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RESEARCH MEMORANDUM

for the

Office of Naval Research, Department of the Navy

WIND-TUNNEL INVESTIGATION AT LOW SPEED OF THE STATIC AERODYNAMIC AND OPERATIONAL CHARACTERISTICS OF A MODEL OF THE KAMAN ROTOCHUTE

By M. J. Queijo

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An experimental investigation has been made at low speeds in the Langley stability tunnel to determine some static aerodynamic and operational characteristics of a model of a Kaman Aircraft Corporation Rotochute. The aerodynamic characteristics, consisting of the three force and three moment components on the model, were obtained for the Rotochute with rotor blades folded and locked, and with the blades operating. Operational characteristics, consisting of drag coefficient, rotor-blade rotational speed (or rotor-blade tip speed), and free-stream velocity were obtained for the model with various spring governors.

In order to expedite distribution of this information, no analysis of the data has been prepared.

INTRODUCTION

At the request of the Office of Naval Research, Department of the Navy, a low-speed wind-tunnel investigation was made to determine some static aerodynamic and operational characteristics of a model of a proposed Kaman Aircraft Corporation Rotochute. The Rotochute is a device for aerially delivering M-2 cargo containers from high-speed aircraft (ref. 1) and is supposed to function in such a manner that the equilibrium descent velocity can be controlled by presetting certain components of the Rotochute before launching.

The tests of this investigation were made to aid in the development of the Rotochute. In order to expedite distribution of the results of the investigation, no analysis of the data is presented.

SYMBOLS

The symbols used herein are in the form of standard NACA symbols and coefficients. All forces and moments are referred to the wind-axes system (fig. 1), with the origin on the center line and 13.5 inches behind the nose of the model (see fig. 2).

S — disk area of rotor blades operating at zero cone angle, 11.30 sq ft

L — lift, lb

D — drag, lb

Y — side force, lb

M — pitching moment, ft-lb

L' — rolling moment, ft-lb

N — yawing moment, ft-lb

d — rotor diameter at zero cone angle, 3.80 ft

V — tunnel airspeed, ft-sec

V_t — rotor-blade tip speed, ft/sec

ρ — mass density of air, slugs/cu ft

α — angle of attack of Rotochute body, deg

β — sideslip angle, deg

a_0 — cone angle, deg

$$C_Y = \frac{Y}{qS}$$

$$C_L = \frac{L}{qS}$$

$$C_D = \frac{D}{qS}$$

$$C_l = \frac{L'}{qSd}$$

$$C_m = \frac{M}{qSd}$$

$$C_n = \frac{N}{qSd}$$

$$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

MECHANICAL OPERATION OF THE ROTOCHUTE

The mechanical operation of the Rotochute is outlined briefly herein, not as an analysis of its performance, but to provide an insight to the significance of the results obtained in the investigation. The Rotochute is a device ultimately intended as a means for aerially delivering M-2 cargo containers from high-speed aircraft. The purpose of the blades is to control the drop velocity of the Rotochute. The Rotochute is carried on an airplane in the blades folded and locked position. At release the blades are unlocked and begin to spin because of the blade angle relative to the wind. The centrifugal force on the blades forces them away from the axis of rotation. The equilibrium cone angle is determined largely by the equilibrium rotational velocity of the blades. This in turn is dependent on the blade pitch angle. The blade pitch angle is controlled by the spring constant and preload of a spring governor. The governor permits the blade pitch angle to attain a position where the resultant pitching moment attributable to air loads, spring load, and centrifugal force are zero.

MODEL AND APPARATUS

The model used in the present investigation was supplied by the Kaman Aircraft Corporation. Pertinent dimensions of the model are given in figure 2. The blades and nose of the Rotochute were made of wood; all other components were made of metal. Three sets of springs were used in the blade-pitch governors. The spring constants were determined and had approximately the following values:

Springs	Spring constants
1	24.0 lb/in.
2	77.2 lb/in.
3	32.7 lb/in.

No attempt was made to measure spring preload; however, the relative preloads are noted for runs with the same springs.

All tests were made in the Langley stability tunnel. The model was attached to a single-strut support (fig. 3), which was in turn fastened to a six-component balance system. Rotational speeds of the rotor blades were measured with a Strobotac. Cone angles were measured visually with the aid of scales placed on the tunnel window.

TESTS

Two series of tests were made: one to determine some static aerodynamic characteristics of the Rotochute and the other to determine some operating characteristics. The tests with rotor blades folded and locked were made at an airspeed of approximately 233 feet per second. Tests with blades operating were made at airspeeds of from 17 to 103 feet per second. Airspeeds for the various tests with blades operating are given along with the data in the report.

CORRECTIONS

No jet-boundary or tare corrections have been applied to the data. Tare corrections should be negligible for these tests. Jet-boundary effects probably are appreciable but should not affect the trends indicated by the data.

PRESENTATION OF DATA

All data obtained in the investigation are given in tables I to V. Some of the tabulated data are plotted in figures 4 to 7 to indicate variations of aerodynamic and operational characteristics with angular displacement and airspeed, respectively. In plotting some of the data, use was made of the fact that when the stabilizing vane is horizontal the variation of C_m with α (at zero sideslip) is the same as the variation of C_n with $-\beta$ (at $\alpha = 0^{\circ}$) for the model when the vane is vertical.

In order to expedite distribution of these data, no analysis of the results has been prepared.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 1, 1954.

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Approved: Thomas A. Harris
Chief of Stability Research Division

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REFERENCE

1. Tedeschi, L. J., and Robinson, D. W.: Preliminary Report of Rotochute Development. Rep. No. R-29 (Contract No. Nonr 901(00)), Kaman Aircraft Corp., Oct. 15, 1953.

TABLE I.- AERODYNAMIC CHARACTERISTICS OF ROTOCHUTE MODEL WITH ROTOR BLADES FOLDED AND LOCKED AT TOP AND BOTTOM

[Stabilizing vane vertical]

α, deg	β, deg	C_L	C_D	C_Y	C_m	C_l	C_n
-3	0	-0.0045	0.0104	0.0010	0.00032	-0.00015	-0.00005
0		-.0025	.0100	.0013	.00024	-.00011	-.00032
3		-.0007	.0099	.0020	.00022	-.00014	-.00066
6		.0009	.0102	.0024	.00017	-.00023	-.00093
9		.0030	.0112	.0026	.00001	-.00034	-.00118
12		.0050	.0120	.0027	-.00019	-.00056	-.00119
-3	-6	-.0010	.0112	.0132	-.00101	.00014	-.00321
	-3	-.0029	.0104	.0069	-.00021	-.00002	-.00144
	0	-.0039	.0105	.0010	.00036	-.00008	-.00007
	3	-.0051	.0111	-.0053	.00081	-.00005	.00167
	6	-.0056	.0120	-.0113	.00115	-.00007	.00328
0	-6	.0002	.0113	.0130	-.00104	-.00007	-.00310
	-3	-.0005	.0101	.0075	-.00039	-.00013	-.00186
	0	-.0024	.0101	.0014	.00027	-.00012	-.00034
	3	-.0035	.0103	-.0047	.00085	-.00001	.00122
	6	-.0045	.0110	-.0106	.00131	.00011	.00298
3	-6	.0019	.0116	.0125	-.00094	-.00032	-.00298
	-3	.0010	.0105	.0075	-.00047	-.00023	-.00198
	0	-.0008	.0101	.0020	.00016	-.00011	-.00073
	3	-.0015	.0103	-.0039	.00069	.00007	.00076
	6	-.0022	.0107	-.0099	.00116	.00027	.00240
6	-6	.0037	.0121	.0123	-.00103	-.00061	-.00288
	-3	.0026	.0112	.0075	-.00047	-.00043	-.00200
	0	.0016	.0104	.0026	.00009	-.00022	-.00095
	3	.0006	.0107	-.0032	.00041	-.00006	.00040
	6	.0003	.0114	-.0089	.00075	.00017	.00198
9	-6	.0062	.0132	.0124	-.00135	-.00085	-.00285
	-3	.0052	.0119	.0078	-.00076	-.00065	-.00205
	0	.0045	.0115	.0034	-.00042	-.00044	-.00120
	3	.0041	.0116	-.0021	-.00017	-.00018	.00007
	6	.0036	.0123	-.0078	.00009	-.00005	.00158
12	-6	.0085	.0143	.0121	-.00164	-.00106	-.00276
	-3	.0076	.0131	.0075	-.00101	-.00083	-.00190
	0	.0072	.0129	.0034	-.00083	-.00078	-.00128
	3	.0066	.0128	-.0015	-.00070	-.00049	-.00025
	6	.0065	.0136	-.0067	-.00059	-.00013	.00088

