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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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EFFECT OF WIND VELOCITY ON PERFORMANCE OF
HELICOPTER ROTORS AS INVESTIGATED WITH
THE LANGLEY HELICOPTER APPARATUS

By Paul J. Carpenter

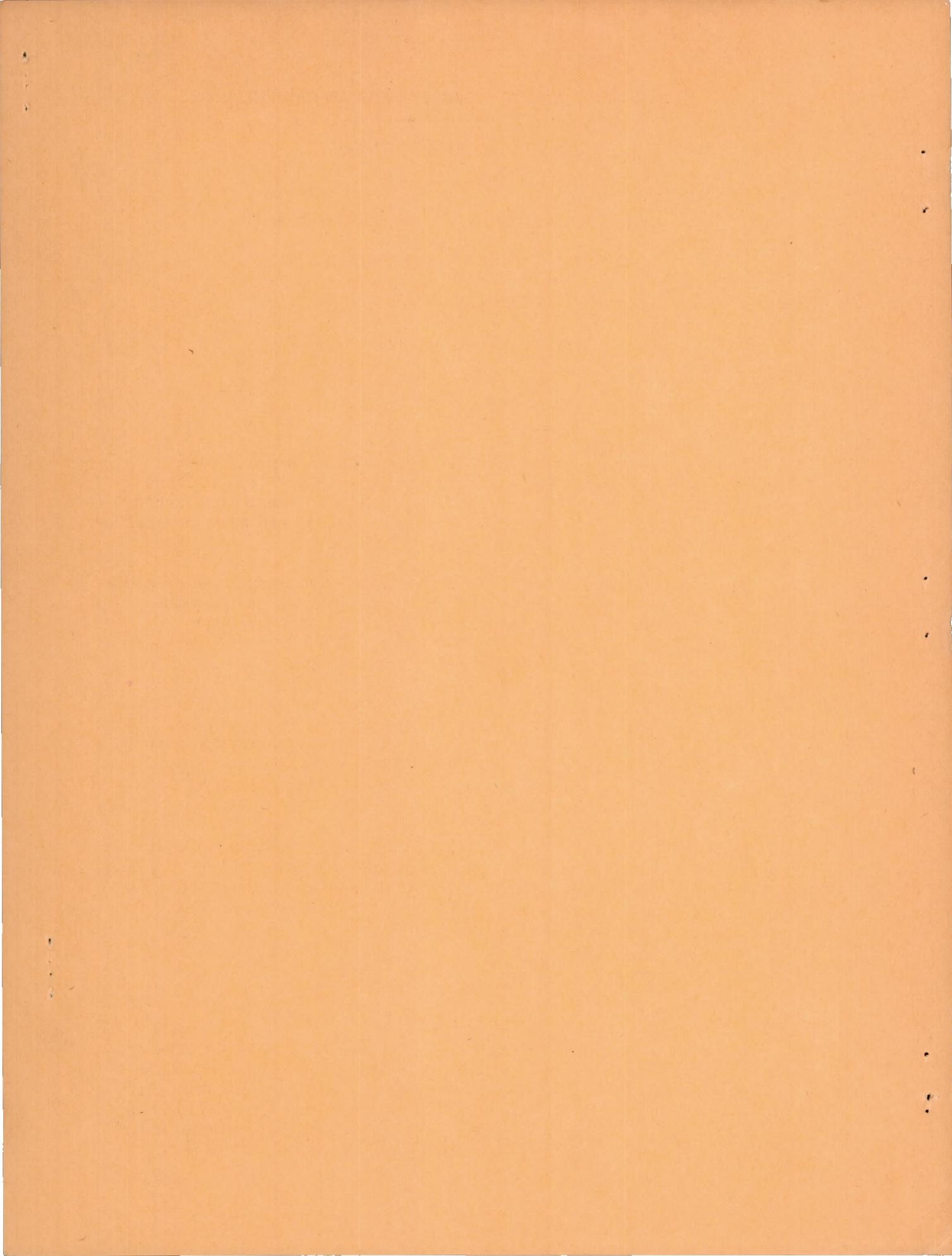
Langley Aeronautical Laboratory
Langley Field, Va.



Washington

October 1948

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SUMMARY

Two representative helicopter rotors with widely different characteristics were investigated to determine the effect of wind velocity on the power required for sustentation. The rotors were investigated with the Langley helicopter apparatus and were powered by a 1350-horsepower engine.

The results of this investigation showed an appreciable decrease in power required for both rotors for a given thrust as the wind velocity increased; for example, at a thrust of 2500 pounds decreases of about 5 percent in power required at 8 miles per hour and about 17 percent at 15 miles per hour were shown.

The results obtained for both rotors were essentially the same although the rotors had different plan forms, airfoil sections, blade twists, and solidities. Comparisons of the results with theoretical values showed that the theory satisfactorily predicted the effects of wind velocity on the performance of both rotors for airspeeds from 0 to at least 15 miles per hour.

A study of the results indicated that, in order to reduce errors brought about by wind velocity to less than 3 percent, rotor hovering performance tests should be run at wind velocities of less than 5 miles per hour or the test results should be adjusted to allow for the increase in performance due to wind velocity.

INTRODUCTION

Although experimental data for full-scale helicopter rotors are fairly extensive, the test conditions of these investigations have been limited to the range of variables of the particular helicopter being studied. The National Advisory Committee for Aeronautics has consequently constructed a testing apparatus suitable for obtaining accurate measurements on full-scale helicopter rotors for a wide

range of variables. This equipment is designated the Langley helicopter apparatus.

The rotor blades to be tested are attached to a part of the apparatus called the "helicopter tower." Inasmuch as the wind conditions at the tower cannot be controlled, the effect of wind velocity on the aerodynamic data obtained must first be determined in order to correlate the results of the tests made under different wind conditions and with different rotors. For example, it is generally known and has been theoretically proved by simple momentum theory (reference 1) that rotor performance increases appreciably with an increase in airspeed. Full-scale experimental confirmation of the theory, however, has been very limited in the airspeed range of most interest for the tower tests (0 to 15 mph). Tests were therefore made on a representative rotor in this airspeed range to determine the decrease in rotor power required at constant thrust at various wind speeds. These tests were then repeated with a rotor having widely different characteristics from the first rotor in order to determine whether the effect of wind velocity was dependent on rotor characteristics. The results of both series of tests were analyzed and compared with the theory of reference 2. Only the effect of wind velocity on the power required at constant thrust is given herein, inasmuch as the hovering performance at approximately zero airspeed of two similar rotors has been analyzed in reference 3.

The results and analysis of these tests are considered of general interest inasmuch as they provide not only a means for the correlation of data taken at various low wind speeds but also a knowledge of the effect of wind speed on power required in the low-speed range, which is necessary for the evaluation of helicopter hovering performance and for take-off and landing studies.

SYMBOLS

b	number of blades per rotor
R	blade radius, feet
c	blade section chord, feet
r	radial distance to blade element, feet

c_e equivalent blade chord, feet

$$\left(\frac{\int_0^R cr^2 dr}{\int_0^R r^2 dr} \right)$$

σ	rotor solidity ($bc_e/\pi R$)
ρ	density of air, slugs per cubic foot
T	rotor thrust, pounds
Q	rotor-shaft torque, pound-feet
Ω	rotor angular velocity, radians per second
C_T	rotor thrust coefficient $\left(\frac{T}{\pi R^2 \rho (\Omega R)^2} \right)$
C_Q	rotor-shaft torque coefficient $\left(\frac{Q}{\pi R^2 \rho (\Omega R)^2 (R)} \right)$
C_{Q_0}	rotor-shaft profile-drag torque coefficient
C_{Q_i}	rotor-shaft induced torque coefficient
$C_{Q_{i\text{hov}}}$	induced torque coefficient of rotor shaft in hovering at zero airspeed
P_i	induced rotor power, horsepower
V	true airspeed of helicopter along flight path (used herein as the true wind velocity relative to rotor)
v	induced inflow velocity at rotor, feet per second
V_{hov}	induced inflow velocity at rotor in hovering at zero airspeed, feet per second

APPARATUS AND TEST METHODS

Description of Langley Helicopter Apparatus

General.— The helicopter tower is constructed of steel plate formed in the shape of a circular cone 39 feet high having a base diameter of 16 feet and a top diameter of 3 feet. A movable work stand gives access to the tower from the outside. A 40-foot pole located 180 feet from the helicopter tower is used for obtaining wind-velocity data. A general view of the Langley helicopter apparatus is shown in figure 1.

