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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF TRANSONIC AILERON FLUTTER

By Albert L. Erickson and Robert L. Mannes

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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF TRANSONIC AILERON FLUTTER

By Albert L. Erickson and Robert L. Mannes

SUMMARY

A partial-span wing was tested to determine the cause of a flutter which had occurred in high-speed flight. During the investigation changes were made to the wing stiffness, the location of the center of gravity of the wing, and the mass balance of the aileron. The first two changes had no appreciable effect on the flutter, but the last change altered its frequency. It was concluded that this flutter was a new type requiring only one degree of mechanical motion. It was also found that restriction of the aileron motion, such as was obtained by the use of a damper in the control system, would prevent flutter to a Mach number of at least 0.830.

INTRODUCTION

During flight tests of a jet-powered fighter airplane, a high-frequency, low-amplitude aileron flutter occurred. During one test flight at a higher Mach number, a serious flutter occurred, causing a permanent deformation of the aileron. Because of the extreme danger involved in investigating such a phenomenon in flight, a partial-span wing of the airplane was installed for investigation in the Ames 16-foot high-speed wind tunnel.

The flutter was believed to be closely associated with local supersonic flows and, therefore, the ordinary flutter analyses were not considered applicable.

The tests in the wind tunnel were terminated due to failure of the aileron. The results obtained are presented in this report.

SYMBOLS AND DIMENSIONS

The aerodynamic coefficients given in this report are computed on the basis of the dimensions of the partial-span wing actually in the wind tunnel. The symbols and dimensions used are as follows:

S	wing area in tunnel, 45 square feet
$\bar{c}$	mean aerodynamic chord of partial span, 4.833 feet
$\bar{c}_a$	aileron root-mean-square chord, 1.18 feet
b	partial span in tunnel, 9.85 feet
b_a	aileron span, 7.5 feet
α_u	angle of attack, degrees (angle of attack of fuselage reference line $= \alpha_u - 0.40^\circ$)
δ_a	aileron deflection, degrees
V	free-stream velocity, feet per second
ρ	mass density, slugs per cubic foot
q	dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot
a	speed of sound, feet per second
M	Mach number (V/a)
C_L	lift coefficient
C_{D_u}	drag coefficient uncorrected for tare of plate at tunnel wall
$C_{m_{0.35}}$	pitching-moment coefficient about 35 percent mean aerodynamic chord
ΔC_L	lift-coefficient increment due to aileron deflection
ΔC_D	drag-coefficient increment due to aileron deflection
H_a	aileron hinge moment, foot-pounds
C_{h_a}	aileron hinge-moment coefficient $\left(\frac{H_a}{q b_a \bar{c}_a^2}\right)$

$\left(\frac{\partial C_{h_a}}{\partial \delta_a}\right)_{\delta_a, 0^\circ}$ rate of change of aileron hinge-moment coefficient with aileron deflection at 0° aileron angle

DESCRIPTION OF APPARATUS

A partial-span wing of a jet-powered airplane was mounted in the Ames 16-foot high-speed wind tunnel as shown in figure 1. The gas tanks were removed from the wing and two auxiliary ribs were placed between the main beams. The aileron was mass balanced. The following information on the aileron balance weights was obtained from the manufacturer:

Item	Weight (lb)	First moment (lb-in.)	Second moment (lb-in.^{2})
Balance weights	20.18	-80.07	397
Aileron	15.00	69.27	764
Total	35.18	-10.80	1161

Some of the weights broke loose during the tests but this was not immediately discovered. Finally, for run 32, in which the wing tip was restrained in both bending and torsion, all the remaining weights were removed. The aerodynamic forces and moments were measured on the six-component-scale system. Static aileron hinge moments were measured by means of a resistance-type strain gage.

The wind-tunnel calibration was based on the tunnel-empty calibration corrected for constriction effects. (See reference 1.) No tunnel-wall corrections were applied as most of the testing was done near zero lift. The control system was mounted to keep the control-cable length the same as it was on the airplane. Figure 2 shows the mounting of the control stick, the hydraulic boost unit, and the control cables. The frequencies of the wing and aileron motions were measured by the use of Sperry displacement pickups and slide-wire resistors located as shown in figure 3. The data from these units were recorded by oscillographs.

TEST PROCEDURE AND RESULTS

The investigation consisted of determining how changes to the wing and the aileron affected the flutter. After each change was made, the tunnel speed was increased until flutter occurred or the maximum speed of the wind tunnel was reached. The general results of the investigation are summarized in table I.

Successive pictures of the wing and aileron during one cycle of flutter are shown in figure 4. These pictures are from a motion-picture record taken at 128 frames per second. The aileron displacement followed a sinusoidal pattern and led the wing torsional displacement by about 60°, as shown in figure 5. Later tests showed that the wing motion did not contribute to the basic flutter.

Effect of Wing Changes on Flutter

In order to determine the mechanical interrelation of the wing and aileron motion, several changes to the wing were made during the investigation.

A decrease in the torsional rigidity of the wing by the removal of two special ribs between the main beams (fig. 6) had no apparent effect on the flutter (table I, run 5 – cf. run 12).

A boom was attached to the wing tip and extended forward into the air stream as shown in figure 7. This boom changed the natural frequency of the wing in bending from 15 to 13 cycles per second and in torsion from 51 to 26 cycles per second. It also caused a considerable change in the location of the apparent torsional nodes. (See fig. 8.) The locations of the apparent nodes were determined by the intersections of straight-line elements connecting the displacements indicated by the pickups. The torsional nodes indicated are approximately the true nodes. The apparent bending nodes, however, are of value only for comparative purposes. With the boom attached and the aileron fixed, the wing did not flutter. With the aileron free, the boom did not alter the aileron flutter (table I, runs 22 and 22A).

The boom was removed and the wing tip was fastened to a strut so that it was restrained in both bending and torsion. (See fig. 9.) Even this extreme change had no appreciable effect on the aileron flutter. The wing was not completely rigid during flutter although its motion was limited. (See table I, run 27.) Runs 5, 12, 22, 22A, and particularly runs 26 and 27, quite definitely proved that a new type flutter had been found – a type which required only one degree of mechanical motion.

Effect of Aileron Changes on Flutter

As only aileron motion was involved in this new type flutter, the usual method of preventing flutter (elimination of mechanical coupling) could not be applied. It was, therefore, necessary to prevent the flutter by some other means.

With tight control cables and the control stick locked, no flutter occurred; whereas loosening the cables allowed the aileron to flutter. (See table I, runs 7 and 1.) Inasmuch as restraint of the aileron prevented flutter, damping was placed in the control system. This damping prevented flutter to the highest Mach number attained in the wind tunnel (0.830). (See table I, runs 19, 20, and 21.)

Changes made to the aileron moment of inertia and mass balance affected the flutter only by a slight change in the frequency. Table I (runs 1, 5, 26, 27, 28, 31, and 32) shows the results. In all cases, an increase in frequency was associated with a decrease in moment of inertia of the aileron regardless of any other changes which were made.

In an effort to damp the flutter aerodynamically, an antiservo tab was installed on the aileron, as shown in figure 10. This tab floated freely during slow motion of the aileron, but it worked against the aileron during flutter because of the damping cylinder in the linkage. Its effect, however, was not sufficient to prevent flutter. (See table I, runs 28 to 31.)

Shock-Wave Study

A shadowgraph method was used to study the position and motion of the shock waves. The test setup is shown schematically in figure 11. By putting the point source of light in three different positions so that a method of triangulation could be used with the results obtained (fig. 12), it was determined that the shock waves were forward of the aileron for the conditions of this test. The shock waves were fluctuating, but it was not possible to determine the frequency, either directly or from the motion pictures obtained.

Motion pictures of tufts during flutter indicated separation on the aileron when it was approximately in its neutral position, with subsequent recovery when the aileron reached the maximum up-position. (See fig. 13.)

Static Aerodynamic Coefficients

Static-force and hinge-moment data are shown in figures 14 to

19. The change in the aerodynamic characteristics between an angle of attack of -1° and 2° at the higher Mach numbers, had no noticeable effect on the frequency and amplitude of the flutter. Figure 20 reveals considerable increase in the slope $\left[-\left(\frac{\partial H_a}{\partial \delta_a}\right)_{\delta_a, 0^\circ}\right]$ at Mach numbers above 0.74 as the angle of attack was changed from -1° to 2°. The change in slope corresponds to about 25 foot-pounds per degree of aileron angle at the Mach numbers at which flutter occurred.

Additional Tests

Figure 21 shows the Mach number at which flutter started at three angles of attack, indicating that the flutter was probably influenced by the local critical Mach number. (See table I, run 5.)

Various spoilers fastened on the wing in an attempt to fix the shock position gave no conclusive results because the tunnel speed was limited by the extremely high drag of the model with the spoilers in place. (See table I, runs 17, 23, 24, and 25.)

Five 1-1/4-inch-diameter holes were cut in the lower surface of the wing just forward of the aileron. These holes raised the speed at which flutter started, with the aileron floating, from 0.795 to 0.830 Mach number for one trial; but with the number of holes increased to 11, the flutter occurred at 0.791 Mach number, approximately the same as without holes. During this test the aileron failed, as shown in figure 22, and the investigation was terminated. It is believed that the high Mach number attained without flutter, with the five leak holes, was not the result of the holes but of unusually steady flow conditions.

DISCUSSION

The results of this investigation indicate that the flutter encountered was due to a time lag in the changes in hinge moment relative to the aileron motion, and was influenced to a considerable extent by shock-induced separation. The wing underwent a forced vibration which had no apparent effect on the basic flutter.

As shown by the results, damping or restraint of the aileron prevented flutter of the test aileron to at least the highest test Mach number (0.830). It was further indicated that there should be no flexibility between a damper and an aileron such as cables might provide. The amount of damping required to prevent flutter at any Mach number was not determined, but it should be limited to a value such that the maximum rate of control movement required for maneuvering will not be limited seriously. There will be some aileron roughness, however, even if flutter is eliminated.

Complete restraint could be obtained by the use of an irreversible control. This type of control would have the objectionable features of not being self-neutralizing and not providing control feel. Both of these characteristics, however, could be provided artificially. Cables should not be used between any antiflutter unit and the aileron unless some positive method of maintaining tension at all times is provided. In the ordinary system, the extremely low temperatures encountered at high altitude tend to loosen the steel control cables in an aluminum wing.

There is some reason to believe that, if an aerodynamically balanced surface were used, this type of flutter might be less severe, due to the fact that the actuating forces could act on the aerodynamic balance, as well as on the control surface, and the balance might also act as an air damper.

The general problem of the type of flutter obtained on this airplane must be carefully considered in high-speed designs. Consideration might be given to the elimination of ailerons entirely and to the use of other methods of lateral control, such as the spoiler. It is possible that similar difficulties may be encountered with elevators and rudders.