TABLE II.- AERODYNAMIC CHARACTERISTICS OF ROTOCHUTE MODEL WITH

ROTOR BLADES FOLDED AND LOCKED AT SIDES

[Stabilizing vane horizontal]

α, deg	β, deg	C_L	C_D	C_Y	C_m	C_l	C_n
-3	0	-0.0041	0.0104	0.0009	-0.00004	-0.00030	0.00006
0		.0014	.0107	-.0008	-.00178	-.00028	.00072
3		.0074	.0111	-.0023	-.00373	-.00018	.00152
6		.0116	.0119	-.0035	-.00499	.00003	.00190
9		.0160	.0135	-.0049	-.00628	.00014	.00242
12		.0199	.0150	-.0057	-.00736	.00033	.00272
-3	-6	-.0053	.0114	.0065	.00076	-.00022	-.00016
	-3	-.0048	.0110	.0038	.00028	-.00019	.00003
	0	-.0041	.0107	.0012	-.00021	-.00019	.00002
	3	-.0032	.0110	-.0019	-.00047	-.00031	.00008
	6	-.0018	.0117	-.0050	-.00093	-.00047	.00031
	9	-.0005	.0128	-.0084	-.00146	-.00070	.00060
	12	.0013	.0146	-.0122	-.00195	-.00098	.00121
0	-6	-.0003	.0114	.0051	-.00080	-.00022	.00039
	-3	.0006	.0108	.0021	-.00138	-.00030	.00056
	0	.0017	.0105	-.0007	-.00178	-.00035	.00072
	3	.0023	.0111	-.0036	-.00238	-.00039	.00074
	6	.0037	.0118	-.0061	-.00274	-.00058	.00087
	9	.0045	.0133	-.0094	-.00301	-.00085	.00113
	12	.0064	.0149	-.0124	-.00328	-.00122	.00153
3	-6	.0052	.0121	.0037	-.00246	-.00008	.00088
	-3	.0062	.0112	.0006	-.00304	-.00006	.00129
	0	.0076	.0111	-.0023	-.00366	-.00022	.00145
	3	.0079	.0117	-.0047	-.00386	-.00040	.00133
	6	.0085	.0126	-.0070	-.00392	-.00068	.00125
	9	.0089	.0135	-.0092	-.00409	-.00101	.00120
	12	.0100	.0150	-.0117	-.00419	-.00130	.00125
6	-6	.0103	.0128	.0020	-.00416	.00009	.00164
	-3	.0112	.0119	-.0008	-.00468	.00013	.00201
	0	.0119	.0123	-.0033	-.00499	-.00008	.00183
	3	.0123	.0127	-.0058	-.00504	-.00037	.00179
	6	.0127	.0137	-.0077	-.00512	-.00074	.00173
	9	.0130	.0150	-.0099	-.00525	-.00103	.00162
	12	.0138	.0158	-.0124	-.00520	-.00136	.00170
9	-6	.0154	.0139	.0009	-.00574	.00048	.00214
	-3	.0160	.0134	-.0020	-.00597	.00030	.00230
	0	.0168	.0137	-.0044	-.00639	.00007	.00244
	3	.0172	.0143	-.0068	-.00643	-.00036	.00235
	6	.0179	.0156	-.0092	-.00657	-.00076	.00234
	9	.0182	.0164	-.0113	-.00654	-.00109	.00236
	12	.0186	.0176	-.0138	-.00666	-.00136	.00241
12	-6	.0196	.0150	.0005	-.00676	-.00001	.00219
	-3	.0200	.0146	-.0025	-.00699	-.00008	.00248
	0	.0213	.0154	-.0053	-.00739	-.00016	.00277
	3	.0213	.0160	-.0079	-.00748	-.00024	.00298
	6	.0220	.0167	-.0105	-.00760	-.00032	.00308
	9	.0224	.0181	-.0128	-.00800	-.00039	.00318
	12	.0234	.0199	-.0158	-.00832	-.00046	.00342

TABLE III.- AERODYNAMIC AND OPERATIONAL CHARACTERISTICS OF ROTOCHUTE MODEL WITH ROTOR BLADES TURNING

[Stabilizing vane horizontal]

α, deg	β, deg	C_L	C_D	C_Y	C_m	C_l	C_n	Rotor-blade tip speed, V_t, ft/sec	a_0, deg	Tunnel airspeed, V, ft/sec
-3	0	-0.0059	0.2926	-0.0002	0.00158	0.00132	-0.00097	182	3.82	75.3
0		-.0141	.2926	-.0002	.00070	.00139	-.00060			
3		-.0168	.2906	-.0002	-.00016	.00137	-.00038			
6		-.0290	.2943	-.0015	-.00152	.00129	.00054			
0	-6	-.0168	.2958	-.0259	-.00070	.00061	-.00104	182	3.82	75.3
	-3	-.0127	.2960	-.0110	.00037	.00029	-.00097			
	0	-.0195	.2979	-.0002	.00054	.00027	-.00083			
	3	-.0154	.2942	.0120	.00100	.00067	-.00075			
	6	-.0100	.2911	.0269	.00136	.00045	-.00056			
-3	0	-.0086	.3156	-.0001	-.00133	.00055	-.00139	196	3.00	75.3
0		-.0182	.3164	-.0001	-.00236	.00026	-.00075			
3		-.0263	.3152	-.0001	-.00432	.00040	-.00074			
6		-.0372	.3144	-.0001	-.00564	.00069	.00011			
0	-6	-.0168	.3056	-.0272	-.00050	.00018	-.00154	196	3.00	75.3
	-3	-.0114	.3162	-.0136	.00031	-.00013	-.00067			
	0	-.0100	.3133	.0013	.00057	.00001	-.00093			
	3	-.0127	.3128	.0134	.00040	-.00008	-.00053			
	6	-.0127	.3098	.0283	.00035	.00013	-.00031			
-3	0	-.0076	.4230	-.0004	.00218	.00037	-.00211	237	2.19	60.0
0		-.0224	.4304	-.0004	.00004	.00043	-.00204			
3		-.0350	.4316	-.0004	-.00016	.00059	-.00194			
6		-.0561	.4302	-.0004	-.00097	.00056	-.00098			
0	-6	-.0076	.4247	-.0424	-.00035	.00052	-.00417	237	2.19	60.0
	-3	-.0097	.4243	-.0214	.00102	-.00025	-.00285			
	0	-.0076	.4245	-.0046	.00247	.00004	-.00256			
	3	-.0139	.4256	.0143	.00196	.00001	-.00199			
	6	-.0181	.4209	.0353	.00258	.00055	-.00071			

TABLE IV.- STATIC OPERATIONAL CHARACTERISTICS OF ROTOCHUTE MODEL

[Stabilizing vane horizontal; $\alpha = \beta = 0^{\circ}$]

