RESEARCH MEMORANDUM

NOTE ON FLUTTER OF A 60° DELTA WING ENCOUNTERED AT LOW-SUPERSONIC SPEEDS DURING THE FLIGHT OF A ROCKET-PROPELLED MODEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ERRATA

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Page 8, table III, last column: The units for the values of inertia about center of gravity should be in-lb sec^2 instead of ft-lb sec^2.

Table III on page 9 is obsolete and was inadvertently included.

Figure 5 should be replaced by the copy attached because of the poor quality of the print that was originally issued.

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SUMMARY

An analysis of the flight time history of a rocket-propelled model of a 60° delta-wing airplane configuration, fired for the purpose of obtaining zero-lift drag data, indicated wing flutter and subsequent failure at low-supersonic Mach numbers. This flutter occurred during the unpowered decelerating portion of the flight. The behavior of the model during flight is discussed and the mass and stiffness characteristics of a duplicate wing are presented.

INTRODUCTION

During the decelerating portion of the flight test of a rocket-propelled model of a 60° delta-wing tailless-airplane configuration an apparent wing flutter occurred at a Mach number of 1.11 with subsequent structural failure at a Mach number of 0.99. The flight test was part of an investigation of the longitudinal stability and control and drag characteristics of this delta-wing configuration which is being conducted by the National Advisory Committee for Aeronautics. The primary purpose of the test was to obtain zero-lift drag data. Previous aerodynamic tests are reported in reference 1.

In order to obtain structural information which was not obtained before the flight but which would be of interest with regard to flutter, a duplicate of the wing which failed was constructed for laboratory tests. The information thus obtained includes natural frequencies and structural influence coefficients of the complete semispan wing, the mass of sections of the wing associated with the influence coefficients, and mass and inertia properties of streamwise strips of the wing.

Since flutter was considered a possible cause of the structural failure and since there is little, if any, theoretical or experimental information available concerning the flutter of delta wings in the transonic- and low-supersonic-speed range, it is believed that the information presented herein will be of interest and may serve in some capacity as a guide in future design work. This paper presents the structural characteristics of the duplicate wing and a discussion of data obtained during the flight of the model.

APPARATUS AND FLIGHT TESTS

A three-view drawing of the model used in the flight investigation is given in figure 1 and the physical characteristics of the model are presented in table I. Weight and balance data for the model are presented in table II. Photographs of the model are shown as figures 2 and 3. The model fuselage was constructed of balsa, plywood, mahogany, and aluminum alloy and contained the four-channel telemeter and the rocket sustainer motor. The model had a wing of triangular plan form with 60° sweepback of the leading edge and an aspect ratio of 2.31. The wing profile at all spanwise stations was an NACA $65_{(06)}$-006.5 section in the free-stream direction. The vertical fin of the model was of triangular plan form with a leading-edge sweepback of 60° and had the same airfoil section as the wing. The wings and vertical fin of the model were constructed of mahogany and laminated-pattern pine with an aluminum-alloy insert along the chord plane at the trailing edge. Longitudinal trim was provided by sealed-gap constant-chord trailing-edge control surfaces built in with an upward deflection of 0.5° to produce approximately zero lift throughout the test speed range.

The technique of launching and boosting the model to supersonic speeds was essentially the same as the technique described in reference 1.

The data from the flight test were obtained by the use of telemeter, photography, radiosonde, Doppler velocimeter radar, and tracking radar. Four channels of information were transmitted and recorded by a telemeter system as the model traversed the test speed range. The data recorded were time histories of normal and longitudinal acceleration, total pressure, and base pressure. In addition to the telemetered information, records from the two radar units supplied time histories of velocity and flight path. Motion-picture cameras also recorded the flight visually.

The normal accelerometer and the recorder galvanometers have natural frequencies of approximately 100 cycles per second and are damped to about two-thirds critical damping. Only a constant-load calibration was made of the accelerometer response since high-frequency oscillations were not expected. No calibration curves are presented since those obtained are not valid at the high frequencies encountered. The type of accelerometer and recorder galvanometer used in this investigation has been tested in the laboratory from 0 to 250 cycles per second and has been found to give a true frequency response throughout this range. The amplitude response at 200 cycles per second when the two units are used in conjunction is estimated to be about 0.06 of the response at zero frequency. Therefore, in determining the magnitude of the normal acceleration in the vicinity of 200 cycles per second, the recorded amplitude must be multiplied by a factor of about 16.

GROUND TESTS

Since flutter was not anticipated during the flight test, flutter parameters were not obtained prior to the flight. Consequently, following the structural failure of the flight model, a duplicate wing was constructed for a ground investigation of its mass and stiffness characteristics.

