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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF ROOT RESTRAINT ON THE FLUTTER OF A SWEPTBACK, UNIFORM, CANTILEVER WING WITH A VARIABLY LOCATED CONCENTRATED MASS

By John E. Tomassoni and Herbert C. Nelson

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Data from 129 flutter tests conducted in the Langley 4.5-foot flutter research tunnel have been compiled and are reported. The investigation was carried out to obtain information which would test the validity of the assumption of root restraint used commonly in the flutter analyses of swept wings. This investigation was made with wings of 45° and 60° angles of sweepback each having two different lengths. Each configuration included a concentrated mass located at various spanwise positions and at two chordwise positions.

The data obtained provided results which indicate that the assumption of root restraint is fairly well justified, at least for swept wings having length-to-chord ratios of the order of 4.5. However, none of the wings tested with the roots perpendicular to the leading edge showed exactly the same flutter trends over a range of spanwise weight positions as those obtained with the corresponding wing having the root parallel to the stream direction.

INTRODUCTION

The boundary conditions at the root of a sweptback wing make the problem of an exact structural analysis very complicated. In order to circumvent this difficulty, the following simplifying assumptions are sometimes made: that (1) the root is rigidly restrained normal to the elastic axis, and (2) the elastic axis is a straight line. With these assumptions and with the air forces, modified for sweep by the method of reference 1, a flutter analysis of a sweptback wing can be made.

The purpose of this paper is to present experimental data on the flutter characteristics of weighted sweptback wings clamped at the root to approximate the conditions of the previously mentioned assumptions. The models used in the investigation are similar to the swept models of reference 2 but are modified by root-stiffening plates and change of length. The lengths of the models were measured along the elastic axis which was located at the midchord.

By approximating the simplifying assumptions of theory in regard to root restraint and elastic axis, the data presented provide a means of evaluating the sufficiency of theory regarding structural representation and air-force evaluation.

SYMBOLS

w	weight of wing section, pounds per inch
W_w	weight of concentrated weight, pounds
l	length of midchord line, feet
b	half chord of wing section measured perpendicular to the midchord line, feet
t	thickness of wing section, inches
Λ	sweep angle measured from an axis perpendicular to air stream in plane of wing to elastic axis, degrees, positive for sweepback
x_α	distance from elastic axis to center of gravity of wing section, referred to half chord, positive rearward
e_w	distance from elastic axis of wing section to center of gravity of weight, referred to half chord, negative for forward weight location
I_{CG}	mass moment of inertia of wing section about its center of gravity, inch-pound-second^2 per inch
I_{EA}	mass moment of inertia of wing section about its elastic axis, inch-pound-second^2 per inch

I_w mass moment of inertia of weight about its center of gravity, inch-pound-second^2

EI bending rigidity of wing section, pound-inch^2

GJ torsional rigidity of wing section, pound-inch^2

m mass of wing per unit length, slugs per foot

r_α nondimensional radius of gyration of wing section about its elastic axis $\left(\sqrt{\frac{I_{EA}}{mb^2}}\right)$

q_f dynamic pressure at flutter, pounds per square foot

ρ air density at flutter, pounds per square foot

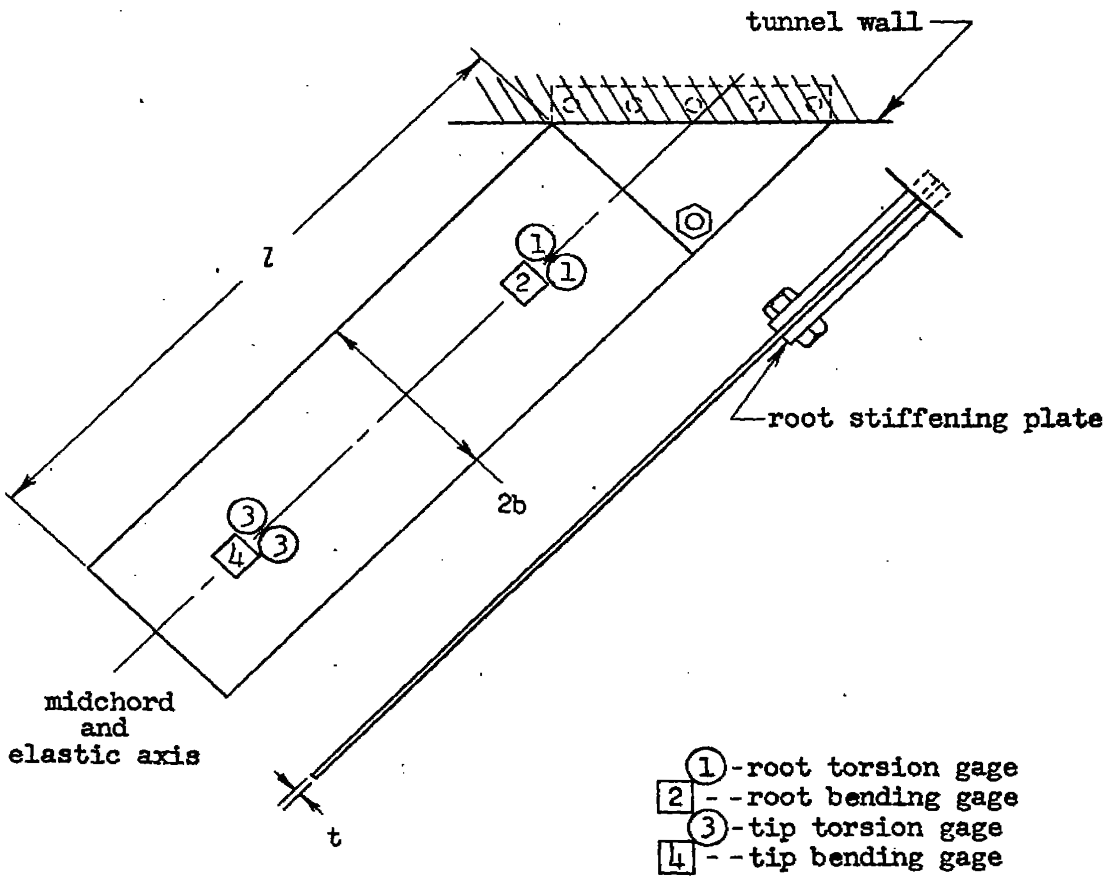
v_f stream velocity at flutter, feet per second

κ wing mass-density ratio at flutter $\left(\frac{\pi\rho b^2}{m}\right)$

g_h, g_α structural damping coefficient in bending and torsional degree of freedom, respectively

APPARATUS

The experimental results presented herein have been obtained in the Langley 4.5-foot flutter research tunnel with air used as the testing medium under atmospheric conditions. In this investigation models B-1 and B-2 were the same as model B of reference 2 except as modified by the root stiffening plates and change of length. Models C-1 and C-2 were of as nearly the same dimensions as model C of reference 2 as manufactured 0.090-inch aluminum sheet stock would permit and were also modified by root stiffening plates and change of length. The accompanying sketch shows how the $\frac{1}{2}$-inch-thick root stiffening plates were attached to the models.



Small changes in the wing length were included to determine if a single effective length could be found which would give the same flutter speeds as the corresponding model of reference 2. The following table lists the models with their respective lengths and sweep angles:

Model	l (ft)	Λ (deg)
B (reference 2) B-1 B-2	3.00 2.75 2.83	45
C (reference 2) C-1 C-2	3.00 2.75 3.00	60

The section properties of the wings are as follows:

Chord, 2b, feet	0.667
Airfoil section	Flat plate
g_h, nondimensional	0.01 (approx.)
g_α, nondimensional	0.005 (approx.)
t, inches	0.090
w, pounds per inch	0.076
I_{CG}, inch-pound-second^2 per inch	0.000995
I_{EA}, inch-pound-second^2 per inch	0.000995
EI, pound-inch^2	0.00506×10^6
GJ, pound-inch^2	0.008×10^6
x_α, nondimensional	0.0
$r_\alpha{}^2$, nondimensional	0.334
$1/\kappa$, (standard air density, no concentrated weight)	34.1

Two weights which were essentially the same were used in the tests. One was attached at various positions along the leading edge and the other along the midchord line of each model. The weight properties are:

Item	Leading-edge weight	Midchord weight
W_W, lb	3.12	3.12
e_W	-1.0	0
I_W, in.-lb-sec^2	0.010	0.0098

Strain gages cemented on the wings used in conjunction with a recording oscillograph provided a means for obtaining the frequencies and phase relationships of the torsional and bending strains at the gage locations. The positions at which the strain gages were attached to the models are shown in the preceding sketch. The gage traces on each of the oscillograph records in figure 1 are numbered from left to right and represent the response of the root-torsion, root-bending, tip-torsion, and tip-bending gages, respectively. The fifth trace on the records is an imposed calibration frequency. The apparatus section of reference 2 gives a complete description of the method used to obtain the phase angles listed in table I.

The attenuation marked on each gage trace is a scale number obtained by electrical multiplication where the value of the attenuation is inversely proportional to the magnification of response. The amplitudes of the traces combine with the attenuation to give relative stresses, torques, or moments. These relative values are obtained in the following manner, the first two traces of a record being used as an example:

$$\frac{\text{Stress (1)}}{\text{Stress (2)}} = \left(\frac{\text{Attenuation (1)}}{\text{Attenuation (2)}}\right)\left(\frac{\text{Amplitude (1)}}{\text{Amplitude (2)}}\right)$$

TEST PROCEDURE

An investigation at zero airspeed was conducted before each series of tests to obtain the first three natural frequencies for each spanwise weight position. Several spanwise positions of the concentrated weight for a constant chordwise station constituted a series for one model. During each test the airspeed in the tunnel was increased slowly. At the critical flutter speed the tunnel conditions were observed, and an oscillograph record of the model vibrations was taken. The tunnel airspeed was then reduced immediately after the critical flutter speed was attained in order to prevent the model from being destroyed. The models were tested initially without any weight and each of the series of tests was accomplished by moving the weight progressively spanwise to the tip. After a series of tests was completed the model was retested without the weight to provide knowledge of any possible damage which may have occurred. No difference was found to exist.

PRESENTATION AND DISCUSSION OF RESULTS

This paper presents the experimental data obtained from flutter testing 45° and 60° sweptback wings with the roots modified by stiffening plates. In all plots the test results are presented as functions of the wing length l.

The experimental results are compiled in table I. The dynamic pressure, flutter speed, Mach number, and the first three natural frequencies for each weight position and the corresponding flutter frequencies are listed. Also the phase relationships of the torsional and bending stresses at the gage locations for the second and third natural and flutter frequencies are given. The Reynolds number for each series of tests is given and the chord length used in its determination was the length parallel to the air stream. A sketch of each model tested is included in table I with its corresponding data.

The oscillograph records taken at flutter for the various cases tested are shown in figure 1. The four traces on the records in the top row only, which represent the vibratory motions of the model, are numbered, but these numbers pertain in the same order to all records. Each is marked with its appropriate attenuation. The unusual type of flutter involving two frequencies simultaneously, as reported in reference 2, also occurred in a few cases during the present tests.

The flutter data of figure 2 show the validity of the commonly used assumptions regarding root restraint for the models tested. In general, the differences between the data from a given unmodified wing and that from the corresponding wing having a modified root are small, indicating that the assumptions are fairly well justified.

The differences in the flutter speed when the concentrated weight was on the wing leading edge were small. This indicates that as the length of the wing with the modified root was increased (B-1 to B-2 or C-1 to C-2) the flutter speed approached that of the unmodified wing (B or C, respectively) for the range of spanwise weight locations 0 to 45 percent l. From the 65 to about 100 percent spanwise weight range an opposite trend is noted. In the range from 45 to 65 percent l an irregular variation exists.

The data for the weight at the midchord line indicate that as the length of the wing was increased the flutter speed approached that of the unmodified wing over both the 0 to 45 percent and the 65 to 100 percent spanwise weight ranges while the range from 45 to 65 percent was irregular.

In figure 3 the first three natural and the flutter frequencies are plotted against spanwise weight position for each of the series of tests. These plots show the relation between the flutter frequency and the first three natural frequencies for each of the configurations tested.

CONCLUDING REMARKS

The structural assumptions usually made in the flutter analysis of swept wings, that the root is rigidly restrained and the elastic axis is a straight line at least for the uniform type of wing tested, appear to be fairly well justified. Exceptions are noted for critical ranges of concentrated weight positions where small changes in the position of the weight produce relatively large changes in the experimentally determined flutter speed.

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REFERENCES

1. Barmby, J. G., Cunningham, H. J., and Garrick, I. E.: Investigation of the Effects of Sweep on the Flutter of Cantilever Wings. NACA RM L8H30, 1948.

2. Nelson, Herbert C., and Tomassoni, John E.: Experimental Investigation of the Effects of Sweepback on the Flutter of a Uniform Cantilever Wing with a Variably Located Concentrated Mass. NACA RM L9F24, 1949.