Elimination of aileron flutter by restraint or damping of the aileron raises the question as to whether or not coupling between the wing motion and the separation caused by shock could cause wing flutter. Up to the maximum Mach number reached during this test (0.830), there was no flutter with the aileron rigidly restrained, although there was some roughness. There was, however, no evidence that the wing will not be subject to this type of flutter if a high enough Mach number is attained.

CONCLUSIONS

An investigation of the flutter of an aileron on a partial-span wing model indicated the following:

1. Flutter of the aileron could be prevented to at least 0.830 Mach number by the installation of a damper in the control system or

by the use of an irreversible control.

2. The aileron flutter apparently was caused by a time lag in the changes of hinge moment relative to the aileron motion, probably being greatly influenced by the separation caused by shock waves.

3. The results of this test show that this flutter is of a new type which does not depend on inter-related mechanical motions and therefore cannot be prevented by the ordinary methods.

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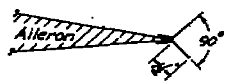
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCE

1. Thom, A.: Blockage Corrections and Choking in the R.A.E. High Speed Tunnel. Rep. No. Aero. 1891, R.A.E. Nov. 1943.

TABLE I.— RUN RECORD OF THE AILERON FLUTTER TESTS

Run number	Changes to standard configuration[1]	Results	Flutter frequency (cps)
1	Two extra ribs between wing main beams, cables loose	Flutter at M = 0.796, α = 1°	--
2	Extra ribs, slight cable tension	Flutter at M = 0.819, α = 1°	21
3	Extra ribs, aileron fixed to wing at both ends and center	No flutter	--
4	Extra ribs, aileron fixed at center	No flutter	--
4A	Extra ribs, aileron push-pull rod locked	No flutter	--
5	Extra ribs, control cables disconnected at aileron	Flutter at M = 0.795, α = 0°; M = 0.792, α = 1°; M = 0.789, α = 1°; M = 0.789, α = 1°; M = 0.800, α = -1°	--
6	Extra ribs	No flutter — shadowgraphs of shock waves	--
7	Extra ribs, cable tension of 130 pounds	No flutter	--
8	Extra ribs, aileron rigged 1 inch high	No flutter	--
9	None	No flutter — data no good, faulty position indicator	--
9A	None	No flutter, static aileron hinge moments, α = 0°	--
10	None	No flutter, data no good, faulty position indicator	--
10A	None	No flutter, aileron static hinge moments, α = -1°	--
10B	None	No flutter, aileron static hinge moments, α = 2°	--
10C	None	No flutter, aileron static hinge moments, α = 1°	--
11	Cable disconnected	Aileron free-floating angles determined at speeds below flutter	--
12	Cables disconnected	Flutter at M = 0.785, α = 1°	23
13	Aileron floating, tufts on wing and aileron	Tufts show separation and recovery on aileron during flutter	--
14	Tufts on wing and aileron	No flutter	--
15	None	No flutter — visual observation of shock waves showed steady shock 5 inches forward of hinge line	--
16	Spoilers on aileron trailing edge 	Spoilers too heavy, low-speed flutter occurred	--
17	Spoiler on lower surface at 10-percent chord with 1/2-inch chord and 60° angle	Flutter at M = 0.773, α = 0°	--
18	Hydraulic boost removed from control system for remainder of runs	Flutter at M = 0.797, α = 0°	--
19	Friction damping applied to control cables	Flutter at M = 0.790, α = 0°; to M = 0.825, α = 0°; or no flutter, depending on friction used	20.4
20	Hydraulic damper with No. 30 oil	No flutter	--
21	Hydraulic damper with half No. 2135 oil and half kerosene	No flutter, wing very rough	--
22	Boom installed at wing tip extending forward into airstream, hydraulic damper used	No flutter	--
22A	Boom at wing tip extending forward into airstream. Hydraulic damper removed.	Flutter at unknown Mach number α = 0°	20
23	Spoiler at 40-percent chord on upper surface with 1/2-inch chord and 60° angle. Control cables loose.	No data, tunnel speed limited by high drag	--
23A	Spoiler at 40-percent chord on upper surface with 1/2-inch chord and 32° angle. Control cables loose.	Tunnel speed limited by high drag	--
24	Spoiler at 40-percent chord on upper surface with 1/2-inch chord and 32° angle. Control cables disconnected.	Appeared to be on the verge of flutter. Tunnel speed limited by high drag.	--
25	Spoilers on upper and lower surface at 40-percent chord. Control cables loose.	Appeared to be on the verge of flutter Tunnel speed limited by high drag	--
26	Wing tip restrained in bending and torsion on all following runs. Additional weight of 6.4 pounds in trailing edge of aileron. Cables loose.	Flutter at M = 0.789, α = 0°	17.8
27	Additional weight removed. Cables loose.	Flutter at M = 0.794, α = 0°	20.5
28	Damping tab on aileron with minimum damping. Cables loose.	Flutter at M = 0.803, α = 0°	20.8
29	Damping tab with 1/2-maximum damping. Cables loose.	Flutter at M = 0.794, α = 0°	20.6
30	Damping tab with maximum damping. Cables loose.	Flutter at M = 0.794, α = 0°	20.5
31	Damping tab on aileron with minimum damping, tab counterbalanced. Cables loose.	Flutter at M = 0.800, α = 0°	20.0
32	Five 1-1/4-inch-diameter holes in wing overhang. Cables loose, all balance weights removed from aileron.	Flutter at M = 0.830, α = 0°	22.0
33	Eleven 1-1/4-inch-diameter holes in wing overhang on lower surface. Cables loose.	Flutter at M = 0.791, α = 0°. Part of aileron failed, ending investigation.	21.6 to 24.0

[1] Standard configuration consists of wing, aileron, and control system with hydraulic boost, and cables tight.

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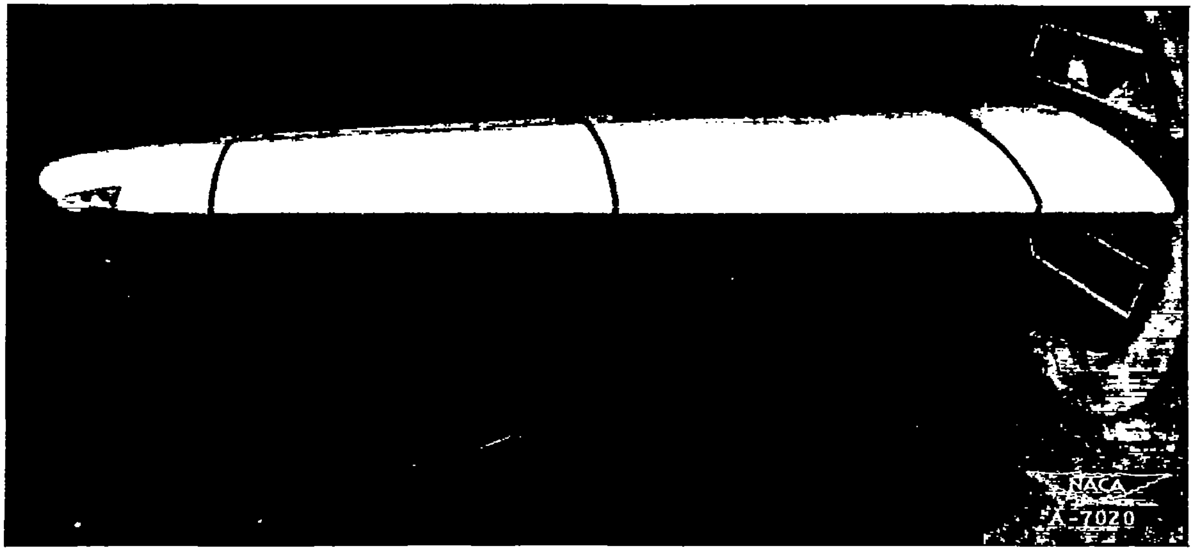
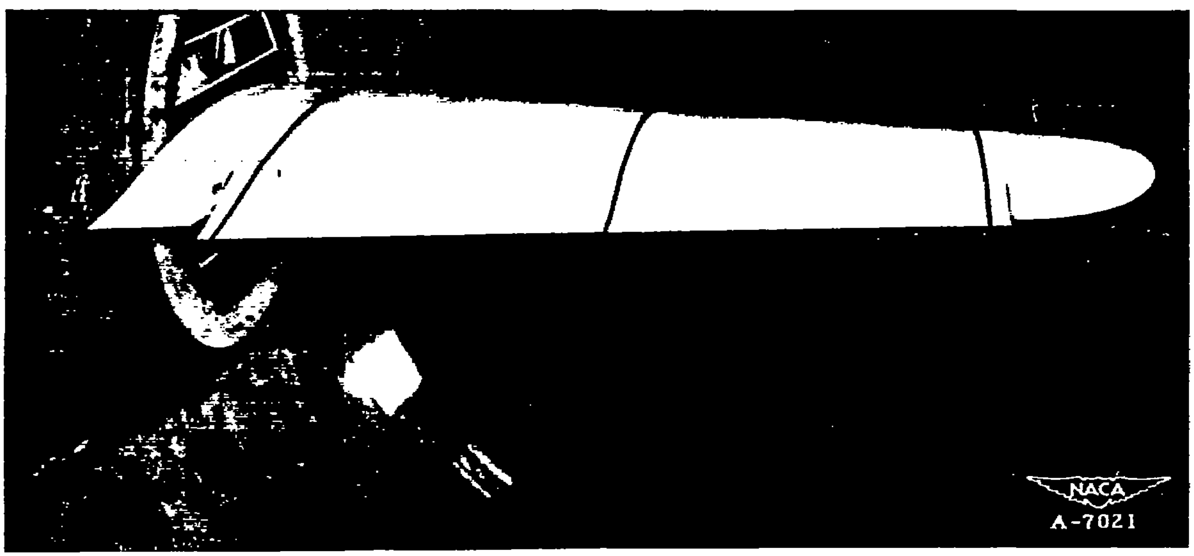
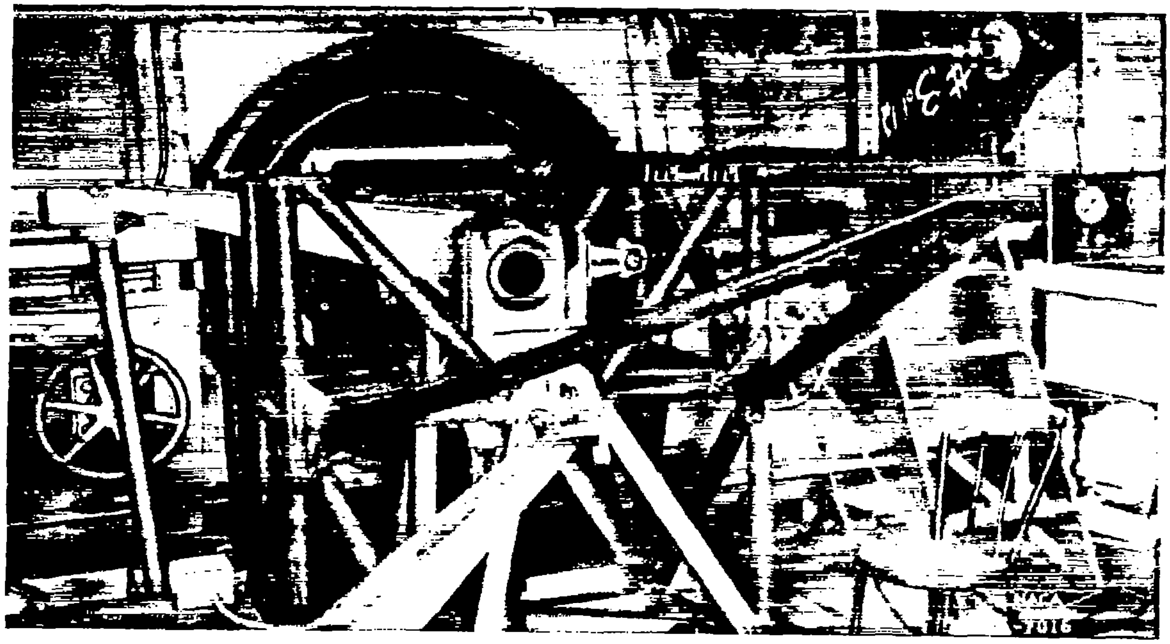


