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RESEARCH MEMORANDUM

PRELIMINARY EXPERIMENTAL INVESTIGATION OF EFFECTS OF AERODYNAMIC SHAPE OF CONCENTRATED WEIGHTS ON FLUTTER OF A STRAIGHT CANTILEVER WING

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY EXPERIMENTAL INVESTIGATION OF EFFECTS OF AERODYNAMIC SHAPE OF CONCENTRATED WEIGHTS ON FLUTTER OF A STRAIGHT CANTILEVER WING

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SUMMARY

Results are presented to show the effect on flutter characteristics of variation of the aerodynamic shape of concentrated weights rigidly mounted on a simplified wing structure. The model was mounted as a rigid cantilever and tested with weights that were $7\frac{1}{2}$ percent and 5 percent of the weight of the wing. In regard to shape, two general types of weights, having similar mass and moment-of-inertia properties, were employed: one a streamlined body resembling in shape an external wing fuel tank and the other a chosen nonstreamlined, or blunt, body. Approximately 20 flutter tests were conducted in a preliminary program at low Mach numbers with weights varied over a wide range of spanwise positions; an additional chordwise position was included at the wing tip. Results show only small changes in flutter speed and flutter frequency due to radical changes in the aerodynamic shape of concentrated weights. A large reduction in flutter speed is shown as relatively light concentrated weights are moved nearer the tip, with only a small change in flutter frequency. Results also demonstrate, experimentally, a considerable influence of moment of inertia on flutter speed and flutter frequency.

INTRODUCTION

The installation of large external fuel tanks on airplane wings has caused attention to be directed to the possible influence of these tanks on certain aeroelastic properties of the wing. For example, an investigation of the cause of wing failure for a certain airplane having an extérnal fuel tank at the wing tip (with the tank in an almost empty condition at the time of failure) suggested the possibility of wing flutter, with a lower flutter speed resulting from the aerodynamic forces acting on the tank. No analytical treatment is available for predicting the oscillatory forces on such bodies, and thus the effect on flutter characteristics of a change in body shape cannot be directly calculated. A systematic experimental study of effects of concentrated weights on flutter characteristics was reported in reference 1, and analytical studies of these effects were made in references 2 and 3. Throughout the studies, however, no particular attention was given to the aerodynamic contours of the concentrated weights employed. The primary objective of this paper is to present experimental results on some effects on the flutter speed and flutter frequency of a wing carrying concentrated weights having widely different aerodynamic shapes.

This paper presents results of a limited study that is part of a broader investigation. For the flutter tests, a straight untapered uniform cantilever wing was used. The concentrated weights employed had similar mass and moment-of-inertia properties, but were of different aerodynamic shapes. One of these weights was a streamlined body resembling in shape an external fuel tank, whereas the other was of a nonstreamlined shape.

The concentrated weights were selected so that the ratio of their weights to that of the wing was comparable to the ratio of the weights of an empty external fuel tank and the wing of a typical airplane. In view of the relatively low ratio of the weight of an empty external fuel tank to the weight of a wing, it seemed unlikely that its mass might exert much influence on the flutter characteristics of the wing. Because of the shape of the tank, however, the moment of inertia of the tank is usually high in comparison with its weight. Since this appreciable moment of inertia may quite conceivably exert strong influence on flutter characteristics, a study of the effect on these characteristics of a variation in the moment of inertia of the external tank has been included.

Flutter tests were conducted with the weights mounted rigidly at the wing tip and at various spanwise positions. In the present preliminary study, the testing was done only at low Mach numbers and only a few wing-weight configurations were used.

SYMBOLS

W	weight of wing, pounds
W_w	weight of concentrated weight, pounds
l	length of wing, feet
b	half-chord of wing, feet
I_w	mass moment of inertia of weight about wing elastic axis, inch-pound-second^2
I_{CG}	mass moment of inertia of wing about center of gravity, inch-pound-second^2
I_{EA}	mass moment of inertia of wing about elastic axis, inch-pound-second^2
EI	bending rigidity of wing, pound-inches^2
GJ	torsional rigidity of wing, pound-inches^2
ρ	density of testing medium, slugs per cubic foot
m	mass of wing per unit length
$\frac{1}{\kappa}$	mass ratio $\left(\frac{m}{\pi\rho b^2}\right)$
r_α	nondimensional radius of gyration relative to elastic axis $\left(\sqrt{\frac{I_{EA}}{12lmb^2}}\right)$
e_w	distance between elastic axis of wing and center of gravity of weight referred to half-chord
f_n	frequency, cycles per second
f_{h_1}	first bending natural frequency, cycles per second

f_{h_2} second bending natural frequency, cycles per second

f_t first torsion natural frequency, cycles per second

f_e experimental flutter frequency, cycles per second

v_i indicated airspeed at flutter, feet per second

v true airspeed at flutter, feet per second

q dynamic pressure at flutter, pounds per square foot

g_{h_1} structural damping coefficient, first bending

g_{h_2} structural damping coefficient, second bending

g_α structural damping coefficient, first torsion

Subscript:

w refers to the corresponding properties or parameters of wing carrying concentrated weights

APPARATUS

The entire series of approximately 20 flutter tests was made on a single uniform wing. The model selected for testing, built of magnesium alloy, was 40 inches long with an 8-inch chord and had an NACA 16-004 airfoil section. As shown in figure 1, the model was mounted rigidly to the top of the test section as a cantilever beam so that the flutter produced may be considered to correspond to a symmetrical mode. The chordwise slots shown along the trailing edge in figure 1 were cut to a depth of approximately $2\frac{3}{4}$ inches at every inch along the span in an effort to move the elastic axis forward and hence keep the divergence speed above the expected flutter speed range. A cross-sectional view of the wing is given in figure 2 and the wing properties were as follows:

Chord, inches	8
Length, inches	40
Aspect ratio (geometric)	5
Taper ratio	1
Airfoil section	NACA 16-004
W, pounds	4.89
I_{CG}, inch-pound-second^2	0.0428
I_{EA}, inch-pound-second^2	0.0434
EI, pound-inches^2	0.0608×10^6
GJ, pound-inches^2	0.0944×10^6
$r_\alpha{}^2$	0.214
$\frac{1}{\kappa}$ (standard air, no weight)	55.0

The model was statically loaded at the tip to obtain the rigidities in torsion and bending.

Concentrated weights which had similar mass and moment-of inertia properties but which differed in shape were used. In regard to shape, two general contours were employed: one, a streamlined body resembling an external fuel tank, and the other, a chosen nonstreamlined, or blunt, body. The weights were made adaptable to various phases of the investigation.

Weights 1 and 2 were the streamlined and the nonstreamlined bodies, respectively, used to examine some effects of aerodynamic shape of tip weights on flutter speed and flutter frequency. These weights were located at two different chordwise positions, designated by "a" and "b". Weights 1a and 2a (figs. 3(a) and 3(b), respectively) were those for which the center of gravity of the weight was close to the wing elastic axis. Weights 1b and 2b (figs. 3(c) and 3(d), respectively) were those for which the center of gravity of the weight was nearer the leading edge of the wing.

Weight 2 was also used to study the effect of varying the moment of inertia of a weight at the tip. Two configurations representing different moments of inertia were used. These were designated as weights 2c and 2d (figs. 3(e) and 3(f), respectively). The centers of gravity of these weights, relative to the elastic axis of the wing, coincided with that of weight 2a.

Weight 3 (fig. 3(g)) and weight 4 (fig. 3(h)) were the streamlined and the nonstreamlined bodies, respectively, used to pursue further the investigation of effects of aerodynamic shape. The weights were made so that they could be varied over a wide range of spanwise positions with their inertial properties remaining constant. The center of gravity of each weight was located close to the elastic axis of the wing.

The concentrated weight properties are given in the following table, in which the negative values of e_w indicate weight locations forward of the wing elastic axis:

Weight	$\frac{W_w}{W}$	e_w	$\frac{I_w}{I_{EA}}$
1a	0.0744	0.045	0.380
1b	.0754	-.513	.509
2a	.0755	.045	.403
2b	.0755	-.505	.507
2c	.0752	.045	.219
2d	.0749	.045	.070
3	.0485	.023	.310
4	.0485	.023	.308

The flutter tests described herein were conducted in the Langley 4.5-foot flutter research tunnel, the essential features of which are discussed in reference 1.