The quantities determined were the natural frequencies of vibration, structural influence coefficients of the wing, the mass of sections of the wing associated with the influence coefficients, and the mass, moment of inertia, and the center of gravity of streamwise strips of the wing. Their values are given in tables I, III, IV, and V. Figure 4 is a sketch of the wing which shows the root restraint, points of load for influence coefficients, streamwise strips, and the sections of wing whose mass was determined for use with the structural influence coefficients. For the determination of the influence coefficients, the wing was loaded by means of a system of wires and pulleys and deflections were measured with dial gages which could be read directly to 10^{-4} inches. The symmetrically placed terms in table V have been averaged to agree with Maxwell's reciprocity theorem. The moments of inertia of the streamwise strips were determined by the use of a bifilar suspension.

Although the wing used for the laboratory tests could not be expected to be an exact duplicate of the wings tested in flight, the two wings were built from the same drawings and it is believed that the quantities measured should be in good agreement for the two wings.

RESULTS AND DISCUSSION

A study of the telemetered record of the flight, a portion of which is shown in figure 5, shows that a high-frequency oscillation of the normal-acceleration trace started in the decelerating portion of the flight at a Mach number of 1.11 and continued until structural failure at a Mach number of 0.99. This oscillation commenced at a frequency of 205 cycles per second and decreased to a frequency of 185 cycles per second immediately prior to wing failure. Figure 6 shows a plot of velocity and Mach number against time for a portion of the flight during which the oscillation occurred. This oscillation is believed to have been caused by wing vibration since previous experience has shown that the normal accelerometer will follow wing vibrations (references 2 and 3). Although the limitation of the instrumentation system prevents the accurate determination of amplitude at high frequencies, it may be noted that the amplitude, as recorded, indicates a normal acceleration of approximately ±0.3g. This quantity is believed to be low by a factor of approximately 16, as pointed out in the section entitled "Apparatus and Flight Tests." Thus, the oscillating load may have been in the order of ±5g.

An inspection of the flight time history shows an increase in drag at the onset of the oscillations. This phenomenon could be associated with either flutter or buffeting. Further study leads to the conclusion that it was flutter rather than buffeting. The first factor that leads to this conclusion is that the ratio of the frequency of oscillation of the wing tested in flight to the natural torsional frequency of the wing tested in the laboratory is 0.74. This value compares favorably with ratios of flutter frequency to torsional frequency which were obtained in the Langley 4.5-foot flutter research tunnel for 45° delta wings (unpublished data). Secondly, these oscillations were encountered at zero lift, and flight tests of other wings identical in plan form and section but not in construction and stiffness (references 1 and 4) gave no indication of buffeting at lift coefficients near zero, although buffeting was encountered at high lift coefficients. Thirdly, the frequency of the oscillation was more than double the first bending frequency, while in previous flight tests in which buffeting was encountered the frequency of oscillation usually has been at or near the first bending frequency.

CONCLUDING REMARKS

An analysis of the flight time history obtained during the decelerating portion of a flight investigation of a model of a delta-wing (60° sweepback) tailless-airplane configuration indicated wing flutter at a Mach number of 1.11 and subsequent structural failure at a Mach number of 0.99.

The natural frequencies of vibration, the structural influence coefficients of the complete semispan wing, and the mass, moment of inertia, and center of gravity of streamwise strips of a duplicate of the wing were subsequently determined from laboratory tests. These data are presented so that this combination of wing structural characteristics may be avoided in future designs and these data may be of use when a flutter theory is developed for triangular wing plan forms.

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REFERENCES

1. Mitcham, Grady L., Stevens, Joseph E., and Norris, Harry P.: Aerodynamic Characteristics and Flying Qualities of a Tailless Triangular-Wing Airplane Configuration As Obtained from Flights of Rocket-Propelled Models at Transonic and Low Supersonic Speeds. NACA RM L9L07, 1950.

2. Cunningham, H. J., and Lundstrom, R. R.: Description and Analysis of a Rocket-Vehicle Experiment on Flutter Involving Wing Deformation and Body Motions. NACA RM L50I29, 1950.

3. Lauten, William T., Jr., and Nelson, Herbert C.: Results of Two Free-Fall Experiments on Flutter of Thin Unswept Wings in the Transonic Speed Range. NACA RM L51C08, 1951.

