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NATIONAL BUREAU OF STANDARDS REPORT

6A234

AN INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF ROTATING CIRCULAR AND TRIANGULAR CYLINDERS

By R. H. Heald and L. M. Sargent

6.3 Bal 79

To
Army Chemical Center
Maryland
Project Number CP8-405-6468

NBS

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0603-20-3571	May 21, 1959	6A234

AN INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF ROTATING CIRCULAR AND TRIANGULAR CYLINDERS

By R. H. Heald and L. M. Sargent

Fluid Mechanics Section
Mechanics Division

6.3 Bal 79

To
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AN INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF ROTATING CIRCULAR AND TRIANGULAR CYLINDERS

By R. H. Heald and L. M. Sargent

1. INTRODUCTION

This investigation, conducted on request of representatives of the Chemical Warfare Laboratories, Army Chemical Center, Maryland, concerned the question of lift, drag, and spin magnitudes developed by rotating missiles having circular and triangular cross sections was investigated. The models used in the experiments were free to rotate on ball-bearing spindles, and were driven by air impingement on narrow blades extending lengthwise along their surfaces. ~~The models are shown in figure 1, and their principal dimensions are given in the headings of tables 1 - 4.~~ In the cases of the large cylindrical rotor and the ~~two~~ 2 triangular rotors, the lift and drag forces were sufficiently large to permit measurements on the flexure-plate balance as well as the NPL balance. The original bearing and spindle arrangement which supported each model was used in each set of measurements. All force measurements were made during steady rotation of the models.

The experiments were conducted in the National Bureau of Standards 6-foot wind tunnel at air speeds ranging between 53 and 275 feet per second. The corresponding range of Reynolds Numbers was from 0.4×10^5 to 3.3×10^5, where $RN = \frac{Vd}{\nu}$ and V = air speed, fps, d = basic diameter in the case of the circular shapes or face width in the case of the triangular shapes, feet, and ν = coefficient of kinematic viscosity for air at 15°C and 760 mm Hg = 0.0000157 ft^2/sec..

2. EXPERIMENTAL PROCEDURES

The measurements for the small cylinder were all made using the NPL-type of spindle aerodynamic balance which has maximum lift and drag force capacities of about 3 pounds each and is graduated to 0.001 pound. As previously indicated the forces acting on the other three models were measured on both the NPL balance and the high-capacity flexure-plate balance. On the latter, measurements can be obtained with an accuracy of about 0.2 pound.

Each of the models was supported by a 5/16-inch ball-bearing spindle attached endwise as shown in figure 1. Lift and drag measurements were made on each model at a number of air speeds during steady state rotation. The rotational speeds were determined by strobotac at the time the force measurements were made.

The acceleration time of the triangular models was determined at an air speed slightly above 70 miles per hour. For these measurements the model was held stationary from outside the wind tunnel while the air speed in the tunnel was adjusted to the desired steady value. When this was obtained the model was released and rotation began. The time required for the model to reach steady state rotation from rest was determined using a timer reading to 0.01 second.

3. RESULTS

The results of this investigation are given in tables 1 - 4 and the summary table 5 which is based on mean values. They are shown plotted in figures 2 - 5. The curves shown in the figures were faired through the plotted values of rotational speed, lift coefficient C_L, drag coefficient C_D, and the ratio $\frac{C_L}{C_D}$ given in the tables. For clarity individual points are not shown on the figures.

3.1 Rotational Characteristics

As shown in figure 2, the rotational speed of the small rotor varied linearly with air speed within experimental limits, the values ranging from 1690 rpm at a wind speed of 36.3 mph to 10750 rpm at 156.8 mph. For the test range the mean value of the ratio of rotational speed in rpm to wind speed in mph was 60.1 (table 5). The mean value of the ratio of tip speed in fps to air speed in fps for this rotor was 0.208.

The rotational speeds of the large cylindrical rotor and the two triangular rotors departed appreciably from a linear relationship with air speed in the higher speed regions, possibly as a result of model and shaft distortion with consequent increased bearing friction. The speed ratios for these rotors are also given in table 5. Acceleration times were 7.67 seconds at a wind speed of 71.1 mph for the triangular rotor equipped with 90° fins, and 4.57 seconds at 72.7 mph for the rotor with 120° fins.

3.2 Lift and Drag Characteristics

The results of the force measurements are given in tables 1 - 4 and are summarized in table 5. In general the data for the large cylinder and those for the two triangular shapes which were obtained using the two different balance systems are in fair agreement. As previously indicated, the flexure-plate balance is not well adapted to the measurement of small forces, i. e., those amounting to less than about 5 pounds. Although there is considerable range in the values of drag coefficient with Reynolds Number, the mean values of C_D for the two circular cylinders do not differ greatly in the range of Reynolds Numbers of the experiments, 0.4×10^5 to 1.6×10^5 for the small cylinder, and 0.7×10^5 to 3.3×10^5 for the large cylinder. For these ranges of Reynolds Numbers and including the data taken on both balances, the mean value of drag coefficient for the large cylinder is 1.031 as against a mean value of 1.040 for the small cylinder. Correspondingly, the mean values of the lift coefficient were 0.461 for the large cylinder and 0.610 for the small one. However, the values of lift coefficient for the small cylinder obtained on the spindle balance indicate the presence of substantial Reynolds Number effects, C_L ranging downward from 0.861 at R. N. = 0.405×10^5 to 0.45 at R.N. = 1.678×10^5. The measurements of lift of the large cylinder which were made on both balances indicate rather small scale effects in the lower range of Reynolds Numbers, i.e., between 0.7×10^5 and about 1.6×10^5. The data for the large cylinder, obtained using the flexure-plate balance, indicate an increase in C_L of about 25 percent between R.N. = 1.7×10^5 and 2.8×10^5. In the vicinity of the latter value of R.N. the indications are that C_L has reached a maximum and is tending to decrease at R.N. = 3.33×10^5. The variation of $\frac{C_L}{C_D}$ with Reynolds Number for both circular cylinders shows about the same pattern as C_L versus R.N., since C_D varies relatively slightly with R.N.