Power plant.— The power for the rotor is supplied by a 12-cylinder Packard marine engine rated at 1350 horsepower at 2400 rpm. The engine drives the gear reduction unit through a free-wheeling unit. A manually operated cone clutch engages and disengages the engine. The gear reduction

unit has interchangeable gears giving reduction ratios of 12 to 1 and 6 to 1. Part of the gearbox assembly is shown in figure 2.

Shaft.— The rotor shaft is capable of transmitting a driving torque of 30,000 pound-feet. The lower part of the shaft consists of a section on which slip rings are mounted, a flexible coupling, a special necked-down section used as a strain-gage torque meter, a diaphragm coupling, and a thrust bearing to which thrust pickups are attached. The lower shaft installation is seen in figure 2. The top of the shaft is an adapter flange on which is mounted a replaceable $2\frac{1}{2}$ -inch steel shaft. This one is used as an adapter shaft for the rotor in the present investigation. Figure 3 shows the rotor installation atop the helicopter tower.

Instruments.— The helicopter tower is equipped with instruments to indicate the thrust, torque, side forces, shaft rotational speed, blade pitch angle, drag angle, coning angle, wind velocity, and wind direction. A mobile trailer is located about 100 feet from the tower with an oscillograph capable of taking simultaneous records of the data.

The vertical thrust is measured by electric strain gages mounted on the supports of the thrust bearing. Two mounts are available, one with a range of 0 to 3000 pounds and the other with a range of 0 to 10,000 pounds.

The torque is measured in a similar manner by electric strain gages on the necked-down section of the shaft. Shaft sections with a torque range of 0 to 3000 pound-feet, 0 to 9000 pound-feet, and 0 to 30,000 pound-feet are available.

Side forces acting on the rotor are measured by strain gages mounted on the top bearing supports.

Control-position indicators which consist of a slide on a resistance wire are used to indicate the blade pitch angle, drag angle, and coning angle. These indicators are also used to obtain the amount of cyclic pitch.

Wind velocity is indicated by anemometer cups mounted on a pole 180 feet from the tower. A wind-direction indicator is located on top of the pole.

A survey rake to measure the direction and velocity of the induced flow is installed on the tower. The rake can be rotated to any azimuth position and the velocity and direction indicators can be shifted to any blade-radius position.

The instrument panel and the controls located in the base of the tower are shown in figure 4.

Description of Rotors

Two representative rotors (designated rotors A and B) with widely different characteristics were used in the investigation. The blades of rotor A are standard-production models and have a radius of 19 feet measured from the center of rotation. The blades are fabric covered and untwisted, have NACA 0012 airfoil sections, and have a solidity of 0.060.

The blades of rotor B also have a radius of 19 feet. They are plywood covered and have a linear washout of 8° , NACA 23015 airfoil sections, and a solidity of 0.042. Plan forms of the two types of rotors tested are shown in figure 5. A summary of the pertinent characteristics of the rotors is given as follows:

Rotor characteristics	Rotor A	Rotor B
Radius, feet	19	19
Blade twist (linear), deg	None	-8
Solidity, σ	0.060	0.042
Blade area (total three blades), sq ft	65.4	46.3
Blade section	NACA 0012	Modified NACA 23015
Blade weight (one blade), lb	57	60
Type covering	Fabric	Plywood

Description of Tests

The quantities measured for these tests were wind velocity (mph), rotor rotational speed (rpm), rotor thrust (lb), rotor torque (lb-ft), side forces (lb), air temperature ($^{\circ}\text{F}$), and static air pressure (mm Hg).

Wind velocity at the rotor was assumed to be the same as wind velocity at the pole. As the instantaneous wind velocities at the wind-velocity pole and the rotor may not be quite the same, 20 sets of data were taken for each condition. These data were obtained by photographing the instrument-panel dials at 10-second intervals. The readings were then averaged to give mean thrust, torque, rotor speed, and wind velocity for each condition.

The cup anemometers were carefully calibrated and were found to be considerably in error at airspeeds below 10 miles per hour. A correction chart was made from tests in an instrument tunnel to convert dial readings to true wind velocity. Because the anemometer cups were inoperative at wind velocities less than 2.5 miles per hour, a 20-foot streamer of light paper was tied to the work stand at a distance of 125 feet from the tower; zero wind velocity was taken as the point at which the paper hung straight down. No readings were taken at wind velocities between 0 and 2.5 miles per hour.

For each set of conditions, the cyclic pitch was adjusted to give zero side forces acting on the rotor.

METHOD OF ANALYSIS

In order to compare the results with the available theory, isolation of that part of the total power required which is affected by wind speed was first necessary. A study of the problem indicates that the induced power P_i and, hence, the induced torque coefficients would be chiefly affected. Reference 2 presents the available theory in a convenient form of induced velocity $\frac{v}{v_{hov}}$ plotted against $\frac{V}{v_{hov}}$, which is a nondimensional parameter proportional to wind speed.

In order to obtain these two ratios, a curve of total torque coefficients at any thrust coefficient was first obtained for the hovering condition. An estimated profile-drag torque-coefficient curve was drawn and values taken from the curve were subtracted from the total hovering torque coefficients to obtain the hovering induced torque coefficients for any thrust coefficient. The estimated profile-drag torque coefficients used were determined by starting at the minimum value measured and increasing it as a function of increasing thrust coefficient according to the procedure given in reference 4. The induced torque coefficients corresponding to the measured thrust coefficient for each of the data points were then obtained by subtracting the same estimated profile-drag torque coefficient from the measured total torque coefficient obtained at the various wind velocities. Once the values of $C_{Q_{ihov}}$ and C_{Q_i} are determined, the induced velocity ratios can be calculated from the following relationship:

$$\frac{C_{Q_i}}{C_{Q_{ihov}}} = \frac{v}{v_{hov}} \quad (1)$$

where the induced-velocity distributions are assumed to be similar for various wind velocities.

For purposes of calculating the value of $\frac{V}{v_{hov}}$ for each data point, the theoretical value of v_{hov} was calculated from the expression

$$v_{hov} = \Omega R \sqrt{\frac{C_T}{2}} \quad (2)$$

in which the induced-velocity distribution is assumed to be uniform. The values of $\frac{V}{v_{hov}}$ were then calculated and plotted against $\frac{v}{v_{hov}}$.

RESULTS AND DISCUSSION

A summary of the data and results obtained with rotors A and B is presented in tables I and II, respectively. The ratios $\frac{v}{v_{hov}}$ and $\frac{V}{V_{hov}}$ were calculated only for points of 1500 pounds thrust or greater because, as the induced power approaches zero, the experimental error can become very large. Because the method of analysis required a curve of total hovering torque coefficient plotted against thrust coefficient, the data taken at zero airspeed were plotted in figures 6 and 7. In order to assist in fairing the curves through the limited number of data points at zero airspeed, points at very low airspeeds are included in the figures.

The agreement between the experimental data and the theoretical curves of induced-velocity parameter and wind-velocity parameter is shown in figure 8. The results obtained for both rotors were essentially the same although their airfoil sections, plan forms, blade twists, and solidities are different.

Good agreement is obtained with the theoretical curve for values of $\frac{V}{V_{hov}}$ from 0 to 1.0, which for normal disk loadings correspond to airspeeds of 0 to about 15 miles per hour. These tests are considered to show clearly the validity of the theory for this range of airspeeds for rotors whose geometric parameters fall within the range covered by conventional design. A somewhat smaller experimental than theoretical reduction in power required is shown at ratios of $\frac{V}{V_{hov}}$ above 1.0.

Although some such discrepancy may be expected from considerations of the dissymmetry of induced flow, the limited amount of data obtained and the increase in experimental error due to gustiness at high wind velocities allow no definite conclusions to be drawn. For this reason the experimental curve in figure 8 is a dashed line above a value of $\frac{V}{V_{hov}}$ of 1.0 to indicate its provisional nature.