4. Purser, Paul E.: Notes on Low-Lift Buffeting and Wing Dropping at Mach Numbers Near 1. NACA RM L51A30, 1951.

TABLE I

PHYSICAL CHARACTERISTICS OF THE MODEL OF A DELTA-WING TAILLESS-

AIRPLANE CONFIGURATION

Wing:	
Area, sq ft (including fuselage intercept)	6.25
Span, ft	3.80
Aspect ratio	2.31
Mean aerodynamic chord, ft	2.19
Sweepback of leading edge, deg	60
Dihedral (relative to mean thickness line), deg	0
Taper ratio (Tip chord/Root chord)	0
Airfoil section	NACA $65_{(06)}$-006.5
Natural frequencies, cps	
First bending	87
Second bending	202
First torsion	256
Vertical tail:	
Area (outside of fuselage), sq ft	0.81
Height (outside of fuselage), ft	0.97
Aspect ratio	2.31
Sweepback of leading edge, deg	60
Taper ratio (Tip chord/Root chord)	0
Airfoil section	NACA $65_{(06)}$-006.5
Control surface:	
Type	Plain flap
Area (aft of hinge line, one), sq ft	0.51
Span (at trailing edge of wing, one), ft	1.78
Chord (hinge line to trailing edge), ft	0.37
Deflection, deg	0.5

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TABLE II

WEIGHT AND BALANCE DATA FOR A MODEL OF A DELTA-WING TAILLESS-AIRPLANE CONFIGURATION

Model with rocket fuel:	
Weight, lb	148.4
Wing loading, lb/sq ft	23.8
Center-of-gravity position, percent M.A.C.	25.5
Moment of inertia (in pitch), slug-ft^2	9.37
Model without rocket fuel:	
Weight, lb	123.4
Wing loading, lb/sq ft	19.8
Center-of-gravity position, percent M.A.C.	20.0
Moment of inertia (in pitch), slug-ft^2	8.37

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TABLE III

PROPERTIES OF STREAMWISE STRIPS OF WING SHOWN IN FIGURE 4

Streamwise strips	Spanwise station (in.)	Center of gravity (in. from T.E.)	Mass (slugs)	Inertia about center of gravity (in-lb sec^2)
I	0 to 1.5	16.06	0.0296	0.134
II	1.5 to 4.5	13.94	.047	.167
III	4.5 to 7.5	10.94	.031	.076
IV	7.5 to 10.5	7.97	.019	.027
V	10.5 to 13.5	5.37	.012	.007
VI	13.5 to 17.8	2.94	.005	.001

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TABLE III

PROPERTIES OF STREAMWISE STRIPS OF WING SHOWN IN FIGURE 4

OBSOLETE

Streamwise strips	Spanwise station (in.)	Center of gravity (in. from T.E.)	Mass (slugs)	Inertia about center of gravity (ft-lb sec^2)
I	0 to 1.5	16.06	0.0296	0.134
II	1.5 to 4.5	13.94	.047	.167
III	4.5 to 7.5	10.94	.031	.076
IV	7.5 to 10.5	7.97	.019	.027
V	10.5 to 13.5	5.37	.012	.007
VI	13.5 to 18.3	2.94	.005	.001

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TABLE IV

MASS OF NUMBERED PORTIONS OF WING SHOWN IN FIGURE 4

Portion	Mass (slugs)
1	0.00820
2	.01194
3	.00740
4	.01235
5	.00970
6	.00611
7	.00942
8	.00897
9	.00806
10	.00658
11	.00493
12	.00510
13	.00518
14	.00520
15	.00461

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TABLE V

STRUCTURAL INFLUENCE COEFFICIENTS

[50-lb load; deflections are in 10^{-4} inches]

Deflection at station - / Load at station -	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	42	15	47	5	20	51	2	11	28	55	1	5	13	32	58
2	15	21	36	13	26	45	5	18	34	54	2	10	24	44	64
3	47	36	130	17	59	143	7	30	80	160	2	14	43	100	173
4	5	13	17	20	24	33	12	27	38	42	6	18	36	45	49
5	20	26	59	24	80	110	12	51	100	142	7	28	76	133	184
6	51	45	143	33	110	295	13	63	177	351	6	30	102	229	412
7	2	5	7	12	12	13	26	25	25	25	20	44	43	36	27
8	11	18	30	27	51	63	25	83	96	107	15	65	123	141	151
9	28	34	80	38	100	177	25	96	223	281	11	61	175	309	417
10	55	54	160	42	142	351	25	107	281	669	9	54	192	473	911
11	1	2	2	6	7	6	20	15	11	9	175	79	24	13	9
12	5	10	14	18	28	30	44	65	61	54	79	253	152	96	76
13	13	24	43	36	76	102	43	123	175	192	24	152	377	327	295
14	32	44	100	45	133	229	36	141	309	473	13	96	327	726	858
15	58	64	173	49	184	412	27	151	417	911	9	76	295	858	2090