Springs on governor	C_D	Rotor-blade tip speed, V_t, ft/sec	a_0, deg	Tunnel airspeed, V, ft/sec
Springs 1 (Negligible preload)	0.4326	127	0.55	17.3
	.6193	232	1.10	37.0
	.3262	186	2.72	60.7
	.2878	184	3.82	80.5
	.2471	192	4.92	102.0
	.2421	200	6.38	121.5
Springs 1 (Small preload)	.4250	123	0	17.3
	.6271	255	.82	37.0
	.5068	206	1.92	45.0
	.3443	196	3.01	66.5
	.3287	188	3.27	68.5
	.3006	192	3.55	80.5
	.2606	208	4.64	102.0
Springs 1 (Moderate preload)	.4527	122	0	17.3
	.5960	272	.82	37.0
	.4662	216	1.92	49.3
	.3450	206	3.27	70.8
	.2740	207	4.37	102.0
Springs 1 (Large preload)	.528	278	----	37.0
	.527	300	----	42.8
Springs 2 (Negligible preload)	.4477	118	.55	17.3
	.6160	225	1.64	37.0
	.4267	225	2.72	60.7
	.3011	184	4.64	80.5
	.2551	196	5.46	102.0
Springs 2 (Small preload)	.4401	117	.55	17.3
	.5782	260	1.10	37.0
	.4821	258	2.72	60.7
	.3485	220	4.10	80.5
Springs 2 (Moderate preload)	.5080	120	.55	17.3
	.5610	264	.82	37.0
	.4930	280	2.18	60.7
Springs 3	.4577	121	.55	17.3
	.6371	250	1.64	37.0
	.4598	222	2.73	53.7
	.3164	198	4.10	80.5

TABLE V.- AERODYNAMIC CHARACTERISTICS OF ROTOCHUTE BODY

[$\alpha = 0^{\circ}$]

β, deg	C_L	C_D	C_Y	C_m	C_l	C_n
-6	-0.0035	0.0074	0.0039	0.00060	0.00003	0.00083
-3	-.0036	.0068	.0026	.00060	.00003	.00047
0	-.0032	.0064	.0003	.00062	.00011	.00015
3	-.0038	.0069	-.0024	.00058	.00010	-.00018
6	-.0034	.0076	-.0043	.00058	.00021	-.00061

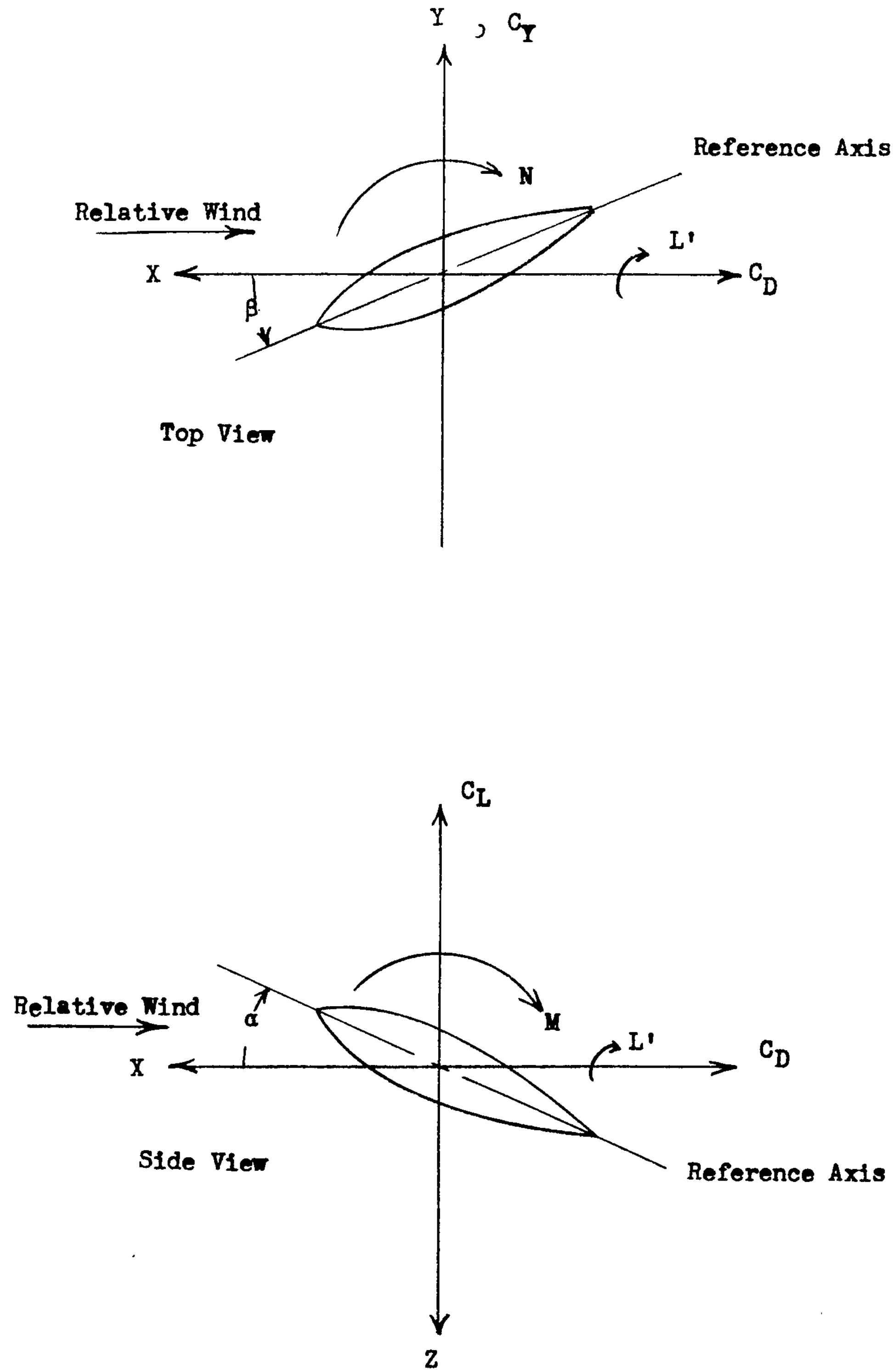
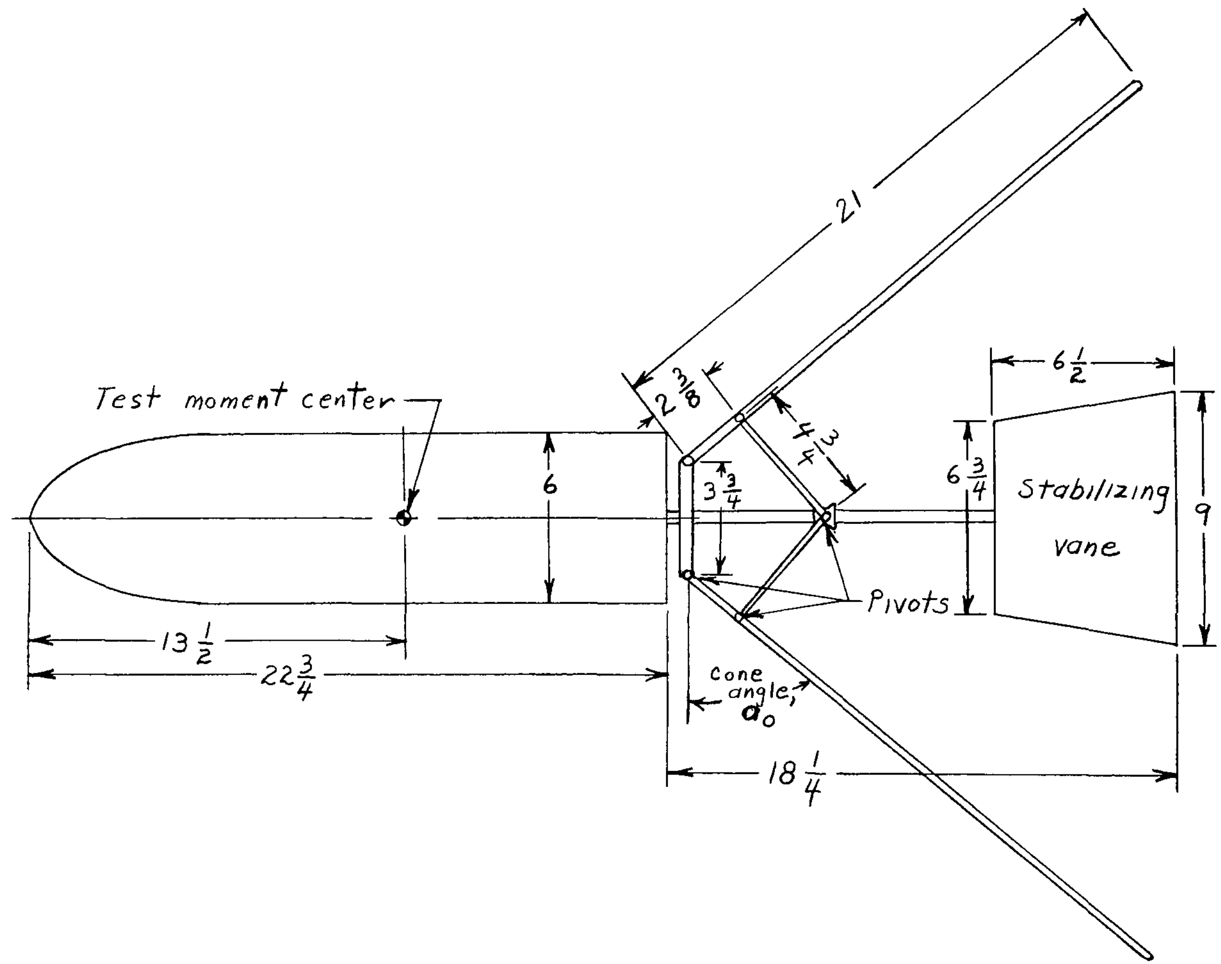
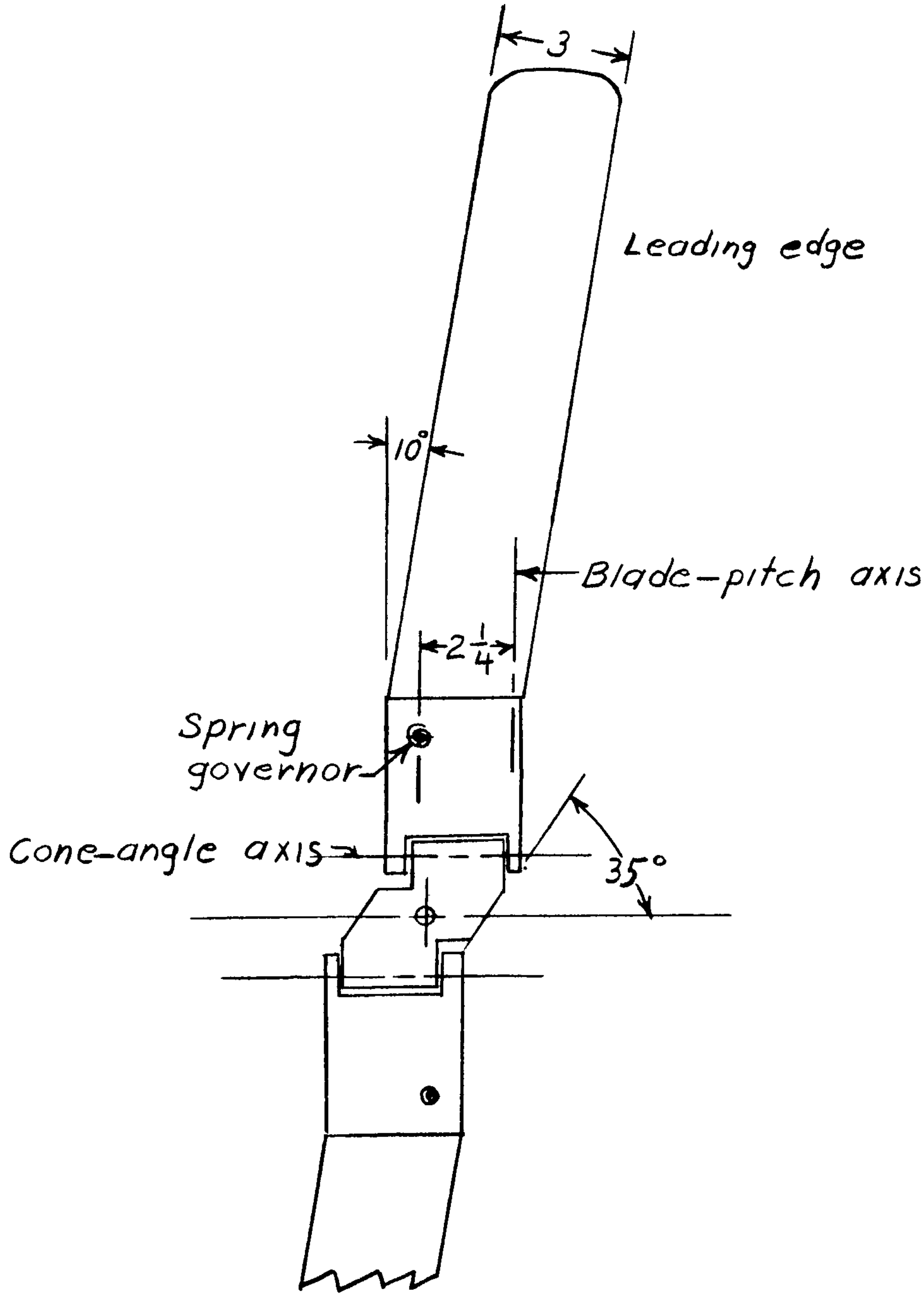