The effect of wind velocity on power required as well as the agreement between theory and experiment can be more easily understood in terms of conventional parameters. As an example, the faired results of figure 8 are presented in figure 9 as a plot of rotor power against wind velocity for rotor A operating at a thrust of 2500 pounds. The figure shows decreases in power required for sustentation of about 5 percent at 8 miles per hour and about 17 percent at 15 miles per hour. Examination of the figure also shows that, in order to reduce errors brought about by wind velocity to less than 3 percent, rotor hovering performance tests should be run at wind velocities of less than 5 miles per hour or the test results should be adjusted to allow for the increase in performance due to wind velocity.

CONCLUSIONS

The effect of wind velocity on the performance of helicopter rotors has been experimentally determined with the Langley helicopter apparatus for two sets of rotor blades with widely different characteristics, and the experimental results have been compared with theoretical values. From the performance data obtained, the following conclusions may be drawn for rotors whose geometric parameters fall within the range covered by conventional design:

1. As predicted by theory, the power required for sustentation decreased appreciably as the airspeed increased; for example, a decrease of about 5 percent in power required was noted at 8 miles per hour and a decrease of about 17 percent was noted at 15 miles per hour at a rotor thrust of 2500 pounds.

2. The results obtained for both rotors were essentially the same although the rotors had different plan forms, airfoil sections, blade twist and solidities. Comparisons of the results with theoretical values showed that the theory predicted satisfactorily the effects of wind velocity on rotor performance for airspeeds from 0 to at least 15 miles per hour.

3. In order to reduce errors brought about by wind velocity to less than 3 percent, either rotor hovering performance tests should be run at wind velocities of less than 5 miles per hour or the test results should be adjusted to allow for the increase in performance due to wind velocity.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 17, 1948

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TABLE I.- SUMMARY OF DATA AND RESULTS OBTAINED WITH ROTOR A

Symbol notation	Rotor thrust, T (lb)	Total rotor power, (hp)	Rotor speed (rpm)	Wind velocity (mph)	Air temperature (°F)	Atmospheric pressure (mm Hg)	Rotor thrust coefficient, C _T	Rotor-shaft torque coefficient, C _Q	Profile-drag torque coefficient, C _{Q₀}	Induced-velocity parameter, $\frac{v}{v_{hov}}$	Wind-velocity parameter, $\frac{v}{v_{hov}}$
○	20.5	21.65	200.3	3.9	73	766.4	0.000049	0.0000711	0.000071	----	----
	494	31.62	200.2	3.9	73	766.4	.001176	.000104	.000071	----	----
	974	48.50	199.7	3.9	73	766.4	.002325	.000160	.000072	----	----
	1418	68.63	199.7	4.8	73	766.4	.003382	.000227	.000074	----	----
	1902	95.18	200.3	4.8	73	766.4	.00456	.000309	.000079	0.937	0.371
	2342	123.90	200.0	5.2	73	766.4	.00563	.000408	.000087	.988	.361
□	61.5	21.2	199.7	9.2	82	766.5	.000149	.0000716	.000071	----	----
	477	27.4	199.7	10.1	82	766.5	.001162	.0000926	.000071	----	----
	1027	46.2	198.9	8.8	82	766.5	.00252	.000157	.000072	----	----
	1476	65.95	199.3	8.4	82	766.5	.00360	.000223	.000075	.843	.733
	1875	86.1	199.7	10.1	82	766.5	.004585	.000290	.000080	.852	.779
	2339	114.0	199.9	9.0	82	766.5	.005635	.000383	.000088	.911	.625
◇	40	28.75	220.5	3.6	82	768.3	.000080	.0000719	.000071	----	----
	485.5	36.76	216.0	4.6	82	768.3	.001002	.0000968	.000071	----	----
	947	52.93	216.0	5.4	82	768.3	.001955	.000140	.000071	----	----
	1436	74.18	217.6	4.4	82	768.3	.00299	.000192	.000073	----	----
	1965	104.9	218.0	0	82	768.3	.00385	.000270	.000076	1.00	0
	△	2.4	27.66	217	4.2	73	766.4	.000005	.0000712	.000071	----
457		35.70	218	4.3	73	766.4	.000914	.0000919	.000071	----	----
959		53.58	217.5	5.1	73	766.4	.001945	.000137	.000071	----	----
1390		73.20	216.8	4.6	73	766.4	.00282	.000189	.000072	----	----
1880		100.6	217.5	3.4	73	766.4	.00378	.000257	.000076	.963	.265
2384		129.0	217.5	4.3	73	766.4	.00487	.000330	.000082	.931	.295
◇	39.6	32.91	233.5	5.6	79	766.7	.000007	.0000691	.000071	----	----
	457	43.01	233.9	6.5	79	766.7	.000806	.0000899	.000071	----	----
	979	60.04	233.5	5.6	79	766.7	.001736	.000126	.000071	----	----
	1384	77.9	233.5	4.2	79	766.7	.002449	.000163	.000072	----	----
	1814	102.4	232	3.5	79	766.7	.00323	.000216	.000074	.953	.277
	2320	135.8	233	4.2	79	766.7	.00419	.000288	.000078	.963	.290
◇	30.2	26.92	217.5	10.4	88	769.6	.000062	.0000705	.000071	----	----
	501	36.0	217	12.8	88	769.6	.001036	.0000949	.000071	----	----
	2390	117.1	217.5	12.8	88	769.6	.004975	.000307	.000082	.851	.870
	2358	118.1	217.2	12.2	88	769.6	.00488	.000310	.000082	.854	.839
	1816	86.8	217.4	13.8	84	769.6	.003732	.000227	.000076	.817	1.08
	1791	86.6	217.6	12.9	84	769.6	.00366	.000225	.000075	.831	1.02
	1384	64.5	217.7	16.1	84	769.6	.002828	.000167	.000073	----	----
	1310	66.3	217.2	12.2	84	769.6	.00271	.000174	.000072	----	----
	2321	107.0	217.2	14.7	84	769.6	.004782	.000281	.000081	----	----
	2288	106.9	217.1	17.3	84	769.6	.004715	.000281	.000080	.784	1.21
	1920	87.9	217.5	13.9	84	769.6	.003938	.000229	.000076	.763	1.06
	1379	63.69	217	15.0	84	769.6	.002811	.000166	.000073	----	----
	16	27.57	218	12.6	84	769.6	.000033	.0000711	.000071	----	----
	2382	109.4	217.7	15.0	84	769.6	.00487	.000284	.0000815	.758	1.03
	2400	109.1	217.4	17.6	84	769.6	.00493	.000284	.000082	.745	1.20
	◇	43.6	26.12	217.8	10.9	83	770.4	.000089	.0000674	.000071	----
452		33.24	216.8	10.8	83	770.4	.000928	.0000873	.000071	----	----
924		47.1	217	9.8	83	770.4	.001894	.000123	.000071	----	----
1494		71.14	217.4	10.9	83	770.4	.00306	.000185	.000073	.809	.946
1850		87.95	217	10.7	83	770.4	.003805	.000231	.000076	.814	.834
2450		118.2	217.4	14.0	83	770.4	.00501	.000308	.000082	.813	.950
△	10.4	32.7	233.8	5.1	73	766.4	.000018	.0000677	.000071	----	----
	497	42.98	233.5	4.6	73	766.4	.000870	.0000891	.000071	----	----
	950	57.83	233.5	4.7	73	766.4	.001676	.000121	.000071	----	----
	1367	77.92	233	4.1	73	766.4	.002402	.000163	.000072	----	----
	1820	101.0	232.9	3.9	73	766.4	.003205	.000211	.000074	.929	.309
	2311	130.4	234	4.5	73	766.4	.00402	.000268	.000077	.927	.317
◇	40.4	32.4	232.2	8.2	86	766.5	.000073	.0000696	.000071	----	----
	568.5	42.6	233.5	10.5	86	766.5	.001016	.0000898	.000071	----	----
	967	55.7	233.2	9.2	86	766.5	.001736	.000119	.000071	----	----
	1456	76.0	234	9.6	86	766.5	.00260	.000160	.000072	----	----
	1870	98.4	234.1	10.3	86	766.5	.00333	.000207	.000074	.850	.795
	2310	122.5	233	9.6	82	766.5	.00416	.000260	.000078	.843	.666
◇	25	33.2	233	7.9	82	768.3	.000045	.0000703	.000071	----	----
	494.5	43.87	233.8	6.5	82	768.3	.000871	.0000921	.000071	----	----
	945	59.10	233	8.2	82	768.3	.001700	.000126	.000071	----	----
	1401	81.62	233.9	7.1	82	768.3	.002493	.000172	.000072	----	----
	1879	104.3	233.5	7.6	82	768.3	.00337	.000222	.000074	.928	.586
	2430	131.9	233.8	9.1	82	768.3	.00433	.000279	.000078	.878	.617
◇	9	33.85	233	5.0	82	768.3	.000002	.0000708	.000071	----	----
	471	43.04	232.5	5.8	82	768.3	.000843	.0000916	.000071	----	----
	936	58.51	232	5.9	82	768.3	.001684	.000125	.000071	----	----
	1412	82.41	234.1	5.2	82	768.3	.002486	.000171	.000072	----	----
	1807	105.4	233.5	4.1	82	768.3	.003212	.000222	.000074	1.00	.323
	2320	139.0	233.8	3.3	82	768.3	.004121	.000292	.000077	1.01	.229
▽	2330	134.8	234	2.5	82	770.1	.00405	.000286	.000077	1.00	.175
	2356	132.8	217.2	0	75	770.1	.00477	.000342	.000081	1.00	0
	2280	128.4	217.5	0	75	770.1	.00459	.000325	.000080	.992	0
	2310	127.1	217.5	2.5	75	770.1	.00465	.000327	.000080	.982	.176