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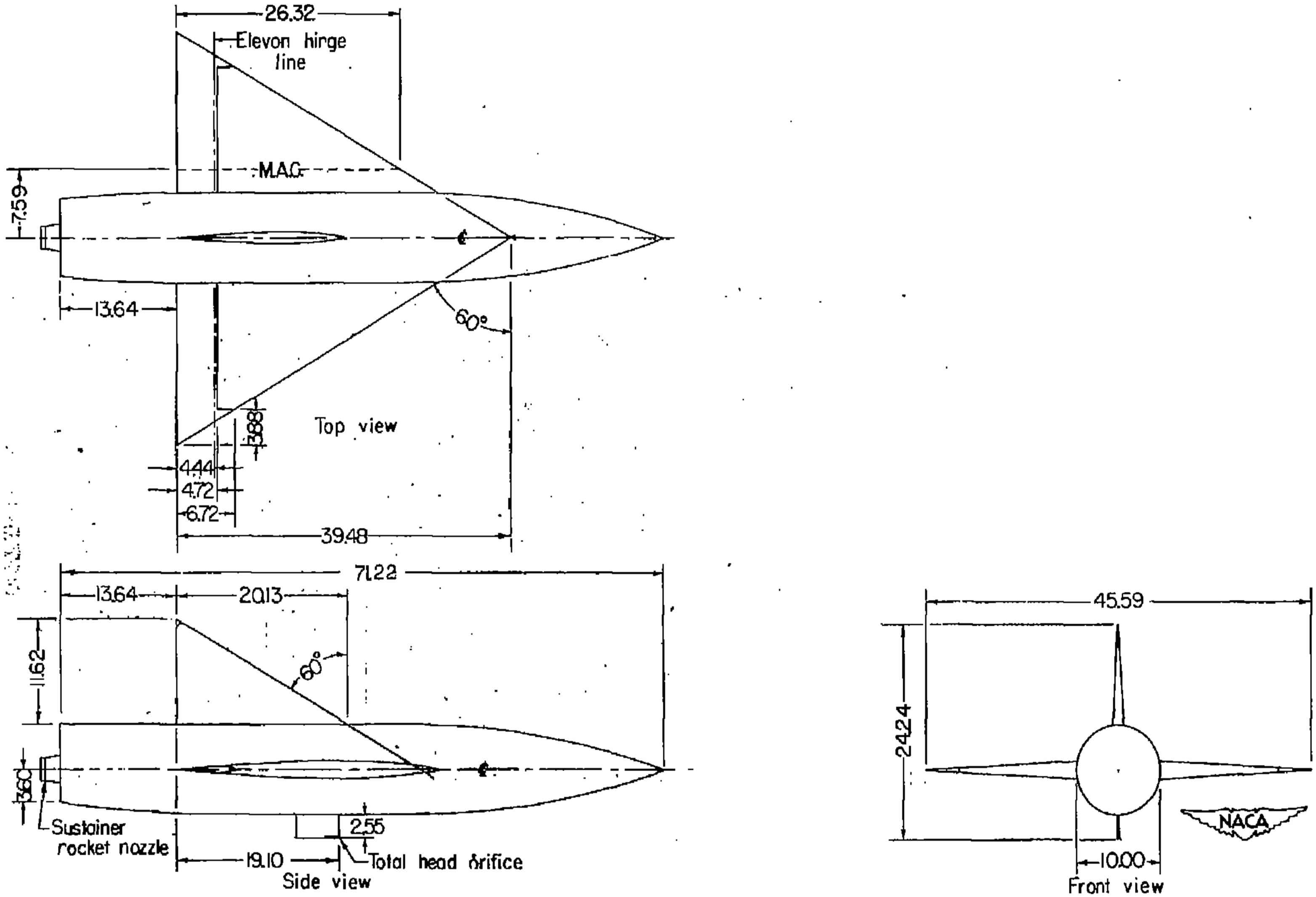

Figure 1.- Three-view drawing of the rocket-powered flight model.
(All dimensions are in inches.)