Figure 1.- System of wind axes. Arrows indicate positive directions of forces, moments, and displacements.



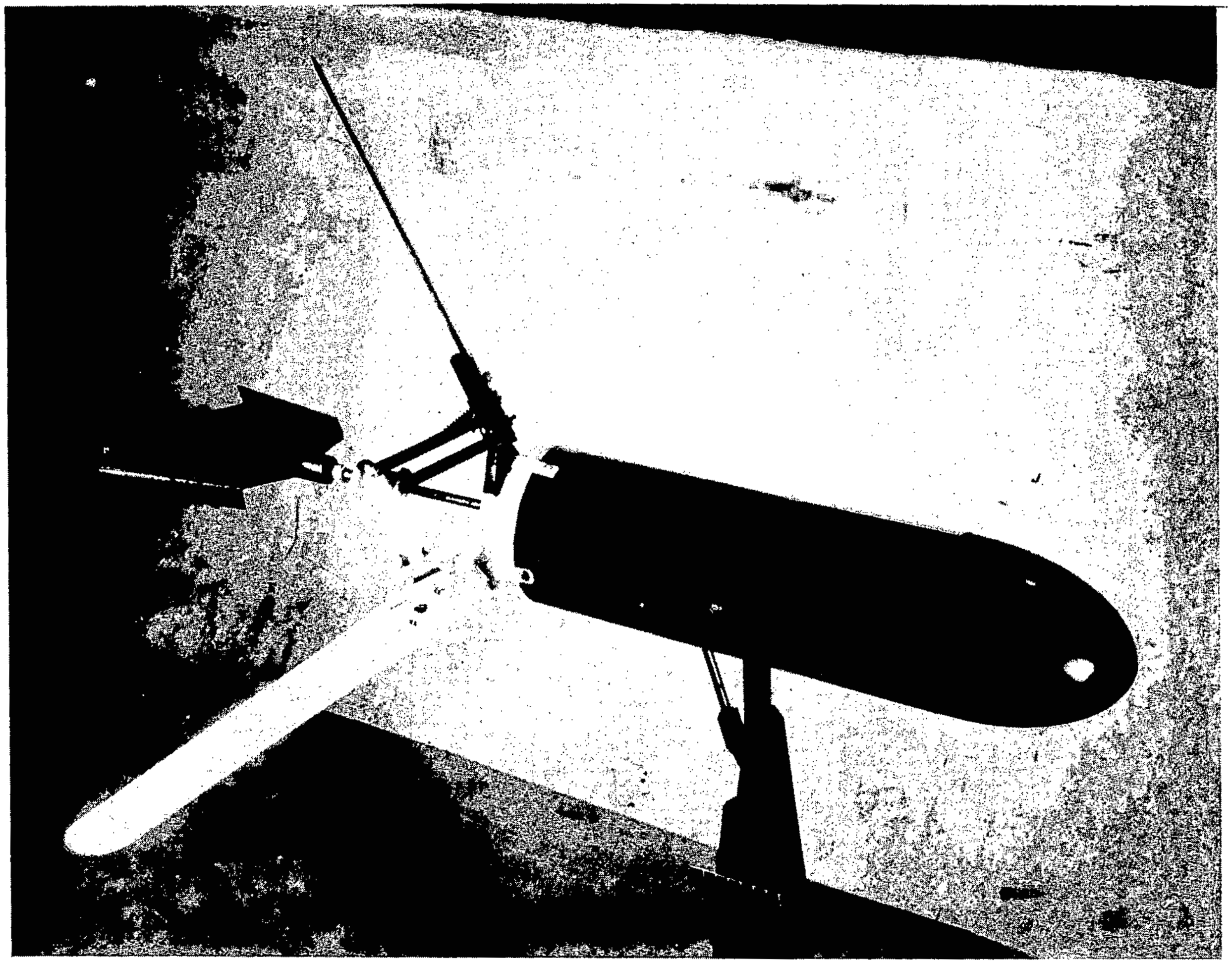
(a) Side view of Rotochute.