(a) Front view.

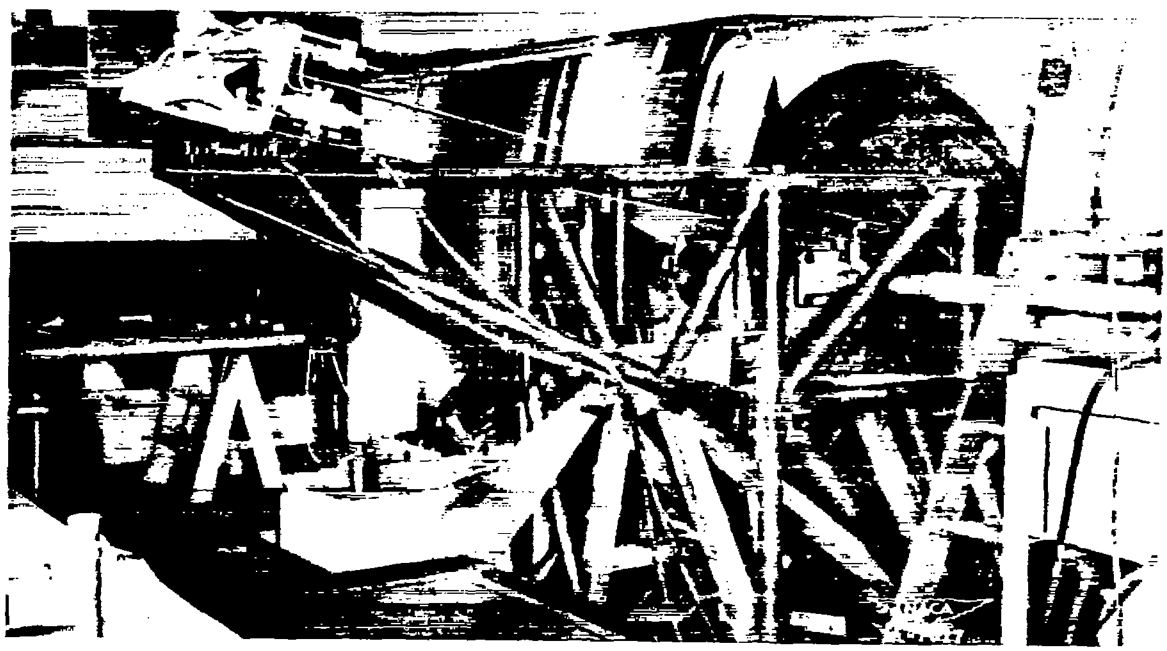


(b) Rear view.

Figure 1.– The partial-span wing mounted in the Ames 16-foot high-speed wind tunnel.



(a) View showing control stick.



(b) View showing hydraulic boost.

Figure 2.– Arrangement of aileron control system for tests of a partial-span wing in the Ames 16–foot high-speed wind tunnel.

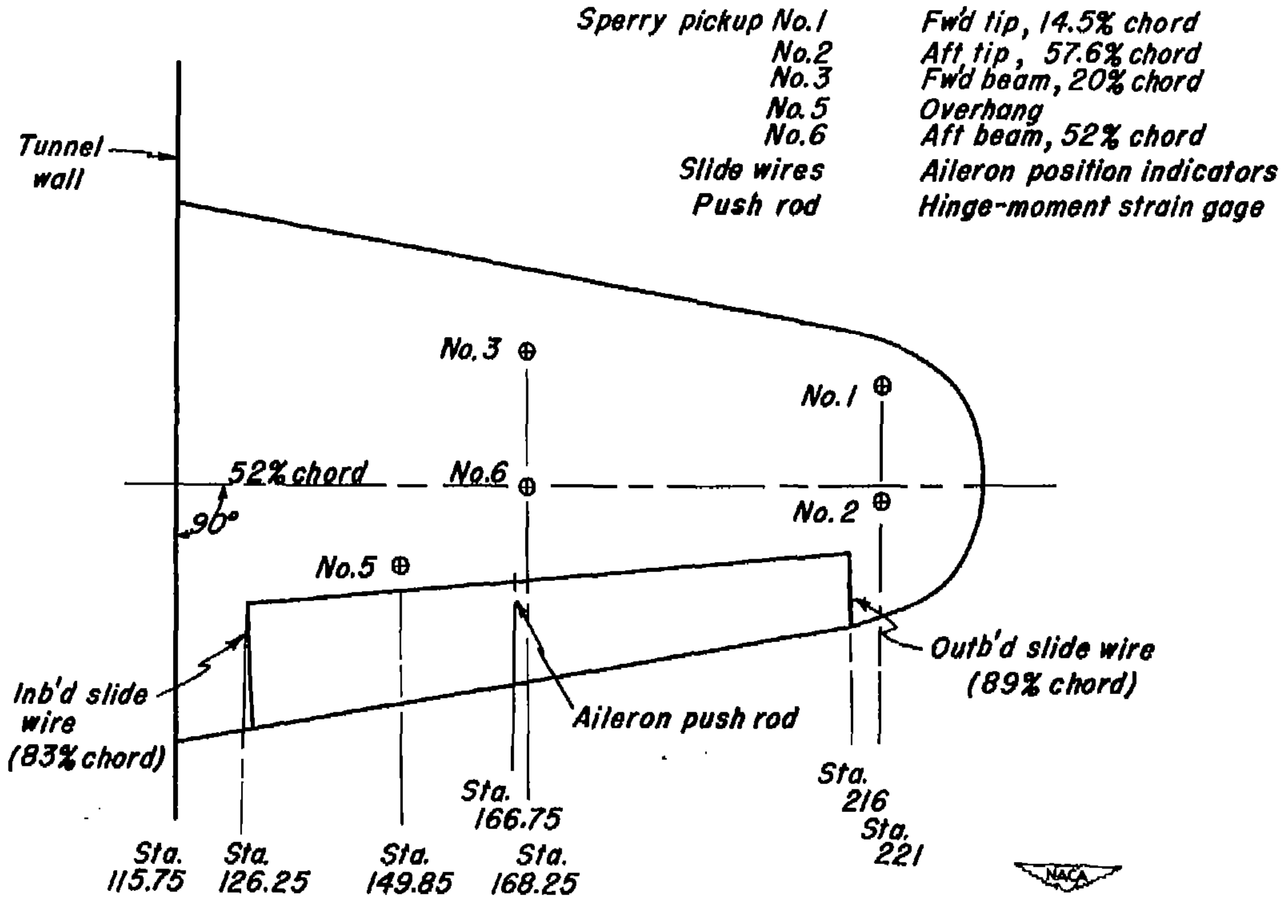


Figure 3.— Schematic drawing of the partial-span wing showing location of Sperry pickups, hinge-moment strain gage, and aileron-position indicators.