Strain gages mounted on the wing near the root, as shown in figure 1, permitted vibration records to be made of the bending and torsional oscillations of the wing during flutter. The square indicates the location of the bending gages and the circles indicate the locations of the torsion gages. The strain-gage signals were recorded on a recording oscillograph.

In order to prevent destruction of the wing as a result of divergence, restraining wires were attached from the tunnel walls to the wing quarter chord near the tip. As can be seen in figure 1, these wires had sufficient slack in them to permit adequate amplitude in flutter but could still save the wing if divergence occurred.

TEST PROCEDURE

In the flutter testing of the model, velocity of flow in the tunnel was increased slowly until the critical flutter speed was attained. At this point, the tunnel conditions were observed and, simultaneously, an oscillograph record of the vibrations of the model was taken. These data, from which the experimental flutter speed and flutter frequency were obtained, have been recorded in table I. For most runs, the natural frequencies were tabulated both before and after the actual run to determine whether or not the wing had been damaged by flutter. The remarks in table I regarding the flutter characteristics are based almost entirely on visual observations made at the time of the run; because of the sudden and violent occurrence of flutter, these remarks are inclined to be somewhat arbitrary. The structural damping coefficients recorded in table I have been determined from the rate of decay of oscillations on the vibration records of the natural frequencies.

RESULTS AND DISCUSSION

In presenting the results of this investigation, three phases of the problem are considered: first, some effects of aerodynamic shape of concentrated weights; second, effects of variation in the spanwise position of light concentrated weights; third, effects of moment of inertia of light concentrated weights. The second and third phases are included as logical outgrowths of this program and may be regarded as incidental to the first phase, which is concerned with the primary objective of the paper. As in reference 1, the variations in flutter speed and flutter frequency, the two flutter parameters studied, have been compared to the corresponding parameters of the unweighted wing.

Effects of Aerodynamic Shape of Concentrated Weights

Attention may first be directed to the effect on flutter speed and flutter frequency of the aerodynamic shape of concentrated weights mounted at the wing tip. In the following table these parameters have been compared for two different chordwise positions of weights 1 and 2:

Weight	Weight shape (see figs. 3(a) to 3(d))	Weight location (percent chord)	$\frac{W_w}{W}$	$\frac{I_w}{I_{EA}}$	$\frac{(v_i)_w}{v_i}$	$\frac{(f_e)_w}{f_e}$	Run (see table I)
1a	Streamlined	47.3	0.0744	0.380	0.845	0.846	2
2a	Nonstreamlined	47.3	.0755	.403	.874	.754	3
1b	Streamlined	19.4	.0754	.509	.763	.824	5
2b	Nonstreamlined	19.8	.0755	.507	.792	.904	6

Examination of the flutter speeds shows a maximum difference of $3\frac{1}{2}$ percent between streamlined and nonstreamlined shapes. A radical change in the shape of weights located at the tip appears to have produced only a small change in flutter speed. A somewhat greater effect of shape on flutter frequency is noted with the changes occurring in opposite directions for the two different chordwise positions.

The effects of aerodynamic shape of weights for a wide range of spanwise positions are presented in figures 4 and 5 for weight 3 (fig. 3(g)) and weight 4 (fig. 3(h)). Comparison of the flutter speeds in figure 4 for streamlined and nonstreamlined shapes shows a difference of not more than 4 percent at any point along the span. Thus, a radical change in aerodynamic shape of weights at any spanwise location has produced only a small change in flutter speed, although for most spanwise positions as well as for the tip position the flutter speed was lower for the streamlined shape than for the nonstreamlined shape. Examination of figure 5 shows that with the exception of the tip position the flutter frequency differed by less than 3 percent between streamlined and nonstreamlined shapes at any point along the span.

Although the effect on flutter of aerodynamic shape of the weights is shown to be small, it should be remarked that shape may be very significant in regard to such static aeroelastic instabilities as wing divergence. However, the static cases are not considered in this investigation.

Effects of Spanwise Variation of Light Concentrated Weights

For these tests, the influence of aerodynamic shape was shown to be small as the spanwise location of the light concentrated weights was varied from root to tip. The general reduction in flutter speed, similar to that shown in reference 1 for weights having a comparable chordwise center-of-gravity location, may therefore be attributed wholly to the effect of the concentrated weights. In the present investigation a maximum reduction in flutter speed of 17 percent was obtained with weights which were approximately 5 percent of the weight of the wing. In reference 1 a maximum reduction of 13 percent is shown for weights which were approximately 60 percent of the weight of the wing. A comparison on the basis of weight alone with the results of reference 1 shows the reduction in flutter speed in the present cases to be of much larger magnitude than might be expected. That the effect is one of moment of inertia rather than one of mass is indicated by examination of figure 6, in which is shown the variation of natural frequencies with span position for weight 3. The bending frequencies appear to be relatively unchanged, indicating that the effect of mass is small; but in the torsional frequency there is noted a marked reduction, which can be attributed to the appreciable moment of inertia of the weight, for weight positions near the tip.

The flutter frequencies for weights 3 and 4 were not greatly affected by the variation in spanwise position of the weights (see figs. 5 and 6). As shown in figure 5, a maximum reduction of $17\frac{1}{2}$ percent was found. In reference 1 the maximum reduction amounted to 59 percent for weights that were approximately 60 percent of the weight of the wing and had chordwise center-of-gravity positions comparable to those of weights 3 and 4.

Effects of Moment of Inertia of Light Concentrated Weights

The effects of the moment of inertia of the weight on flutter speed and flutter frequency have been studied with the aid of tip weights 2c (fig. 3(e)) and 2d (fig. 3(f)), in addition to weight 2a. The results are presented in figures 7 and 8. As can be seen in these figures, an increase in moment of inertia produced a decrease both in flutter speed and flutter frequency. Comparison among the natural frequencies in figure 8 further shows that the main effect of variation in moment of inertia has been on the torsional degree of freedom, with the bending frequencies remaining essentially unchanged. This fact, together with the data observed in the variation in spanwise position of weights 3 and 4, indicates that even though a relatively light concentrated weight is used, its moment of inertia may be such that considerable influence is exerted on flutter speed and flutter frequency.

CONCLUDING REMARKS

In a preliminary experimental program consisting of over 20 flutter runs at low Mach numbers, results have been presented to show some effects on flutter speed and flutter frequency of the aerodynamic shape of concentrated weights. These parameters have been compared for streamlined and nonstreamlined shapes of rigidly mounted weights that were varied over a wide range of spanwise positions on a straight cantilever wing. In regard to shape, two general types of weights having similar mass and moment-of-inertia properties were employed: one a streamlined body resembling in shape an external wing fuel tank and the other a chosen nonstreamlined body. Because of the preliminary nature of this investigation, the following remarks are necessarily restricted to data on this wing and therefore cannot be regarded as general.

Results, concerning the main objective of the investigation, show that both flutter speed and flutter frequency are relatively unaffected by radical changes in the aerodynamic shape of the concentrated weights.

Further observations in this investigation are possible on two other results which are considered to be logical, though perhaps incidental, outgrowths of the main objective. In regard to the first of these auxiliary results, the variation in spanwise position of relatively light concentrated weights (approximately 5 percent of the weight of the wing) produces an effect on the flutter speed that is large when compared with the results of reference 1 for much heavier weights; the effect on flutter frequency, however, is small compared with that found in reference 1 for heavier weights. In regard to the second of these other results, it is experimentally demonstrated that the effect on flutter speed and flutter frequency of the moment of inertia of a relatively light concentrated weight may be large.