On the basis of mean values the triangular rotors show larger values of both lift and drag coefficient in the test range than do the cylindrical rotors. As shown in table 5, the mean value of C_L for the triangular rotor with 90° fins is 0.784, the individual values ranging from 0.624 to 0.859. The mean value of C_L for the triangular rotor equipped with 120° fins is 0.828, individual values ranging from 0.745 to 0.925. The mean values of

C_D for the 90° fin rotor is 1.392 compared with 1.577 for the rotor equipped with 120° fins. In the former case, individual values of C_L range from 1.348 to 1.471; in the latter case, the range is from 1.418 to 1.706. The mean value of $\frac{C_L}{C_D}$ for the triangular rotor equipped with 90° fins is 17 per cent greater than that for the rotor with 120° fins.

4. CONCLUSION

The lift and drag characteristics of the four rotors included in these experiments show considerable variation with Reynolds Number in the test range. The values of lift and drag coefficient and $\frac{C_L}{C_D}$ decrease continuously as the Reynolds Number is increased. On the other hand values of C_L, C_D, and $\frac{C_L}{C_D}$ for the large cylindrical rotor show less consistency with increased Reynolds Number. Referring to figure 3, C_L for this cylinder shows a decrease of the order of 10 per cent from about 0.48 between R.N. = 0.7×10^5 and 1.7×10^5, followed by an increase above the minimum value (of about 0.43) amounting to about 40 per cent at the maximum. Two points above R.N. = 2.8×10^5 indicate the rate of increase in this region to be lessening. The values of C_D for this rotor show considerably less variation with R.N. than the values of C_L. The range of C_D is of the order of 15 per cent, generally upward, and then downward as R.N. is increased from 0.7×10^5 to 3.3×10^5. The value of $C_D = 1.00$ at 3.3×10^5 is close to that at R.N. = 0.7×10^5. Variations in the values of $\frac{C_L}{C_D}$ with R.N. for this model follow somewhat the same pattern as of C_L.

The values of lift coefficient for the two triangular rotors, excluding three divergent points, and their means differ by only a few per cent. In both cases a downward trend in C_L is shown for values of R.N. above 1.8×10^5. The shapes of the C_D vs. R.N. curves differ quite appreciably, the values of C_D for the triangular rotor equipped with 120° fins averaging about 14 per cent greater than for the rotor with 90° fins.

For the Director,

G. B. Schubauer

G. B. Schubauer, Chief
Fluid Mechanics Section

Table 1
Cylindrical Rotor (Small)
$(C_4-D_1L_1H_3A_3B_1)$
Length 4.60 inches, Diameter 1.50 inches
Fin Angle 30 degrees, Fin Width 0.187 inches
Lift, Drag, and Rotational Speed

Air Speed fps	Air Speed mph	Lift lb	Drag lb	Rotation rpm	Coefficients Drag (C_D)	Coefficients Lift (C_L)	$\frac{C_L}{C_D}$	Reynold's Number	Tip Speed, fps / Air Speed, fps	Rotational Speed, rpm / Air Speed, mph
Spindle (NPL) Balance										
53.3	36.3	0.139	0.169	1690	1.046	0.861	0.822	0.405×10^5	0.208	46.6
72.9	49.7	.244	.322	2600	1.061	.804	.758	.553	.233	52.3
87.2	59.4	.327	.460	3250	1.062	.755	.711	.659	.244	54.7
100.8	68.7	.391	.606	3950	1.044	.674	.645	.757	.257	57.5
117.5	80.1	.509	.832	4550	1.055	.646	.612	.883	.254	56.8
133.2	90.8	.621	1.063	5550	1.04[illegible]	.613	.584	.999	.273	61.1
143.8	98.0	.684	1.233	6000	1.046	.580	.555	1.077	.273	61.2
166.8	113.7	.858	1.659	7150	1.045	.541	.517	1.250	.281	62.9
181.5	123.7	.913	1.938	7950	1.031	.486	.471	1.351	.289	64.3
192.9	131.5	.970	2.126	8700	1.001	.457	.456	1.420	.295	66.2
208.9	142.4	1.095	2.481	9750	.996	.448	.441	1.531	.306	68.5
230.0	156.8	1.359	3.144	10750	1.041	.450	.432	1.678	.306	68.5
				averages	1.040	0.610	0.584		0.268	60.1

$$C_L = \frac{L}{1/2\rho AV^2} \qquad C_D = \frac{D}{1/2\rho AV^2} \qquad 1/2\rho A = 0.0000571$$