TABLE II.- SUMMARY OF DATA AND RESULTS OBTAINED WITH ROTOR B

Symbol notation	Rotor thrust, T (lb)	Total rotor power (hp)	Rotor speed (rpm)	Wind velocity (mph)	Air temperature (°F)	Atmospheric pressure (mm Hg)	Rotor thrust coefficient, C_T	Rotor-shaft torque coefficient, C_Q	Profile-drag torque coefficient, C_{Q_0}	Induced-velocity parameter, $\frac{v}{v_{hov}}$	Wind-velocity parameter, $\frac{V}{v_{hov}}$
○	-38.7	16.22	217.5	8.0	70	769.9	-0.000076	0.0000413	0.000042	-----	-----
	164	18.0	218.1	14.6	66	774.0	.000322	.0000448	.000042	-----	-----
	1160	36.9	218.5	17.4	66	774.0	.00217	.0000915	.000042	-----	-----
	1660	58.9	217.1	15.0	66	774.0	.00320	.0001494	.000045	0.701	1.27
	2085	76.9	216.5	15.2	66	774.0	.00405	.0001956	.000048	.716	1.15
	2535	118.4	216.5	7.7	70	769.9	.00500	.000304	.000052	.934	.525
	2645	108.75	217.5	17.0	66	774.0	.00512	.000273	.000053	.792	1.14
□	2770	142.4	216.1	2.5	54	772.4	.00537	.000355	.000055	1.02	.165
	2565	130.0	217.1	3.1	54	772.4	.00493	.000319	.000051	1.01	.212
	1969.7	93.7	216.6	4.7	54	772.4	.003805	.0002315	.000047	.971	.367
	1476	66.7	215.8	3.9	54	772.4	.002875	.000167	.000044	-----	-----
	1511.6	69.0	216.6	4.8	54	772.4	.00292	.0001706	.000044	.966	.428
	956	43.9	217.5	4.6	54	772.4	.00185	.000108	.000042	-----	-----
	959	42.0	216.3	7.0	54	772.4	.00186	.000104	.000042	-----	-----
	2795	141.0	216.6	5.0	54	772.4	.00542	.000350	.000055	.993	.327
	2440	119.8	216.0	3.4	54	772.4	.00479	.000302	.000050	.979	.237
	2445	121.4	216.8	3.8	54	772.4	.00474	.000302	.000050	.992	.265
	6.8	19.28	216.6	5.6	54	772.4	.000013	.0000480	.000042	-----	-----
◇	-9	18.41	216.5	3.1	53	766.5	-0.000018	.0000460	.000042	-----	-----
	411	26.0	217.1	2.5	51	766.5	.000797	.0000650	.000045	-----	-----
	1395	67.0	216.6	0.0	52	766.5	.00272	.000167	.000044	-----	-----
	1409	63.1	215.8	0.0	50	766.5	.00275	.0001581	.000044	-----	-----
	2320	116.3	216.3	0.0	53	766.5	.00453	.000291	.000049	1.010	0
	2600	128.9	216.6	3.1	48	766.5	.00503	.0003185	.000052	.978	.211
	2735	142.6	216.3	0.0	52	766.5	.00548	.000356	.000056	.997	0
	2755	137.7	216.0	0.0	53	766.5	.00542	.000348	.000055	.987	0
	1152	49.8	218.1	3.0	53	766.5	.00223	.000122	.000042	-----	-----
	2775	138.4	216.0	2.5	53	766.5	.00543	.000349	.000056	.987	.164
	2805	139.2	216.3	9.6	66	766.0	.00563	.000357	.000058	.966	.616
	2520	121.8	215.8	7.9	66	766.0	.00509	.0003155	.000052	.953	.536
	2635	126.5	215.0	8.8	66	766.0	.00537	.000327	.000055	.925	.583
	2390	108.3	216.3	9.6	66	766.0	.00479	.000278	.000050	.885	.670
	2755	140.0	217.1	3.2	67	763.1	.00555	.000360	.000056	.994	.206
	2830	141.0	217.5	5.4	67	763.1	.00566	.000359	.000058	.965	.344
	2760	134.5	216.5	10.3	67	763.1	.00556	.0003465	.000057	.950	.666
2690	131.9	216.3	7.5	67	763.1	.00542	.000340	.000055	.960	.491	
1595	70.0	217.0	8.1	66	766.0	.003195	.000179	.000045	.899	.688	
△	2905	107.2	214.5	28.5	51	760.0	.00581	.0002765	.000060	.676	1.82
	2845	110.2	215.5	23.8	51	760.0	.00565	.000281	.000058	.717	1.531
	2940	109.2	216.6	27.8	51	760.0	.00576	.000274	.000059	.676	1.76
	3045	110.9	216.6	24.9	51	760.0	.00598	.000278	.000064	.651	1.55
	3015	112.5	216.8	22.2	51	760.0	.00591	.0002805	.000062	.671	1.39
	2966	110.2	216.2	25.6	51	760.0	.00582	.000276	.000061	.672	1.62





Figure 1.- General view of Langley helicopter apparatus.