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TABLE I.- EXPERIMENTAL DATA

Run	Weight	Spanwise position (in. from root)	q (lbs/sq ft)	v_i (fps)	Mach number	Reynolds number (based on wing chord)	v (fps)	ρ (slugs/cu ft)	f_{h_1} (cps)	f_{h_2} (cps)	f_t (cps)	f_e (cps)	g_{h_1}	g_{h_2}	g_α	Remarks
1	None	--------	0	0	0	0	0	--------	4.94	30.9	58.3	----	0.0099	0.0048	0.0030	Fluttered in second bending mode with node about 8 inches from tip; clear, sustained response
	None	--------	208.5	419.9	.3925	1.6654×10^6	443.1	0.002135	----	----	----	34.5	------	------	------	
	None	--------	0	0	0	0	0	--------	5.02	31.1	58.4	----	.0130	.0022	.0011	
2	1a	40 (tip)	0	0	0	0	0	--------	4.45	27.3	42.2	----	.0283	.0069	.0064	Fluttered in second bending mode with $1\frac{1}{2}$-inch tip amplitude
	1a	40 (tip)	148.1	355.0	.3278	1.4326	369.6	.002196	----	----	----	29.2	------	------	------	
	1a	40 (tip)	0	0	0	0	0	--------	4.42	27.2	41.7	----	.0236	.0054	.0075	
3	2a	40 (tip)	0	0	0	0	0	--------	4.51	28.2	43.8	----	.0110	.0047	.0012	Fluttered with 3-inch tip amplitude
	2a	40 (tip)	158.8	366.9	.3393	1.4756	382.6	.002185	----	----	----	26.0	------	------	------	
	2a	40 (tip)	0	0	0	0	0	--------	4.29	27.5	42.9	----	.0166	.0200	.0220	
4	None	--------	204.5	416.0	.3882	1.6596	437.5	.002148	----	----	----	35.7	------	------	------	Check on run 1; flutter response kept smaller to prevent damage to model
	None	--------	0	0	0	0	0	--------	4.92	30.5	57.1	----	.0095	.0037	.0013	
5	1b	40 (tip)	0	0	0	0	0	--------	4.29	26.2	38.9	----	.0070	.0139	.0153	Fluttered with 4 to 5 inch amplitude on forward end of weight; weight bent at angle to airstream because of flutter
	1b	40 (tip)	121.1	320.3	.2960	1.3269	330.0	.002240	----	----	----	28.6	------	------	------	
	1b	40 (tip)	0	0	0	0	0	--------	4.29	26.9	32.2	----	.0143	Not clear	.0137	
6	2b	40 (tip)	0	0	0	0	0	--------	4.34	27.3	40.3	----	.0124	.0107	.0085	Fluttered in second bending mode with strong torsion response; small amplitude
	2b	40 (tip)	130.5	332.5	.3059	1.4314	336.5	.002320	----	----	----	31.3	------	------	------	
	2b	40 (tip)	0	0	0	0	0	--------	4.32	27.7	40.4	----	.0110	.0152	.0299	
7	None	--------	207.0	419.5	.3927	1.7583	433.5	.002225	----	----	----	34.7	------	------	------	Check on run 1; good flutter response
	None	--------	0	0	0	0	0	--------	5.00	30.7	57.0	----	.0107	.0060	.0019	
8	2c	40 (tip)	0	0	0	0	0	--------	4.39	28.0	46.8	----	.0126	.0051	.0140	Fluttered violently in second bending mode with 2-inch tip amplitude
	2c	40 (tip)	178.3	388.9	.3618	1.6272	400.8	.002238	----	----	----	28.5	------	------	------	
	2c	40 (tip)	0	0	0	0	0	--------	4.34	27.7	47.1	----	.0115	.0090	.0136	
9	2d	40 (tip)	0	0	0	0	0	--------	4.34	27.7	53.3	----	.0083	.0131	.0091	Fluttered violently in second bending mode with large amplitude and node 8 to 10 inches from tip
	2d	40 (tip)	197.1	408.9	.3836	1.6687	427.7	.002173	----	----	----	29.5	------	------	------	
	2d	40 (tip)	0	0	0	0	0	--------	4.29	27.4	52.2	----	.0142	.0039	.0038	
10	3	$30\frac{3}{4}$	0	0	0	0	0	--------	4.74	30.8	46.1	----	.0089	.0073	.0059	Good flutter response with small amplitude
	3	$30\frac{3}{4}$	148.0	354.5	.3273	1.4573	366.1	.002229	----	----	----	33.5	------	------	------	
	3	$30\frac{3}{4}$	0	0	0	0	0	--------	4.71	30.7	45.9	----	.0113	.0054	.0019	
11	3	24	0	0	0	0	0	--------	4.83	29.7	48.0	----	.0123	.0039	.0075	Fluttered with about $1\frac{1}{2}$-inch amplitude on trailing edge of weight
	3	24	169.3	379.0	.3514	1.5452	393.6	.002203	----	----	----	32.8	------	------	------	
	3	24	0	0	0	0	0	--------	4.83	30.0	47.8	----	.0142	.0045	.0047	

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TABLE I.- Concluded

Run	Weight	Spanwise position (in. from root)	q (lbs/sq ft)	v_1 (fps)	Mach number	Reynolds number (based on wing chord)	v (fps)	ρ (slugs/cu ft)	f_{h_1} (cps)	f_{h_2} (cps)	f_t (cps)	f_e (cps)	g_{h_1}	g_{h_2}	g_α	Remarks
12	3	16	0	0	0	0	0	--------	4.90	30.6	51.6	----	0.0103	0.0036	0.0032	Fluttered very violently with large amplitude
	3	16	195.1	407.0	.3793	1.6469×10^6	425.5	0.002176	----	----	----	32.6	------	------	------	
	3	16	0	0	0	0	0	--------	4.90	29.6	51.2	----	.0111	.0045	.0041	
13	3	10	0	0	0	0	0	--------	5.07	30.0	54.7	----	.0088	.0036	.0031	Fluttered in second bending mode with large amplitude and node 8 to 10 inches from tip
	3	10	205.0	417.7	.3893	1.6808	437.5	.002165	----	----	----	32.3	------	------	------	
	3	10	0	0	0	0	0	--------	4.92	30.0	54.7	----	.0146	.0040	.0041	
14	3	$38\frac{17}{32}$ (tip)	0	0	0	0	0	--------	4.53	28.9	44.3	----	.0097	.0047	.0024	Violent flutter with large amplitude
	3	$38\frac{17}{32}$ (tip)	146.8	349.5	.3233	1.4170	363.4	.002198	----	----	----	28.7	------	------	------	
	3	$38\frac{17}{32}$ (tip)	0	0	0	0	0	--------	4.55	28.9	44.5	----	.0084	.0055	.0051	
15	3	35	144.7	350.1	.3238	1.4172	364.1	.002197	----	----	----	(a)	------	------	------	Violent flutter with large amplitude
16	None	---------	0	0	0	0	0	--------	4.93	30.6	56.9	----	.0094	.0052	.0037	Check on run 1; excellent, sustained flutter response in second bending mode with node 8 inches from tip
	None	---------	210.0	422.0	.3970	1.6768	446.8	.002120	----	----	----	34.7	------	------	------	
	None	---------	0	0	0	0	0	--------	4.88	30.7	57.2	----	.0076	.0043	.0044	
17	4	$39\frac{3}{4}$ (tip)	0	0	0	0	0	--------	4.53	28.5	44.4	----	.0032	.0066	.0124	Fluttered in second bending mode with 3-inch amplitude and node 8 inches from tip
	4	$39\frac{3}{4}$ (tip)	157.6	365.5	.3399	1.4650	383.0	.002166	----	----	----	30.4	------	------	------	
	4	$39\frac{3}{4}$ (tip)	0	0	0	0	0	--------	4.49	28.5	44.1	----	.0084	.0053	.0127	
18	4	35	0	0	0	0	0	--------	4.62	30.0	44.5	----	.0089	.0098	.0179	Good flutter response with 3-inch amplitude
	4	35	150.2	357.5	.3305	1.4438	372.3	.002193	----	----	----	30.5	------	------	------	
	4	35	0	0	0	0	0	--------	4.62	30.0	44.5	----	.0091	.0013	.0165	
19	4	31	0	0	0	0	0	--------	4.71	30.6	45.5	----	.0114	.0138	.0146	Good flutter response with 3-inch amplitude
	4	31	154.7	362.0	.3360	1.4529	378.5	.002173	----	----	----	33.4	------	------	------	
	4	31	0	0	0	0	0	--------	4.71	30.0	45.3	----	.0097	.0051	.0100	
20	4	24	0	0	0	0	0	--------	4.71	29.8	47.7	----	.0089	.0084	.0094	Fluttered in second bending mode with 3-inch amplitude with node 8 inches from tip
	4	24	180.5	390.2	.3630	1.5547	410.0	.002154	----	----	----	32.0	------	------	------	
	4	24	0	0	0	0	0	--------	4.71	29.4	47.1	----	.0113	.0047	.0232	
21	4	16	0	0	0	0	0	--------	4.87	29.2	50.8	----	.0074	.0116	.0115	Fluttered violently with large amplitude; strong divergence tendencies; nose section of weight loosened during flutter
	4	16	198.6	410.0	.3813	1.6326	430.9	.002154	----	----	----	32.9	------	------	------	
	4	16	0	0	0	0	0	--------	4.87	29.0	50.5	----	.0121	.0072	.0084	
22	4	10	0	0	0	0	0	--------	4.87	29.9	54.6	----	.0119	.0047	.0083	Fluttered violently with large amplitude; strong divergence tendencies
	4	10	204.6	416.0	.3875	1.6525	437.7	.002147	----	----	----	Not clear	------	------	------	
	4	10	0	0	0	0	0	--------	4.80	29.8	54.3	----	.0051	.0045	.0044	