TABLE I.- TEST DATA

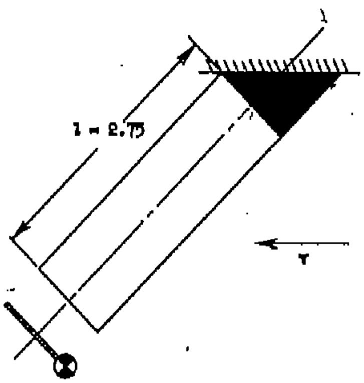
Model	Run	q_r (lb/sq ft)	v_r (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	Frequencies (cps) Natural 2nd	Frequencies (cps) Natural 3rd	Frequencies (cps) Flutter	Phase angle (deg), 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
Model B-1 Swept, untapered wing; $\Lambda = 45^\circ$ Weight moved along leading edge; $e_w = -1$ Reynolds number $\cong 5208.9v_r$ 	1	34.51	175.8	0.1535	0	2.61	16.19	20.97	13.70	----	Ref.	-	180	Ref.	----	0	----	Ref.	92	28	18
	2	35.85	179.3	0.1565	3.03	2.61	16.09	21.13	13.63	----	Ref.	-	180	Ref.	----	0	----	Ref.	95	29	0
	3	34.70	176.6	0.1540	9.09	2.63	15.48	19.81	12.78	Ref.	----	-	0	Ref.	0	0	180	Ref.	45	27	22
	4	30.69	165.9	0.1445	15.15	2.63	12.77	18.57	11.21	Ref.	0	-	0	Ref.	0	0	180	Ref.	24	0	20
	5	25.81	152.1	0.1324	21.21	2.56	9.86	18.18	9.24	Ref.	0	-	0	Ref.	0	0	180	Ref.	0	0	33
	6	28.40	159.7	0.1390	27.27	2.56	8.62	18.00	8.06	Ref.	0	-	0	Ref.	0	0	180	Ref.	0	42	33
	7	45.71	203.2	0.1770	33.33	2.47	7.78	18.18	7.14	Ref.	0	-	0	Ref.	0	0	180	Ref.	82	77	267
	8	87.48	283.1	0.2470	39.39	2.25	7.52	17.86	15.91	Ref.	0	-	0	Ref.	0	0	180	Ref.	0	0	256
	9	93.79	293.4	0.2560	45.45	2.17	7.52	17.65	15.59	Ref.	0	-	0	Ref.	0	0	180	Ref.	27	38	0
	10	119.60	333.1	0.2905	51.51	2.04	7.84	17.31	17.16	Ref.	----	-	0	Ref.	0	0	180	Ref.	0	12	66
	11	245.50	494.5	0.4285	57.57	1.81	8.33	16.90	43.10	Ref.	----	-	0	Ref.	0	0	180	Ref.	60	180	305
	12	236.16	484.8	0.4190	63.63	1.72	9.09	16.63	31.90	Ref.	0	-	0	Ref.	0	0	180	Ref.	0	0	180
	13	178.40	416.9	0.3600	69.69	1.61	10.07	16.35	16.67	Ref.	0	0	0	Ref.	0	0	180	Ref.	0	277	288
	14	74.27	263.9	0.2270	75.75	1.51	10.63	16.09	16.39	Ref.	0	0	0	Ref.	0	0	180	Ref.	114	353	284
	15	35.15	180.7	0.1550	81.81	1.41	11.04	15.95	16.10	Ref.	0	0	0	Ref.	180	-	0	Ref.	170	31	0
	16	19.70	134.8	0.1155	87.87	1.26	10.94	15.60	41.20 13.68	Ref.	0	0	---	Ref.	180	0	0	Ref.	0	24	336
	17	16.79	124.4	0.1065	93.93	1.21	10.56	15.39	40.70 13.85	Ref.	0	0	180	Ref.	180	0	0	Ref.	78	39	0
	18	14.93	117.4	0.1005	98.50	1.14	10.10	15.33	14.30	Ref.	0	0	180	Ref.	180	0	0	Ref.	180	29	0

TABLE I.– TEST DATA – Continued

Model	Run	q_f (lb/sq ft)	v_f (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	Natural 2nd	Natural 3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg) 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
Model B-1 Swept, untapered wing; $\Lambda = 45^{\circ}$ Weight moved along midchord line; $a_w = 0$ Reynolds number $\cong 5045.5 v_f$	19	34.07	178.6	0.1525	0	2.61	16.19	20.97	13.29	----	Ref.	-	180	Ref.	---	0	---	Ref.	92	28	18
	20	34.04	178.1	0.1525	3.03	2.60	16.54	21.36	13.60	----	Ref.	-	180	Ref.	---	0	---	Ref.	56	0	0
	21	34.04	178.1	0.1525	9.09	2.60	15.96	21.49	13.27	----	Ref.	-	180	Ref.	---	0	---	Ref.	45	0	0
	22	34.06	178.2	0.1525	21.21	2.61	12.42	21.59	11.48	----	Ref.	-	0	Ref.	---	0	---	Ref.	32	0	0
	23	35.63	182.3	0.1560	27.27	2.54	10.61	20.58	10.67	----	Ref.	-	0	Ref.	---	0	---	Ref.	40	0	0
	24	41.96	197.9	0.1694	33.33	2.45	9.90	19.92	14.71	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	21
	25	41.29	196.3	0.1680	39.39	2.34	9.53	19.79	14.81	----	Ref.	-	180	Ref.	---	0	---	Ref.	10	0	0
	26	38.89	190.6	0.1630	45.45	2.19	9.70	18.57	14.41	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	15	20
	27	37.74	187.8	0.1605	51.51	2.04	10.37	18.13	14.29	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	22
	28	34.73	180.2	0.1590	57.57	1.90	11.37	17.69	13.95	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	20
	29	60.25	238.3	0.2040	63.63	1.76	12.92	17.09	9.43	----	Ref.	-	180	Ref.	---	0	---	Ref.	21	9	---
	30	55.23	228.0	0.1950	69.69	1.63	14.77	16.06	8.70	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	---
	31	53.08	223.3	0.1910	75.75	1.52	16.13	16.55	8.00	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	---
	32	50.94	218.8	0.1870	81.81	1.40	16.29	16.32	7.73	----	Ref.	-	180	Ref.	---	0	---	Ref.	26	0	---
	33	40.30	194.2	0.1660	93.93	1.21	13.13	15.21	4.66	----	Ref.	-	180	Ref.	---	0	---	Ref.	---	0	0.

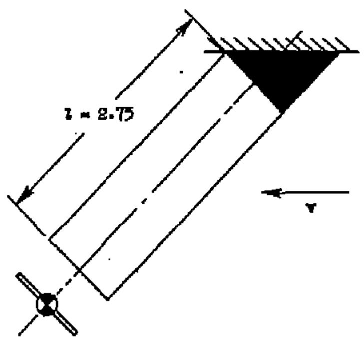


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TABLE I.- TEST DATA – Continued

Model	Run	q_f (lb/sq ft)	V_f (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	Natural 2nd	Natural 3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg) 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
Model B-2 Swept, untapered wing; $\Lambda = 45^{\circ}$ Weight moved along leading edge; $c_w = -1$ Reynolds number $\approx 5205.1 v_f$	34	32.20	170.1	0.1479	0	2.54	15.20	20.3	12.70	----	Ref.	-	180	Ref.	---	-	---	Ref.	180	0	180
	35	32.80	171.9	0.1495	5.88	2.51	15.44	20.3	12.63	----	Ref.	-	180	Ref.	---	0	---	Ref.	180	0	180
	36	28.70	160.7	0.1395	11.76	2.46	13.85	18.25	11.69	Ref.	180	-	180	Ref.	180	0	0	Ref.	180	0	180
	37	25.33	150.9	0.1310	17.65	2.44	11.19	17.56	10.00	Ref.	180	-	180	Ref.	180	0	0	Ref.	180	0	180
	38	24.01	147.1	0.1275	23.53	2.41	9.09	17.42	8.63	Ref.	180	-	180	Ref.	180	0	0	Ref.	185	0	185
	39	29.93	164.4	0.1425	29.40	2.40	8.00	17.42	7.25	Ref.	180	-	180	Ref.	180	0	0	Ref.	200	29	220
	40	51.63	216.6	0.1880	35.29	2.31	7.42	17.45	6.71	Ref.	180	-	180	Ref.	180	0	0	Ref.	273	116	273
	41	79.34	270.1	0.2345	41.18	2.17	7.14	16.92	15.25	Ref.	180	-	180	Ref.	180	0	0	Ref.	180	34	248
	42	91.86	291.5	0.2530	47.06	2.94	7.43	16.79	15.91	Ref.	180	-	180	Ref.	180	0	0	Ref.	193	13	251
	43	111.4	322.6	0.2800	52.94	1.75	7.72	16.54	16.33	Ref.	180	-	180	Ref.	---	0	0	Ref.	210	30	300
	44	226.6	475.4	0.4090	58.82	1.78	8.37	16.37	42.11	Ref.	180	-	180	Ref.	---	0	0	Ref.	180	172	329
	45	202.3	447.6	0.3844	64.71	1.64	8.99	15.85	30.40	Ref.	180	-	180	Ref.	---	0	0	Ref.	148	0	339
	46	158.3	364.6	0.3130	70.59	1.54	9.74	15.27	19.10	Ref.	180	0	180	Ref.	---	0	0	Ref.	180	270	0
	47	61.07	239.4	0.2050	76.47	1.43	10.36	15.05	15.12	Ref.	180	0	180	Ref.	180	0	0	Ref.	---	333	102
	48	27.93	161.0	0.1375	82.35	1.38	10.73	14.81	13.50 40.00	Ref.	180	0	180	Ref.	---	-	180	Ref.	---	48	160
	49	16.83	124.8	0.1065	88.24	1.23	10.59	14.30	13.18 39.26	Ref.	180	0	180	Ref.	180	0	---	Ref.	204	14	204
	50	13.52	111.9	0.0955	94.12	1.16	10.16	14.56	13.20	Ref.	180	0	0	Ref.	---	0	180	Ref.	234	28	185
	51	12.30	106.7	0.0910	98.53	1.08	9.66	14.52	13.10	Ref.	180	0	0	Ref.	---	0	180	Ref.	198	8	144

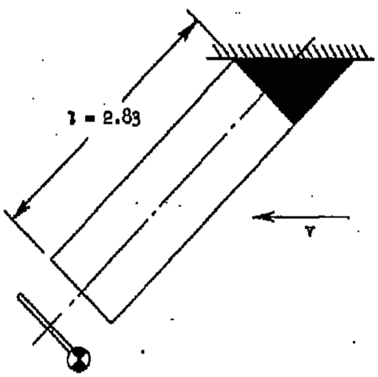

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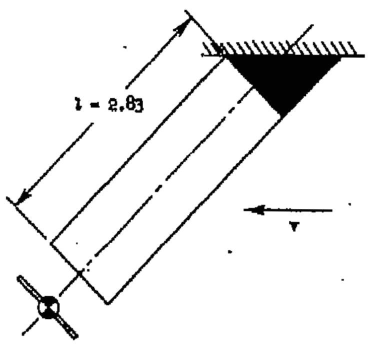
TABLE I.- TEST DATA — Continued

Model B-2
Swept, untapered wing; $\Lambda = 45^{\circ}$
Weight moved along midchord line; $e_w = 0$
Reynolds number $\approx 6060.8 v_r$



Run	q_r (lb/sq ft)	V_r (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	Natural 2nd	Natural 3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg) 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
52	32.18	163.9	0.1479	0	2.44	15.00	20.3	12.20	----	----	-	Ref.	Ref.	---	0	---	Ref.	198	0	167
53	33.11	166.2	0.1499	5.88	2.44	15.25	20.60	12.60	----	----	-	Ref.	Ref.	---	0	---	Ref.	180	0	180
54	33.98	168.7	0.1520	11.76	2.45	14.10	20.50	12.60	----	Ref.	-	0	Ref.	---	0	---	Ref.	180	0	180
55	33.98	168.7	0.1520	25.53	2.44	10.71	20.00	10.59	----	Ref.	-	0	Ref.	---	0	---	Ref.	170	0	180
56	38.13	178.7	0.1610	29.40	2.31	9.48	19.30	9.61	----	Ref.	-	0	Ref.	---	0	---	Ref.	171	0	180
57	38.06	178.7	0.1609	35.29	2.28	8.93	18.68	13.90	----	Ref.	-	0	Ref.	---	0	---	Ref.	200	0	210
58	38.33	179.4	0.1615	41.18	2.14	8.84	18.45	13.50	----	Ref.	-	0	Ref.	---	0	---	Ref.	195	0	224
59	35.11	171.8	0.1545	47.06	2.02	9.35	17.72	13.90	----	Ref.	-	0	Ref.	---	0	---	Ref.	190	0	205
60	33.09	166.8	0.1499	52.94	1.88	9.84	17.20	13.50	----	Ref.	-	0	Ref.	---	0	---	Ref.	168	0	237
61	33.11	166.9	0.1499	58.82	1.77	10.88	16.81	13.40	----	Ref.	-	0	Ref.	---	0	---	Ref.	187	0	202
62	54.12	214.3	0.1925	64.71	1.61	12.35	16.45	9.10	----	Ref.	-	Ref.	Ref.	---	0	---	Ref.	164	0	---
63	50.16	206.2	0.1851	70.59	1.52	13.80	16.13	8.65	Ref.	----	-	180	Ref.	---	0	---	Ref.	193	0	---
64	48.65	203.1	0.1823	76.47	1.41	15.51	15.80	7.95	Ref.	----	0	180	Ref.	---	0	---	Ref.	185	0	---
65	45.66	196.7	0.1765	82.35	1.30	15.00	15.63	6.63	Ref.	----	0	----	Ref.	---	0	---	Ref.	189	0	---
66	36.22	175.1	0.1570	94.12	1.14	12.10	15.16	4.31	Ref.	0	0	180	Ref.	---	0	---	Ref.	166	11	187

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TABLE I.- TEST DATA - Continued