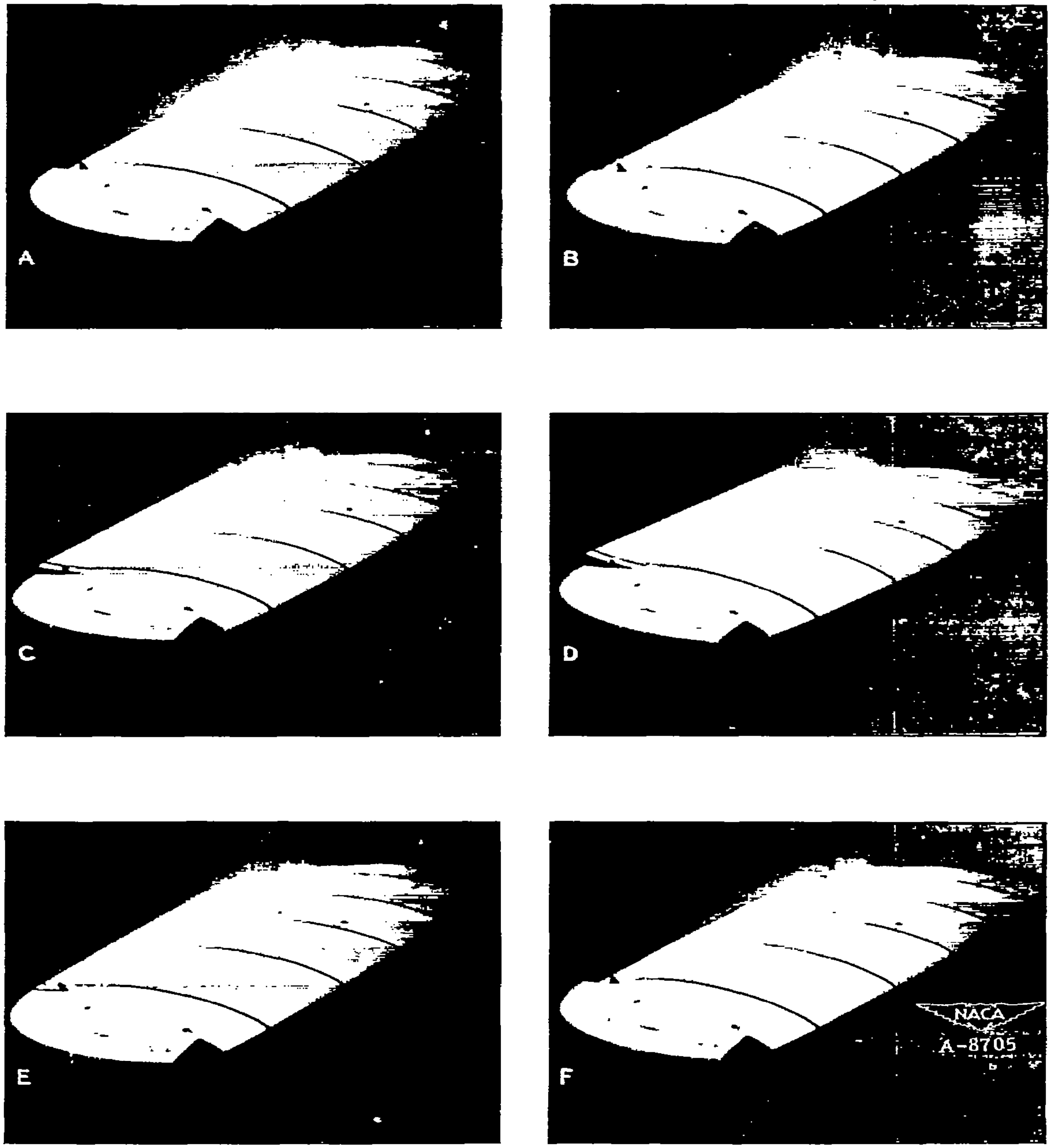


Figure 4.– Flutter of the aileron shown by successive pictures taken from a 128-frame-per-second motion picture.

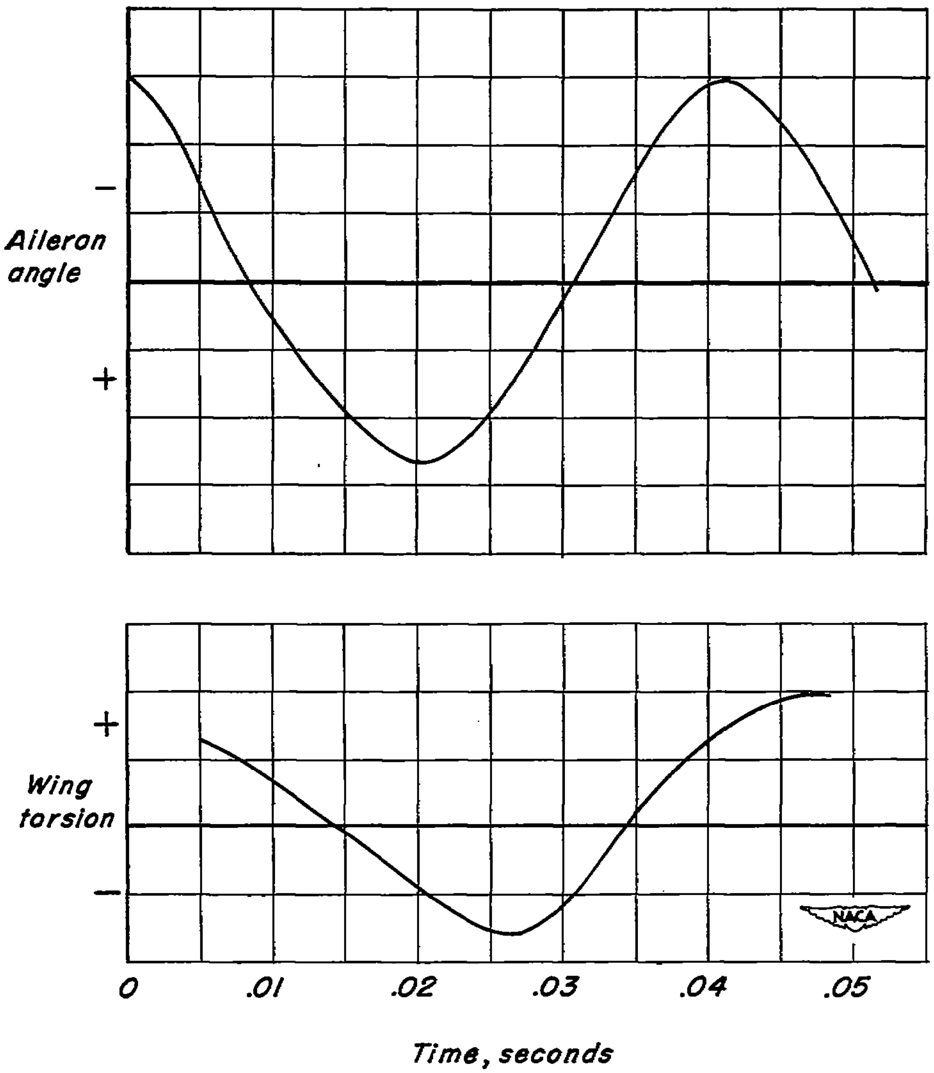


Figure 5.– Phase relation of wing and aileron motion during flutter for the partial–span wing with the aileron free.

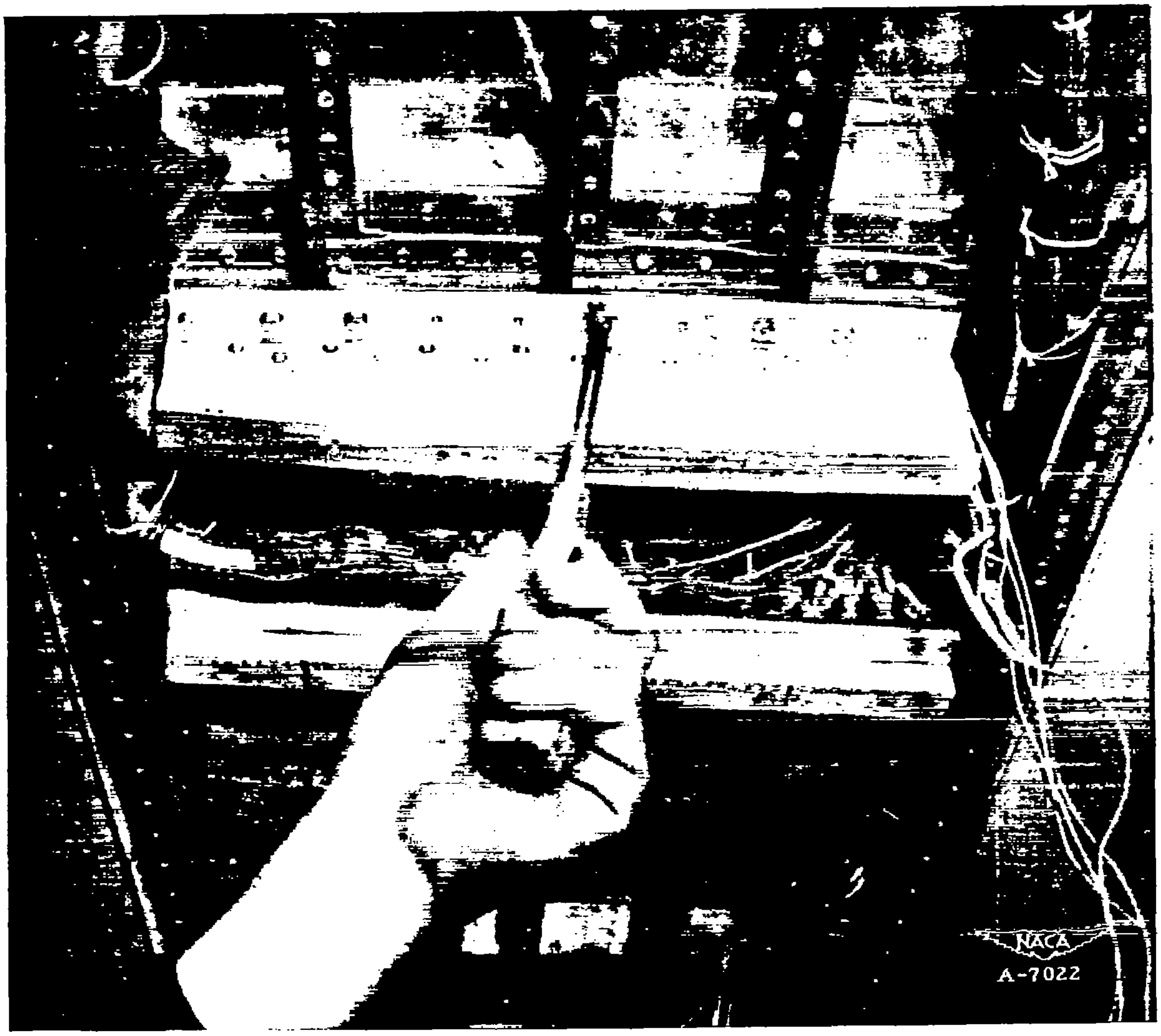
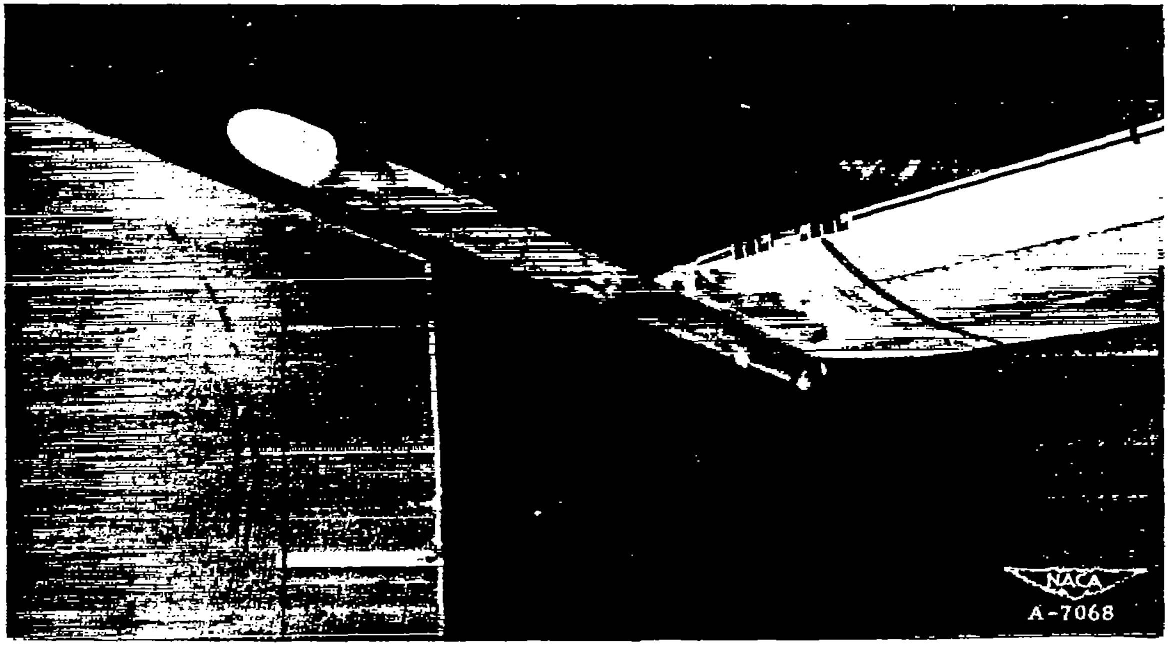
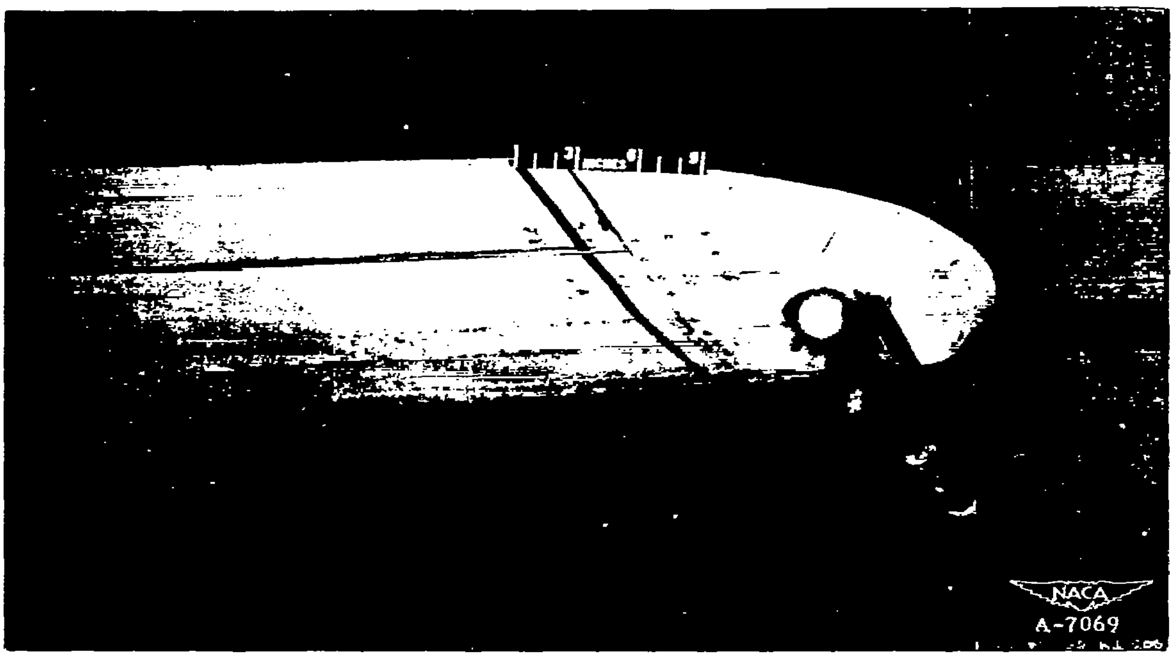