Area computed on basis of basic diameter (1.50 inches)
Tip speed computed on basis of basic diameter (1.50 inches)
Reynold's Number computed on basis of basic diameter (1.50 inches)

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Table 2
Cylindrical Rotor (Large)
$(C_4\text{-}D_2L_2H_6A_3B_2)$

Length 7.62 inches, Diameter 2.50 inches
Fin Angle 30 degrees, Fin Width 0.230 inches
Lift, Drag, and Rotational Speed

Air Speed fps	Air Speed mph	Lift lb	Drag lb	Rotation rpm	Coefficients Drag(C_D)	Coefficients Lift(C_L)	$\frac{C_L}{C_D}$	Reynold's Number	$\frac{\text{Tip Speed, fps}}{\text{Air Speed, fps}}$	$\frac{\text{Rotational Speed, rpm}}{\text{Air Speed, mph}}$
					Spindle (NPL) Balance					
56.8	38.7	0.240	0.507	1650	1.002	0.474	0.473	0.718×10^5	0.317	42.6
80.3	54.7	.487	1.039	2410	1.030	.483	.469	1.012	.328	44.0
104.6	71.3	.763	1.710	3180	.996	.444	.446	1.318	.332	44.6
128.8	87.8	1.149	2.605	4010	1.001	.442	.441	1.619	.339	45.7
158.0	107.7	1.719	3.904	5100	.997	.439	.440	1.979	.352	47.3
182.2	124.2	2.635	5.169	6500	.970	.494	.510	2.275	.389	52.3
				averages	0.999	0.463	0.463		0.363	49.1

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Table 2 (continued)

Air Speed fps	Air Speed mph	Lift lb	Drag lb	Rotation rpm	Coefficients Drag (C_D)	Coefficients Lift (C_L)	$\frac{C_L}{C_D}$	Reynold's Number	$\frac{\text{Tip Speed, fps}}{\text{Air Speed, fps}}$	$\frac{\text{Rotational Speed, rpm}}{\text{Air Speed, mph}}$
Flexure Plate Balance										
59.6	40.6	-	0.6	1820	1.020	-	-	0.750×10^5	0.332	44.8
80.3	54.7	0.5	1.1	2560	1.090	.496	0.455	1.009	.347	46.8
106.4	72.5	.8	2.0	3520	1.129	.451	.400	1.336	.361	48.5
134.2	91.5	1.2	3.2	4650	1.132	.425	.375	1.681	.378	50.8
157.1	107.1	1.9	4.2	5600	1.085	.491	.452	1.962	.388	52.3
182.1	124.1	2.4	5.5	6000	1.058	.462	.436	2.262	.359	43.3
208.2	141.9	3.8	6.9	6380	1.015	.559	.551	2.508	.334	44.9
234.1	159.6	5.1	8.[illegible]	7420	1.012	.593	.586	2.863	.346	46.5
274.5	187.1	6.8	11.8	7360	0.999	.576	.576	3.327	.292	39.6
				averages	1.060	0.459	0.479		0.350	46.9

$$C_L = \frac{L}{1/2\rho A V^2} \qquad C_D = \frac{D}{1/2\rho A V^2} \qquad 1/2\rho A = 0.0001569$$

Area computed on basis of basic diameter (2.50 inches)
Tip speed computed on basis of basic diameter (2.50 inches)
Reynold's Number computed on basis of basic diameter (2.50 inches)

Table 3
Triangular Rotor (90° Fins)
Length 10.00 inches, Width of Face 3.25 inches
Fin Angle 90 degrees, Fin Height 0.43 inches
Lift, Drag, and Rotational Speed

Air Speed fps	Air Speed mph	Lift lb	Drag lb	Rotation rpm	Coefficients Drag(C_D)	Coefficients Lift(C_L)	$\frac{C_L}{C_D}$	Reynold's Number	Tip Speed, fps / Air Speed, fps	Rotational Speed, rpm / Air Speed, mph
Spindle (NPL) Balance										
57.1	38.9	0.731	1.181	2190	1.348	0.835	0.619	0.904×10^5	0.629	56.3
72.8	49.6	1.199	1.959	2850	1.380	.624	.612	[illegible] 149	.641	57.4
				averages	1.364	0.730	0.616		0.635	56.9
Flexure Plate Balance										
55.2	37.6	-	1.2	2080	1.471	-	-	0.892	0.618	55.3
81.4	55.5	1.5	2.5	3150	1.404	0.843	0.600	1.313	.635	56.8
104.2	71.0	2.5	4.1	4050	1.408	.859	.610	1.680	.637	57.1
125.7	85.7	3.6	5.9	4800	1.390	.848	.610	2.022	.626	56.0
157.3	107.2	5.3	9.5	5350	1.431	.798	.558	2.522	.558	49.9
				averages	1.421	0.839	0.595		0.615	55.0

acceleration time - 7.67 sec at an air speed of 71.1 mph

$$C_L = \frac{L}{1/2\rho AV^2} \qquad C_D = \frac{D}{1/2\rho AV^2} \qquad 1/2\rho A = 0.0002687$$

Area computed on basis of one face (3.25 inches)
Tip speed computed on basis of circumference of circumscribed circle (radius equal 1.88 inches)
Reynold's Number computed on basis of one face (3.25 inches)