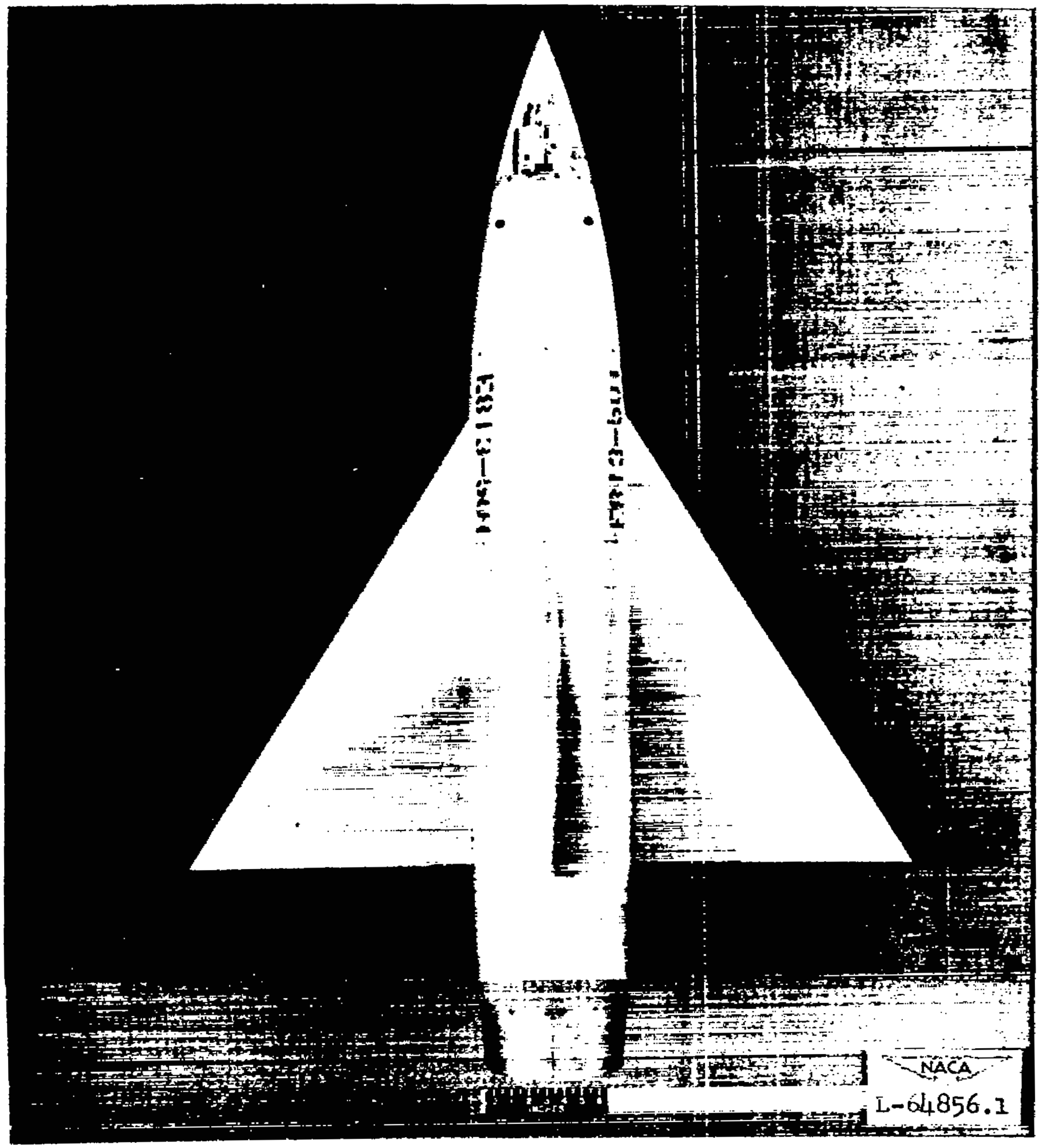

Figure 2.- Plan view of flight model.