Figure 6.– One of the two special ribs installed at the partial-span wing.

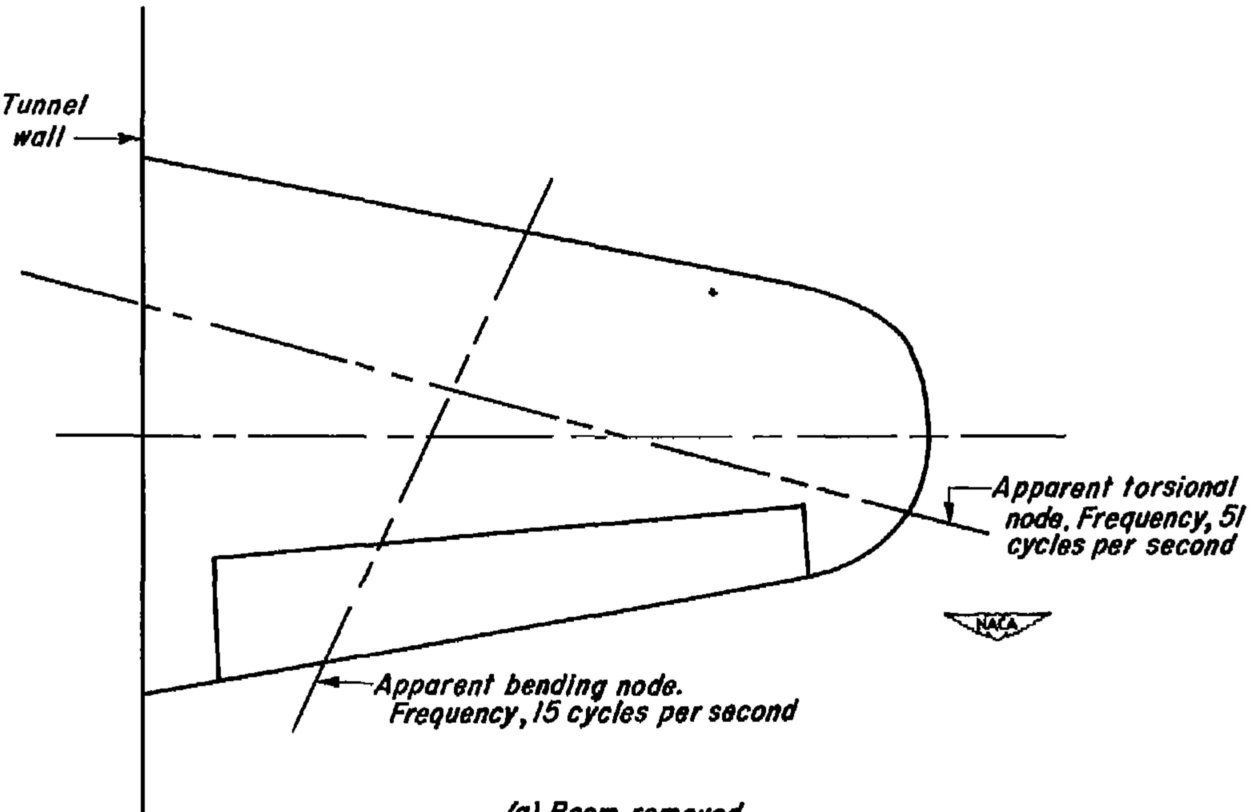


(a) Front view.



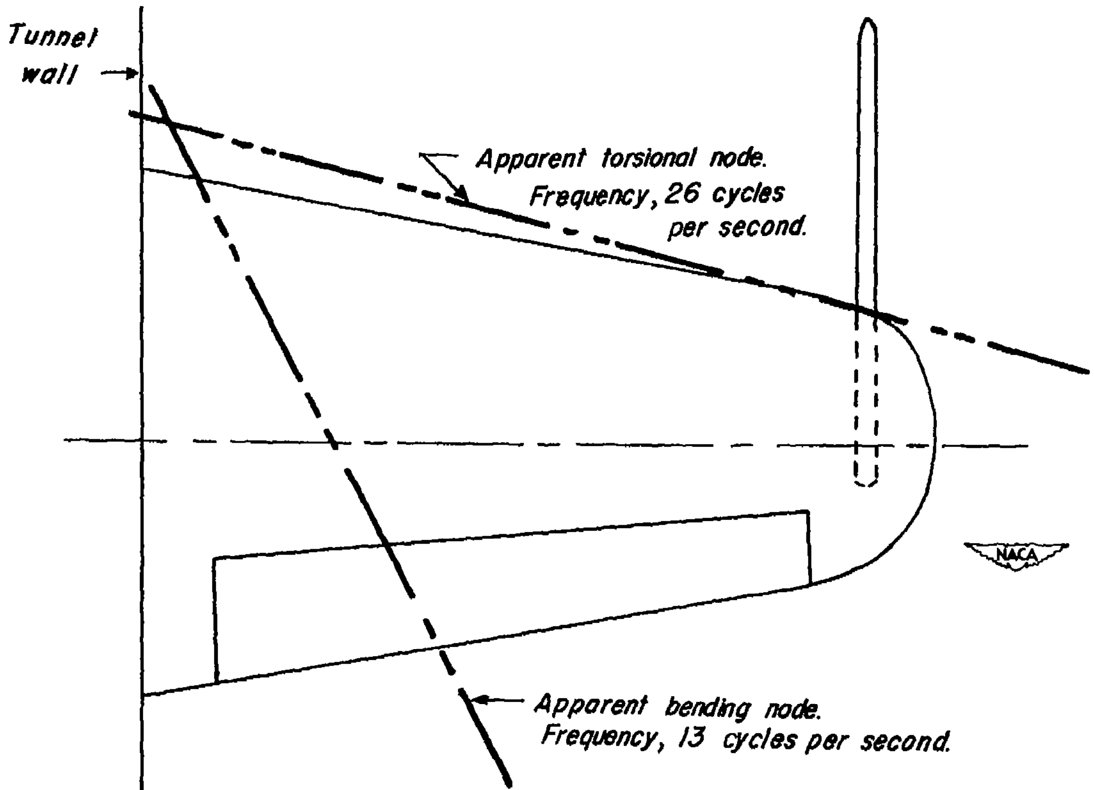
(b) Rear view.

Figure 7.– Wing-tip boom mounted on the partial-span wing.



(a) Boom removed.

Figure 8.— Apparent nodes in torsion and in bending of the partial-span wing.



(b) Boom attached.

Figure 8.– Concluded.