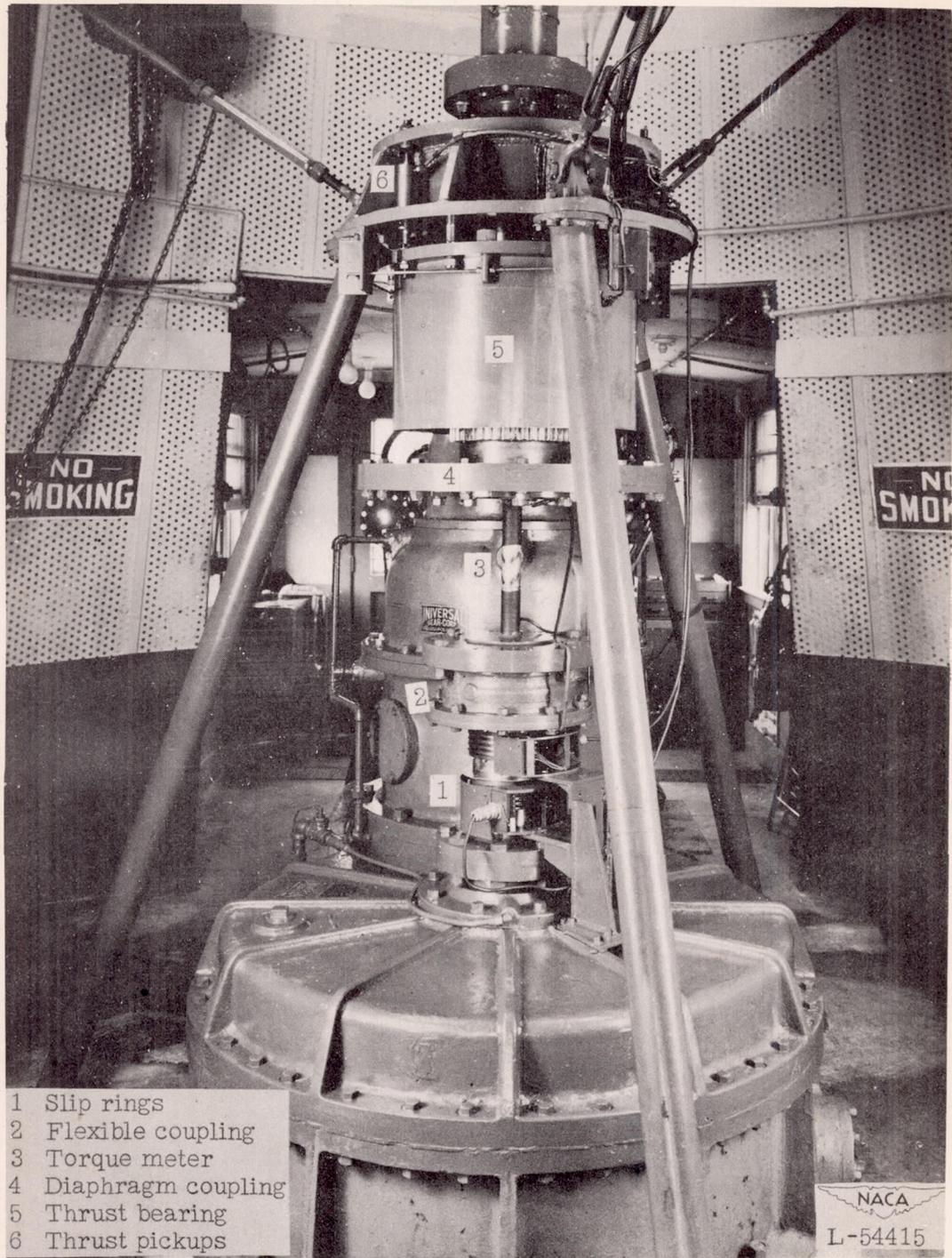
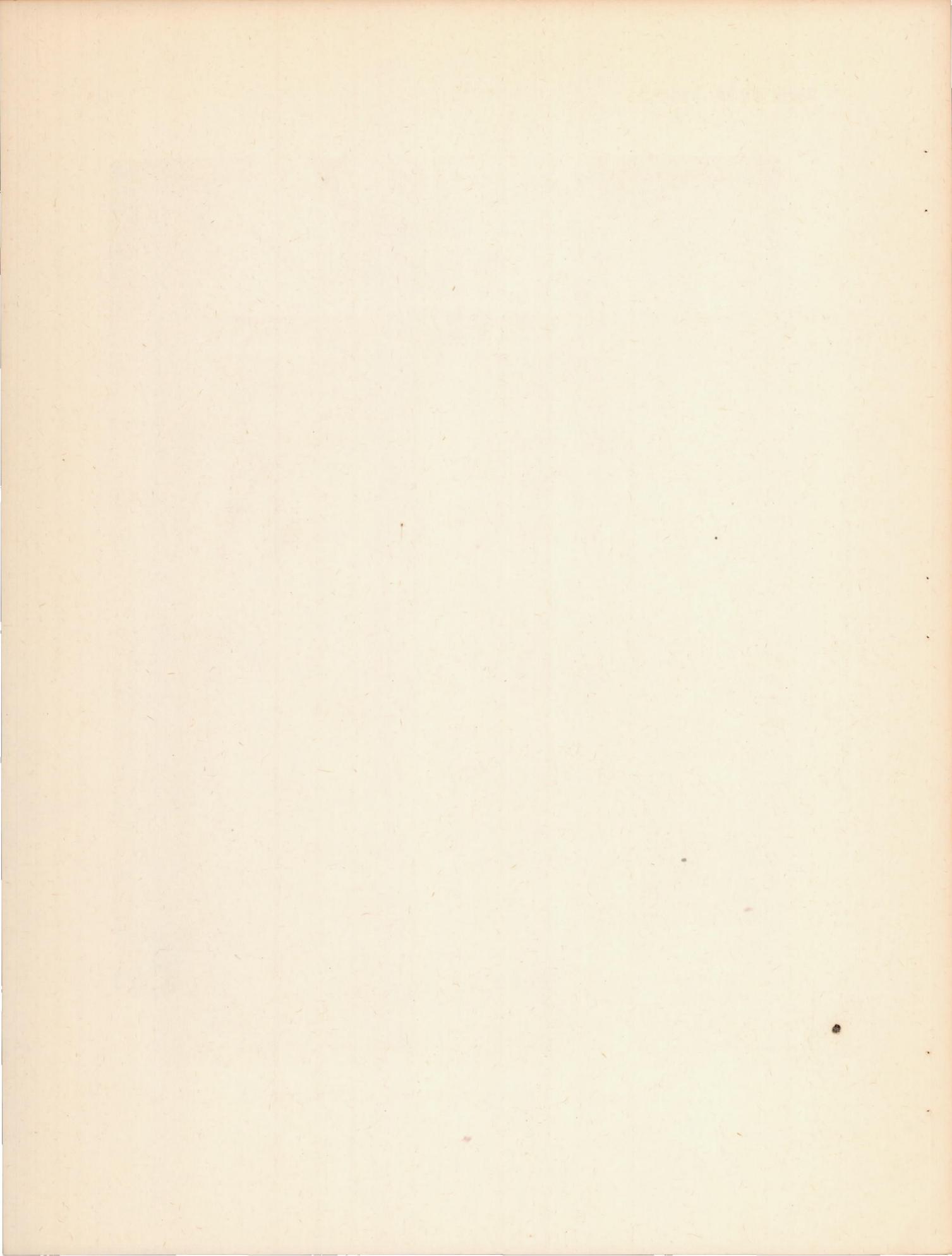


Figure 2.- Gearbox and lower shaft assembly.