Figure 2.- Geometric characteristics of Rotochute model. All dimensions in inches.



(b) Additional rotor geometric characteristics.

Figure 2.- Concluded.



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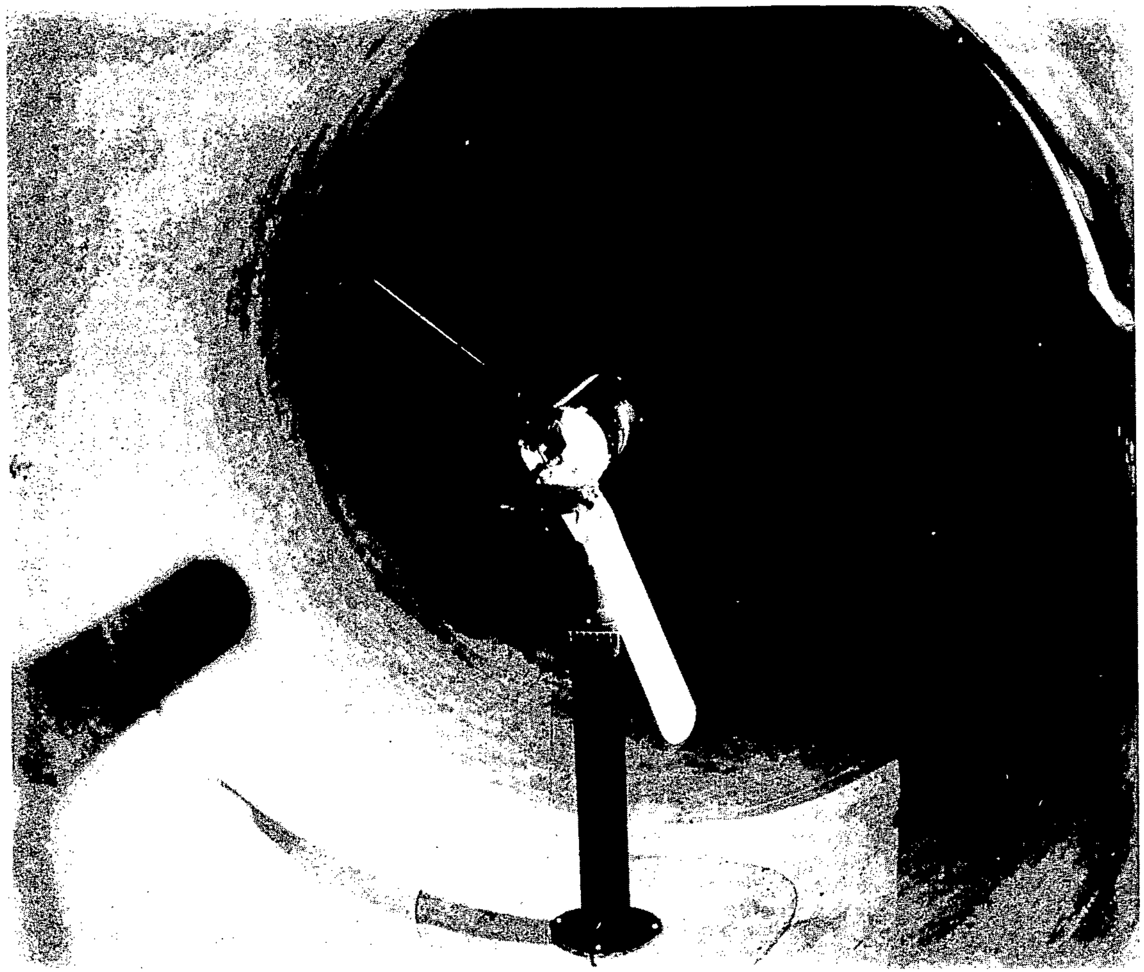
(a) Side view.

Figure 3.- Photographs of Rotochute model in the Langley stability tunnel.



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(b) Rear view.

Figure 3.- Concluded.

[redacted]