[a]No vibration records.

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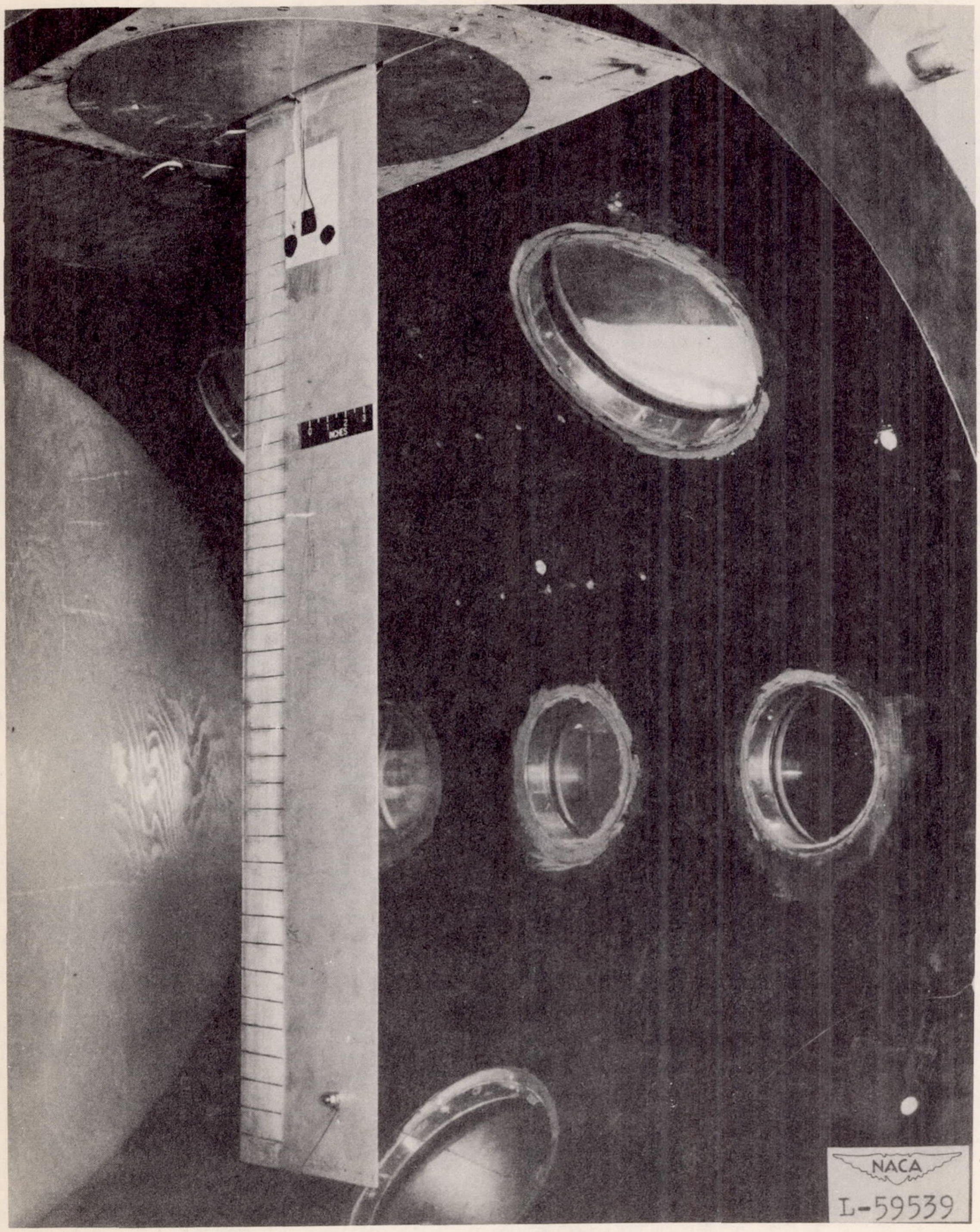


Figure 1.– General view of test section and model. Note divergence restraining wires near tip.