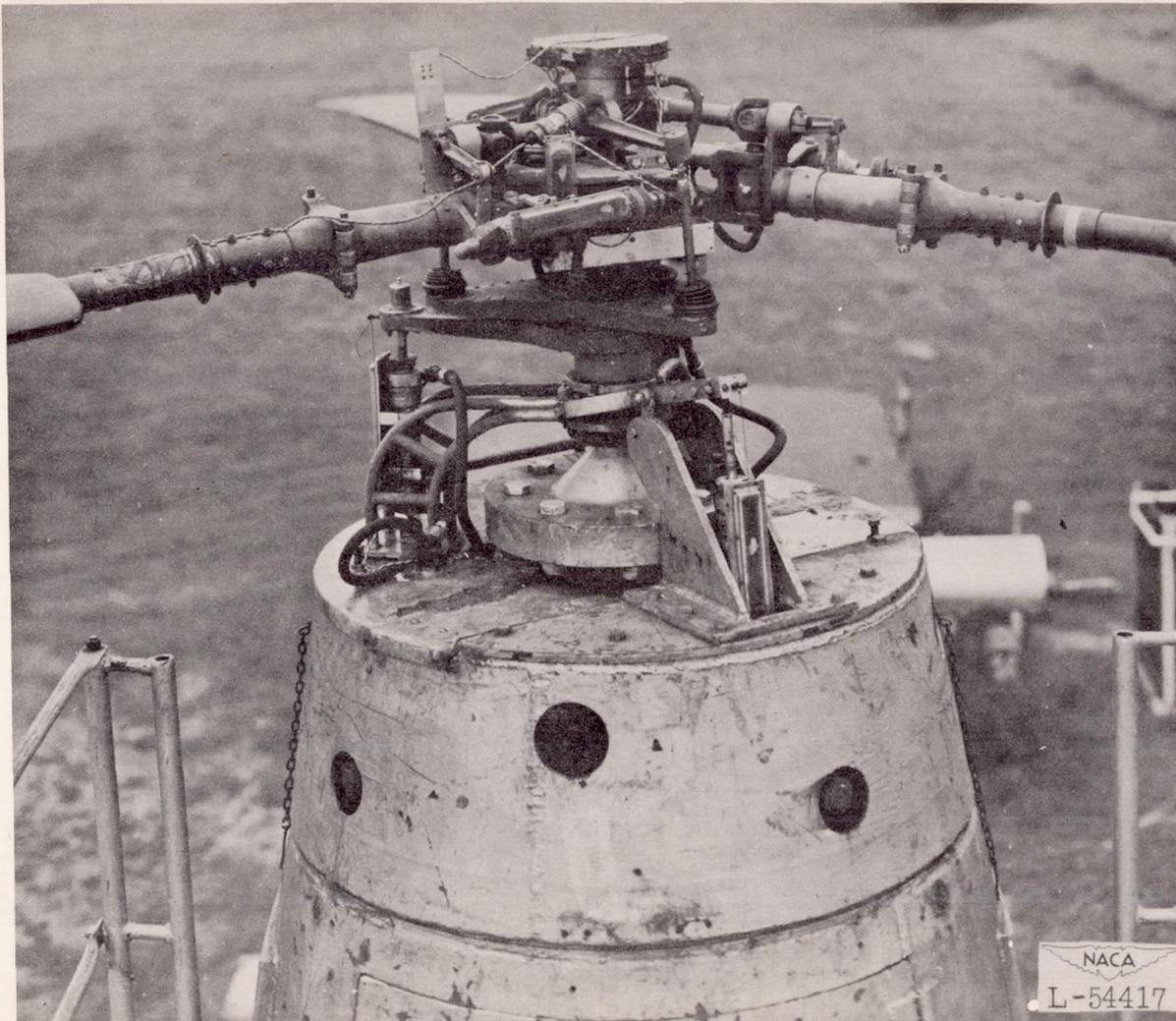
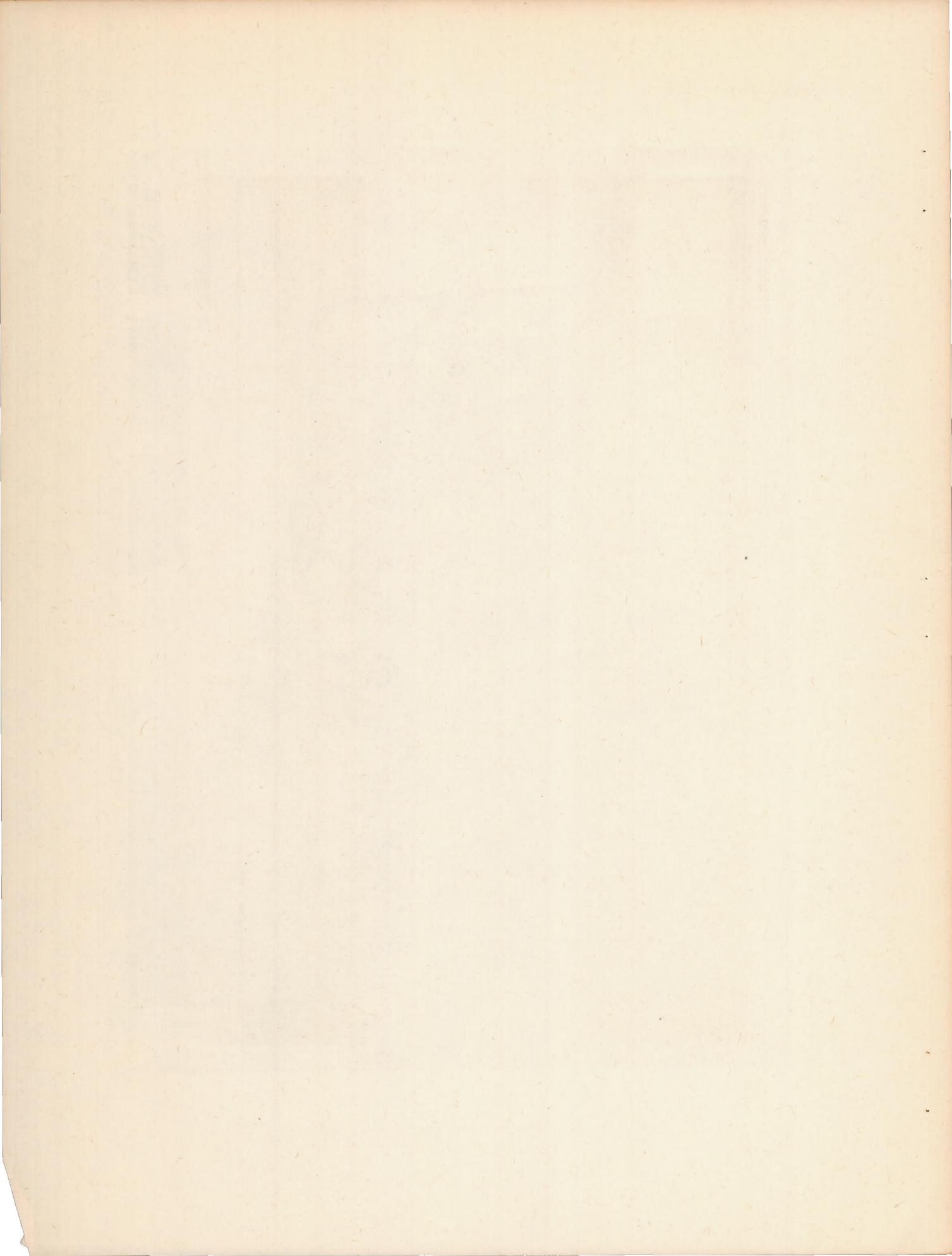
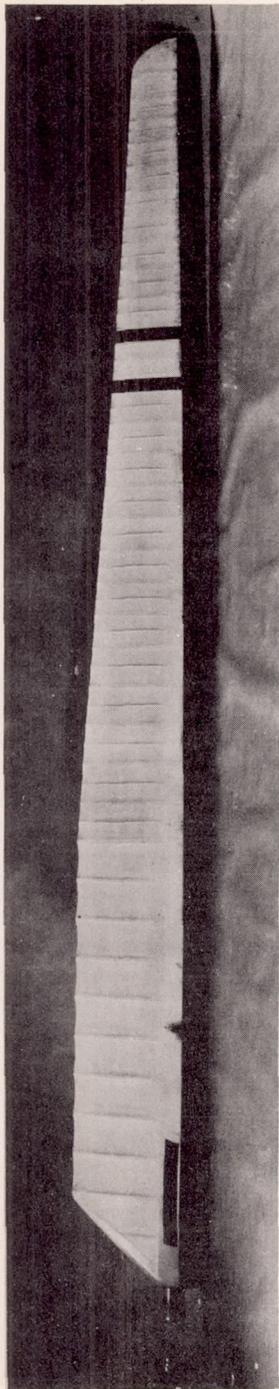


Figure 3.- Rotor installation atop helicopter tower.

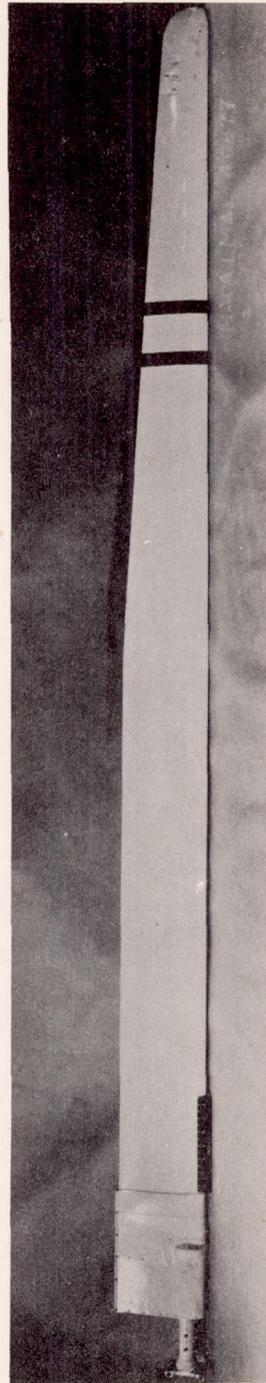


Figure 4.- Instrument panel and controls.