Table 4
Triangular Rotor (120° Fins)
Length 10.00 inches, Width of Face 3.25 inches
Fin Angle 120 degrees, Fin Height 0.43 inches
Lift, Drag, and Rotational Speed

Air Speed fps	Air Speed mph	Lift lb	Drag lb	Rotation rpm	Coefficients Drag(C_D)	Coefficients Lift(C_L)	$\frac{C_L}{C_D}$	Reynold's Number	$\frac{\text{Tip Speed, fps}}{\text{Air Speed, fps}}$	$\frac{\text{Rotational Speed, rpm}}{\text{Air Speed, mph}}$
					Spindle (NPL) Balance					
54.0	36.8	0.637	1.161	1760	1.418	0.813	0.549	0.856×10^5	0.535	47.8
72.9	49.7	1.321	2.431	2610	1.702	.925	.540	1.152	.453	52.5
97.9	66.7	2.134	3.911	3310	1.522	.830	.546	1.541	.555	49.6
				averages	1.547	0.856	0.545		0.514	50.0
					Flexure Plate Balance					
60.9	41.5	0.8	1.7	2030	1.706	0.803	0.471	0.984	0.547	48.9
83.6	57.0	1.4	3.0	2830	1.590	.745	.467	1.349	.555	49.6
107.2	73.1	2.6	4.9	3610	1.583	.842	.531	1.730	.552	49.4
132.8	90.5	4.0	5.4	4450	1.141*	.845	.741*	2.139	.550	49.2
161.5	110.1	5.6	11.0	5300	1.570	.799	.509	2.589	.538	48.1
181.6	123.8	6.8	14.1	5550	1.580	.767	.482	2.905	.501	44.8
				averages	1.606	0.800	0.492		0.541	48.3

Acceleration time - 4.57 sec at an air speed of 72.7 mph.
* Omitted from mean and range data in table 5.

$$C_L = \frac{L}{1/2\rho A V^2} \qquad C_D = \frac{D}{1/2\rho A V^2} \qquad 1/2\rho A = 0.0002687$$

Area computed on basis of one face (3.25 inches)
Tip Speed computed on basis of circumference of circumscribed circle, (radius equal 1.88 inches)
Reynold's Number computed on basis of one face (3.25 inches)

Table 5

Summary

Designation of Model	Air Speed Range fps	Air Speed Range mph	R. N. Range	C_L Range	C_L Mean	C_D Range	C_D Mean	$\frac{C_L}{C_D}$ Range	$\frac{C_L}{C_D}$ Mean	Speed Ratios: Rotational Speed, rpm to Air Speed, mph Range	Speed Ratios: Rotational Speed, rpm to Air Speed, mph Mean	Speed Ratios: Tip Speed, fps to Air Speed, fps Range	Speed Ratios: Tip Speed, fps to Air Speed, fps Mean
Small Cylindrical Rotor (See Table 1)	53.3 to 230.0	36.3 to 156.8	0.405×10^5 to 1.678×10^5	0.450 to 0.861	0.610	0.996 to 1.062	1.040	0.432 to 0.822	0.584	46.6 to 68.5	60.1	0.208 to 0.306	0.268
Large Cylindrical Rotor (See Table 2)	56.8 to 274.5	38.7 to 187.1	0.718×10^5 to 3.327×10^5	0.439 to 0.593	0.461	0.970 to 1.132	1.031	0.375 to 0.586	0.472	39.6 to 52.3	48.0	0.292 to 0.389	0.357
Triangular Rotor, Fin Angle 90°	57.1 to 157.3	38.9 to 107.2	0.904×10^5 to 2.522×10^5	0.624 to 0.859	0.784	1.348 to 1.471	1.392	0.558 to 0.619	0.606	49.9 to 57.4	55.9	0.558 to 0.641	0.625
Triangular Rotor, Fin Angle 120°	54.0 to 181.6	36.8 to 123.8	0.856×10^5 to 2.905×10^5	0.745 to 0.925	0.828	1.418 to 1.706	1.577	0.467 to 0.549	0.519	44.8 to 52.5	49.2	0.453 to 0.555	0.528

Note: The maximum and minimum values of C_L, C_D and $\frac{C_L}{C_D}$ given in the "Range" columns do not always correspond to the maximum and minimum values of Air Speed and R. N. See detailed data given in Tables 1 - 4. Mean values of C_L, C_D and $\frac{C_L}{C_D}$ and the speed ratios are based on data obtained on both the spindle balance and the flexure-plate balance.