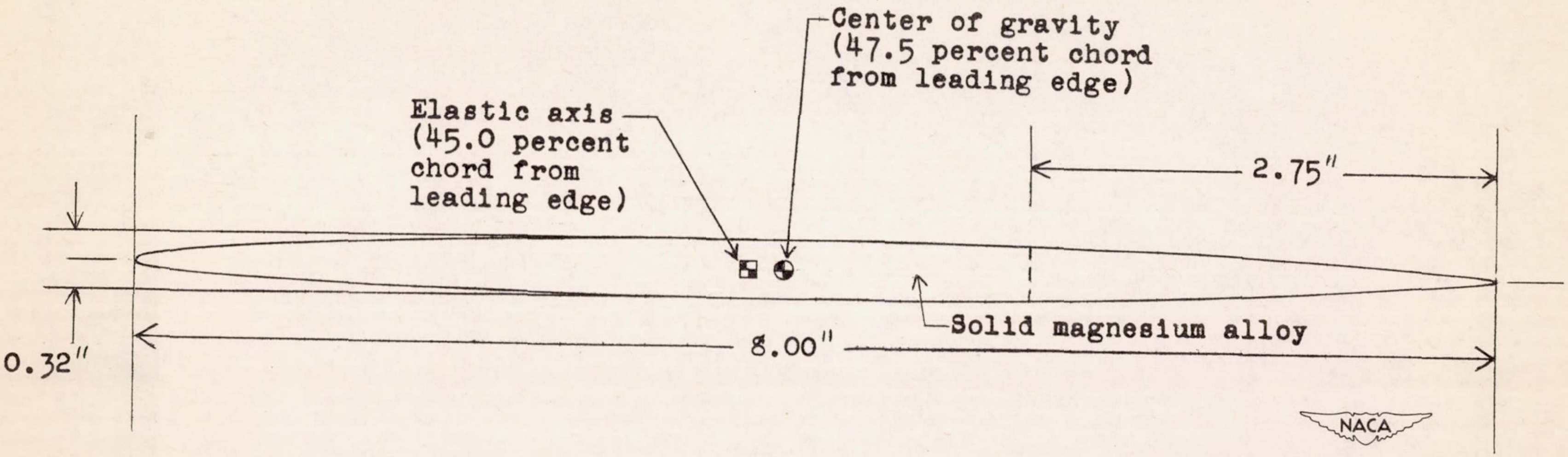
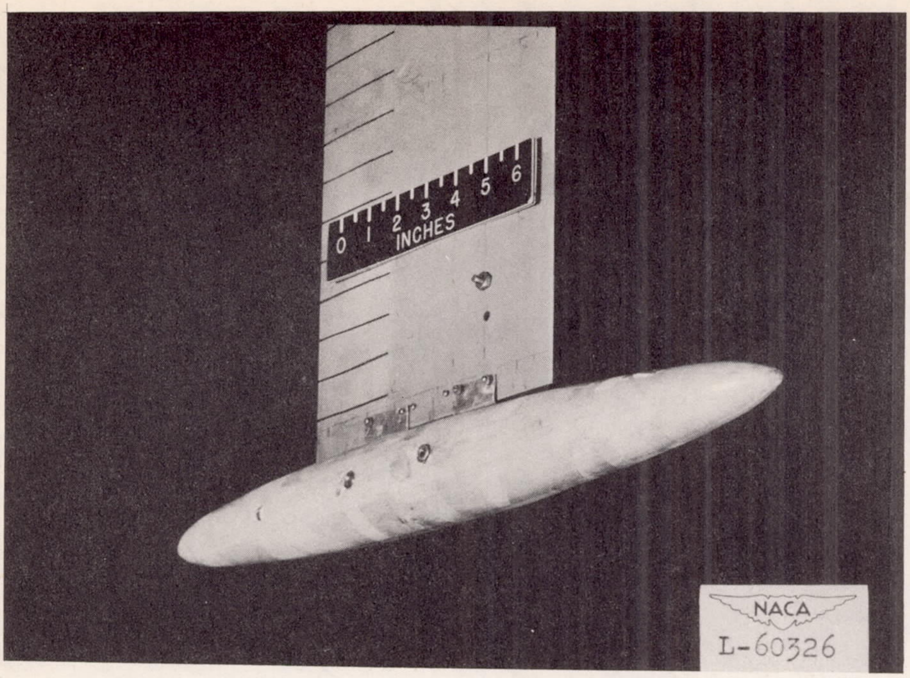
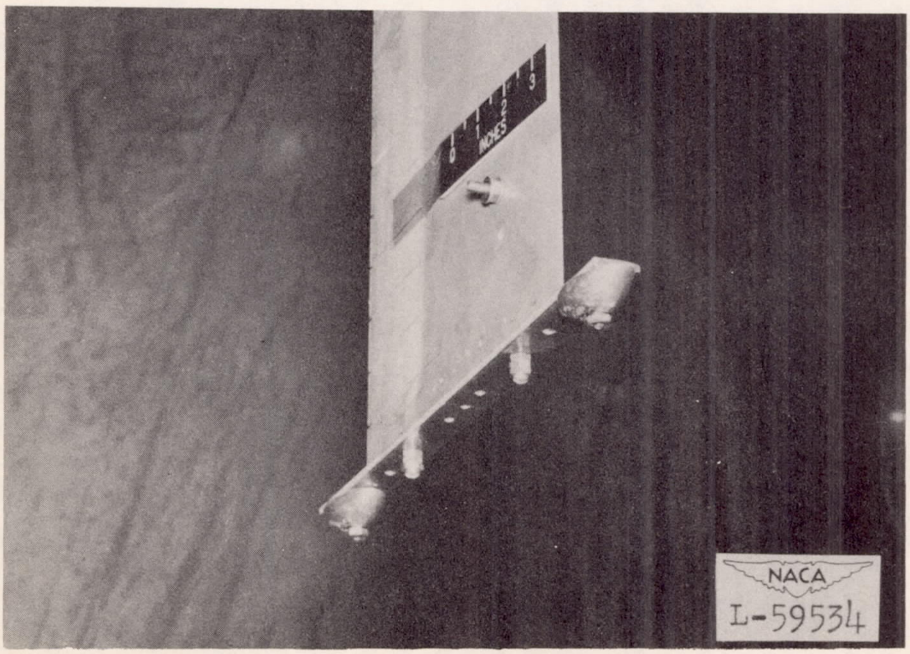


Figure 2.- Cross-sectional view of model; dashed line indicates depth of $\frac{1}{16}$-inch chordwise slots cut in trailing edge at every inch along span.

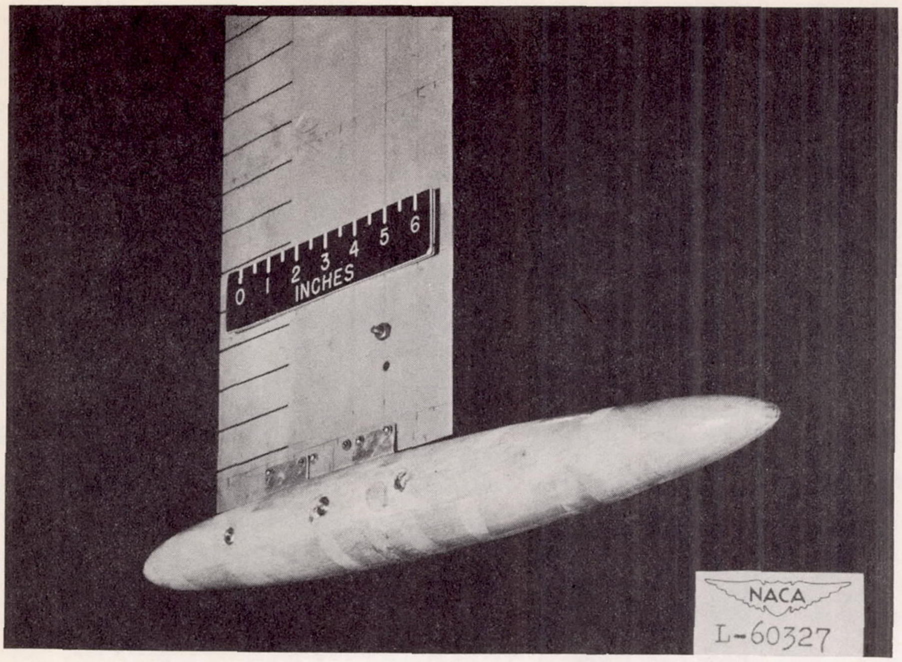


(a) Weight 1a.

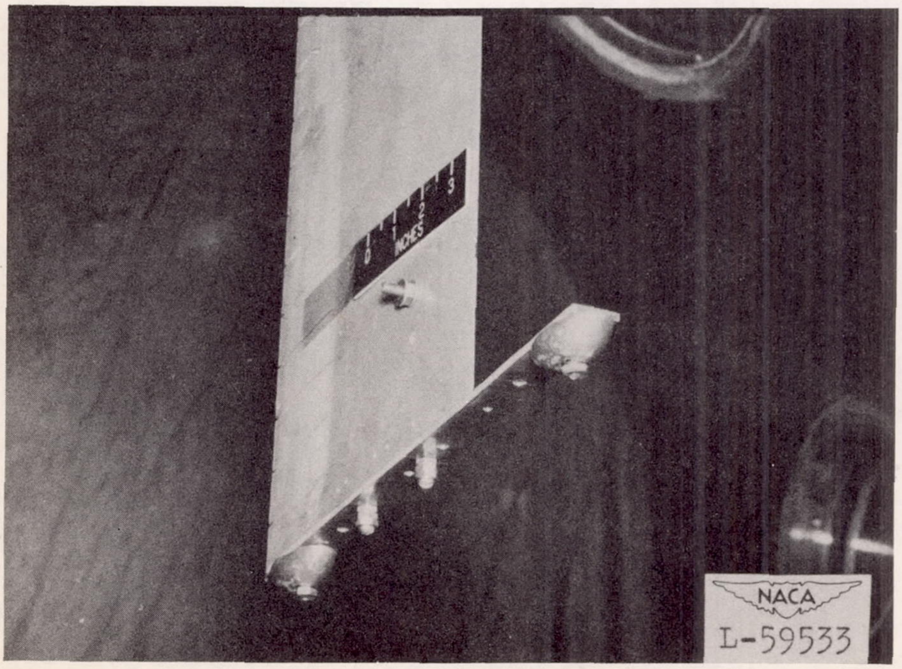


(b) Weight 2a.

Figure 3.— Concentrated weights.