Model	Run	q_f (lb/sq ft)	V_f (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps): Natural 1st	Natural 2nd	Natural 3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg): 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
Model C-1 Swept, untapered wing; $\Lambda = 60^{\circ}$ Weight moved along leading edge; $e_w = -1$ Reynolds number ≈ $8728.3V_f$	67	60.42	222.4	0.2033	0	2.86	17.55	23.80	15.44	----	Ref.	-	180	Ref.	----	0	---	Ref.	162	16	11
	68	58.60	219.2	0.2000	6.06	2.86	17.50	23.25	15.44	Ref.	180	0	0	Ref.	0	0	180	Ref.	140	11	0
	69	51.37	205.2	0.1870	12.12	2.86	15.97	21.20	14.08	Ref.	180	0	0	Ref.	0	0	180	Ref.	---	20	10
	70	49.59	201.7	0.1837	18.18	2.84	12.71	20.35	11.78	Ref.	0	0	0	Ref.	0	0	180	Ref.	20	0	0
	71	48.21	198.7	0.1810	24.24	2.82	10.31	20.25	9.82	Ref.	----	0	0	Ref.	0	0	180	Ref.	38	28	24
	72	60.24	222.9	0.2030	30.30	2.74	9.20	20.15	8.83	Ref.	180	0	0	Ref.	0	0	180	Ref.	80	73	68
	73	125.16	324.6	0.2963	36.36	2.63	8.70	20.10	8.33 32.70	Ref.	180	0	0	Ref.	0	0	180	Ref. ----	180 ---	---- Ref.	--- 0
	74	139.40	344.2	0.3140	42.42	2.50	8.46	19.80	37.20	Ref.	180	0	0	Ref.	0	0	180	----	---	Ref.	0
	75	156.00	359.9	0.3330	48.48	2.32	8.80	19.52	43.50	Ref.	180	0	0	Ref.	0	0	180	----	---	Ref.	0
	76	320.50	540.9	0.4965	54.54	2.16	9.24	19.06	48.30	Ref.	180	0	0	Ref.	0	0	180	Ref.	---	196	164
	77	339.40	558.1	0.5130	60.60	2.01	9.93	18.60	56.00	Ref.	180	0	0	Ref.	0	0	180	Ref.	---	190	200
	78	235.50	458.1	0.4170	66.67	1.85	10.81	18.10	20.55	Ref.	---	0	0	Ref.	0	0	180	Ref.	0	223	194
	79	129.90	332.8	0.3020	72.72	1.71	11.72	17.90	18.03	Ref.	0	0	0	Ref.	0	0	180	Ref.	83	318	255
	80	66.95	236.3	0.2140	78.78	1.58	12.38	17.30	16.46	Ref.	0	0	0	----	Ref.	---	180	Ref.	169	49	0
	81	39.16	179.9	0.1627	84.84	1.48	12.43	16.96	15.40	Ref.	0	0	0	Ref.	180	0	0	Ref.	180	44	5
	82	29.86	156.9	0.1419	90.90	1.35	11.98	17.00	15.63	Ref.	0	0	180	Ref.	180	0	0	Ref.	161	17	0
	83	26.69	148.2	0.1340	96.96	1.26	11.30	16.96	15.60	Ref.	0	0	180	Ref.	180	0	0	Ref.	155	33	0

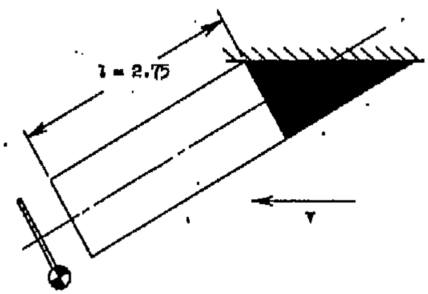


TABLE I.– TEST DATA – Continued

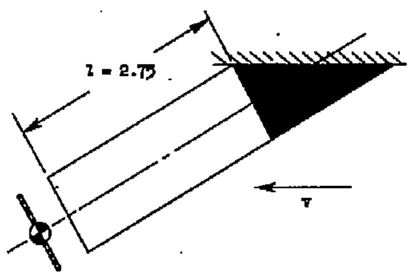
Model	Run	q_r (lb/sq ft)	V_r (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps)				Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg)											
						Natural			Flutter	2nd natural mode				3rd natural mode				Flutter mode			
						1st	2nd	3rd		1	2	3	4	1	2	3	4	1	2	3	4
Model C-1 Swept, untapered wing; Λ = 60° Weight moved along midchord line; e_w = 0 Reynolds number ≈ 8608.7V_r	84	59.72	224.3	0.2019	0	2.86	17.55	23.80	15.2	----	----	-	---	----	---	-	---	Ref.	150	0	0
	85	60.43	224.4	0.2033	6.06	2.90	17.40	24.00	15.40	Ref.	180	-	0	Ref.	---	0	---	Ref.	160	0	10
	86	63.21	229.6	0.2080	24.24	2.78	12.50	23.30	11.80	----	Ref.	-	180	Ref.	---	0	---	Ref.	54	13	0
	87	78.83	256.9	0.2327	30.30	2.74	11.30	22.80	18.70	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	20	33
	88	82.87	264.0	0.2390	36.36	2.62	10.70	22.50	18.30	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	321	51
	89	75.07	250.9	0.2270	42.42	2.47	10.30	21.50	18.00	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	13	26
 l = 2.75 V	90	72.58	246.5	0.2230	48.48	2.30	10.90	20.30	17.70	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	38
	91	70.53	243.3	0.2199	54.54	2.00	13.00	19.50	17.10	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	68
	92	74.44	250.0	0.2261	60.60	1.87	15.00	19.10	17.00	----	Ref.	-	180	Ref.	---	0	---	Ref.	0	0	72
	93	121.00	321.8	0.2910	66.67	1.70	16.60	18.60	10.20	Ref.	180	0	0	Ref.	---	0	---	Ref.	20	0	180
	94	113.90	312.2	0.2823	72.72	1.68	17.25	18.70	10.20	Ref.	180	0	0	Ref.	---	0	---	Ref.	30	0	211
	95	94.17	283.1	0.2555	84.84	1.46	16.50	18.40	8.00	Ref.	180	0	0	Ref.	---	0	---	Ref.	180	0	0
	96	86.02	270.4	0.2438	90.90	1.35	14.80	17.80	7.00	Ref.	180	0	0	Ref.	---	0	---	Ref.	175	15	25
	97	75.72	253.1	0.2280	96.96	1.27	13.30	17.70	6.20	----	Ref.	-	180	Ref.	---	0	---	Ref.	180	17	20

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TABLE I.– TEST DATA – Continued

Model	Run	q_f (lb/sq ft)	v_f (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	Natural 2nd	Natural 3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg) 2nd natural mode 1	2nd natural mode 2	2nd natural mode 3	2nd natural mode 4	3rd natural mode 1	3rd natural mode 2	3rd natural mode 3	3rd natural mode 4	Flutter mode 1	Flutter mode 2	Flutter mode 3	Flutter mode 4
Model 0-2 Swept, untapered wing; Λ = 60° Weight moved along leading edge, e_w = -1 Reynolds number ≅ 7932.2v_f	98	50.17	207.3	0.1854	0	2.37	14.61	21.30	12.80	----	Ref.	-	0	Ref.	---	0	---	Ref.	0	0	0
	99	49.22	205.5	0.1835	8.33	2.35	14.40	20.50	12.80	----	Ref.	-	0	Ref.	0	0	180	Ref.	0	0	0
	100	42.65	191.0	0.1705	13.88	2.35	12.73	17.93	11.80	----	Ref.	-	0	Ref.	0	0	180	Ref.	0	0	0
	101	38.75	182.1	0.1625	19.44	2.34	10.68	17.43	9.80	Ref.	0	0	0	Ref.	0	0	180	Ref.	0	10	20
	102	37.06	178.2	0.1590	25.00	2.30	9.09	17.40	8.54	Ref.	0	-	0	Ref.	0	0	180	Ref.	342	0	0
	103	47.58	202.3	0.1805	30.55	2.27	8.28	17.35	7.61	Ref.	0	0	0	Ref.	0	0	180	Ref.	23	32	24
	104	80.29	264.8	0.2360	36.11	2.15	7.69	17.34	7.30	Ref.	0	0	0	Ref.	---	0	180	Ref.	93	106	83
	105	123.90	332.3	0.2960	41.67	2.10	7.42	17.24	31.35	Ref.	0	0	0	Ref.	---	0	180	----	Ref.	195	195
	106	148.70	367.7	0.3260	47.22	1.98	7.59	16.92	35.30	Ref.	0	0	0	Ref.	180	0	180	Ref.	323	168	168
	107	193.80	424.7	0.3759	52.77	1.85	7.87	16.40	43.20	Ref.	0	0	0	Ref.	180	0	180	Ref.	197	212	150
	108	285.50	507.0	0.4485	58.33	1.80	8.54	15.96	50.30	Ref.	0	0	0	Ref.	180	0	180	Ref.	189	197	197
	109	251.80	494.9	0.4349	63.89	1.61	9.23	15.51	20.20	Ref.	0	0	0	Ref.	180	0	180	Ref.	319	227	198
	110	131.70	348.8	0.3060	69.44	1.52	10.20	15.07	16.14	Ref.	0	0	0	Ref.	180	0	180	Ref.	----	236	214
	111	66.66	243.2	0.2145	75.00	1.43	11.11	14.68	14.58	Ref.	0	0	0	Ref.	180	0	180	Ref.	295	320	295
	112	36.68	179.6	0.1584	80.56	1.32	11.36	14.22	13.33	Ref.	0	0	0	Ref.	0	0	0	Ref.	23	0	341
	113	23.61	143.6	0.1265	86.11	1.25	11.20	14.38	13.44	Ref.	0	0	180	Ref.	0	0	0	Ref.	350	23	14
	114	21.24	136.2	0.1200	91.67	1.15	10.53	14.60	13.61	Ref.	0	0	180	Ref.	0	0	0	Ref.	14	0	340
	115	26.00	150.8	0.1330	97.22	1.06	9.88	14.77	13.40	Ref.	0	0	180	Ref.	0	0	0	Ref.	0	19	337

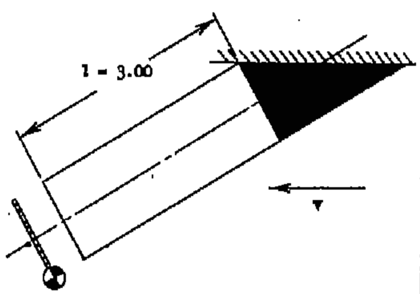
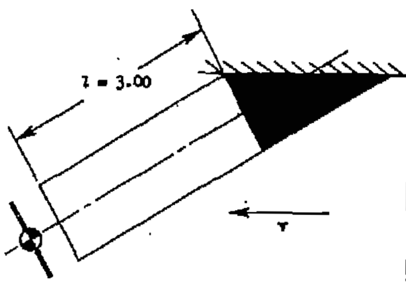


TABLE I.– TEST DATA – Concluded

Model	Run	q_r (lb/sq ft)	V_r (fps)	Mach number	Distance of weight from root (percent l)	Frequencies (cps) Natural 1st	2nd	3rd	Flutter	Phase-angle relationship of bending and torsional stresses (Ref. = Reference strain-gage trace) (deg) 2nd natural mode 1	2	3	4	3rd natural mode 1	2	3	4	Flutter mode 1	2	3	4
Model C-2 Swept, untapered wing; $\Lambda = 60^{\circ}$ Weight moved along midchord line; $a_w = 0$ Reynolds number $\approx 7901.0 V_r$	116	47.92	205.3	0.1813	0	2.37	14.61	21.30	14.10	----	----	-	-	----	---	-	---	Ref.	27	18	9
	117	50.37	210.2	0.1856	13.88	2.35	13.59	21.35	12.14	----	Ref.	-	0	Ref.	---	0	---	Ref.	347	21	339
	118	61.43	233.1	0.2059	30.55	2.22	9.45	20.00	16.65	----	Ref.	-	0	Ref.	---	0	---	Ref.	---	0	0
	119	63.45	236.9	0.2093	36.11	2.17	9.11	19.72	16.10	----	Ref.	-	0	Ref.	---	0	---	Ref.	---	11	34
	120	65.31	240.3	0.2123	41.67	2.11	8.88	19.71	16.05	----	Ref.	-	0	Ref.	---	0	---	Ref.	---	0	---
	121	57.79	226.0	0.1996	47.22	1.96	9.09	18.80	17.25	----	Ref.	-	0	Ref.	---	0	---	Ref.	33	0	50
	122	62.67	235.5	0.2080	52.77	1.87	9.67	17.88	16.54	----	Ref.	-	0	Ref.	---	0	---	Ref.	0	0	48
	123	66.84	243.2	0.2149	58.33	1.74	10.61	18.16	15.89	----	Ref.	-	0	Ref.	---	0	---	Ref.	29	0	43
	124	103.70	305.1	0.2699	63.89	1.63	11.85	17.54	12.80	Ref.	0	-	0	Ref.	---	0	---	Ref.	0	0	---
	125	93.74	289.3	0.2559	69.44	1.49	13.17	17.20	10.64	Ref.	0	-	0	Ref.	---	0	---	Ref.	21	10	---
	126	84.37	274.4	0.2427	75.00	1.41	14.10	16.90	9.90	Ref.	0	-	0	Ref.	---	0	---	Ref.	16	26	48
	127	69.85	248.9	0.2199	86.11	1.22	13.46	16.67	7.20	Ref.	----	0	0	Ref.	---	0	---	Ref.	16	0	0
	128	64.49	238.9	0.2110	91.67	1.16	12.66	16.21	6.17	Ref.	----	0	0	Ref.	---	0	---	Ref.	19	25	19
	129	56.57	223.5	0.1974	97.22	1.09	11.15	16.00	3.48	Ref.	180	0	0	Ref.	---	0	---	Ref.	---	19	17