(a) Rotor A.



(b) Rotor B.

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Figure 5.- Plan forms of test rotor blades.

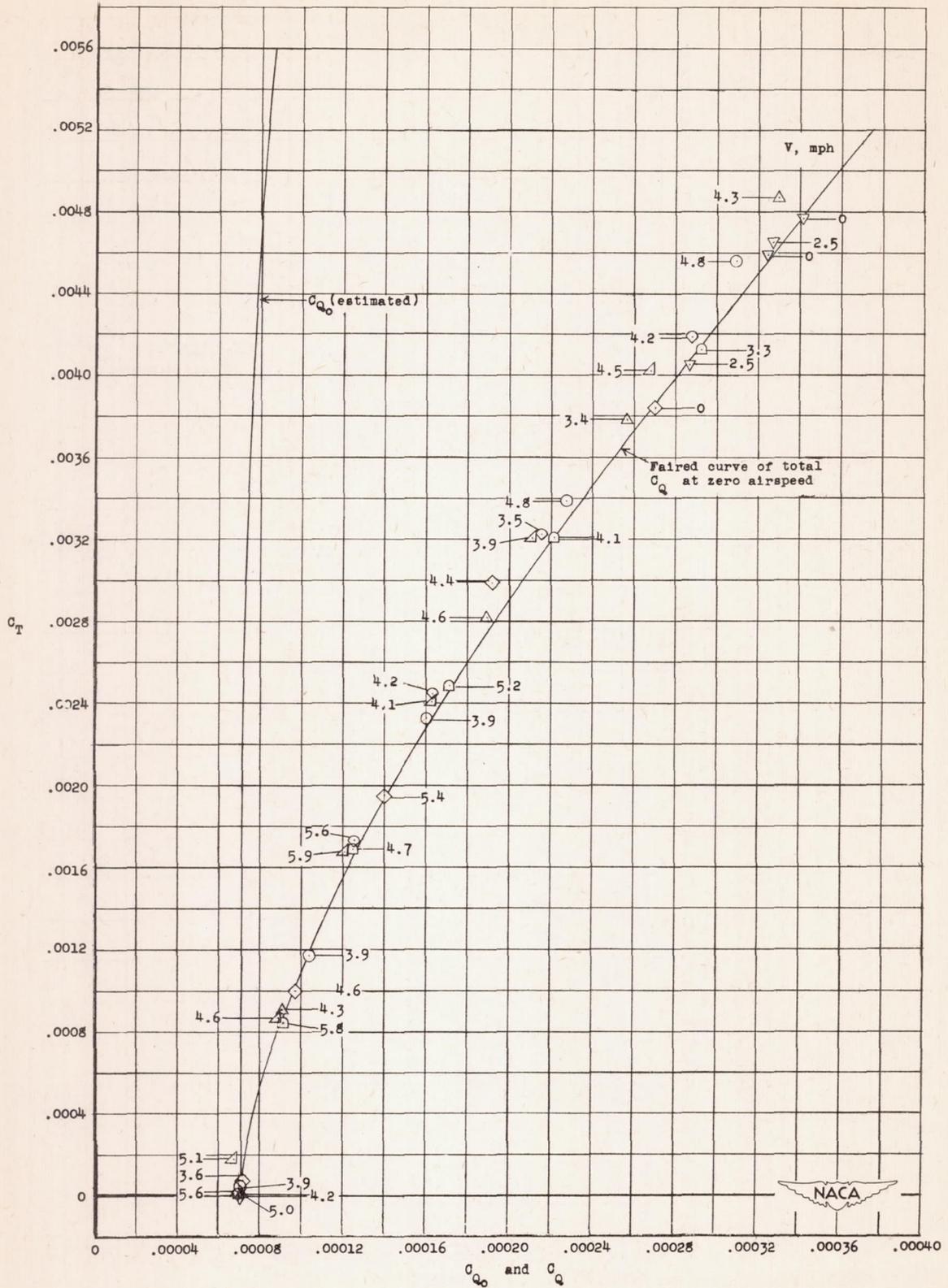


Figure 6.- Total and profile-drag torque coefficients for rotor A at near zero airspeed. (Each symbol represents a different day.)

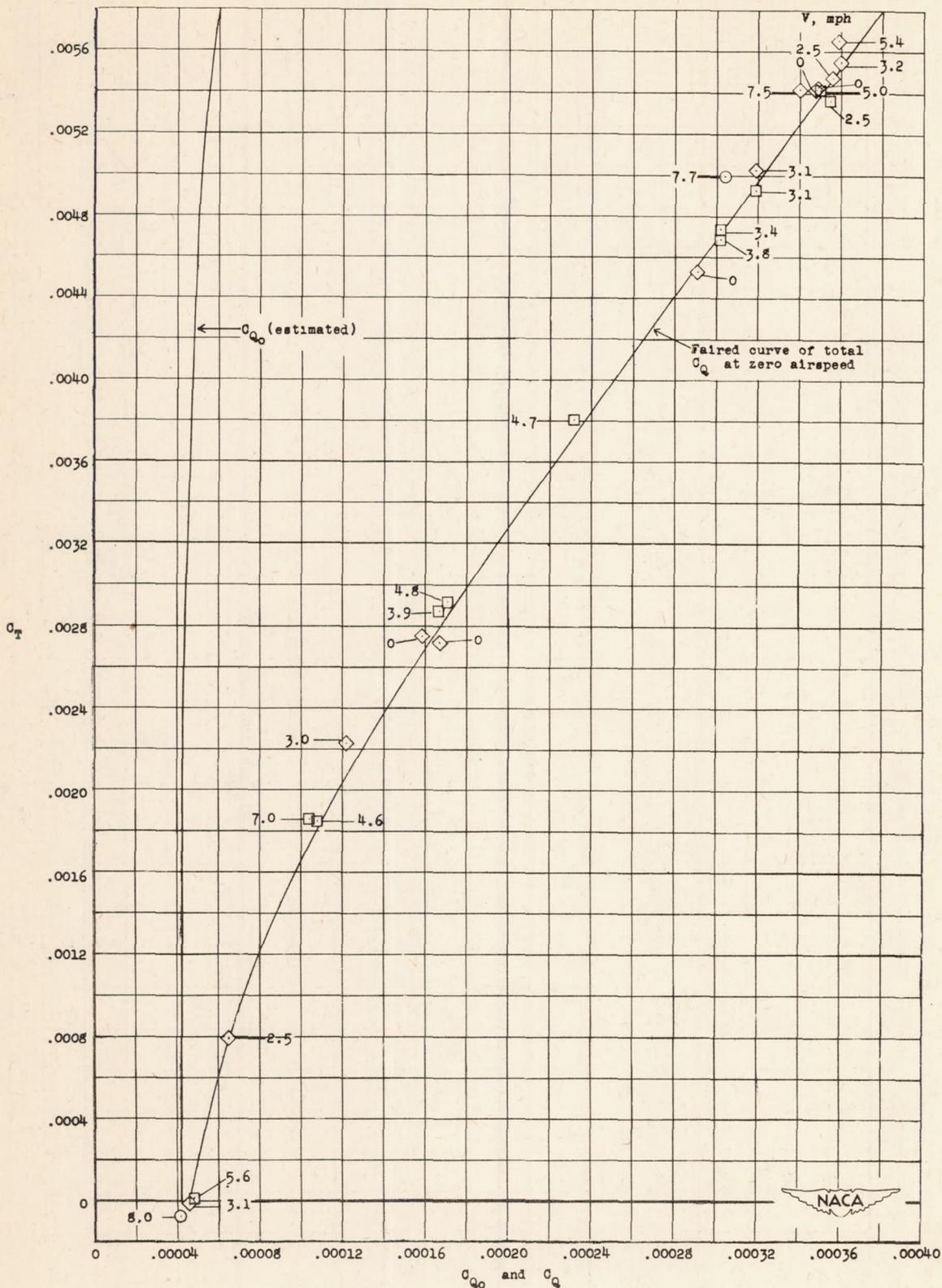


Figure 7.- Total and profile-drag torque coefficients for rotor B at near zero airspeed. (Each symbol represents a different day.)