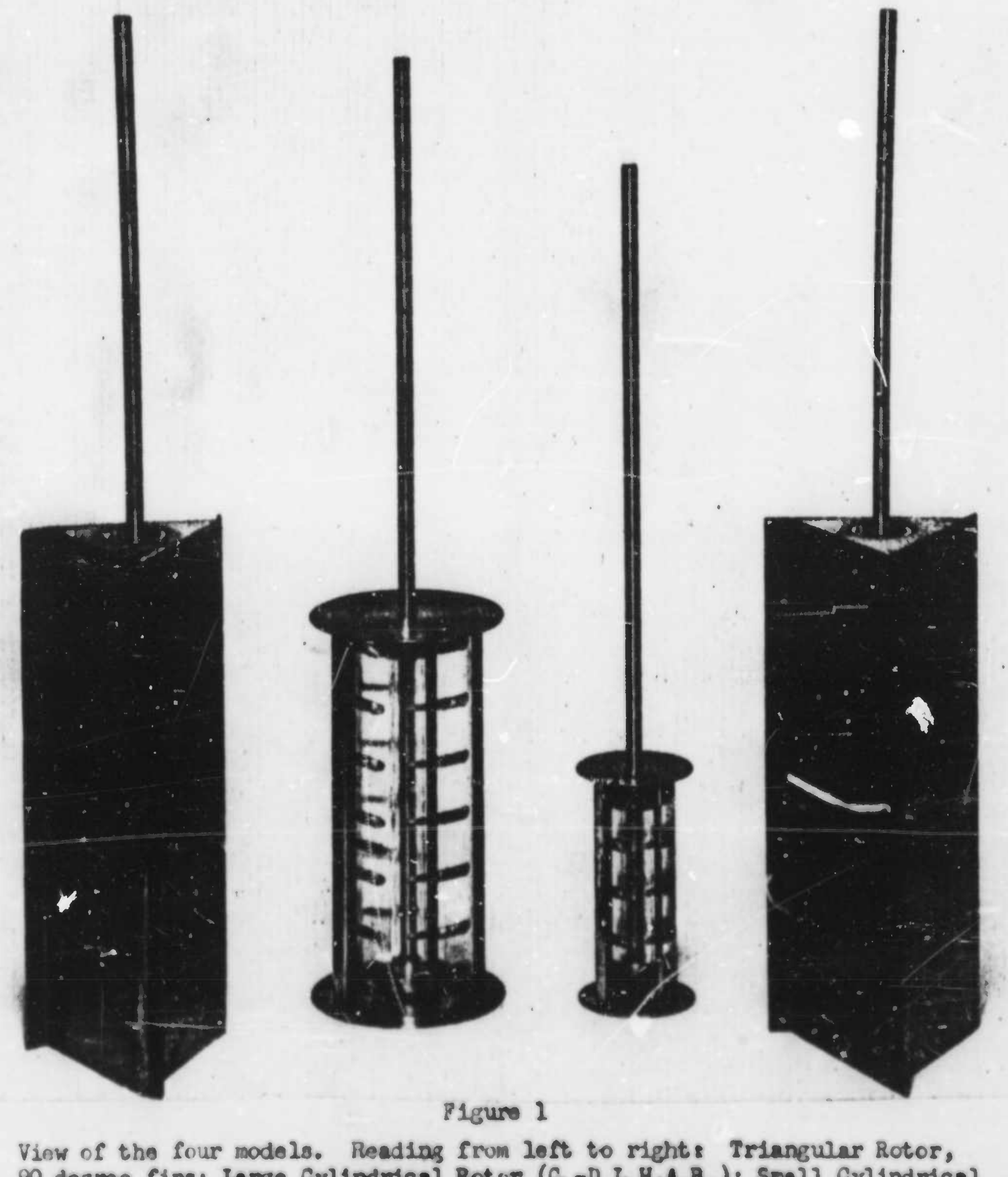

Figure 1

View of the four models. Reading from left to right: Triangular Rotor, 90 degree fins; Large Cylindrical Rotor (C_4-$D_2L_2H_6A_3B_2$); Small Cylindrical Rotor (C_4-$D_1L_1H_3A_3B_1$); Triangular Rotor, 120 degree fins.

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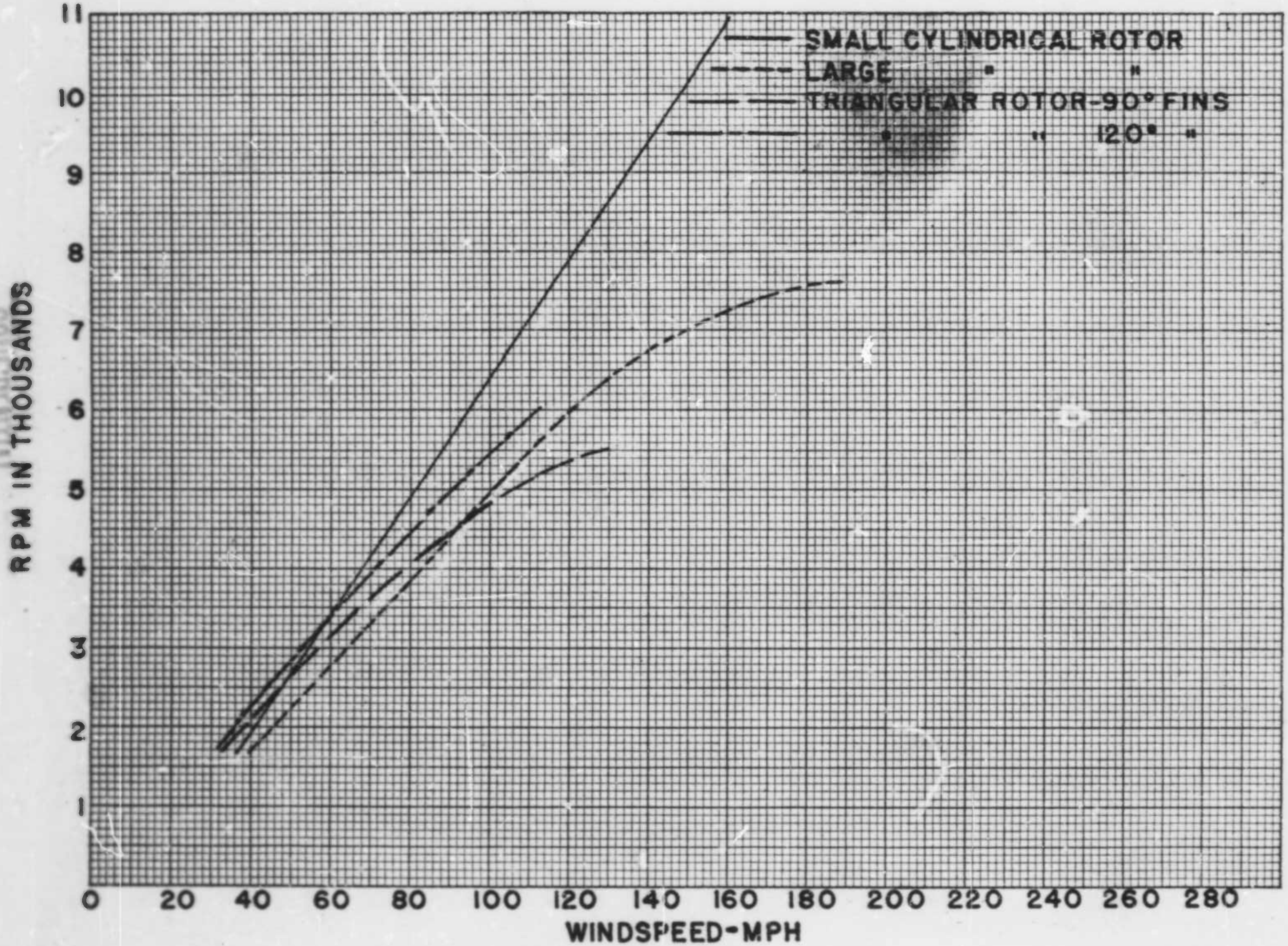