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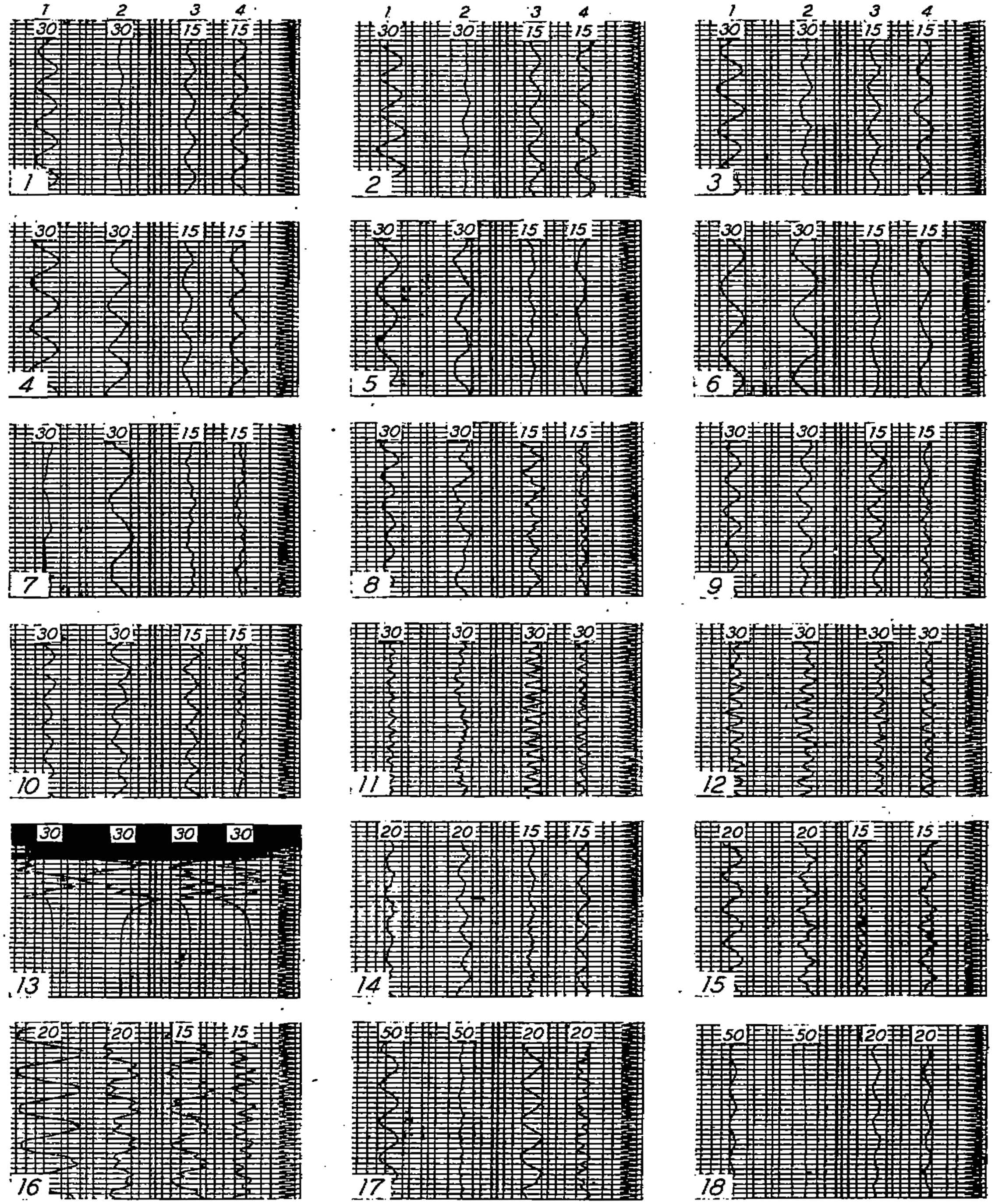
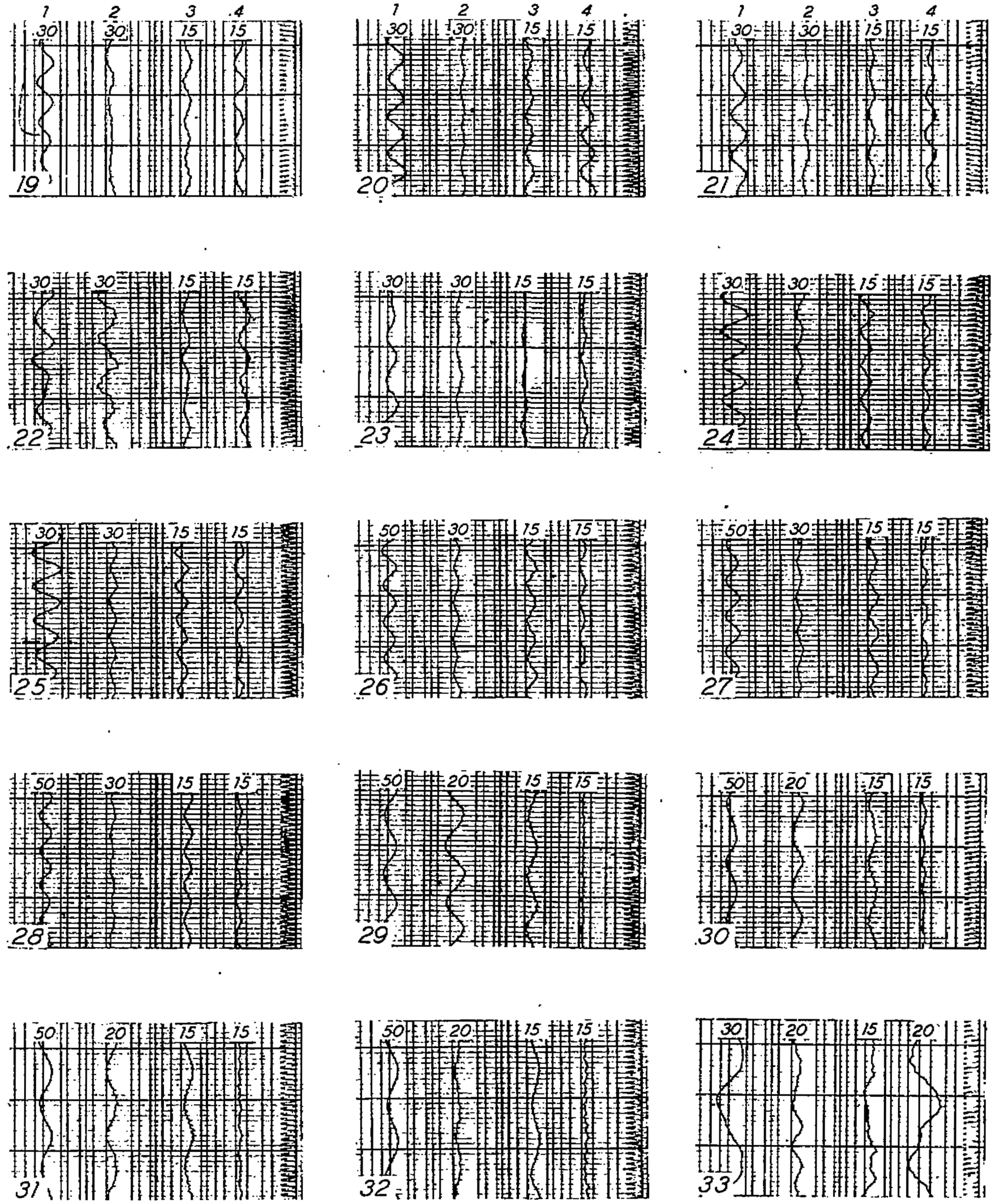


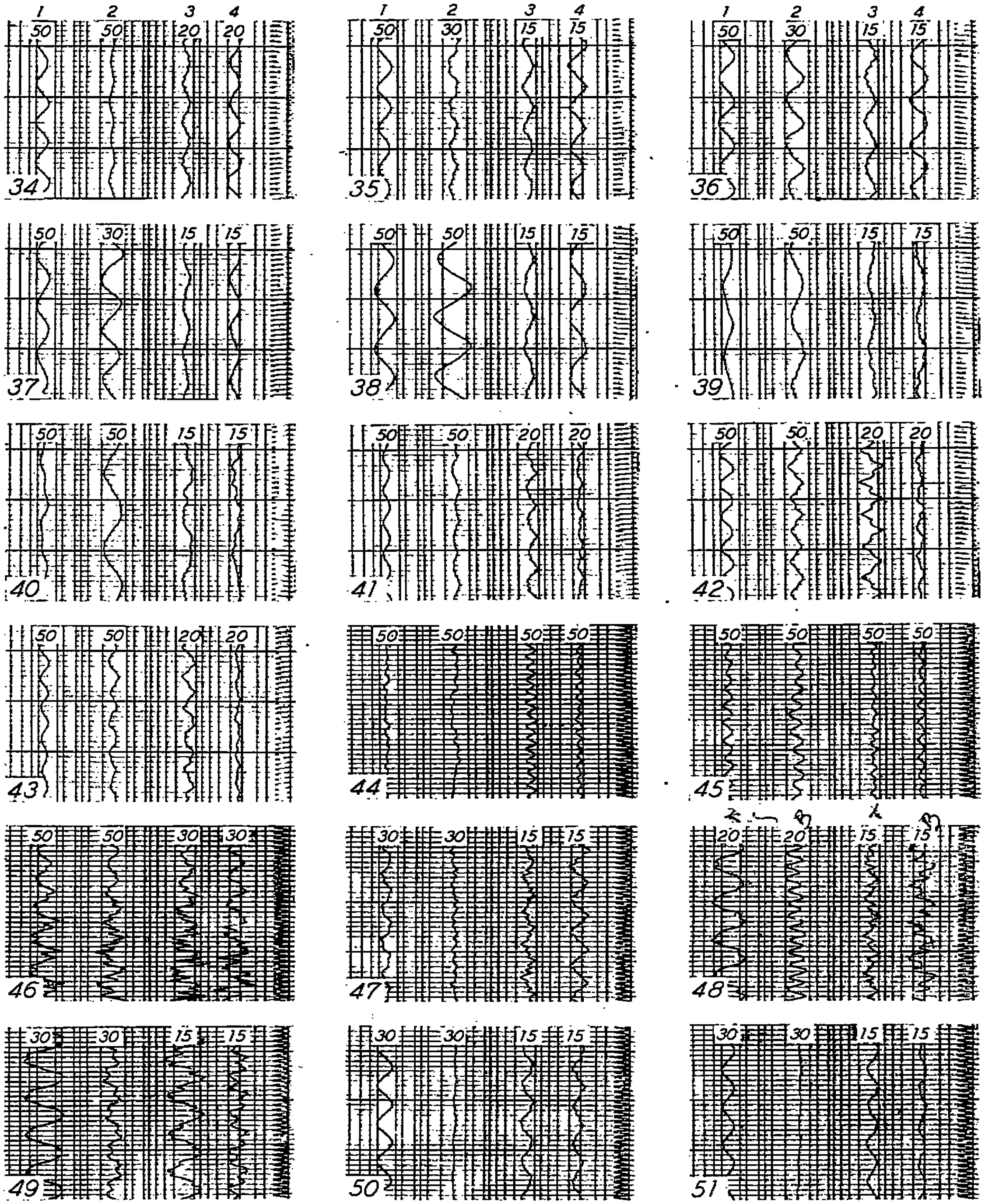
(a) Model B-1; $\Lambda = 45^{\circ}$; $e_w = -1$; Runs 1-18.

Figure 1.— Oscillograph records taken at flutter.



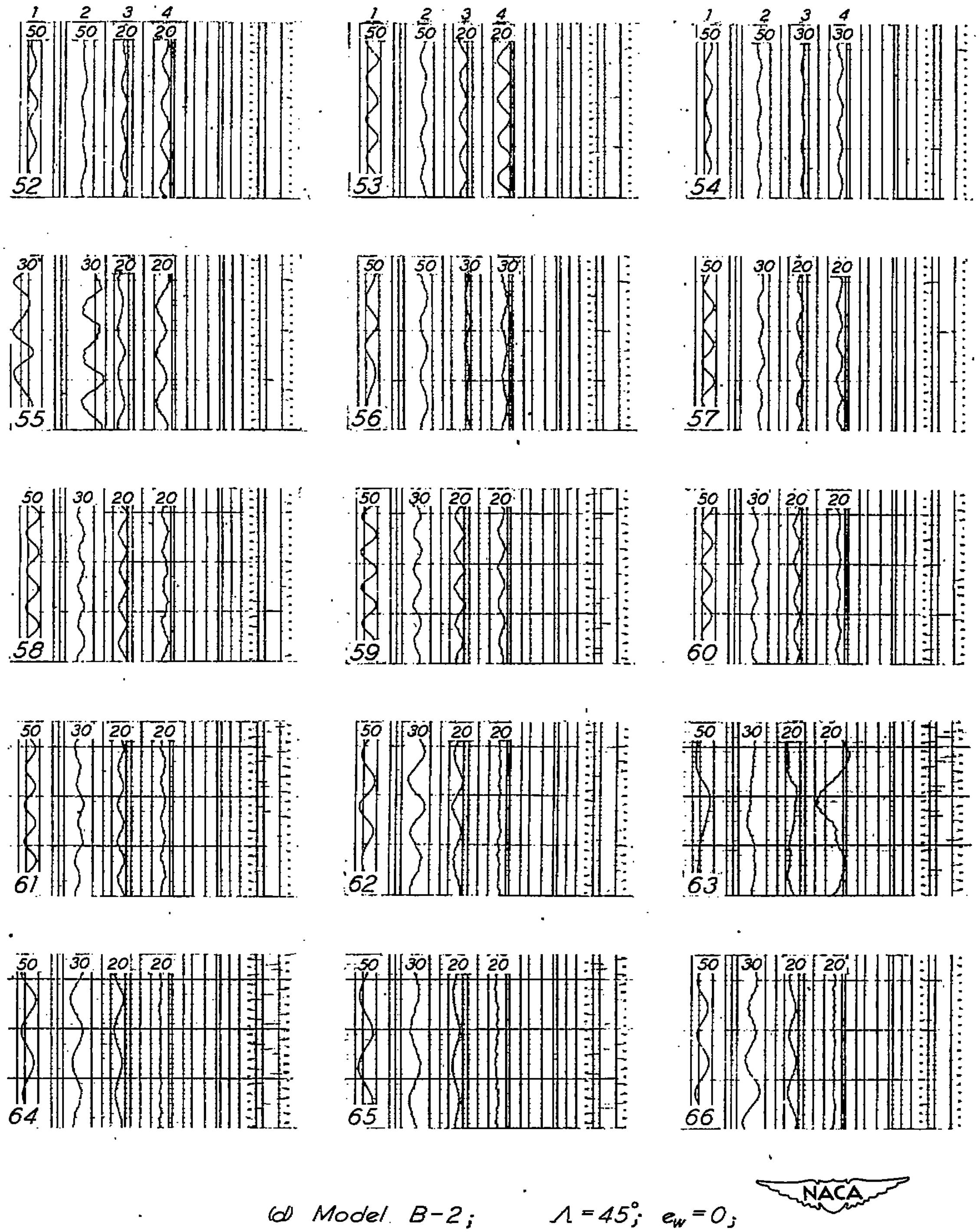
(b) Model B-1; $\Lambda = 45^\circ$; $e_w = 0$;
Runs 19 - 33.

Figure 1.— Continued.