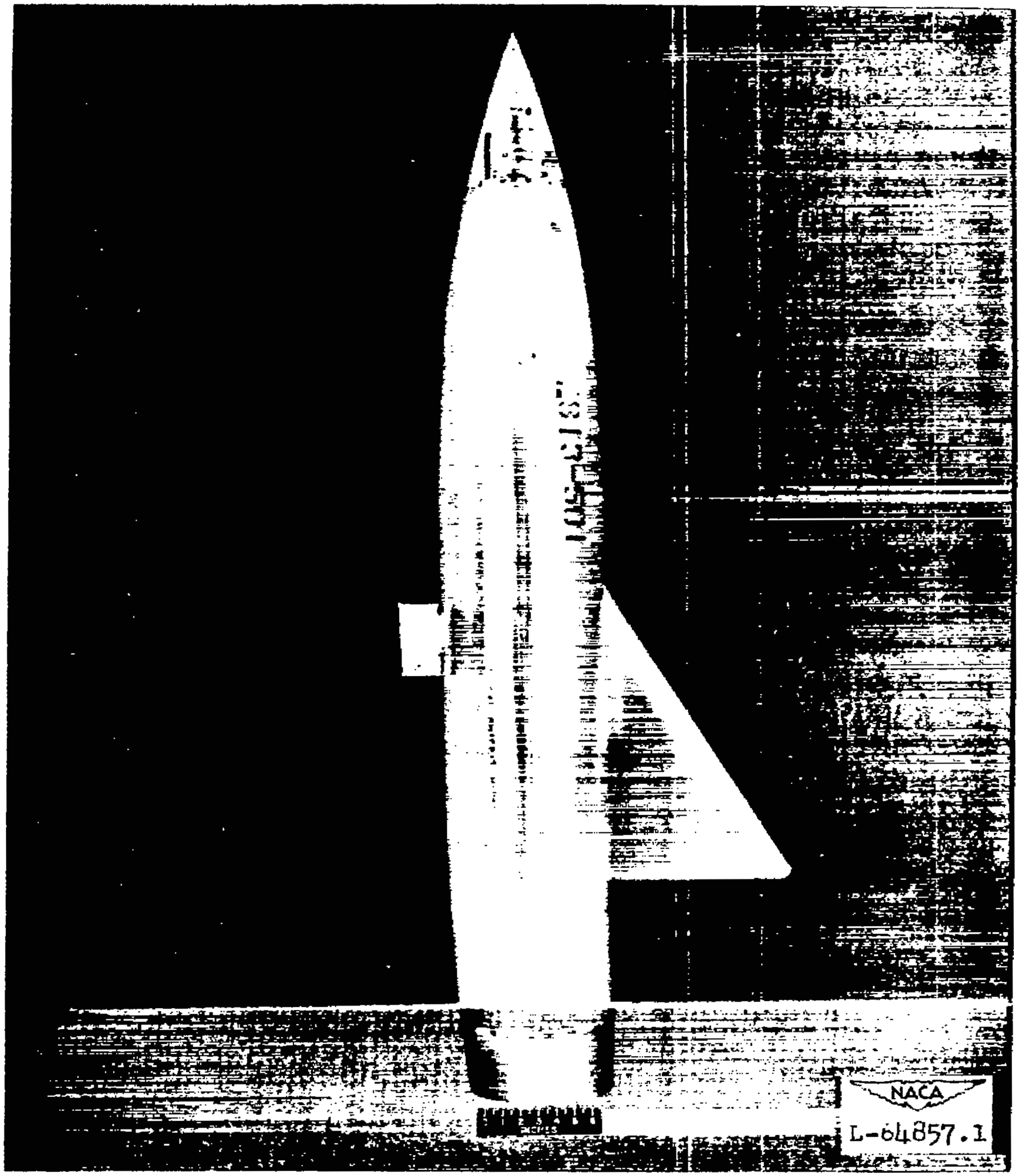

Figure 3.- Side view of flight model.