FIGURE 2

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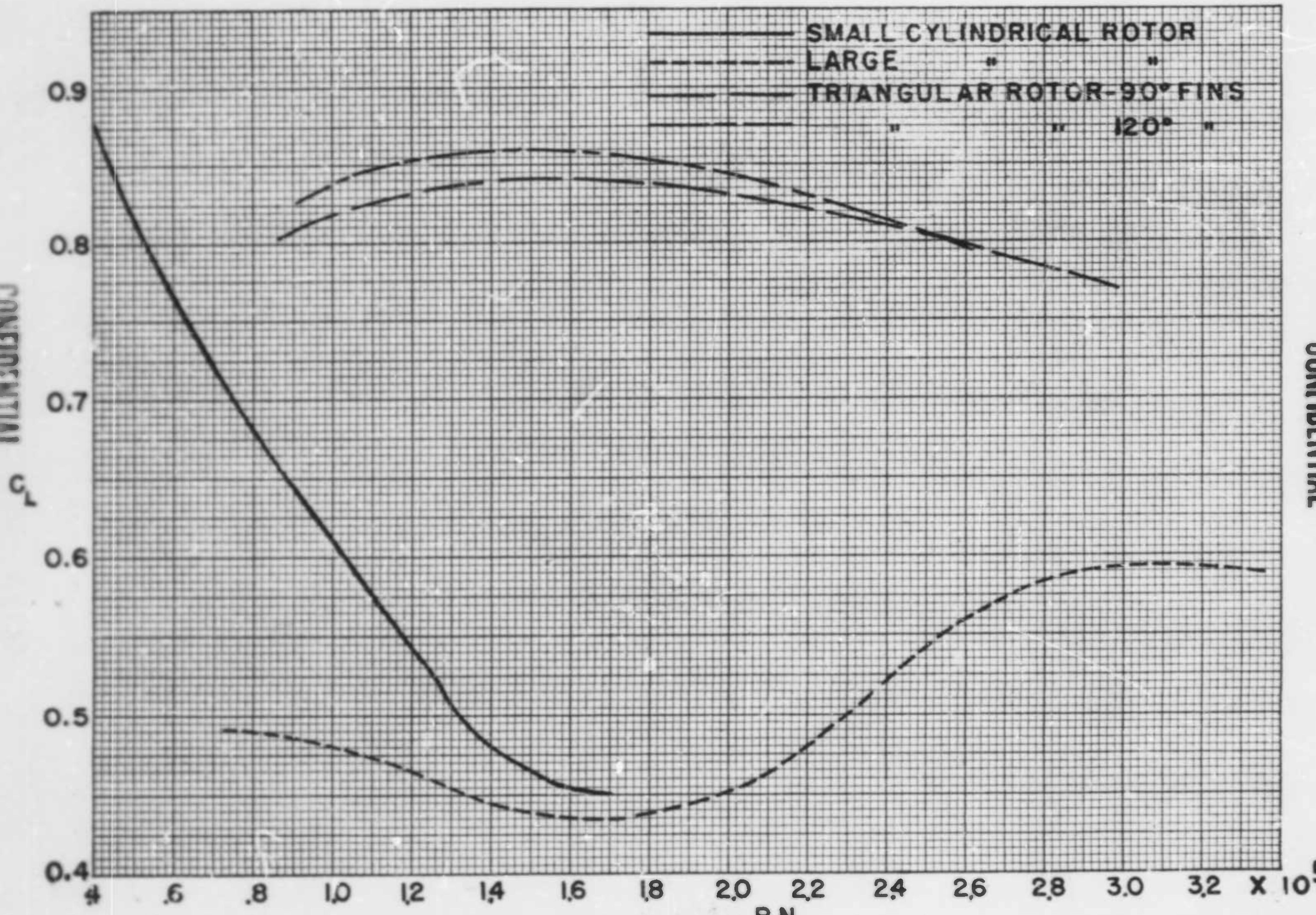
SMALL CYLINDRICAL ROTOR
LARGE " "
TRIANGULAR ROTOR-90° FINS
" " 120° "
0.9
0.8
0.7
0.6
0.5
0.4
C_L
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
X 10^5
RN