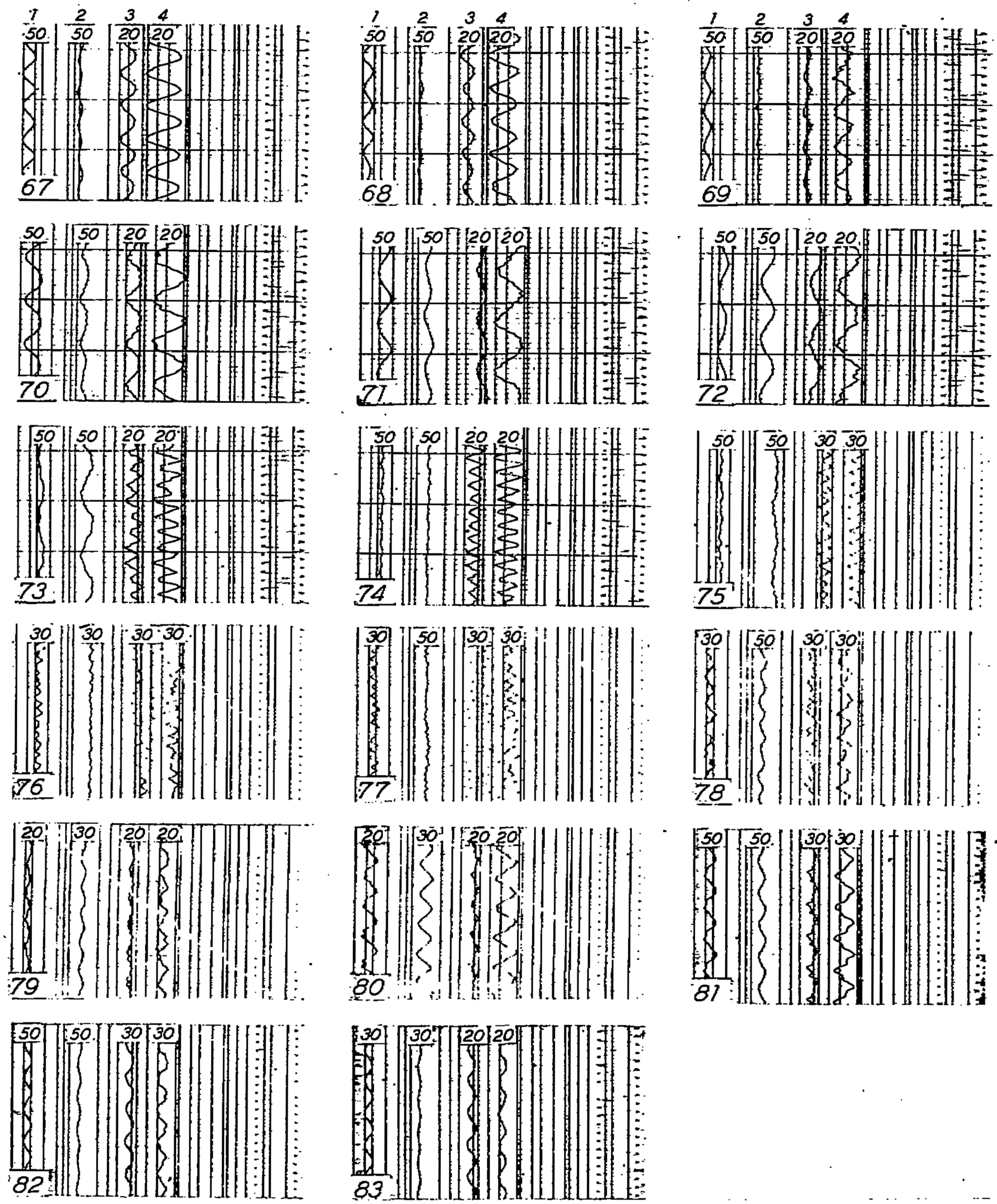
(c) Model B-2: $\Lambda = 45^{\circ}$; $e_w = -1$; Runs 34 - 51.

Figure 1.— Continued.



(d) Model B-2; $\Lambda = 45^{\circ}$; $e_w = 0$;
Runs 52 - 66.

Figure 1.– Continued.

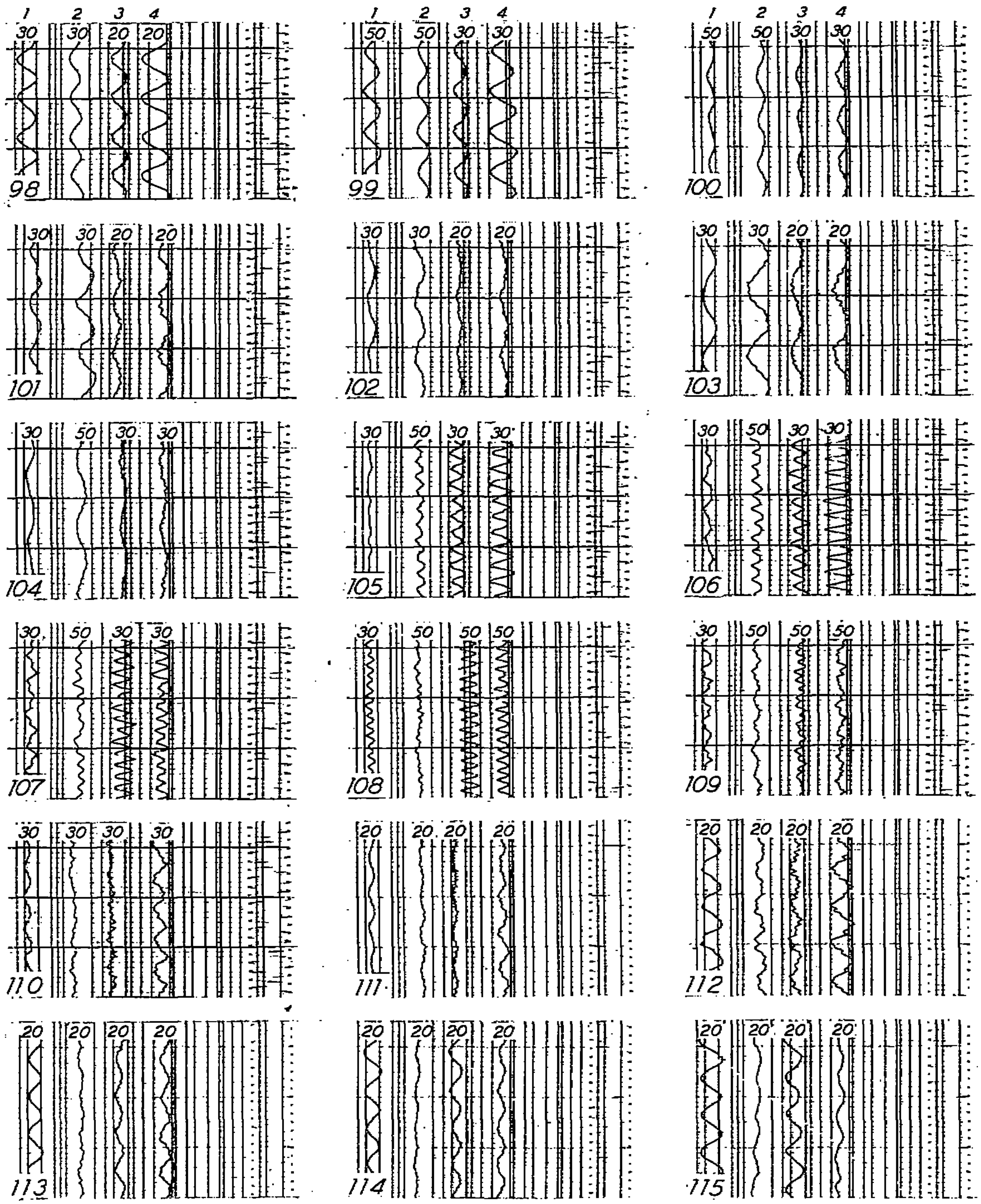


(e) Model C-1; $\Lambda = 60^{\circ}$; $e_w = -1$; Runs 67-83.

Figure 1.- Continued.

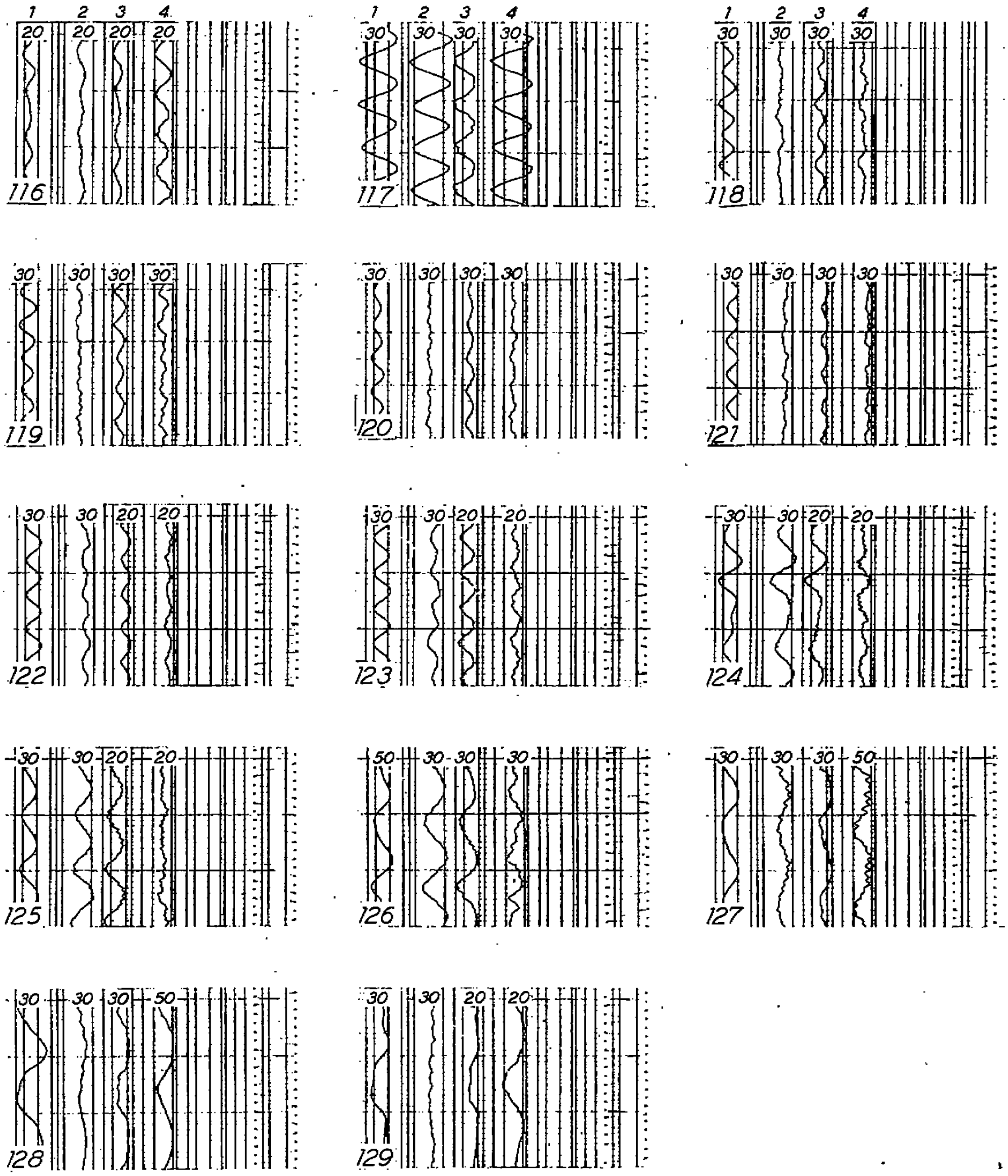
(f) Model C-1; $\Lambda = 60^\circ$; $e_w = 0$;
Runs 84-97.

Figure 1.- Continued.



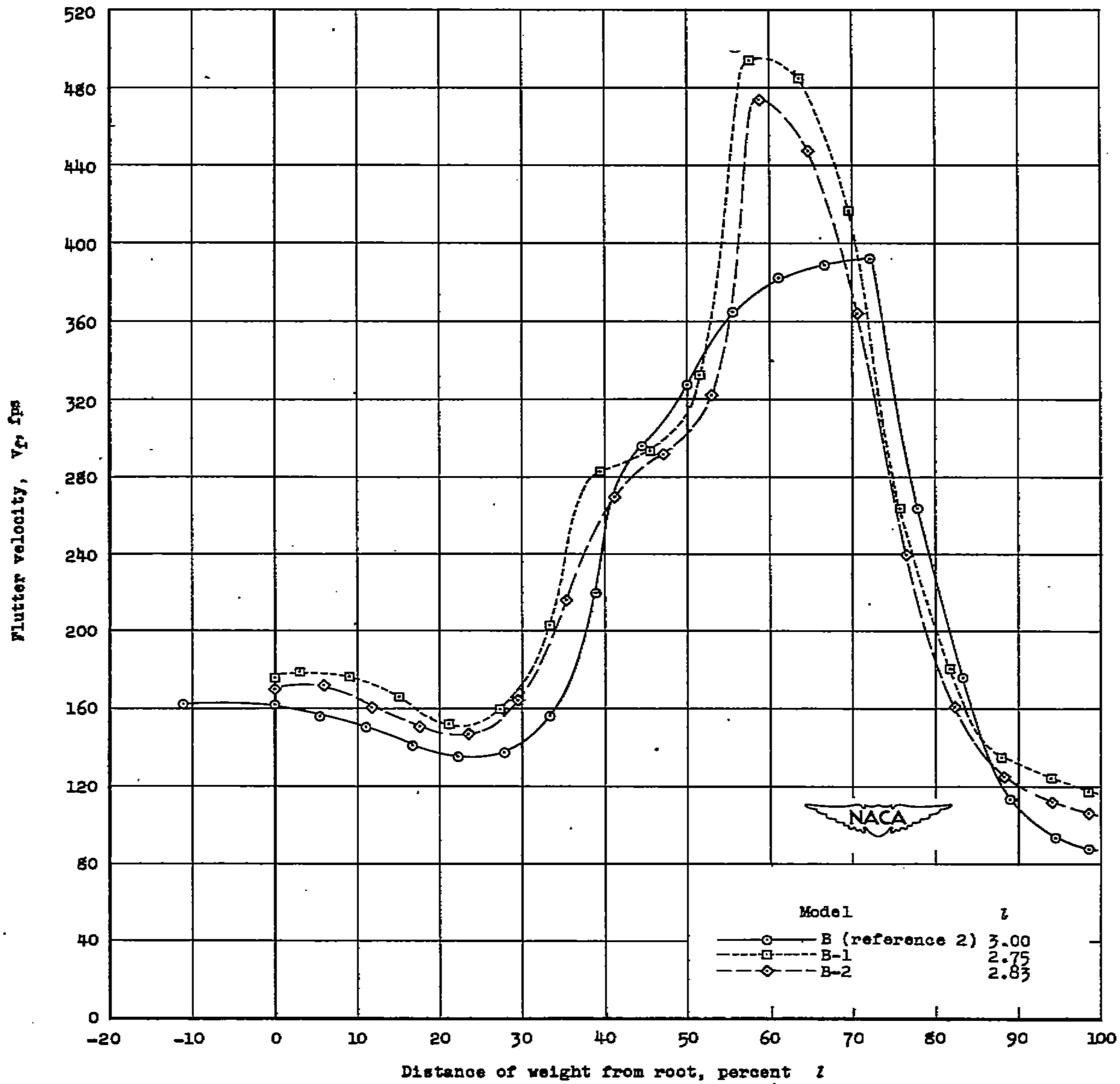
(g) Model C-2 ; $\Lambda = 60^\circ$; $e_w = -1$;
Runs 98 – 115.