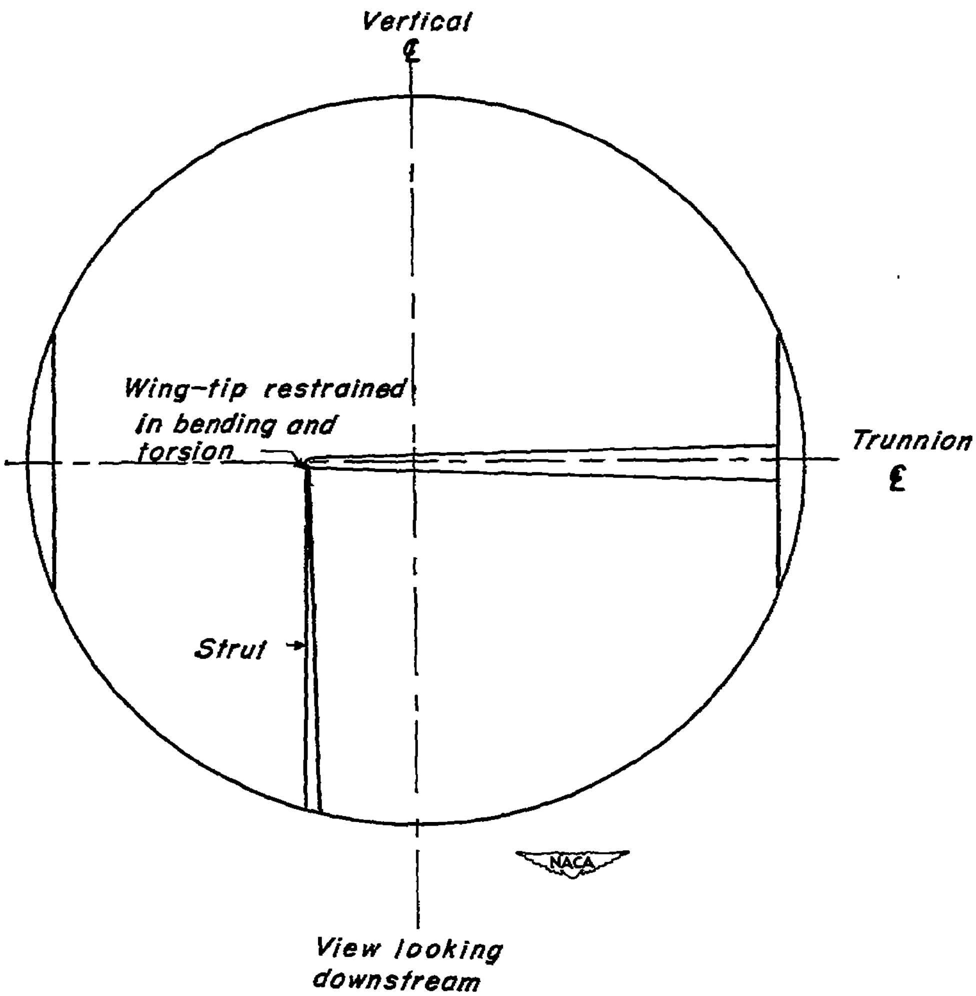


Figure 9.— The partial-span wing mounted in the 16-foot high speed wind tunnel with tip fastened to strut.

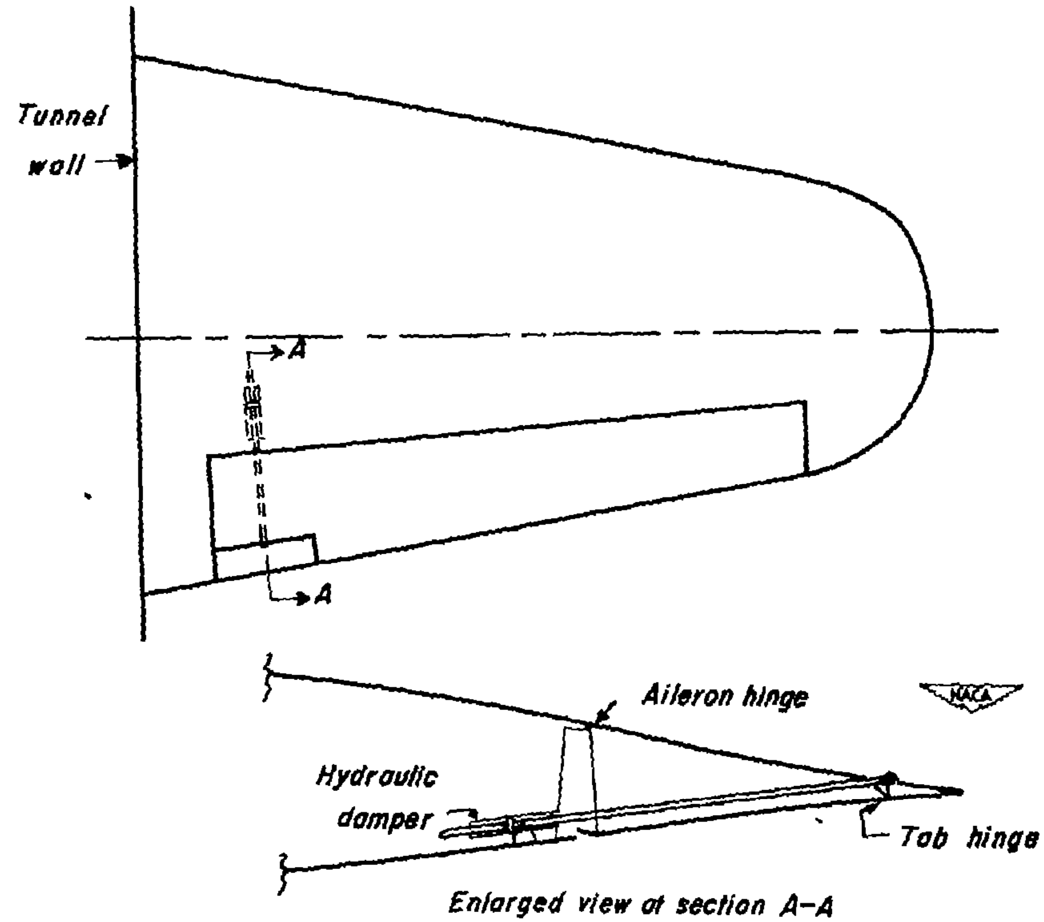


Figure 10.– Schematic drawing of antiservo tab with hydraulic damper

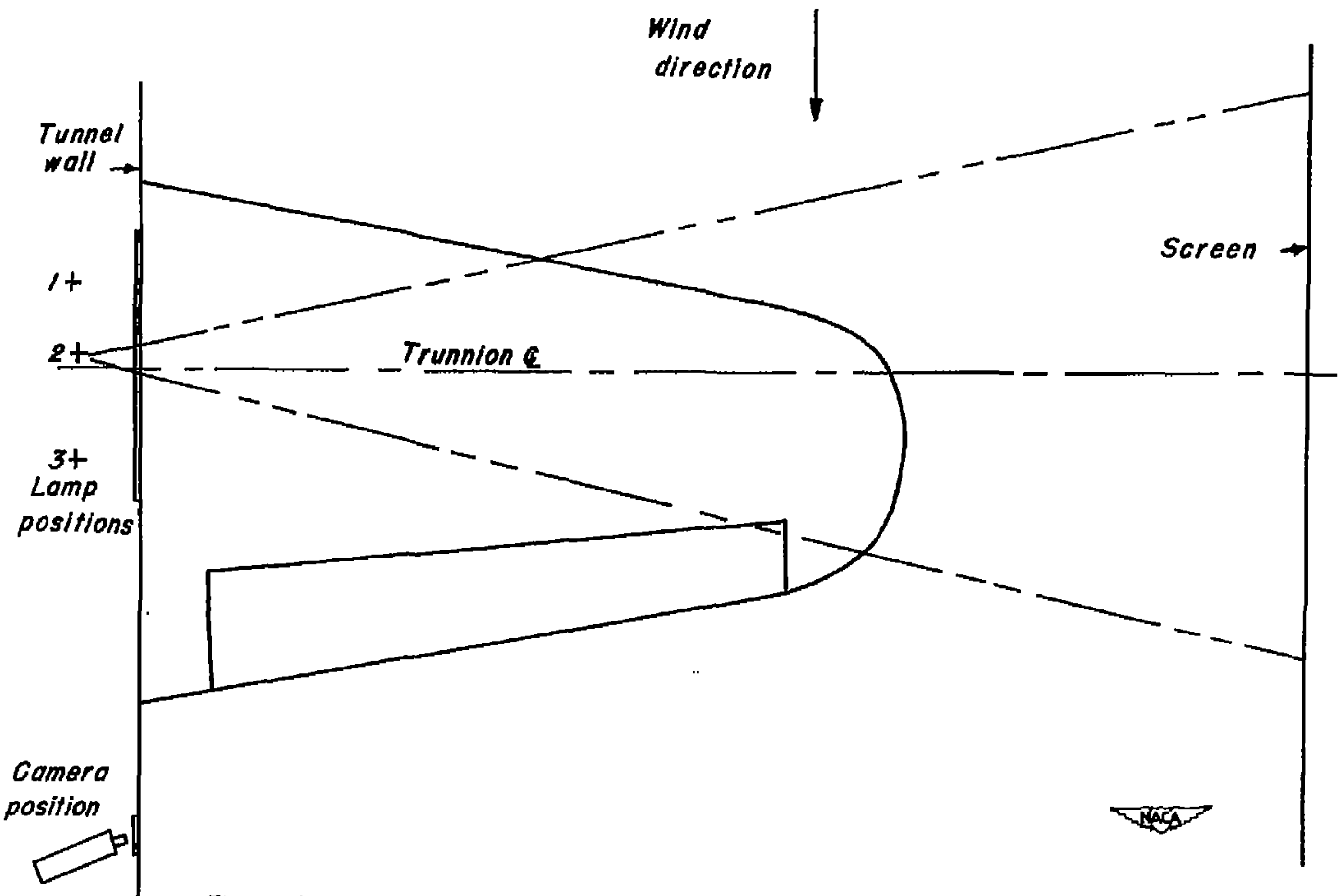
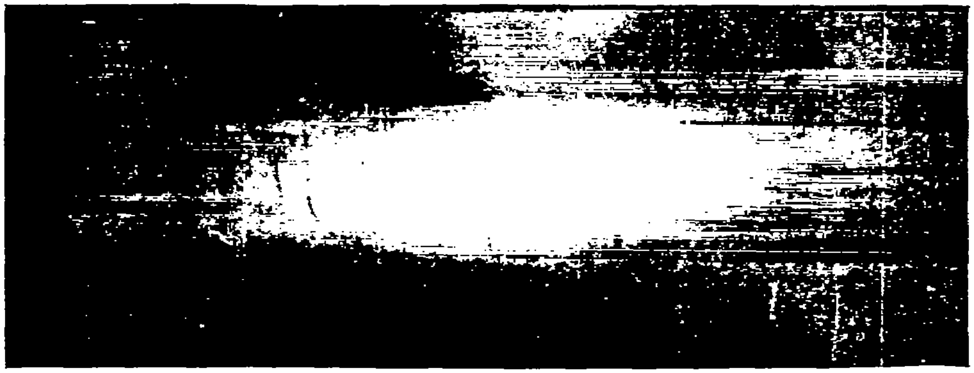
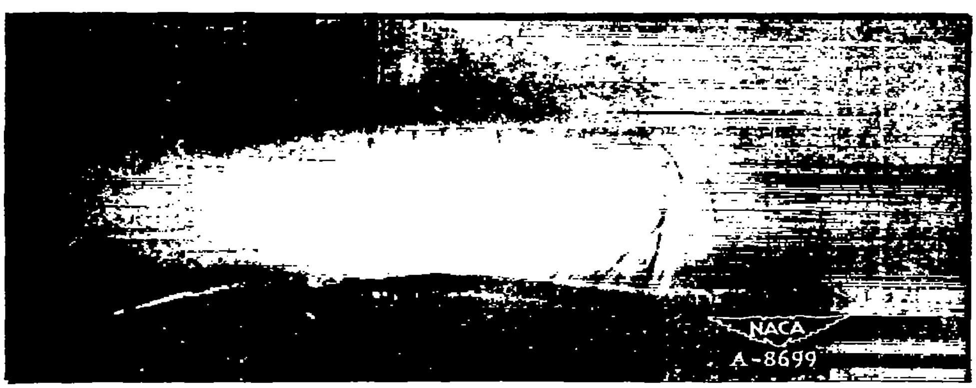


Figure 11.– Schematic drawing showing the location of the light source, screen, and camera used in taking shadowgraphs of shock waves on the partial-span wing.