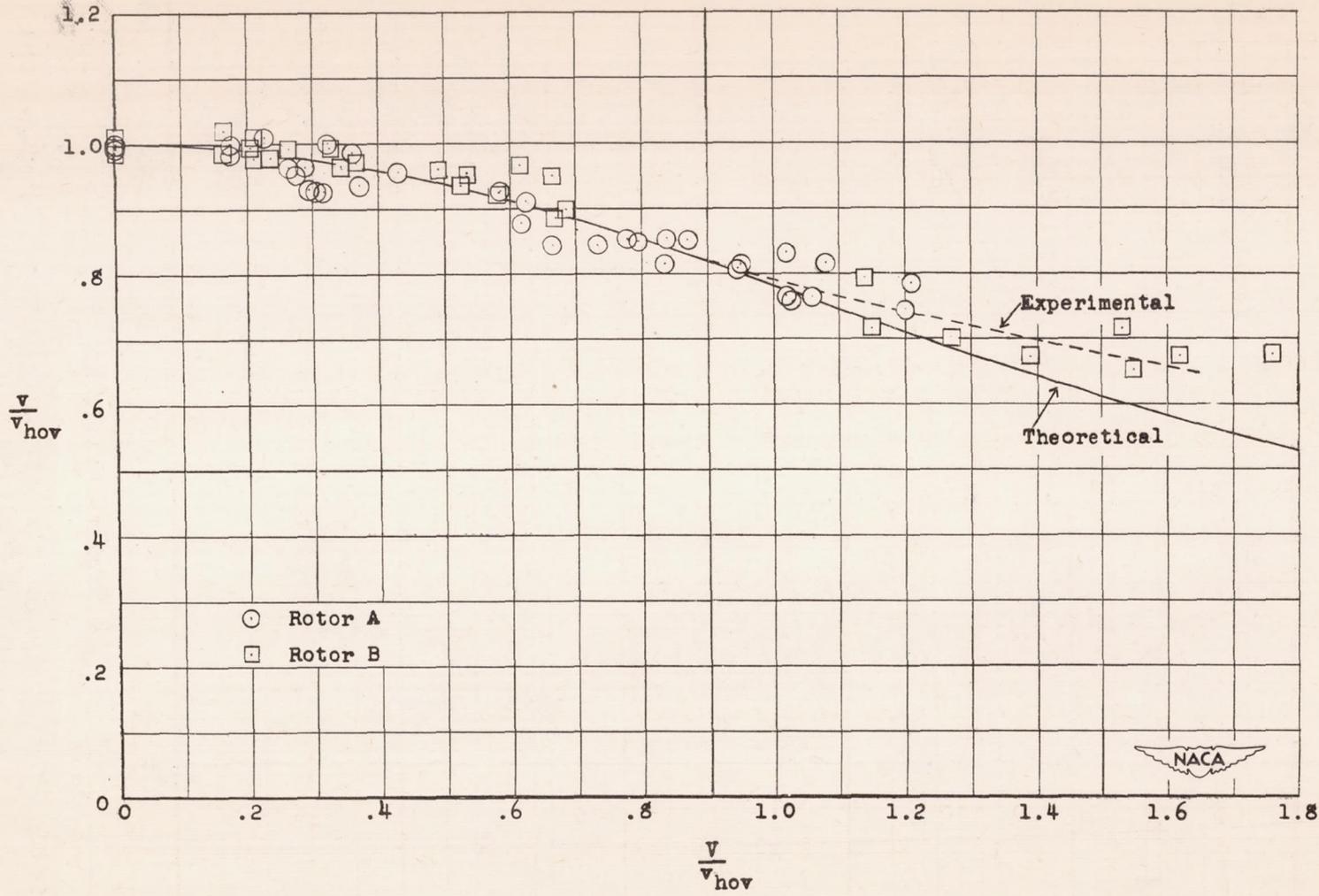


Figure 8.- Comparison of theoretical and experimental values of induced-velocity parameter $\frac{v}{v_{hov}}$ against wind-velocity parameter $\frac{V}{v_{hov}}$.

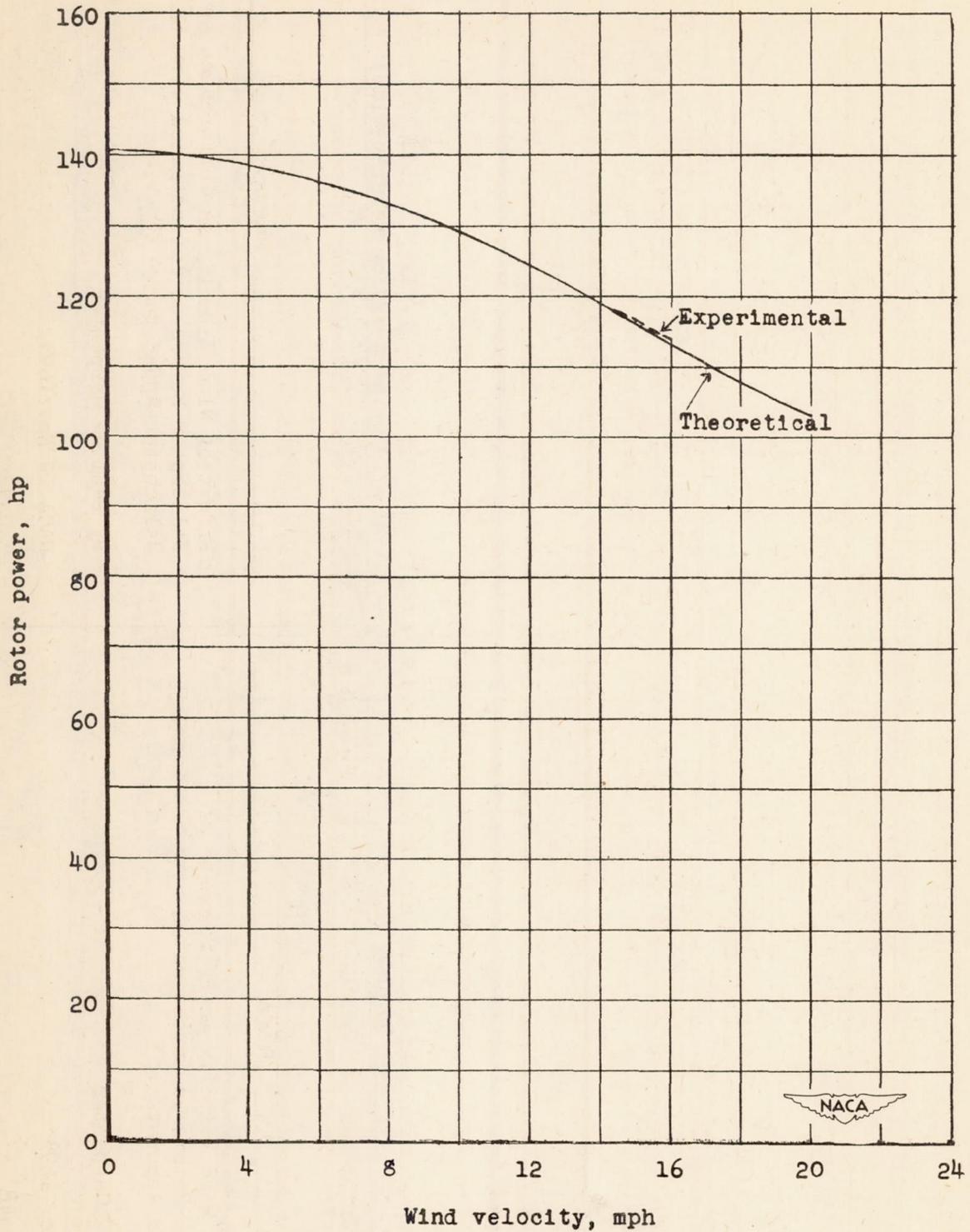


Figure 9.- Effect of wind velocity on the power required for rotor A at a thrust of 2500 pounds and 217 rpm.