Figure 1.– Continued.



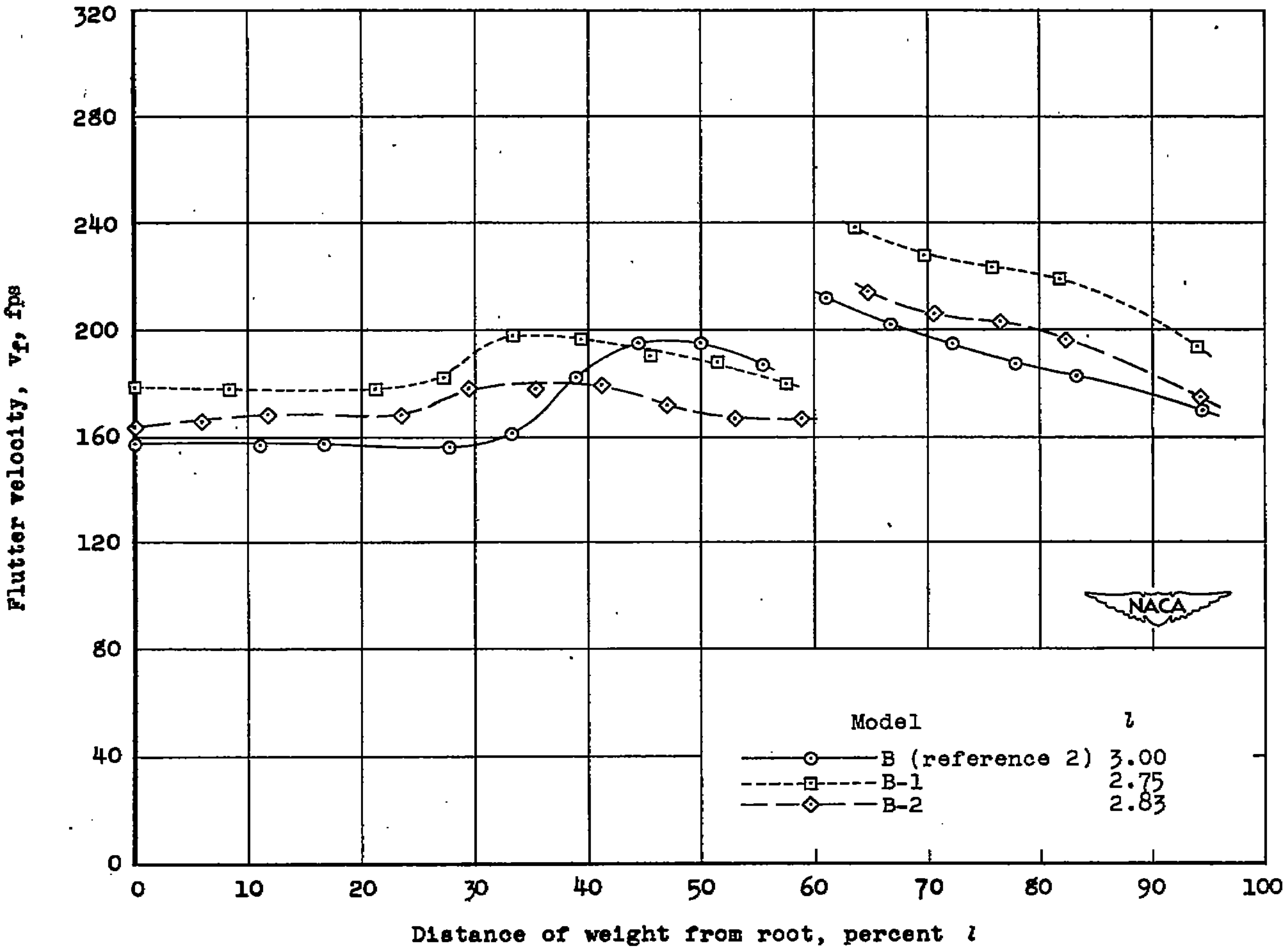
(h) Model C-2; $\Lambda = 60^\circ$; $e_w = 0$;
Runs 116 - 129.

Figure 1.– Concluded.



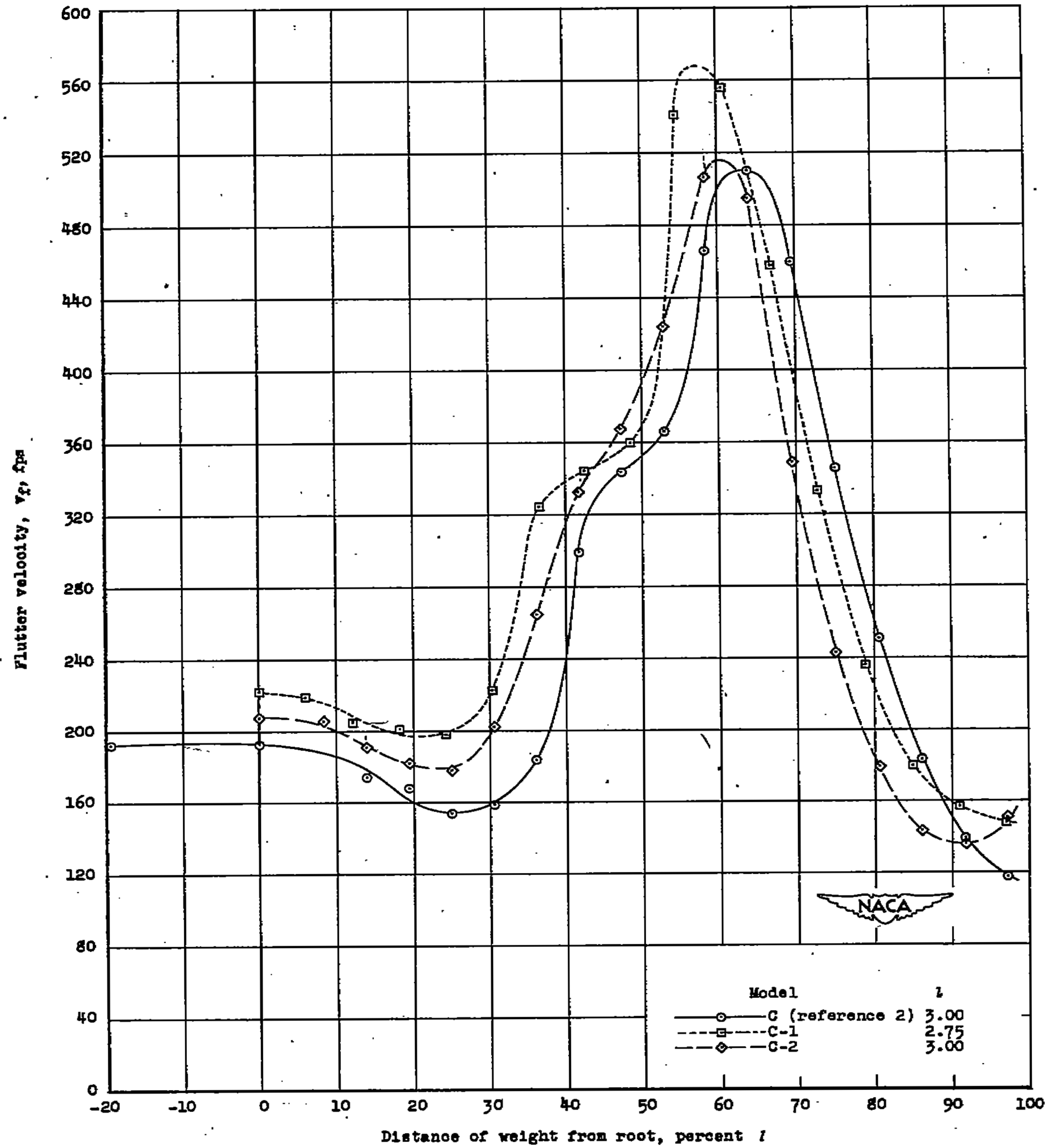
(a) $\Lambda = 45^{\circ}$, $e_w = -1$.

Figure 2.– Variation of the flutter speeds with weight position for each of the models tested.



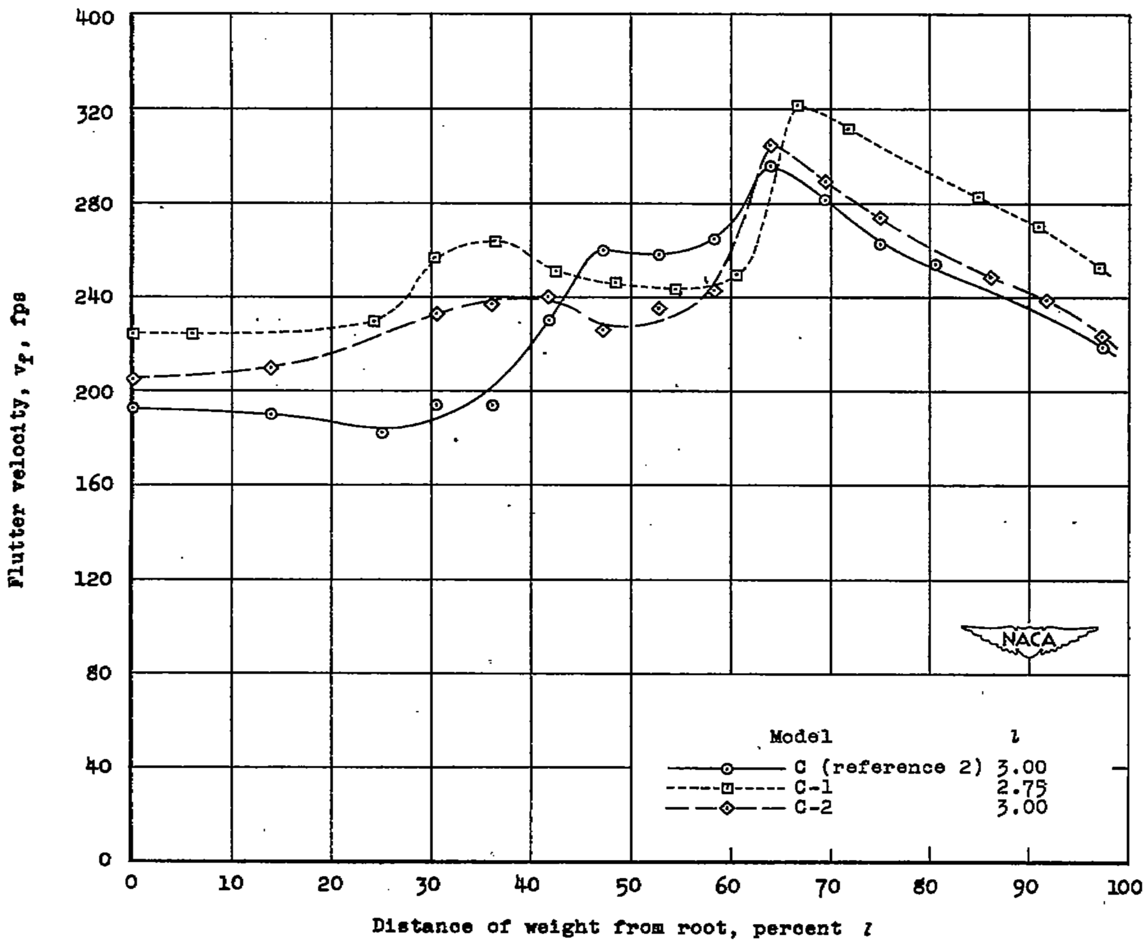
(b) $\Lambda = 45^{\circ}$, $e_W = 0$.

Figure 2.— Continued.