FIGURE 3

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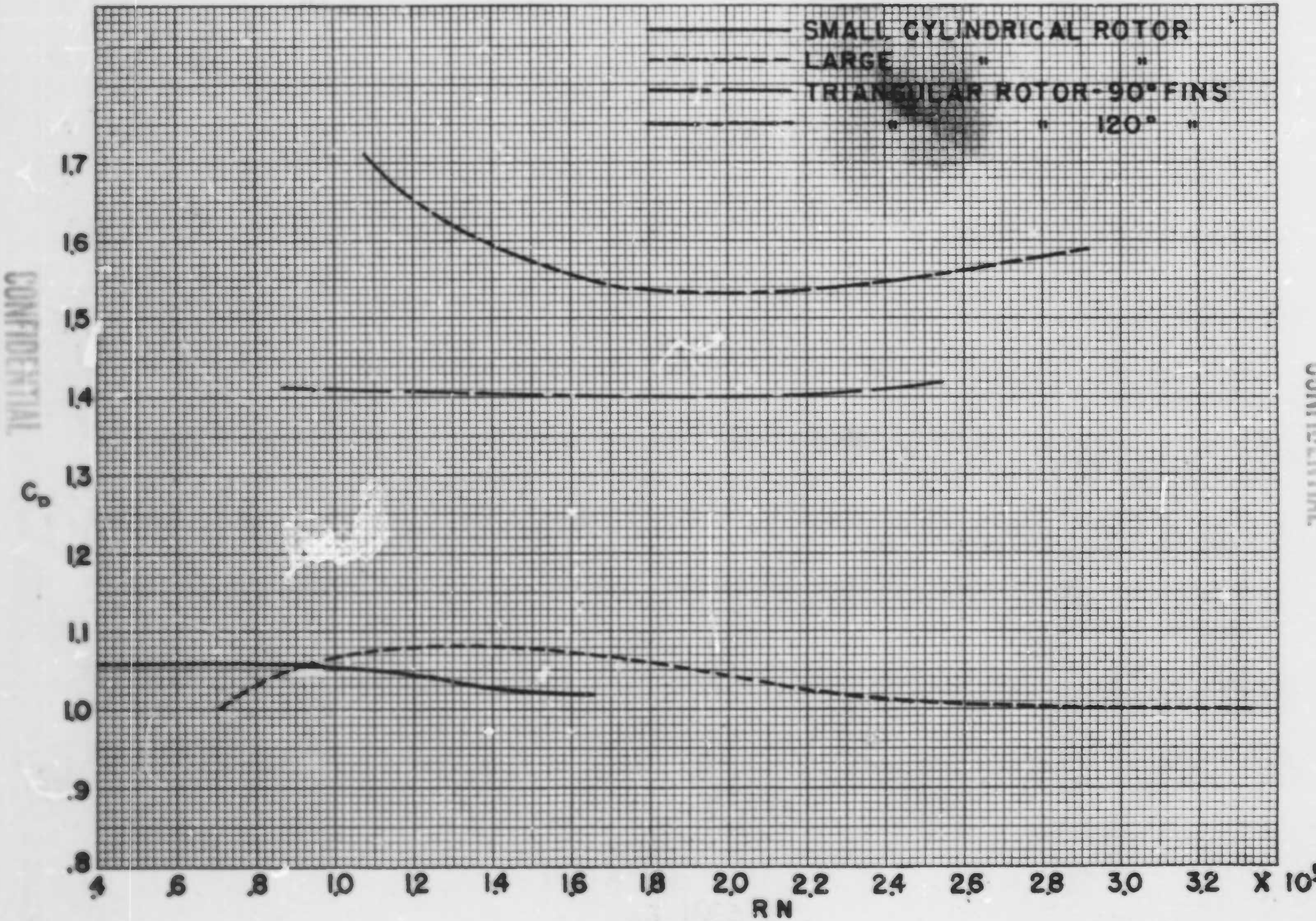