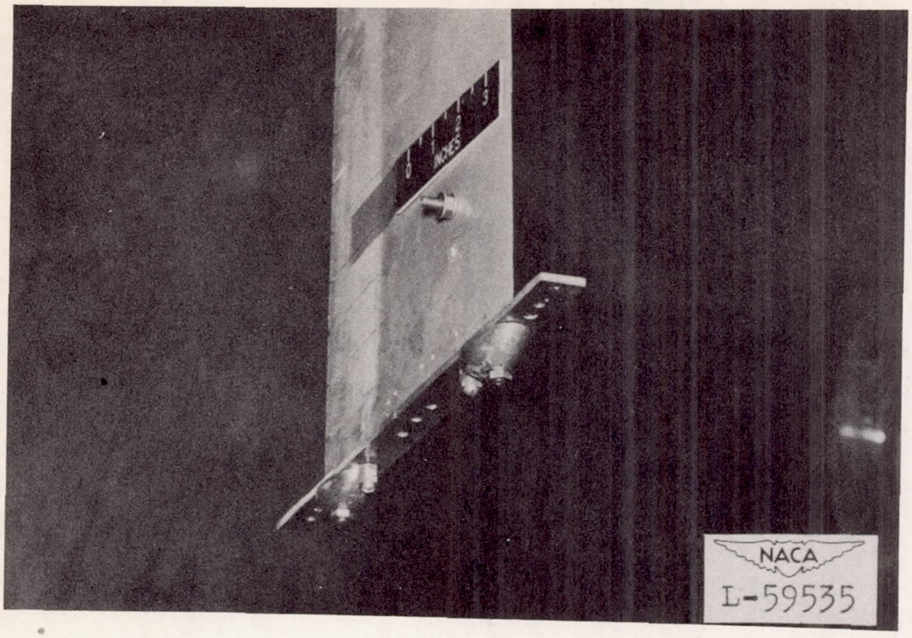


(c) Weight 1b.

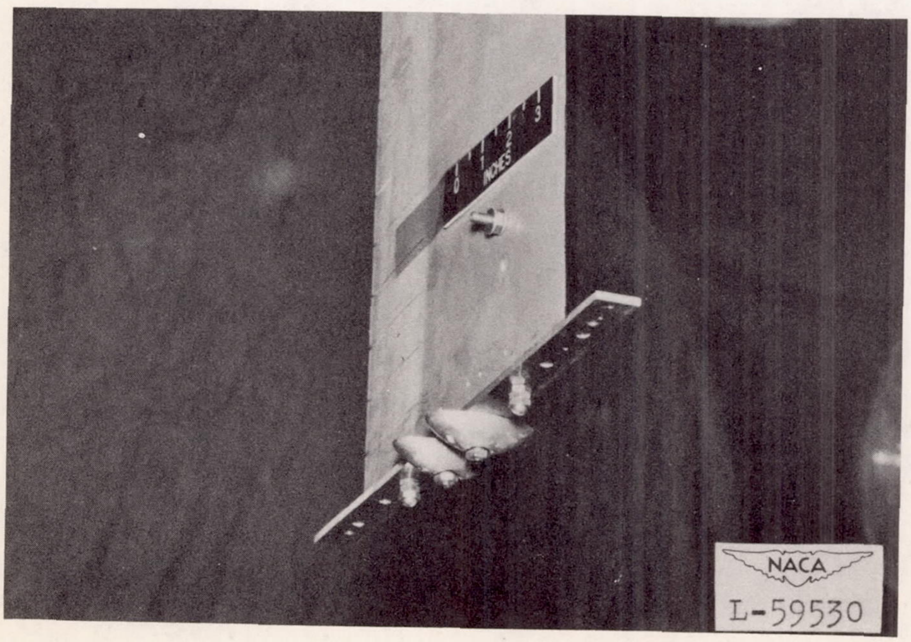


(d) Weight 2b.

Figure 3.— Continued.

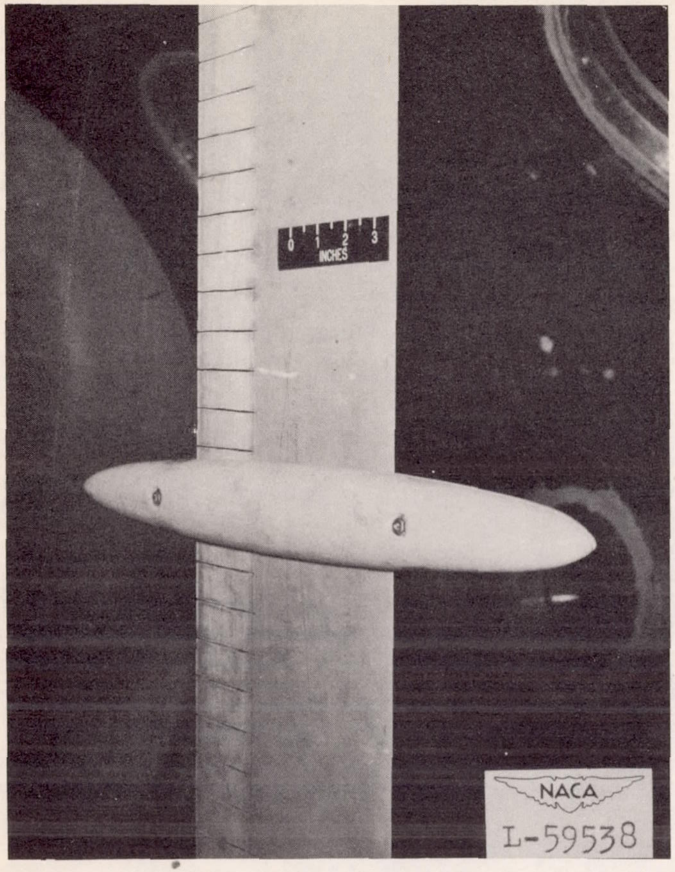


(e) Weight 2c.

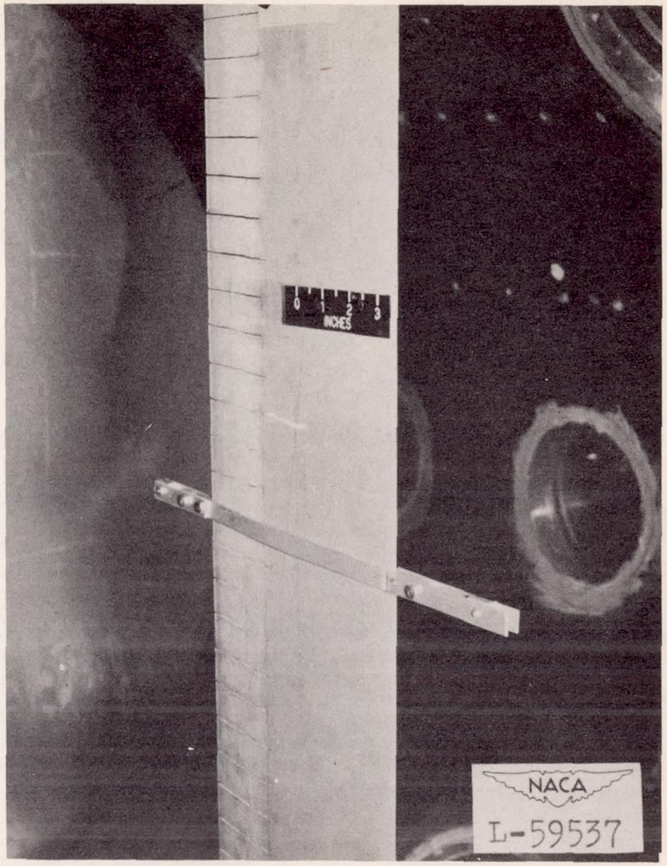


(f) Weight 2d.

Figure 3.– Continued.



(g) Weight 3.



(h) Weight 4.

Figure 3.– Concluded.