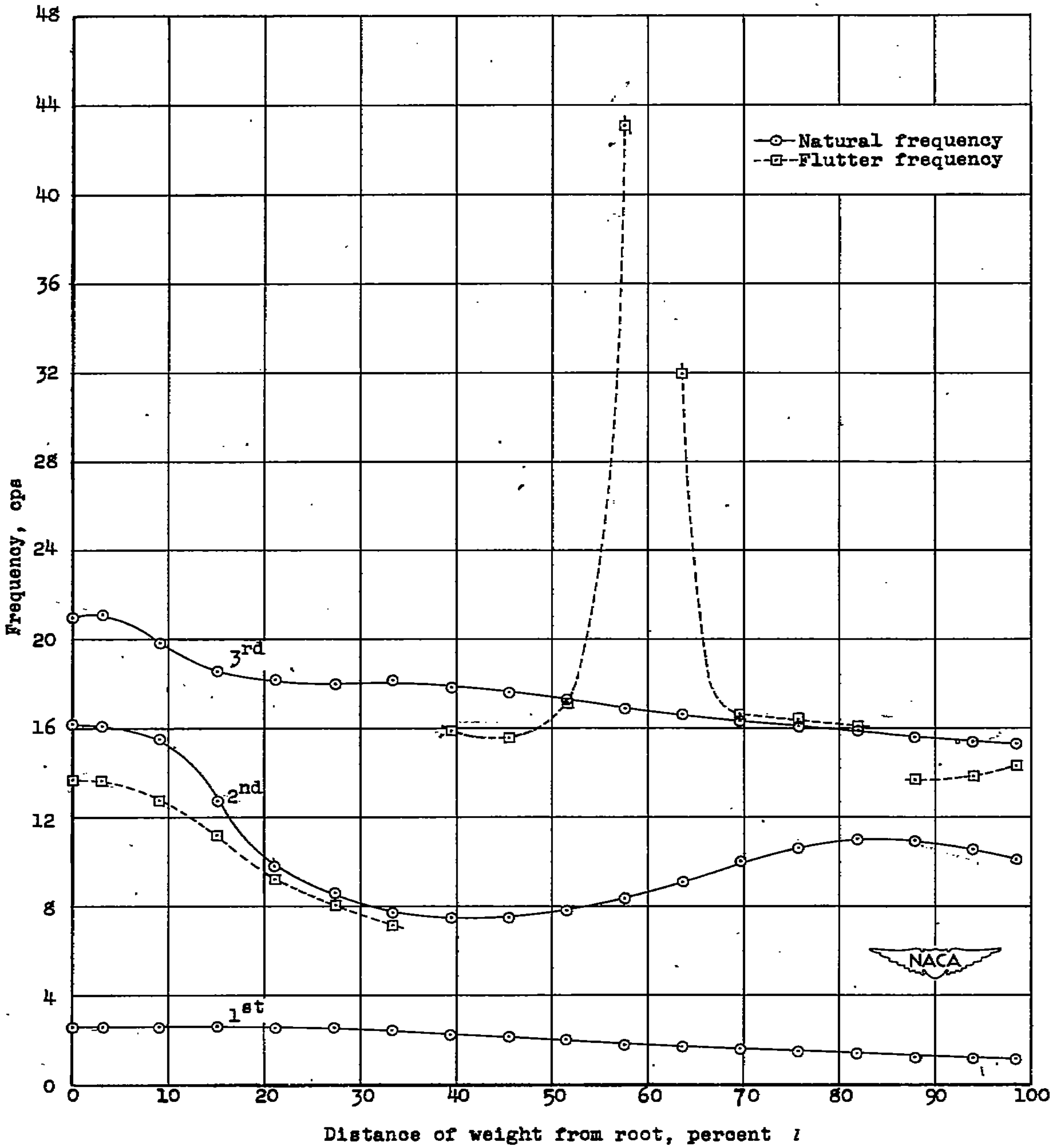
(c) $\Lambda = 60^{\circ}$, $e_W = -1$.

Figure 2.– Continued.



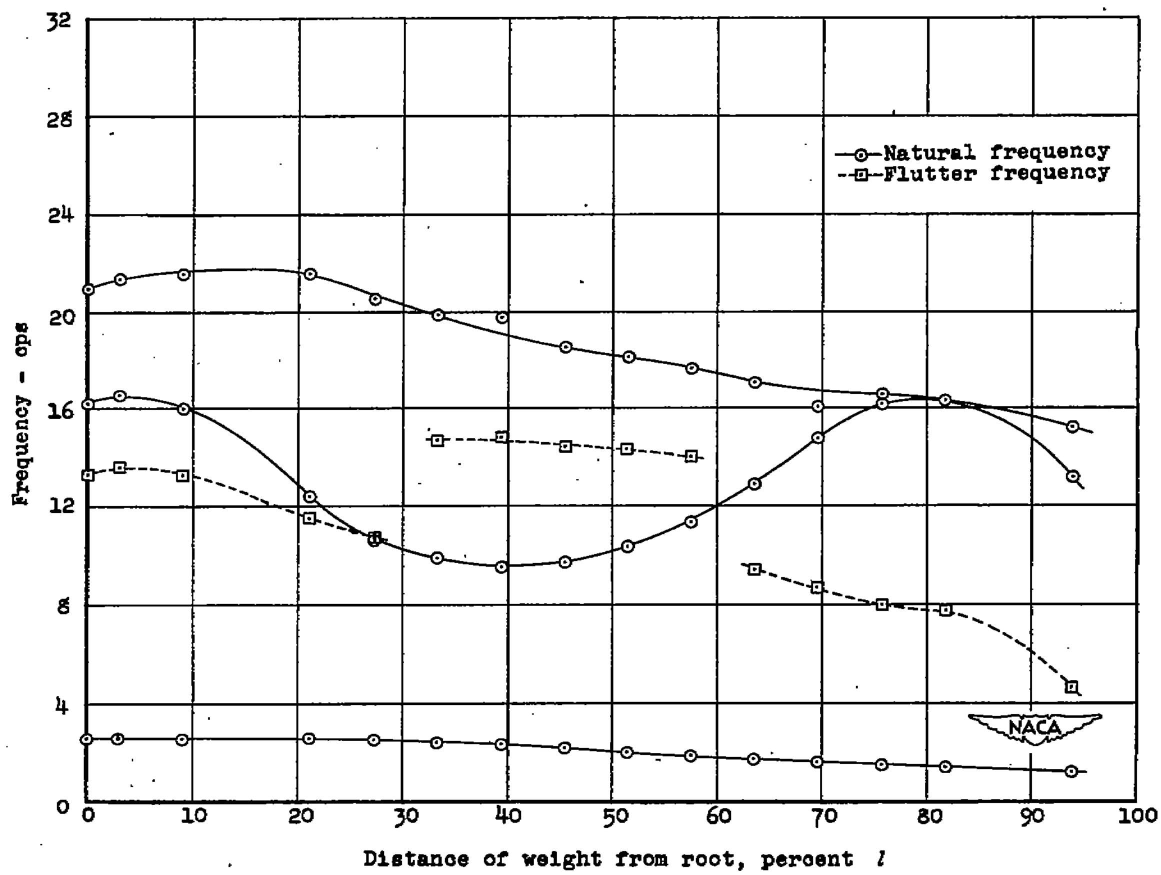
(d) $\Lambda = 60^{\circ}$, $e_w = 0$.

Figure 2.— Concluded.



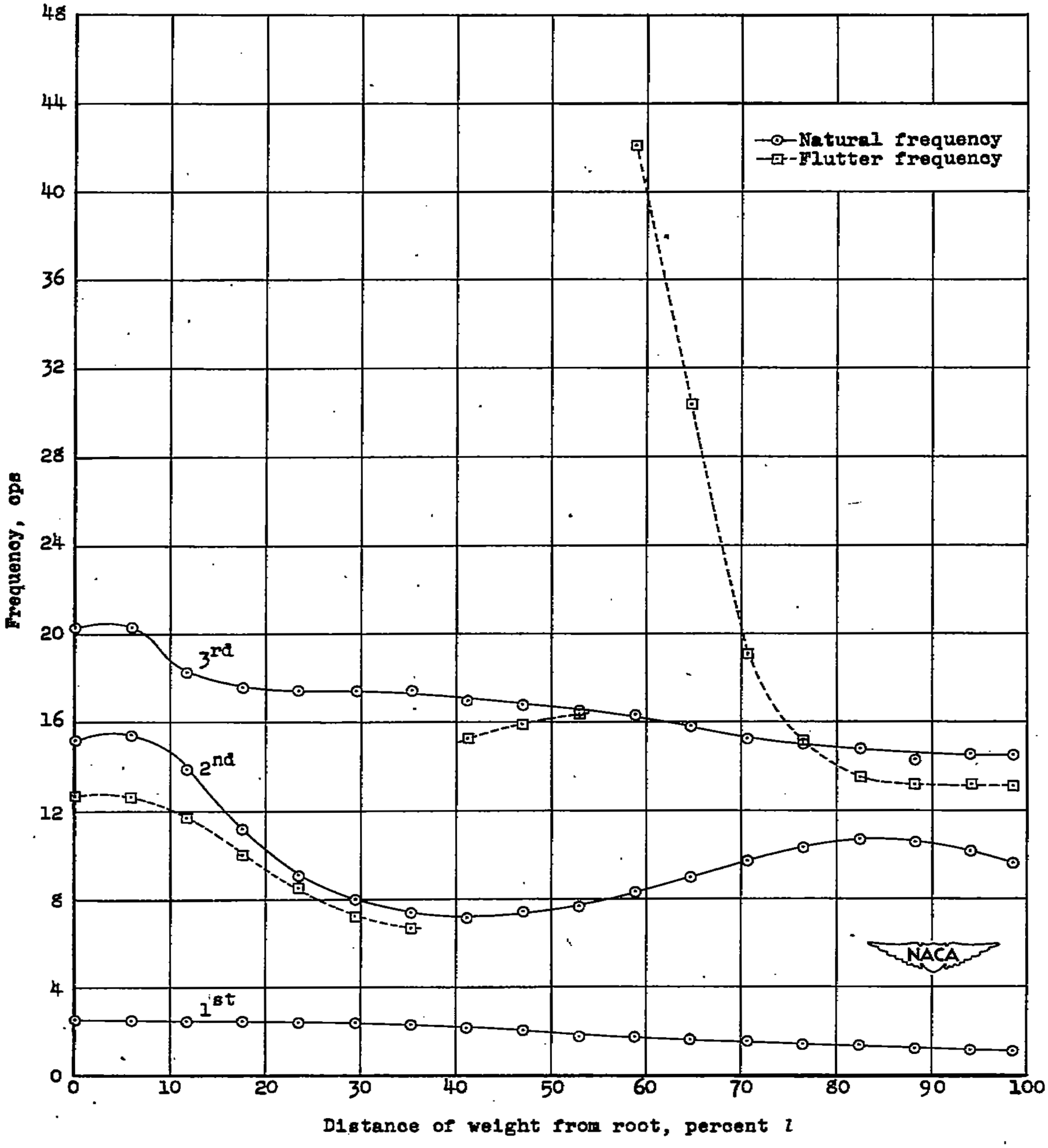
(a) Model B-1, $\Lambda = 45^{\circ}$, $e_W = -1$.

Figure 3.- Variation of the first three natural frequencies and flutter frequency with weight position.



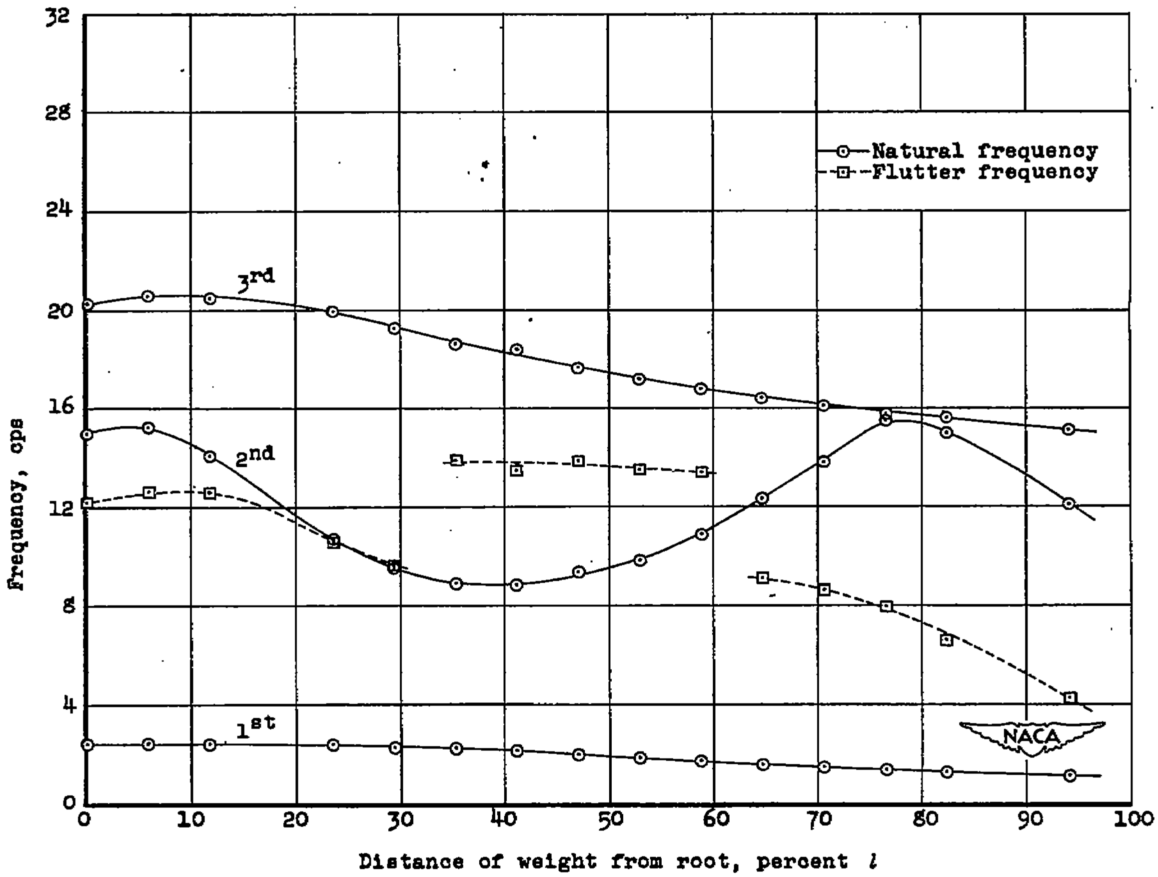
(b) Model B-1, $\Lambda = 45^{\circ}$, $e_w = 0$.

Figure 3.– Continued.