FIGURE 4

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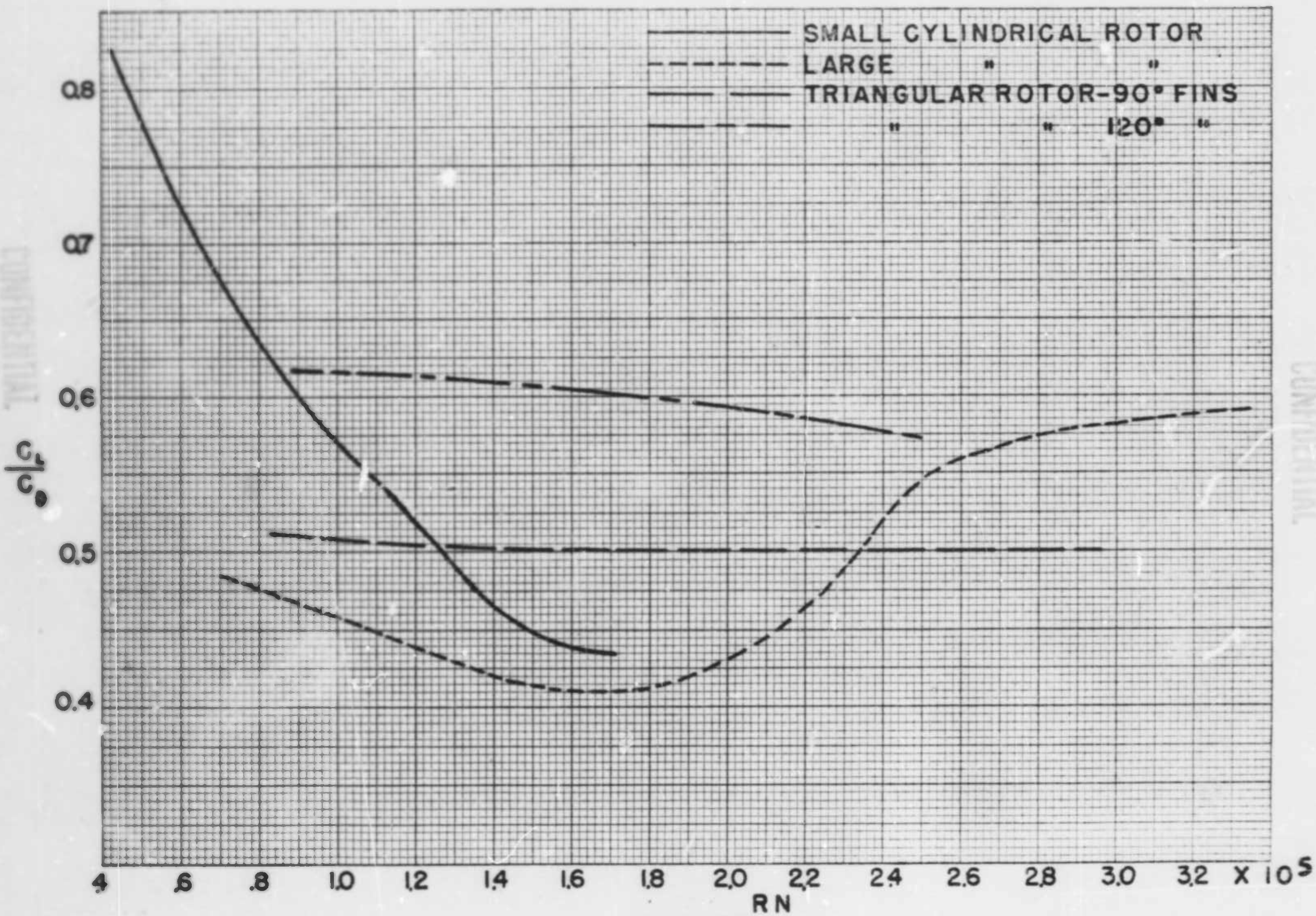
SMALL CYLINDRICAL ROTOR
LARGE " "
TRIANGULAR ROTOR-90° FINS
" " 120° "
0.8
0.7
0.6
0.5
0.4
$\frac{C_L}{C_D}$
4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
X 10^5
RN

FIGURE 5

DEPARTMENT OF THE ARMY
US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
EDGEWOOD CHEMICAL BIOLOGICAL CENTER
5183 BLACKHAWK ROAD
ABERDEEN PROVING GROUND, MD 21010-5424

REPLY TO
ATTENTION OF

17 JAN 2012

RDCB-DPS-RS

MEMORANDUM THRU Technical Director (RDCB-D/Mr. Joseph Wienand), Edgewood Chemical Biological Center (ECBC), 5183 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5424

FOR Office of the Chief Counsel (AMSRD-CCF/Mr. Brian May), US Army Research, Development and Engineering Command (RDECOM), 3071 Aberdeen Boulevard, Aberdeen Proving Ground, MD 21005-5201

SUBJECT: Freedom of Information Act (FOIA) Request

1. The purpose of this memorandum is to recommend the release of information in regard to a Freedom of Information Act (FOIA) Request FA-12-0047.

2. On 3 Jan 2012, ECBC received RDECOM FOIA Tasker #FA-12-0047 from Mr. Brian May, RDECOM FOIA Officer, which originated from DTIC in Fort Belvoir, VA. The original request was from Mr. Michael Ravnitzky.

3. The following document was reviewed by Subject Matter Experts from ECBC on Aberdeen Proving Ground, MD and deemed suitable for declassification and public release.

- AD-309180, An Investigation of the Aerodynamic Characteristics of Rotated Circular and Triangular Cylinders, dated May 21, 1959.

4. The point of contact is Mr. Ronald L. Stafford, the ECBC Information Security Officer, (410) 436-6810 or ronald.l.stafford.civ@mail.mil.

Encl

JUNE K. SELLERS
Security Manager

CF: Defense Technical Information Center (DTIC), 8725 John J. Kingman Road, STE 0944, Fort Belvoir, VA 22060-6218 (w/encl)