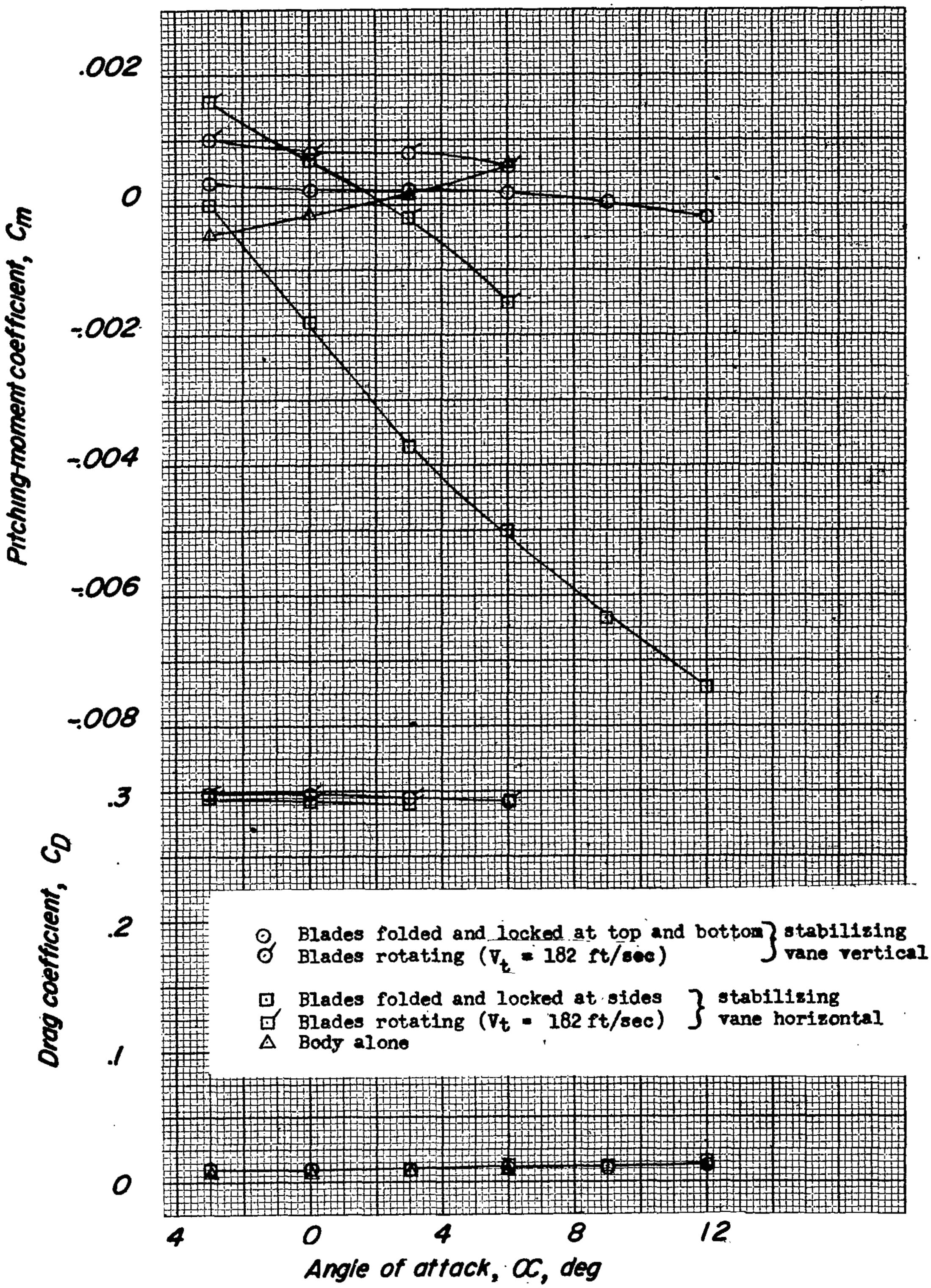
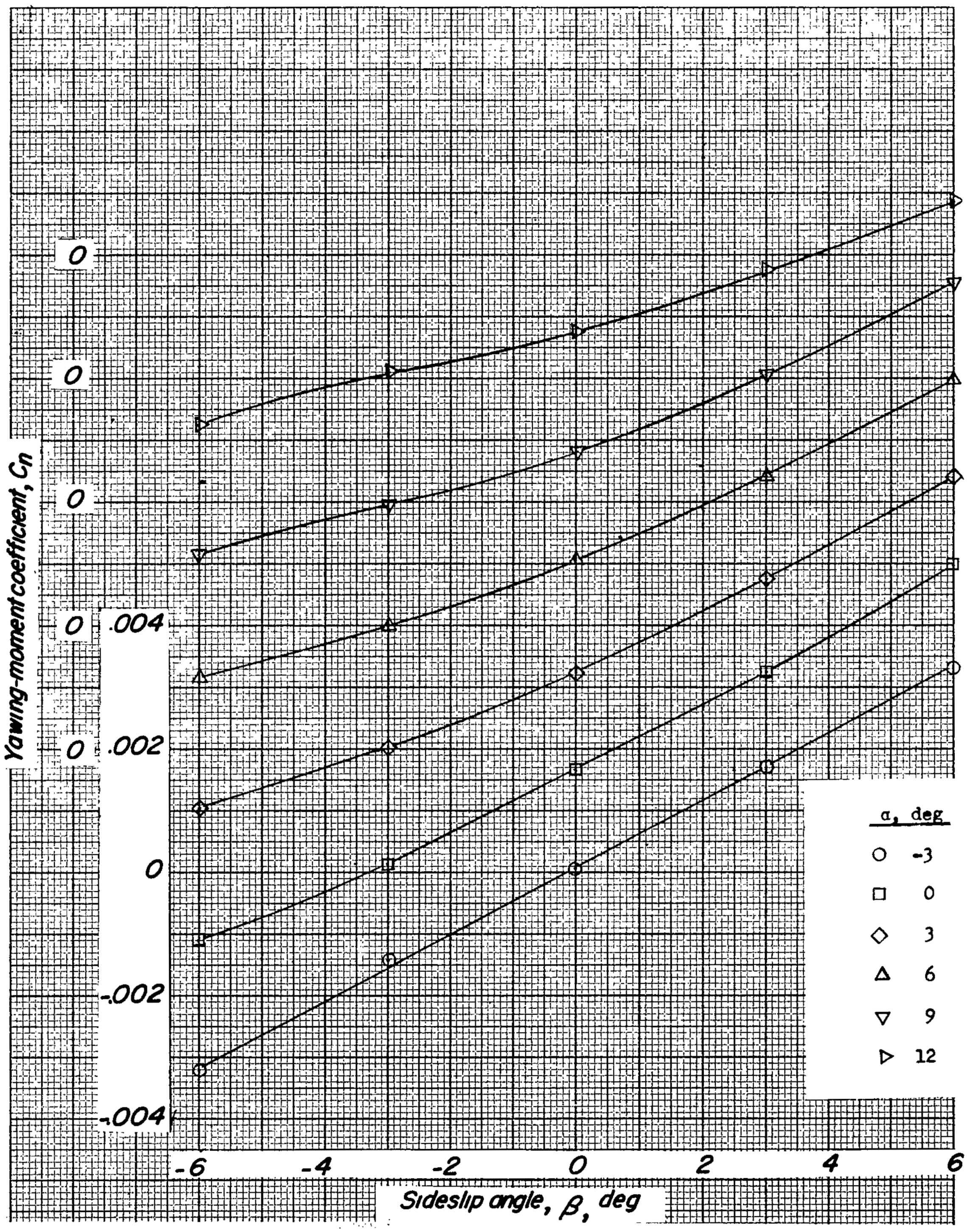


Figure 4.- Variation of C_m and C_D with angle of attack for various Rotochute conditions.

[redacted]

 [redacted]