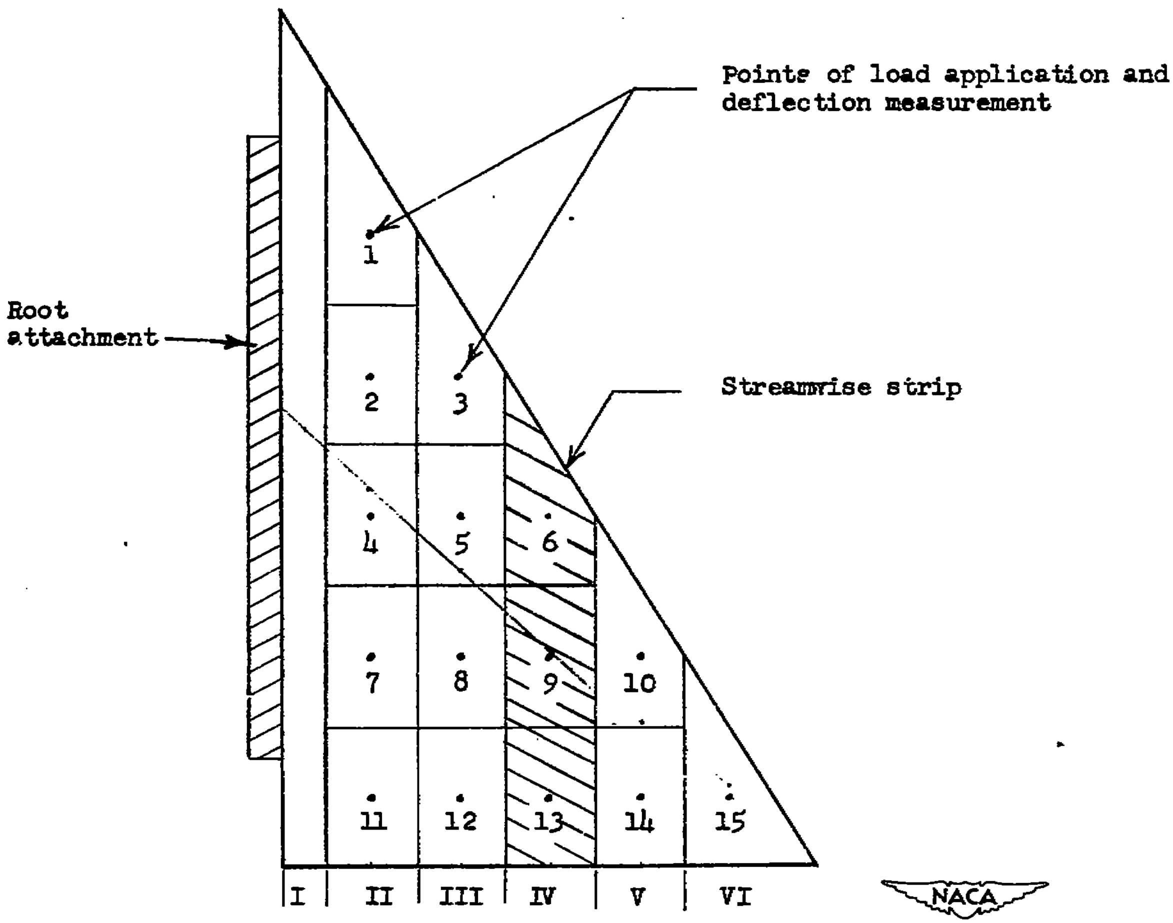

Figure 4.- Schematic drawing of ground-test wing.

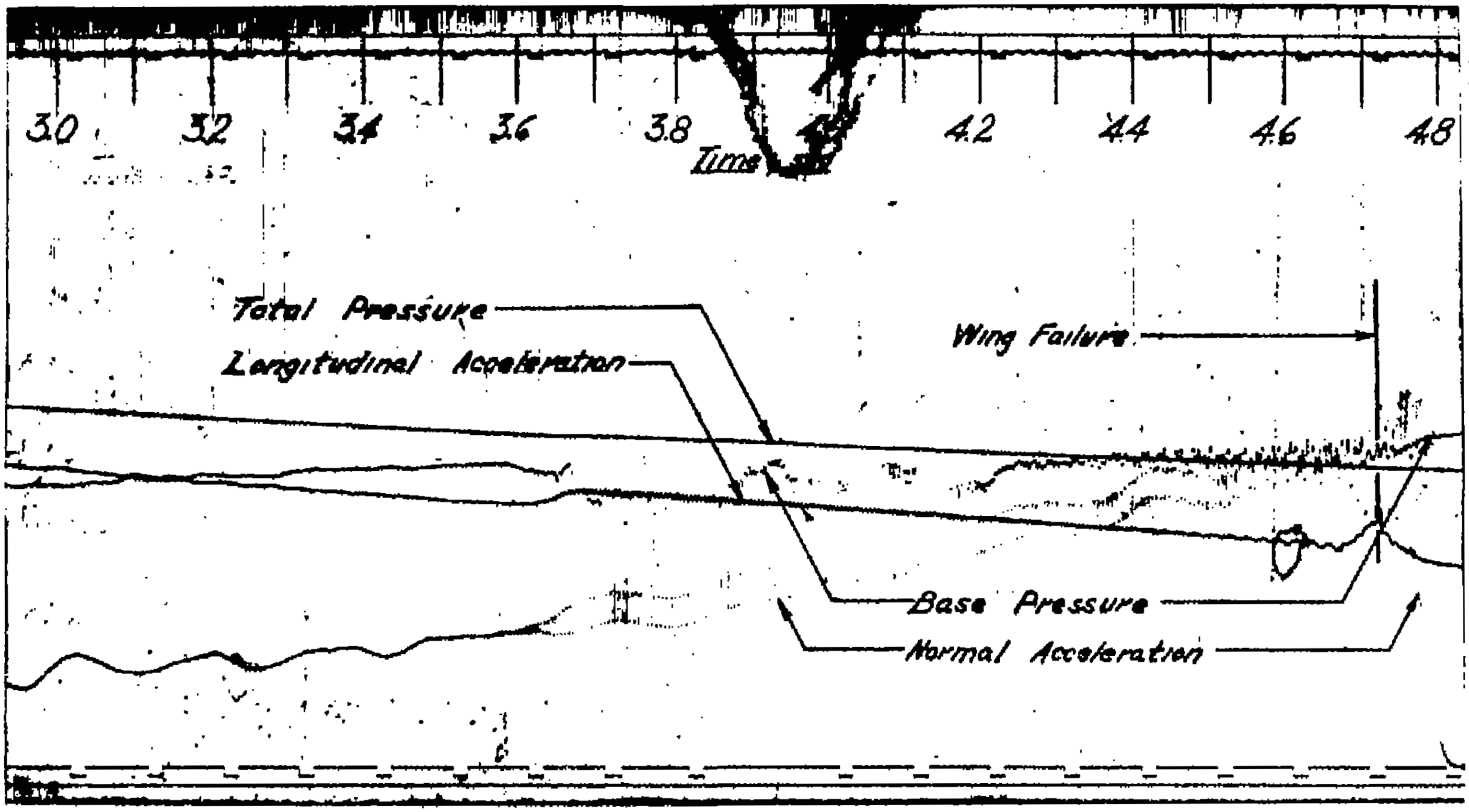

Figure 5.- Portion of telemeter record before and during flutter of flight model.