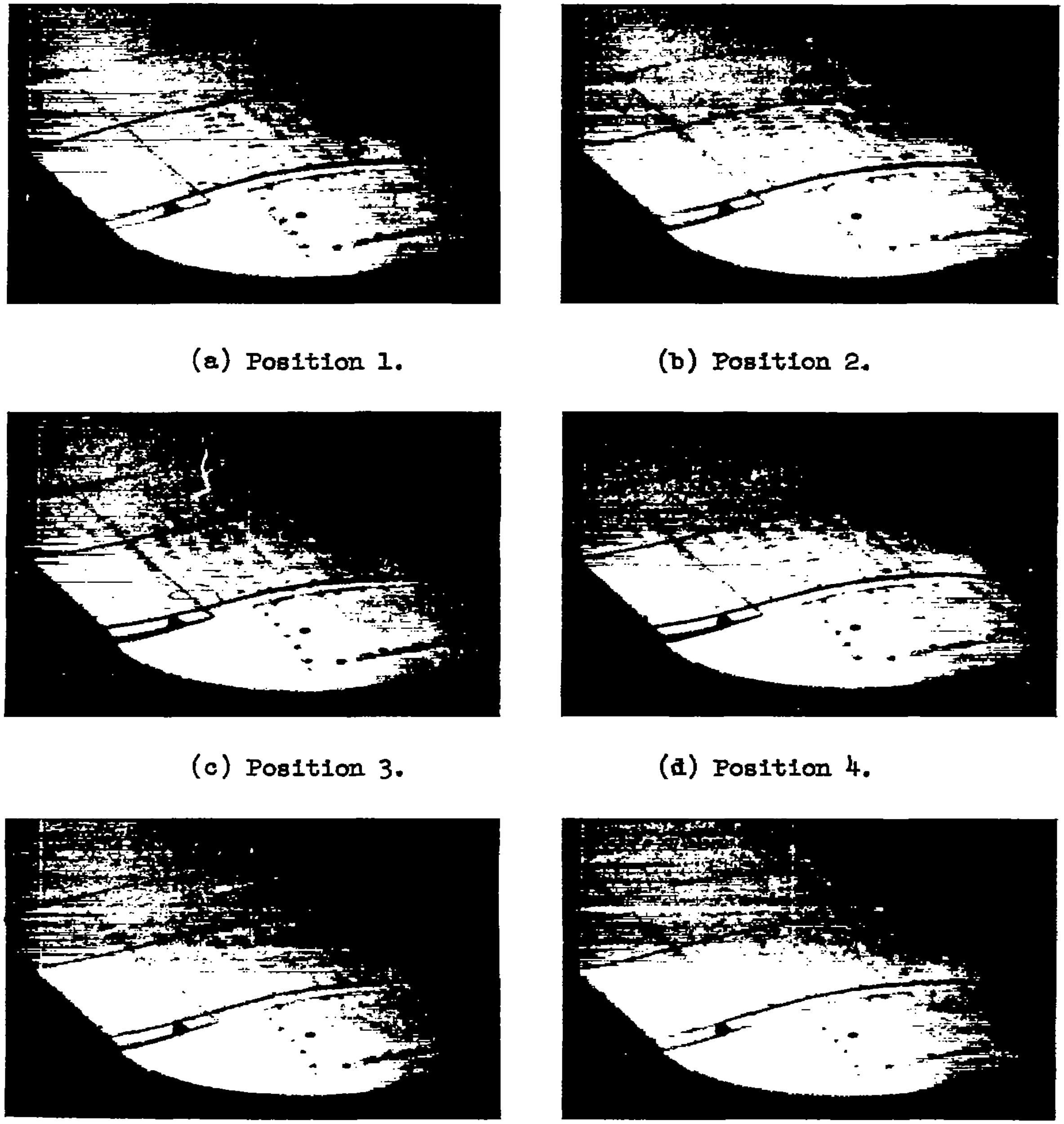
(a) Lamp position 1.

(b) Lamp position 2.



(c) Lamp position 3.

Figure 12.– Shock-wave pictures obtained by the shadowgraph method during tests of a partial-span wing. Mach number, 0.800.



(a) Position 1.

(b) Position 2.

(c) Position 3.

(d) Position 4.

(e) Position 5.

(f) Position 6.

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Figure 13.– Tuft studies on the partial–span wing showing change in flow separation for six aileron positions. Pictures are from a motion picture of the aileron flutter taken at 16 frames per second.

[redacted]

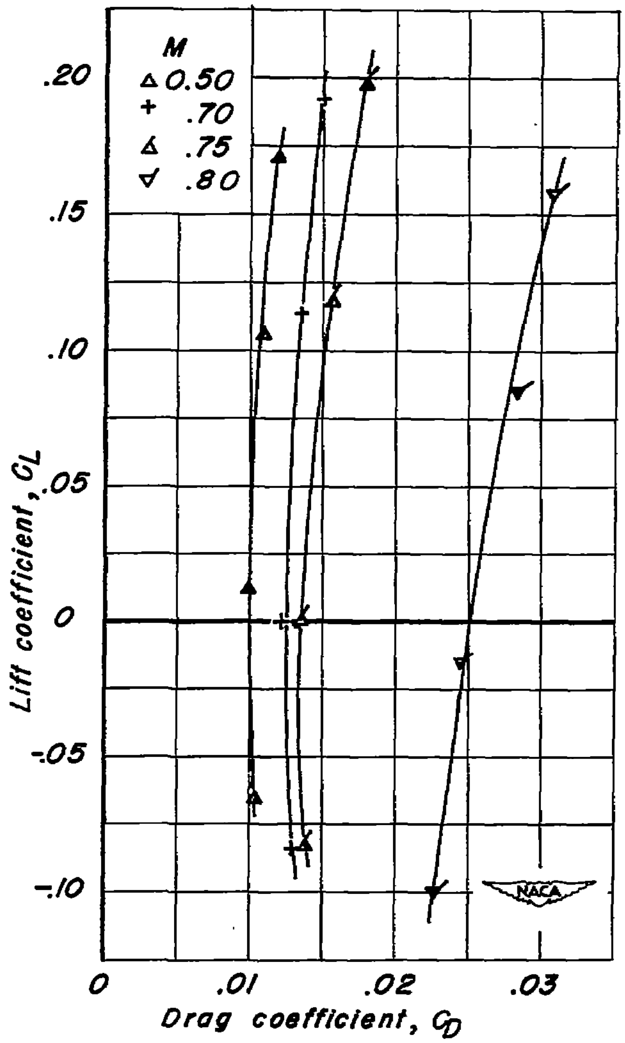


Figure 14.– Variation of lift coefficient with drag coefficient at several Mach numbers for the partial-span wing. δ_a, 0°

[redacted]

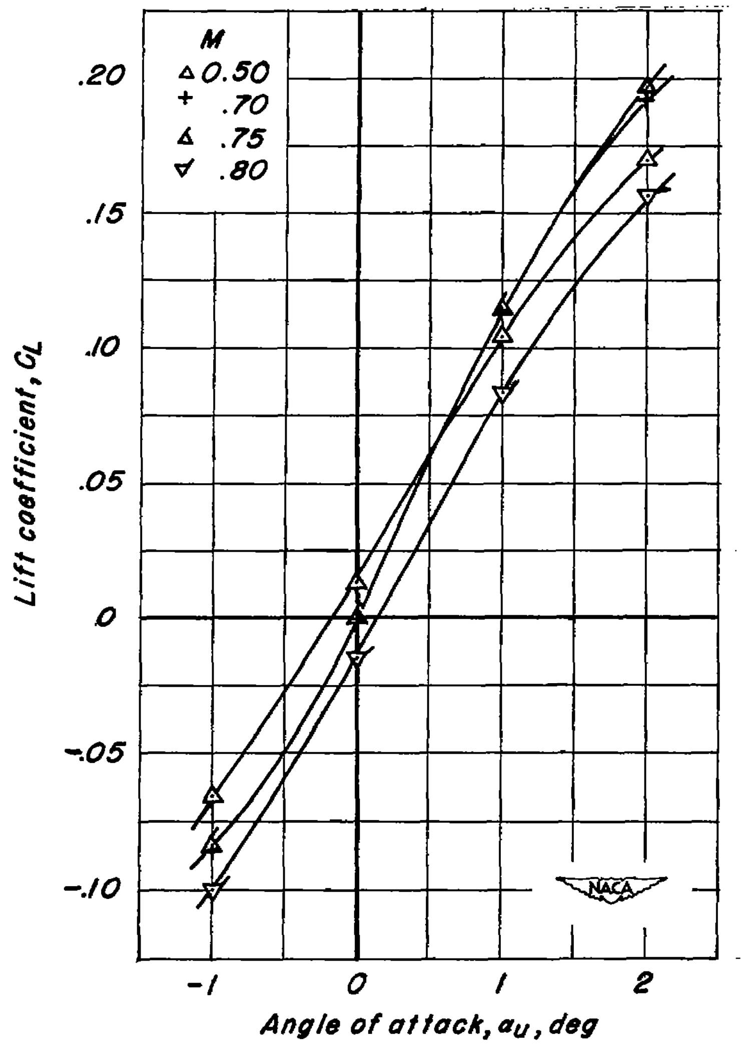
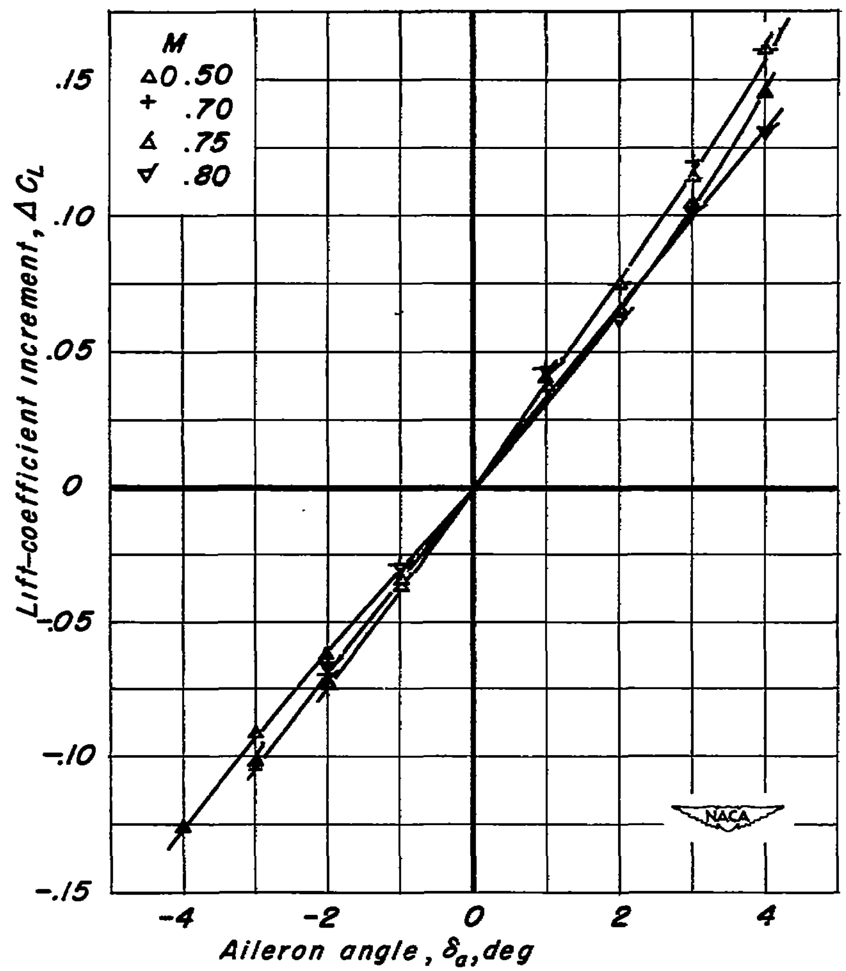