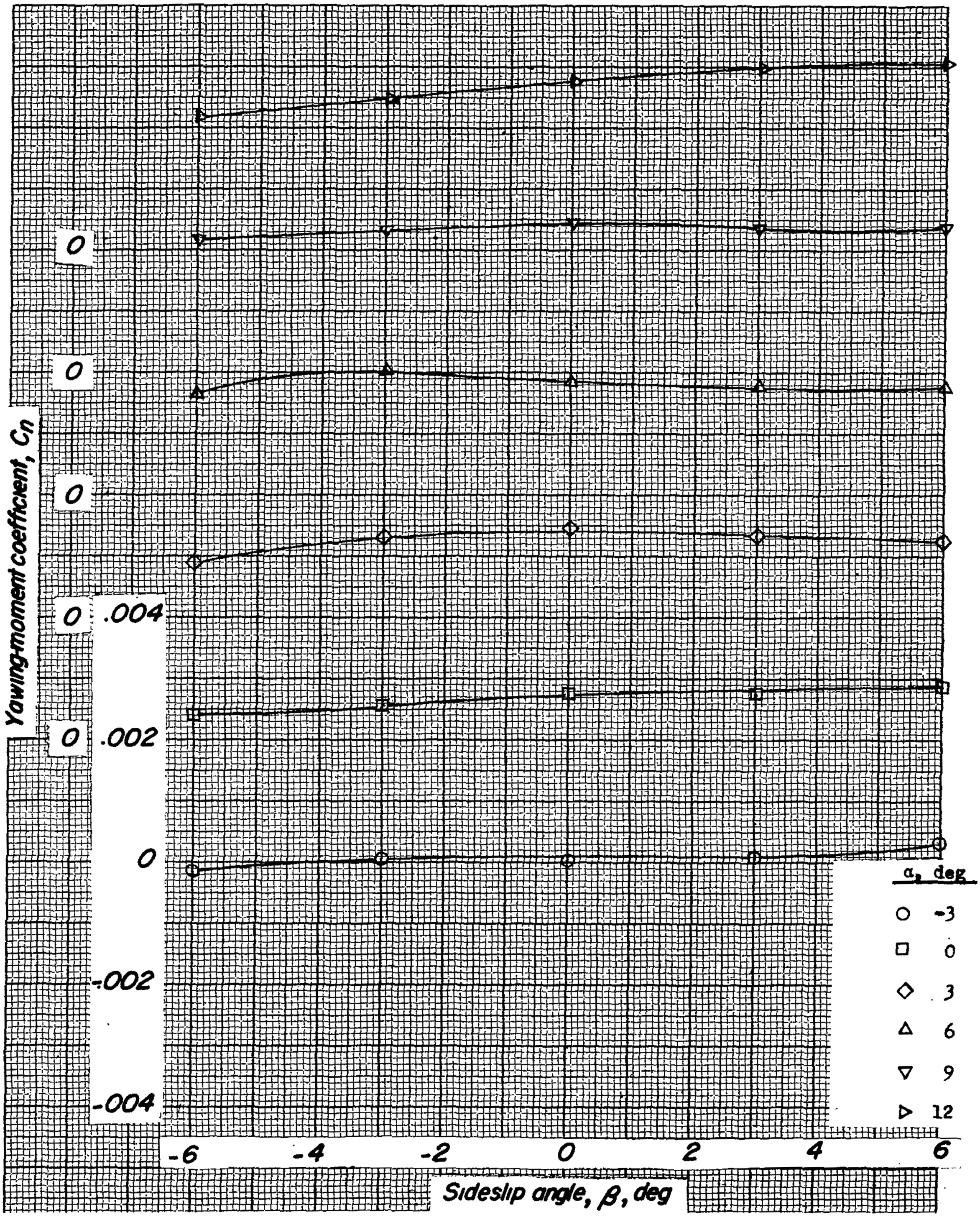


(a) Blades locked at top and bottom. Stabilizing vane vertical.

Figure 5.- Variation of yawing-moment coefficient with sideslip angle for the Rotochute model with blades folded and locked.

[redacted]

[redacted]



(b) Blades locked at sides. Stabilizing vane horizontal.

Figure 5.- Concluded.

[redacted]

○ Blades folded and locked at top and bottom, stabilizing vane vertical

□ Blades folded and locked at sides, stabilizing vane horizontal

◇ Blades rotating, stabilizing vane vertical (V_t = 182 ft/sec)

△ Blades rotating, stabilizing vane horizontal (V_t = 182 ft/sec)

▽ Body alone

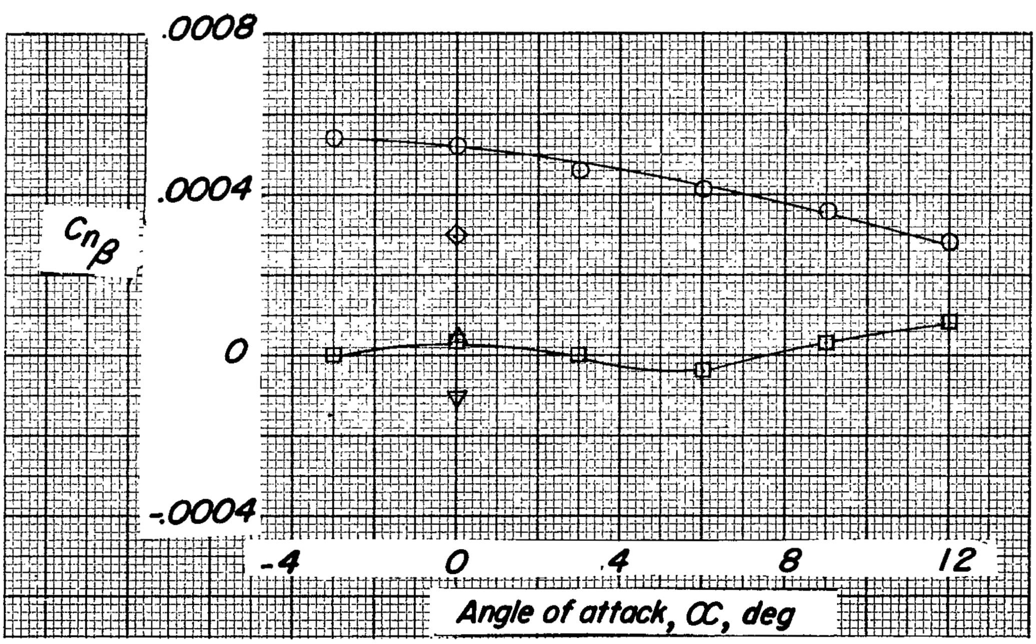
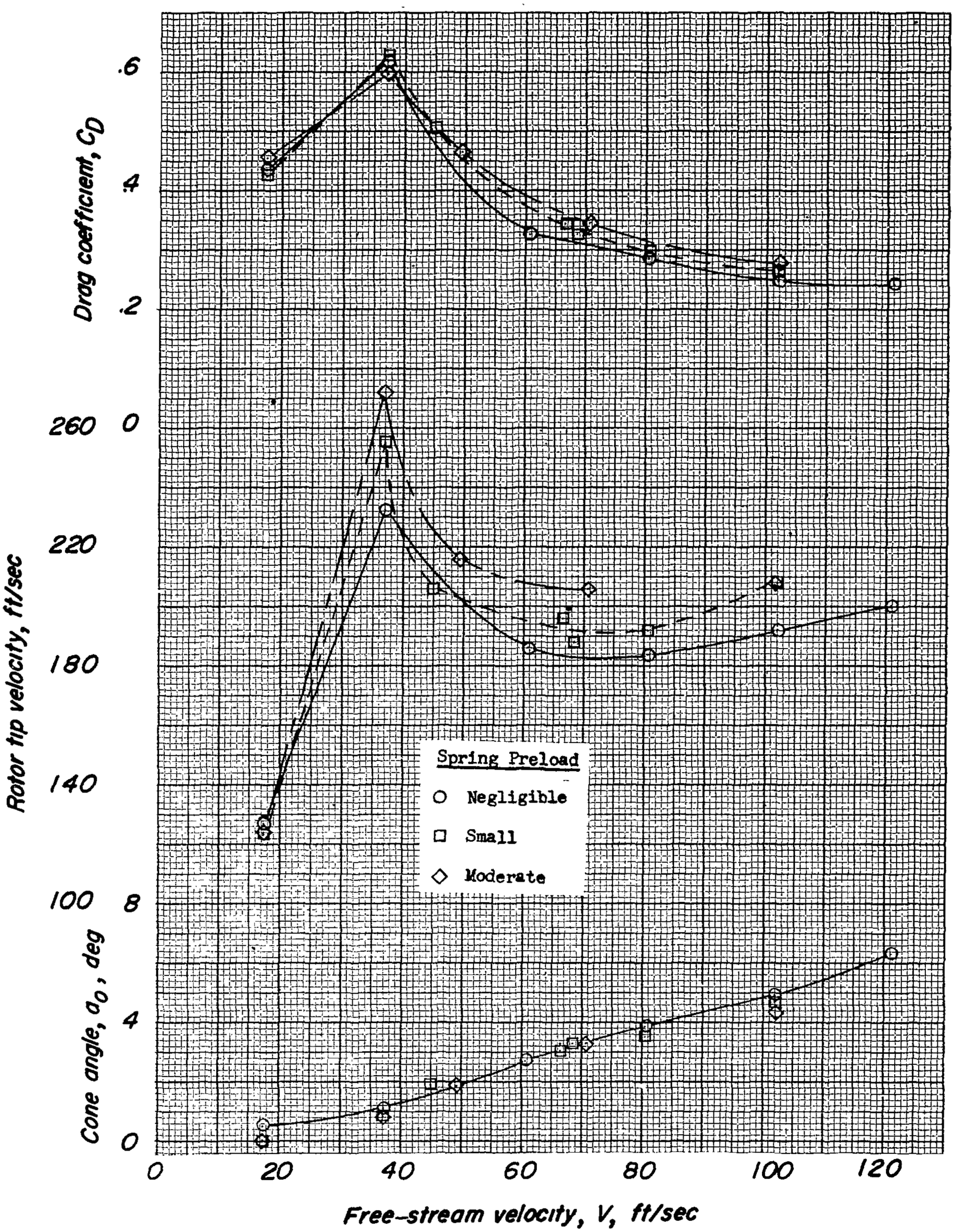