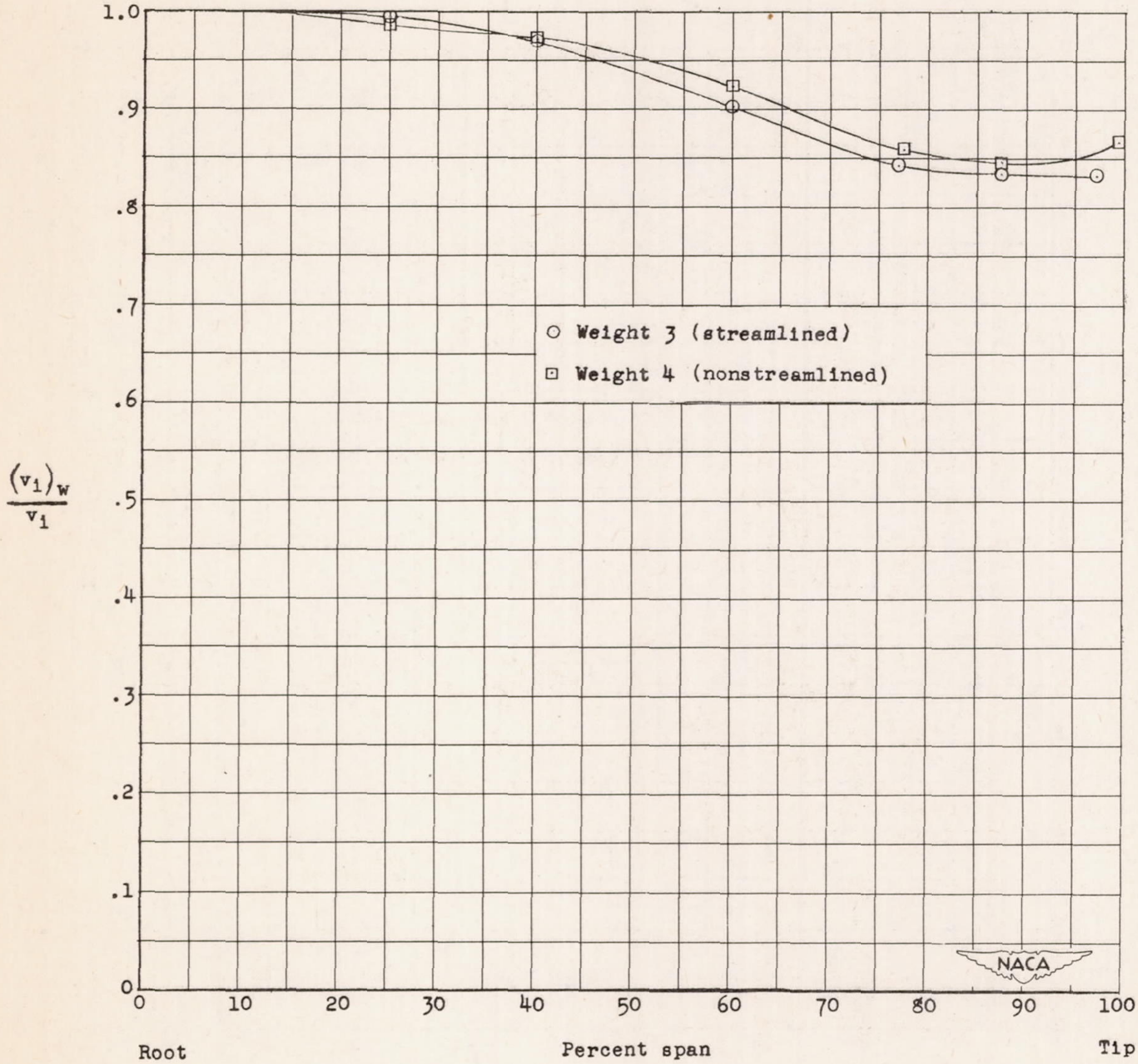


Figure 4.– Variation of flutter speed with spanwise position for weights 3 and 4.

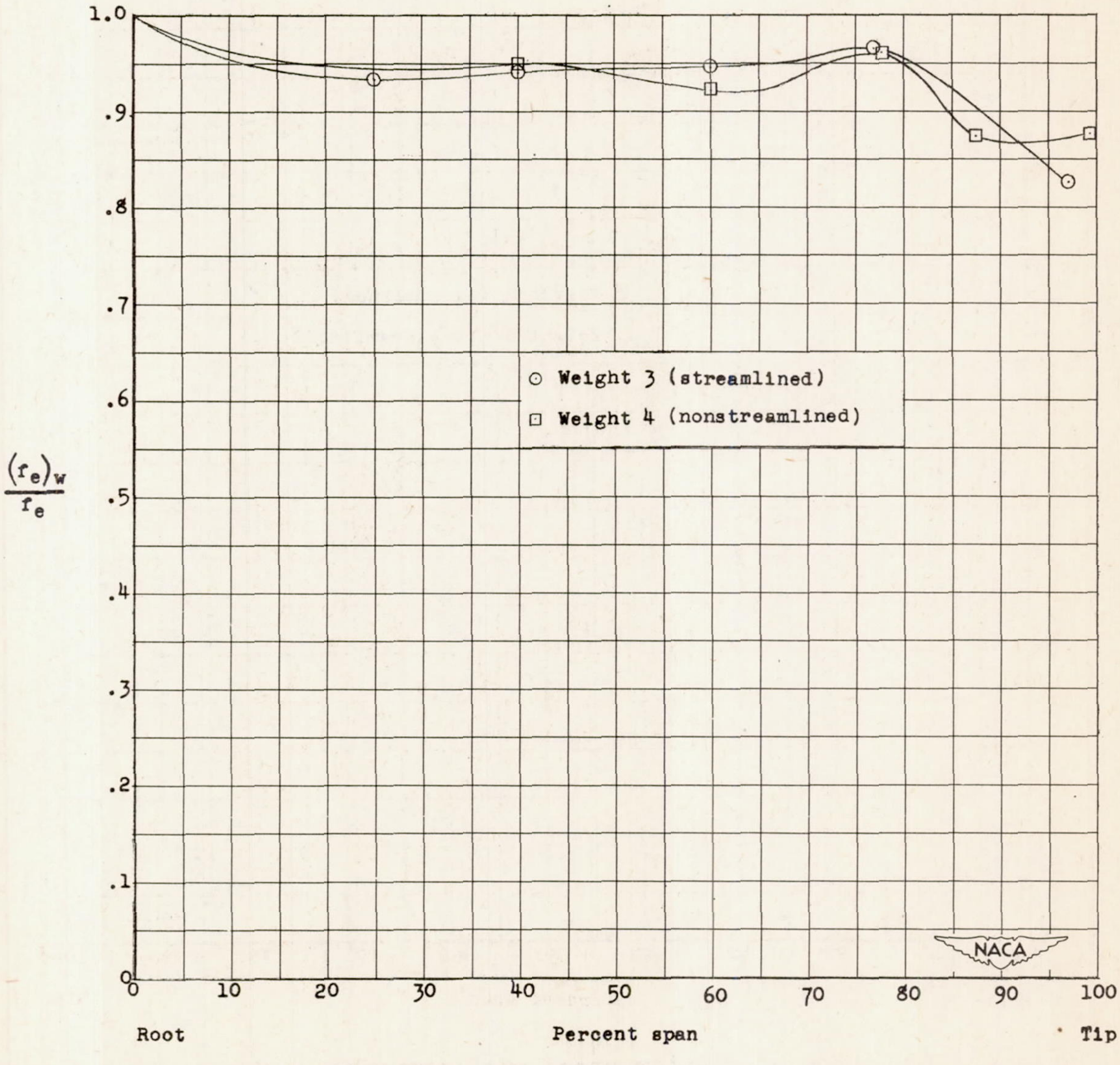


Figure 5.- Variation of flutter frequency with spanwise position for weights 3 and 4.