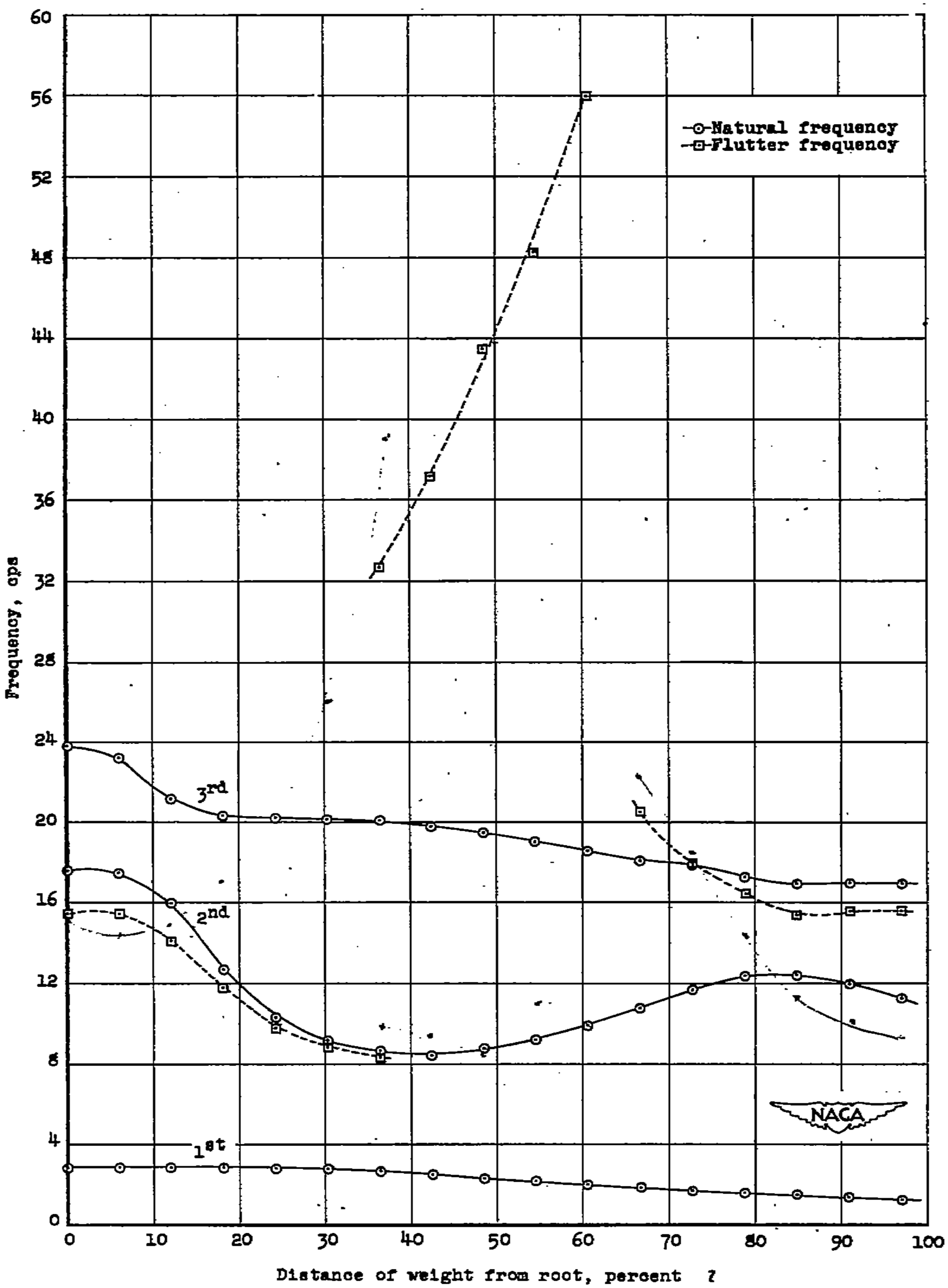
(c) Model B-2, $\Lambda = 45^{\circ}$, $e_W = -1$.

Figure 3.– Continued.



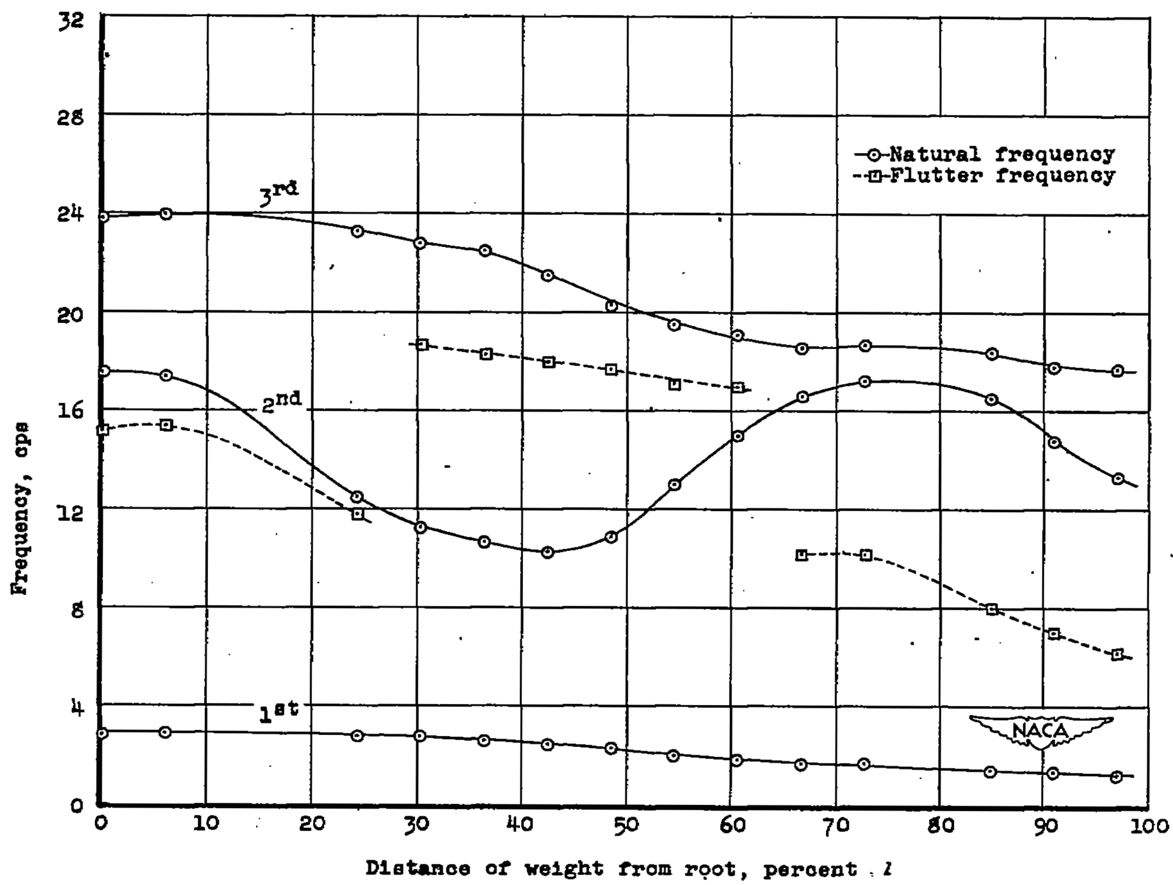
(d) Model B-2, $\Lambda = 45^{\circ}$, $e_W = 0$.

Figure 3.— Continued.



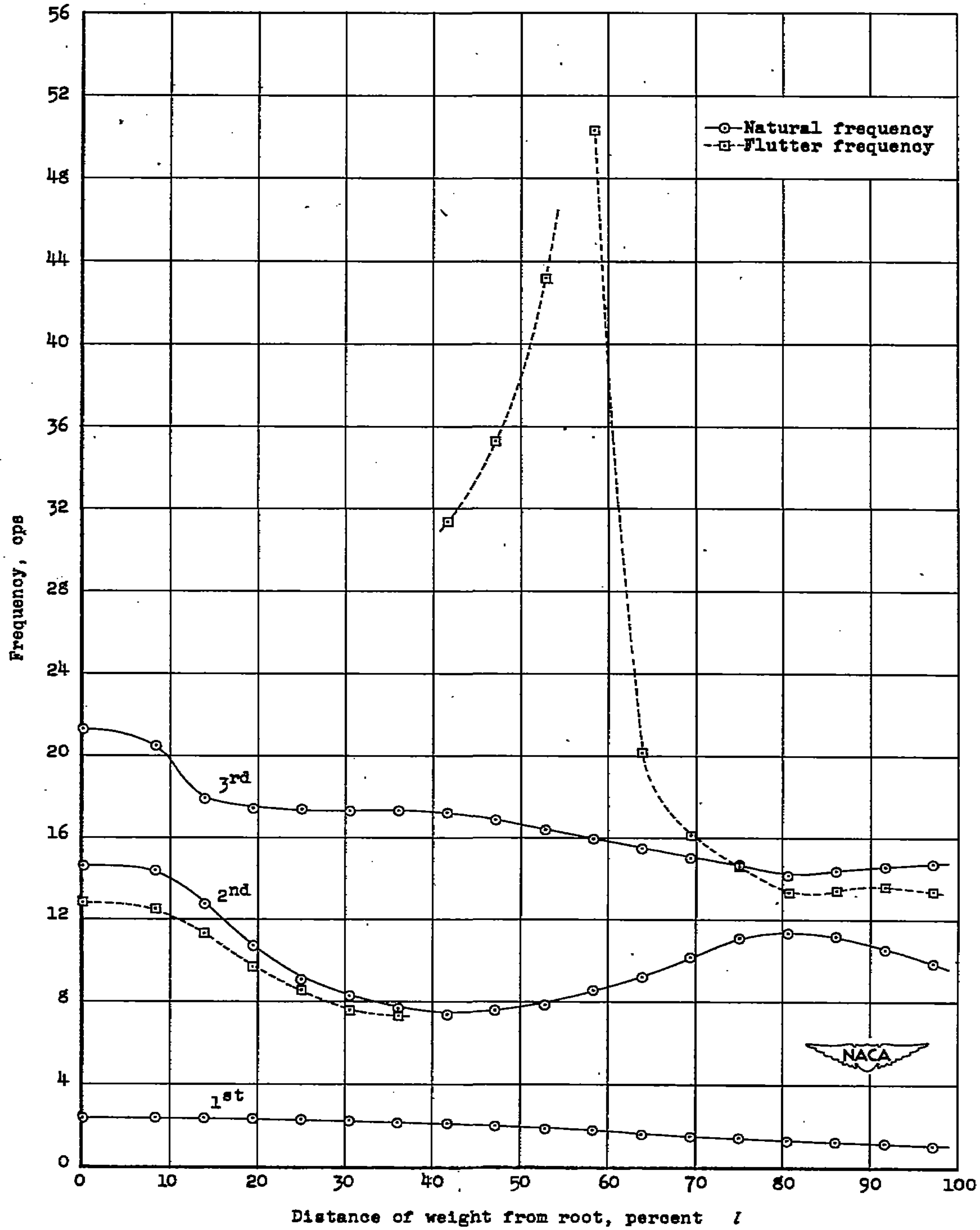
(e) Model C-1, $\Lambda = 60^{\circ}$, $e_{W} = -1$.

Figure 3.— Continued.



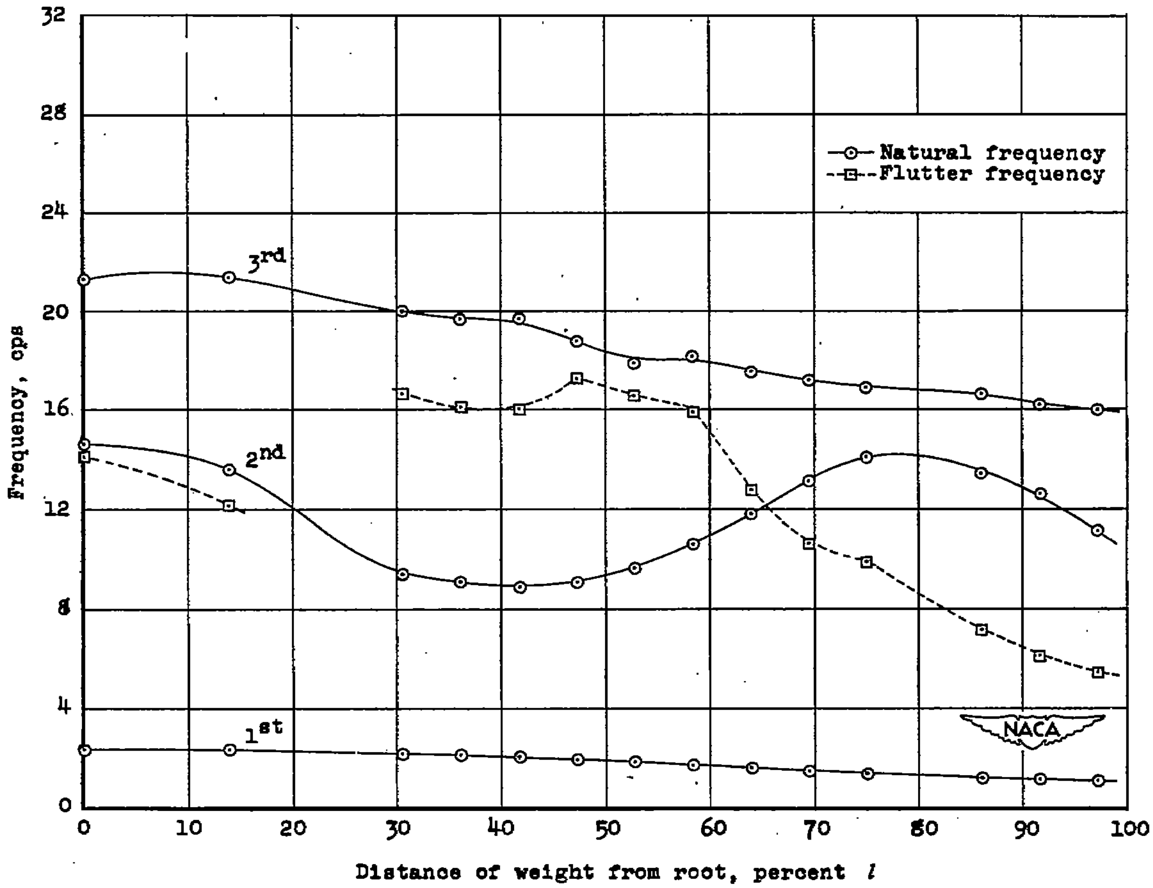
(f) Model C-1, $\Lambda = 60^{\circ}$, $e_W = 0$.

Figure 3.— Continued.



(g) Model C-2, $\Lambda = 60^{\circ}$, $e_W = -1$.

Figure 3.- Continued.



(h) Model C-2, $\Lambda = 60^{\circ}$, $e_w = 0$.

Figure 3.— Concluded.