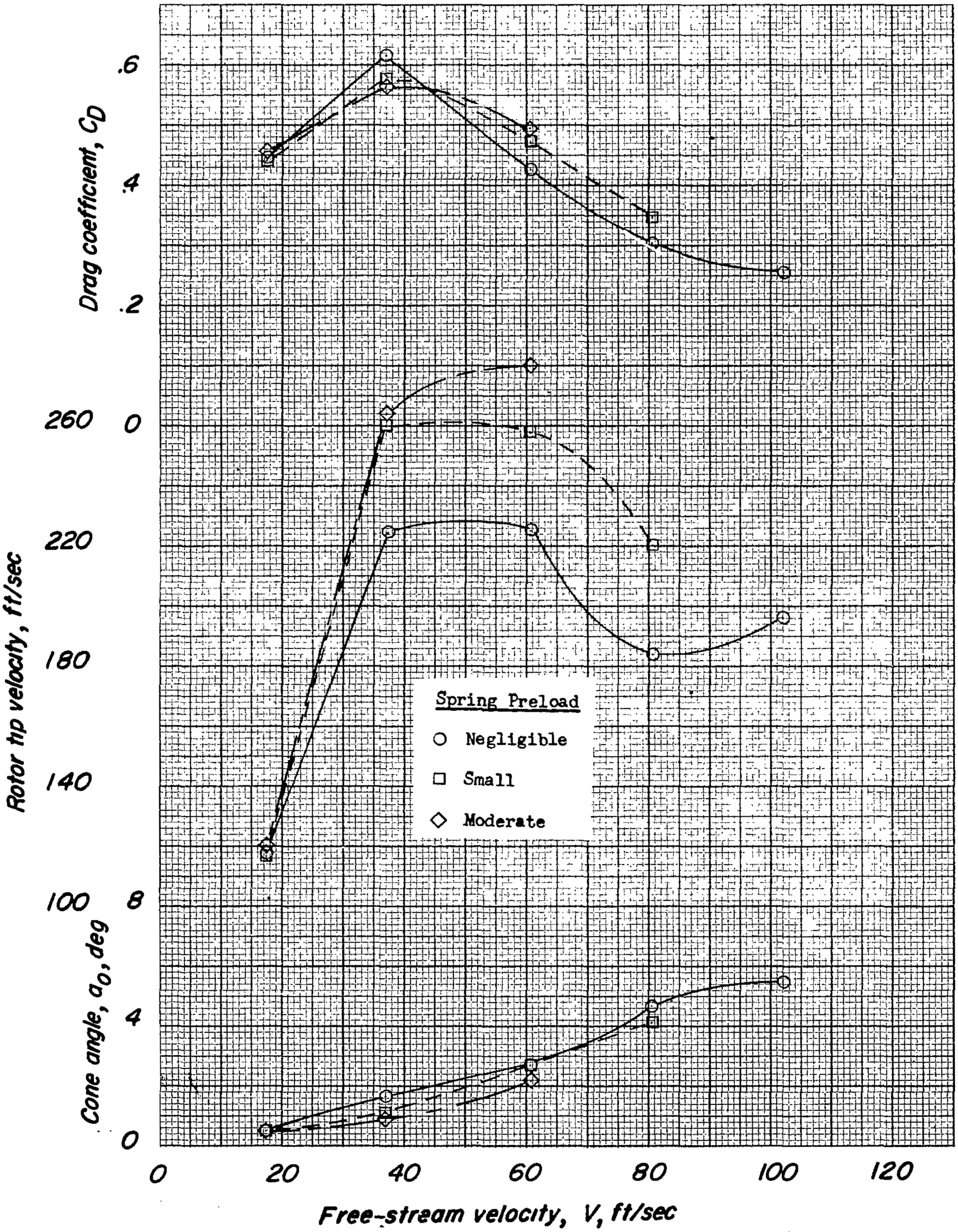
Figure 6.- Directional stability of the Rotochute for various configurations.



(a) Springs 1 on blade-pitch governor.

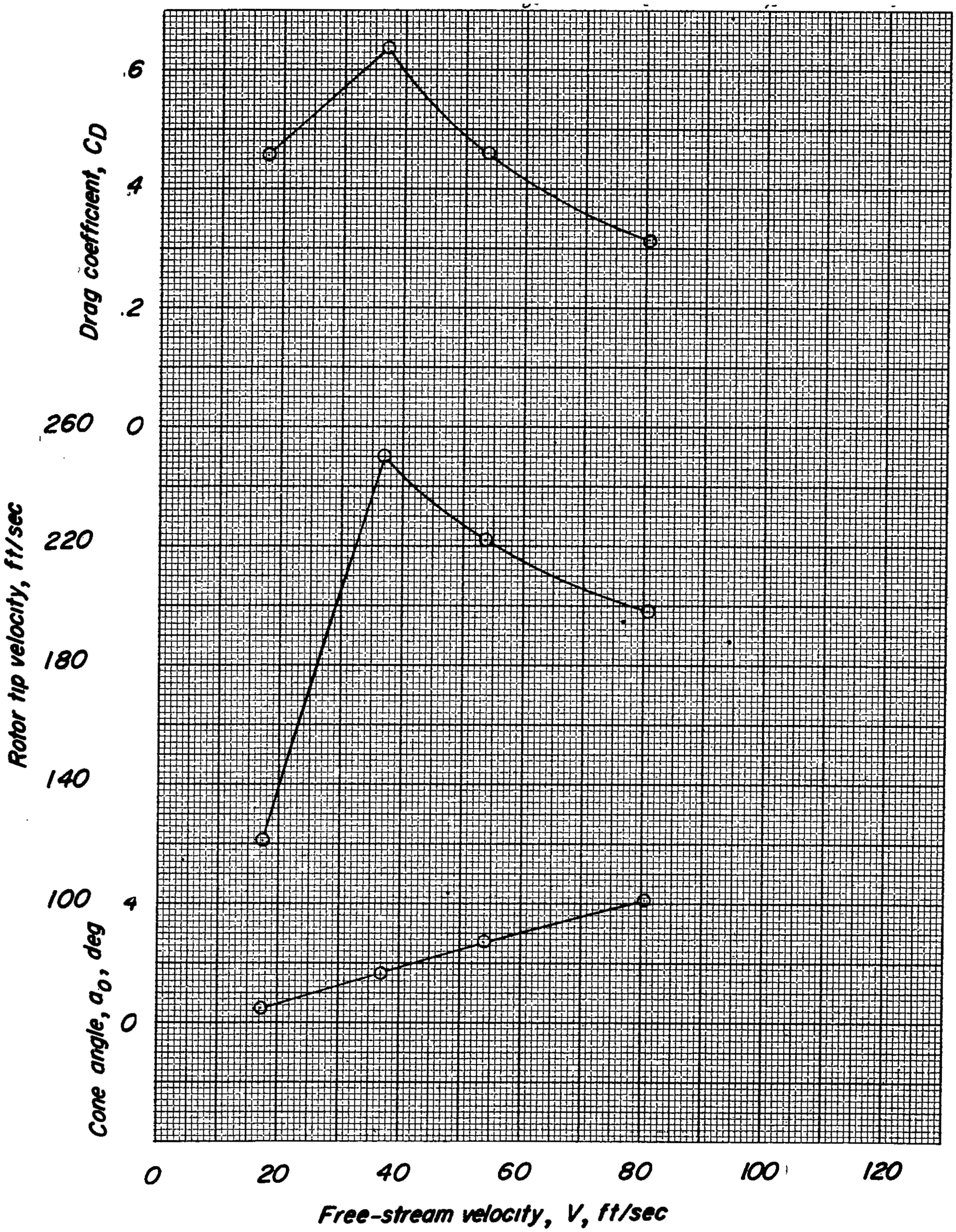
Figure 7.- Operational characteristics of Rotochute model. $\alpha = \beta = 0^{\circ}$.

[redacted]



(b) Springs 2 on blade-pitch governor.

Figure 7.- Continued.



(c) Springs 3 on blade-pitch governor.

Figure 7.- Concluded.

[redacted]