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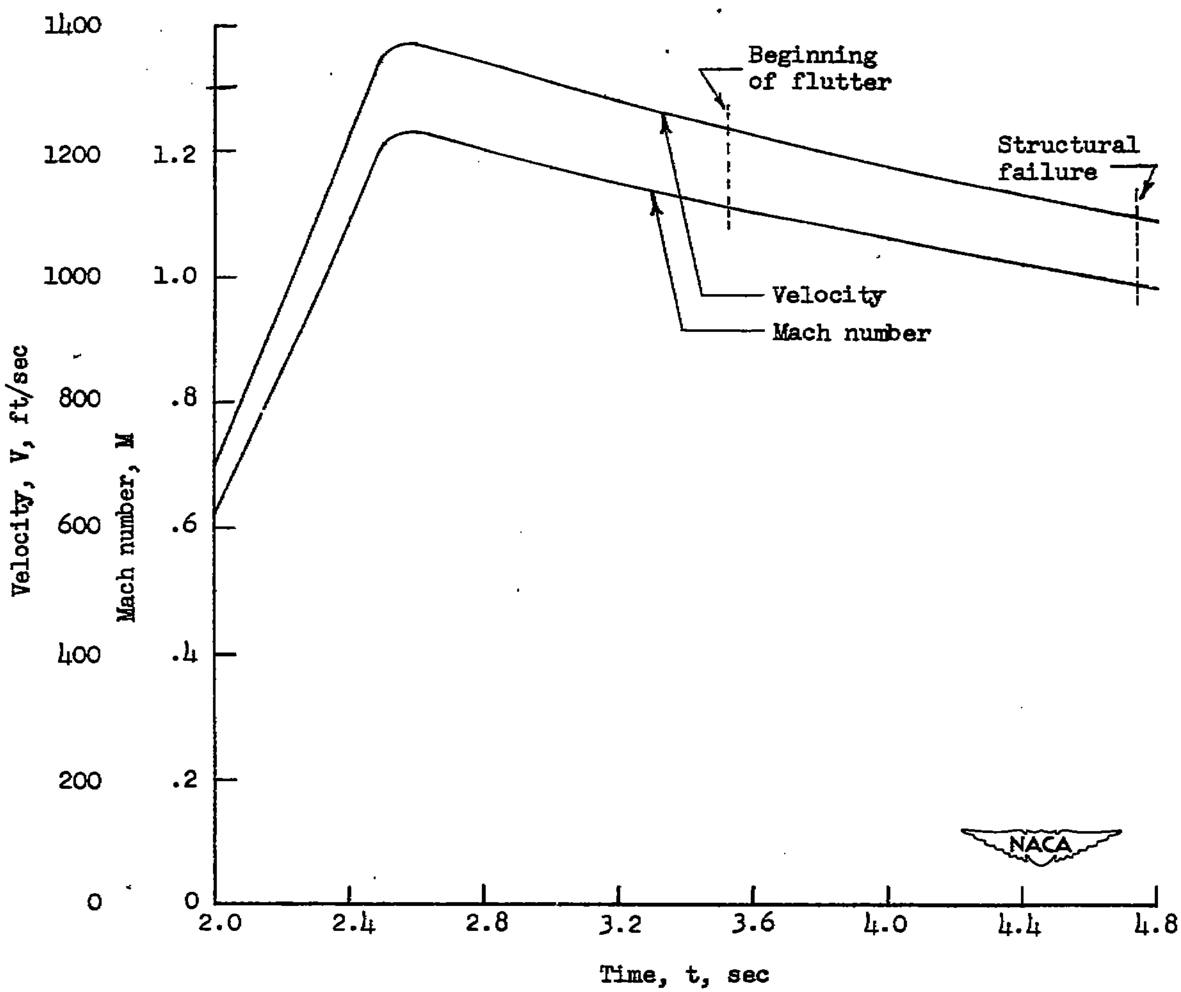

Figure 6.- Plot of velocity and Mach number against time for a portion of the rocket-model flight.