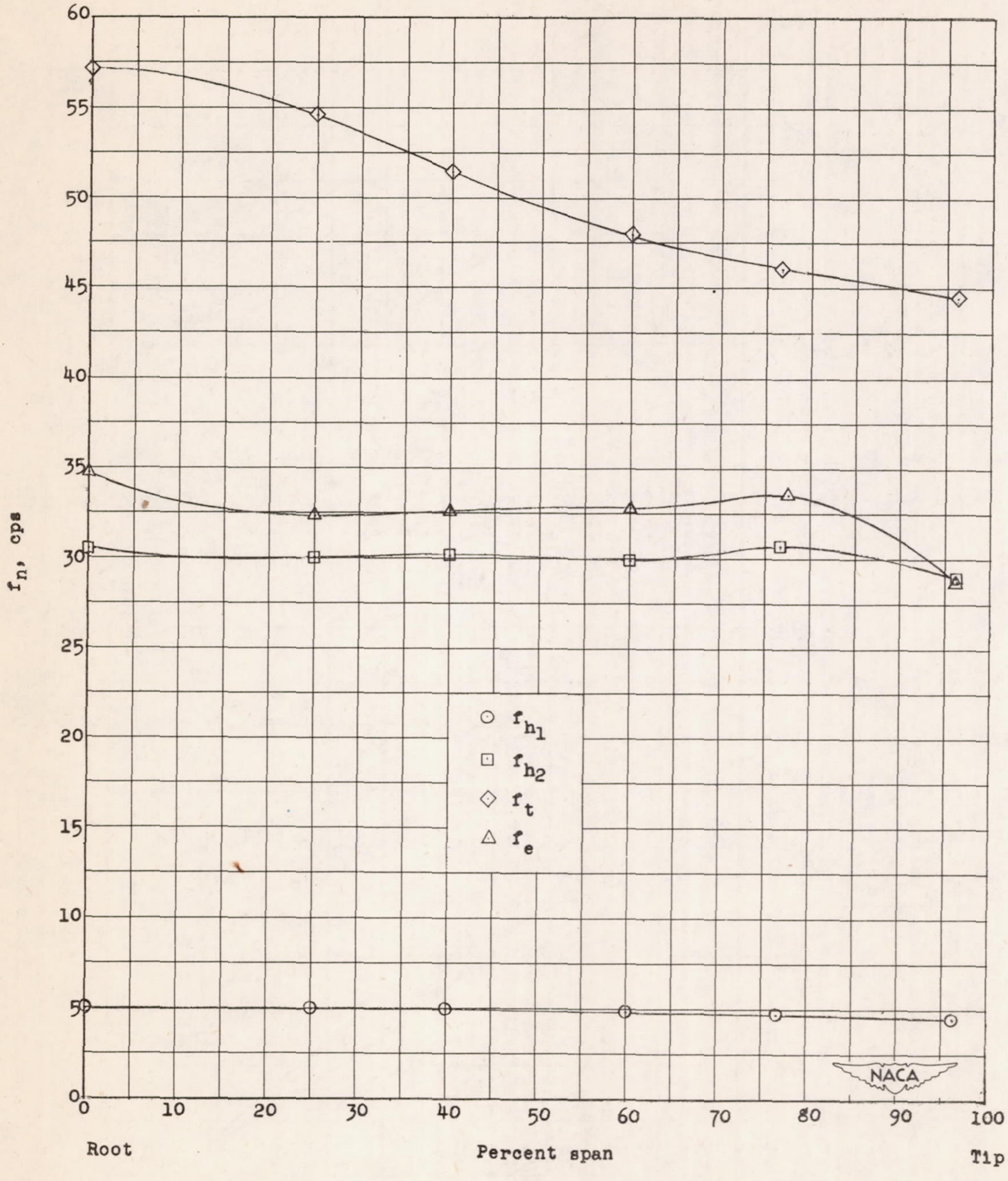


Figure 6.- Variation in natural and flutter frequencies with spanwise position for weight 3.

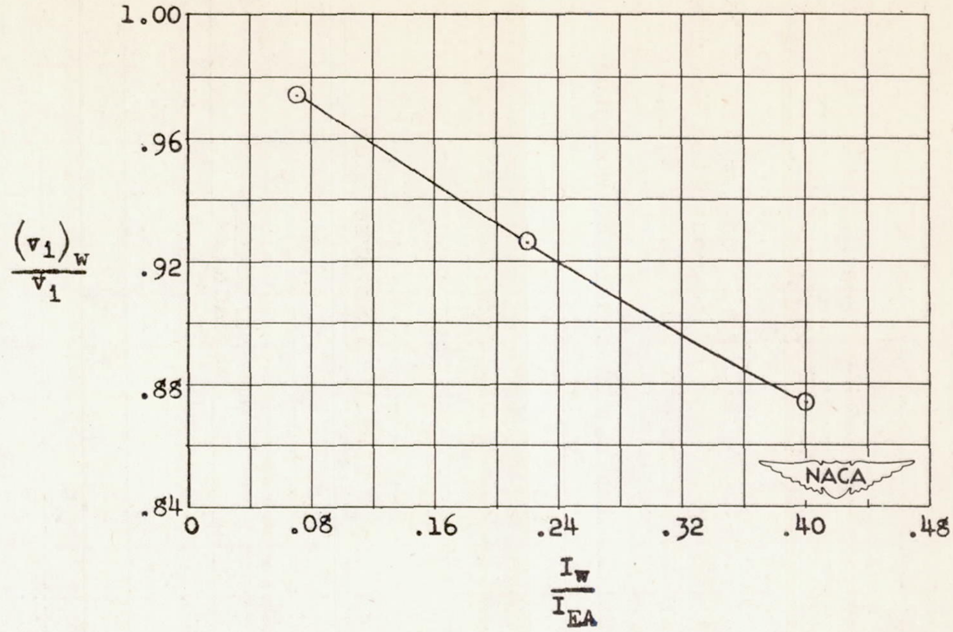


Figure 7.- Variation of flutter speed with mass moment of inertia for tip weights 2a, 2c, and 2d.

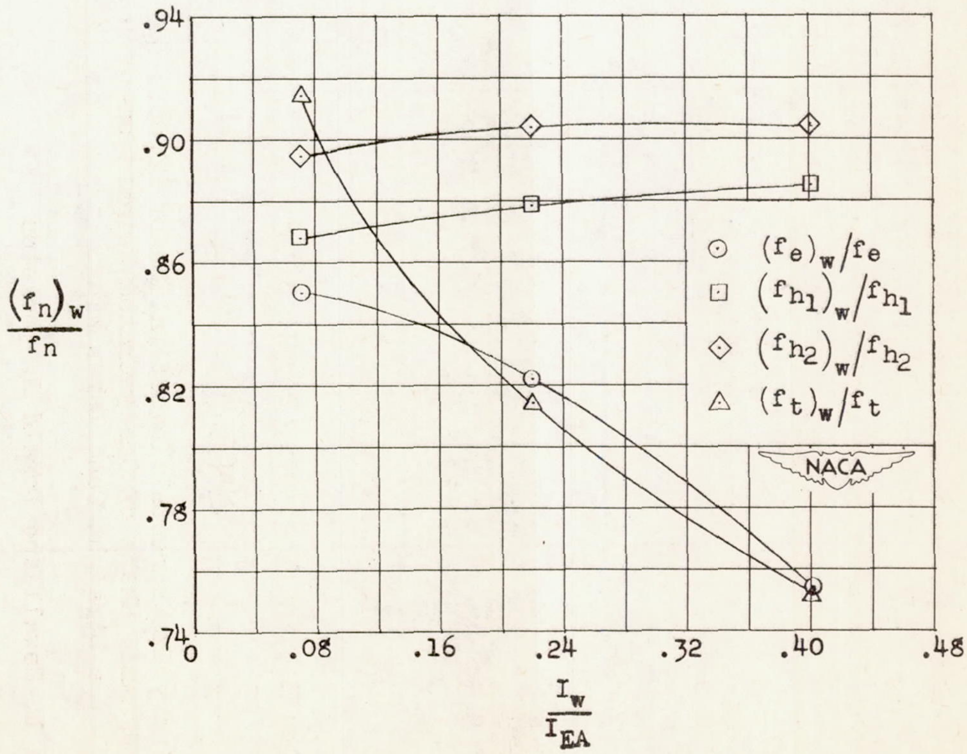


Figure 8.- Variation in frequency with mass moment of inertia for tip weights 2a, 2c, and 2d.