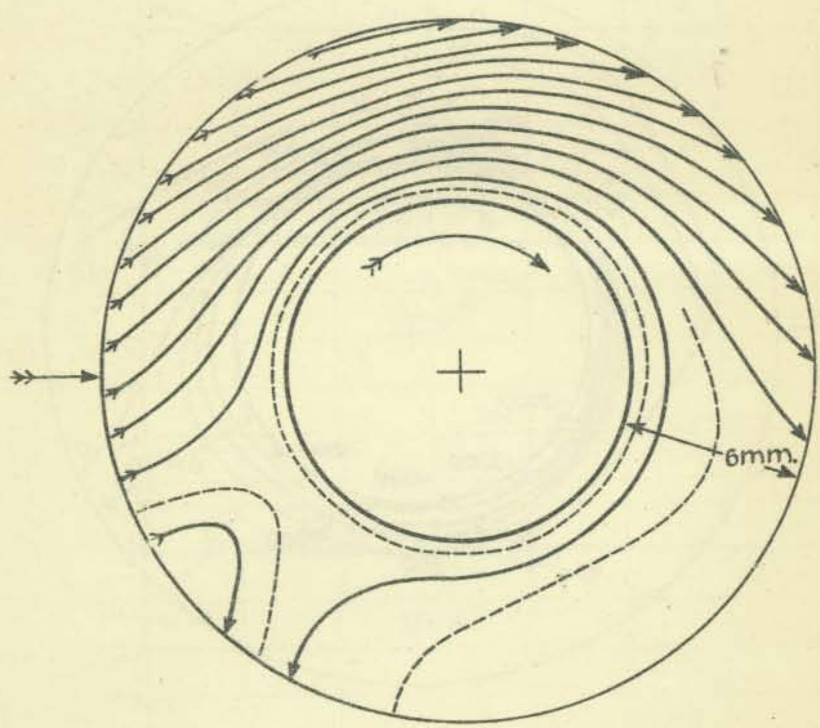

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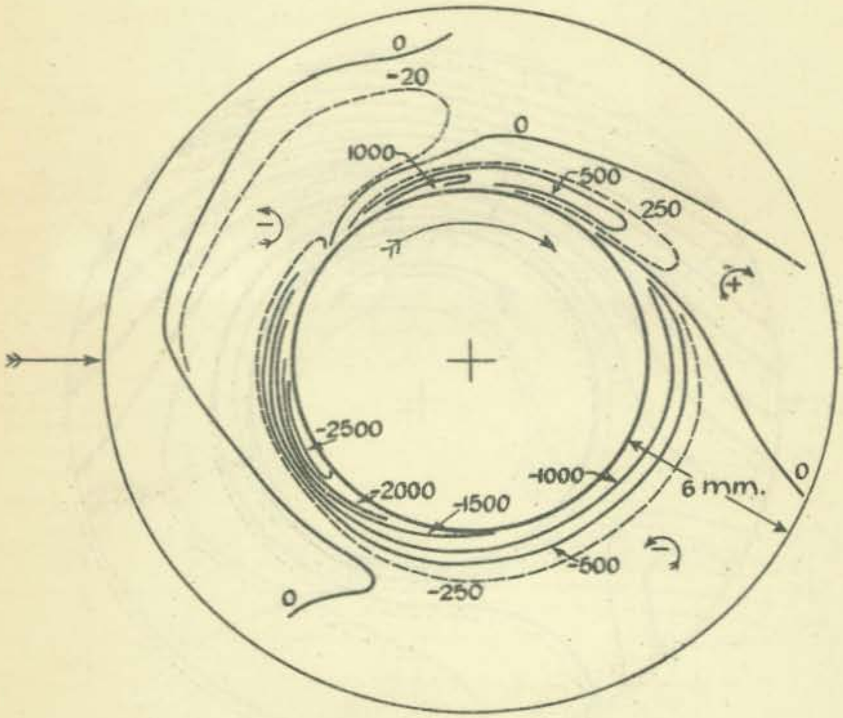
FIG. 14.

EXPERIMENTS ON FLOW PAST A ROTATING CYLINDER.

VORTICITY CONTOURS NEAR CYLINDER ROTATING IN AN AIR STREAM.



Experiments on Flow past a Rotating Cylinder.

Fig. 15.

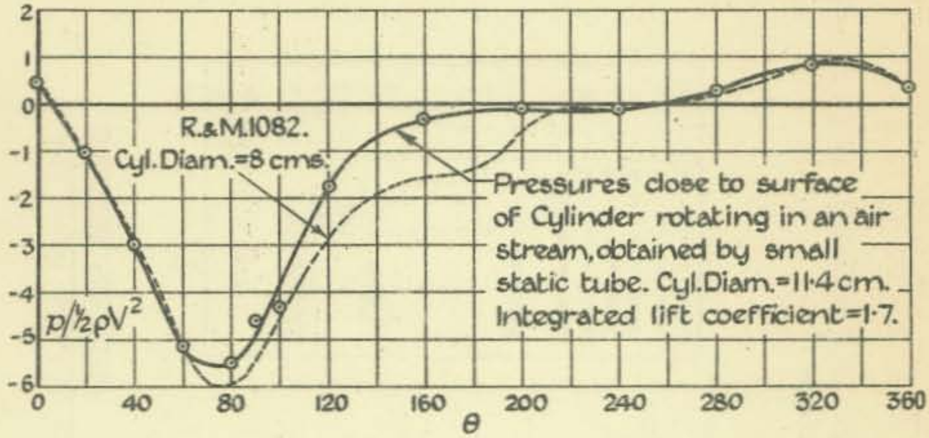


Fig. 16.

Circulation round Circles at Various Distances from Surface.