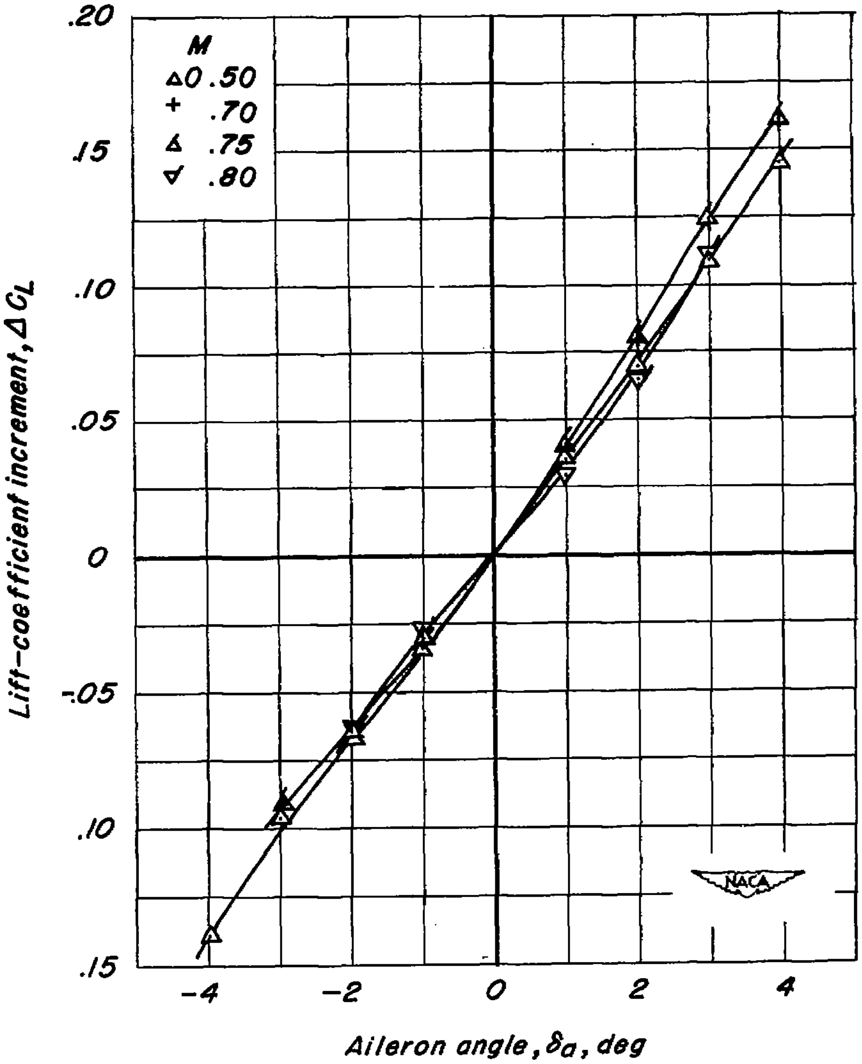
Figure 15.– Variation of lift coefficient with angle of attack at several Mach numbers for the partial-span wing. δ_a, 0°



(a) α_u, −1°

Figure 16.– Variation of the lift-coefficient increment with aileron angle at several Mach numbers for the partial-span wing.

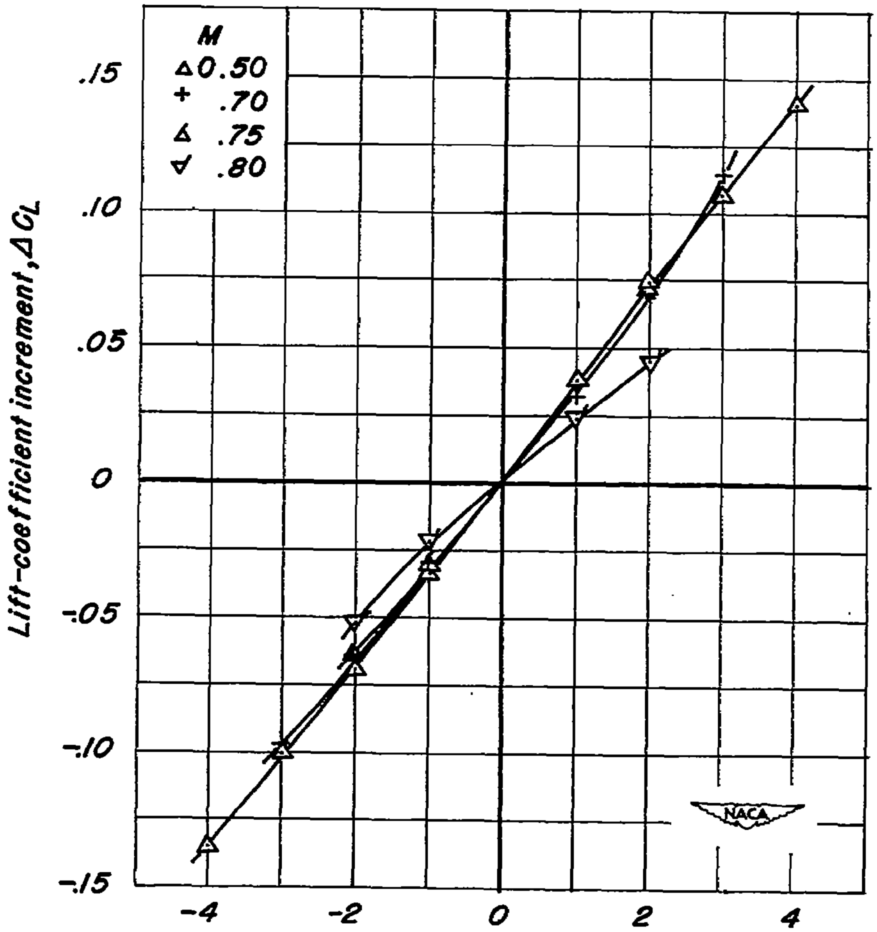
[redacted]



(b) α_u ,0°.

Figure 16.—Continued.

[redacted]

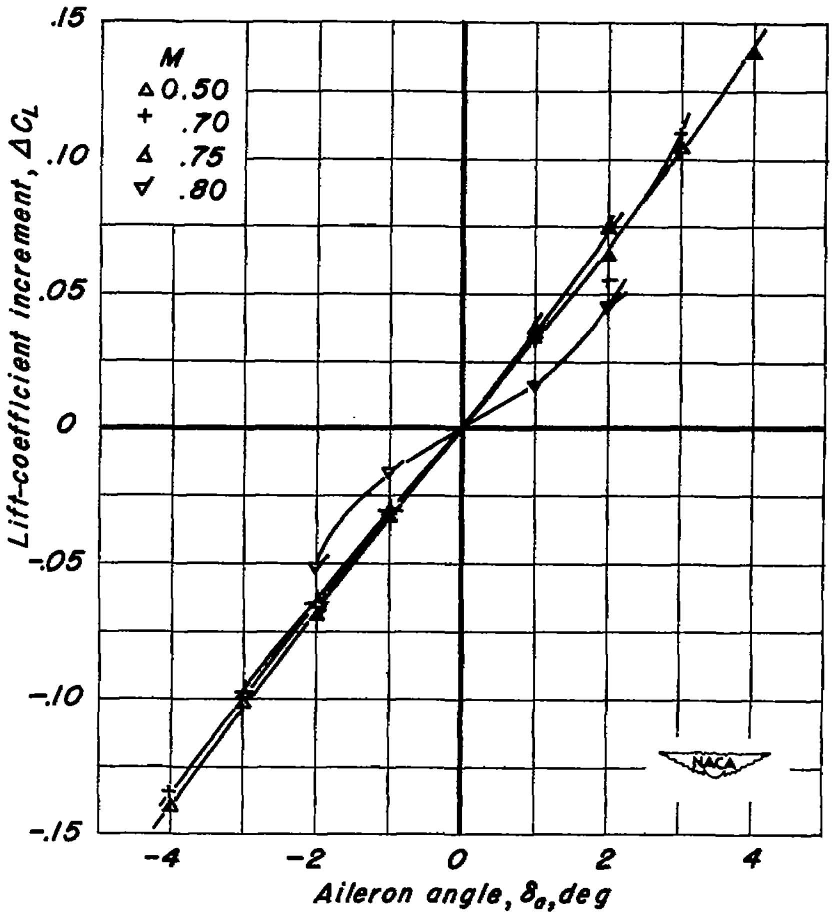


Aileron angle, δ_a, deg

(c) α_u, 1°.

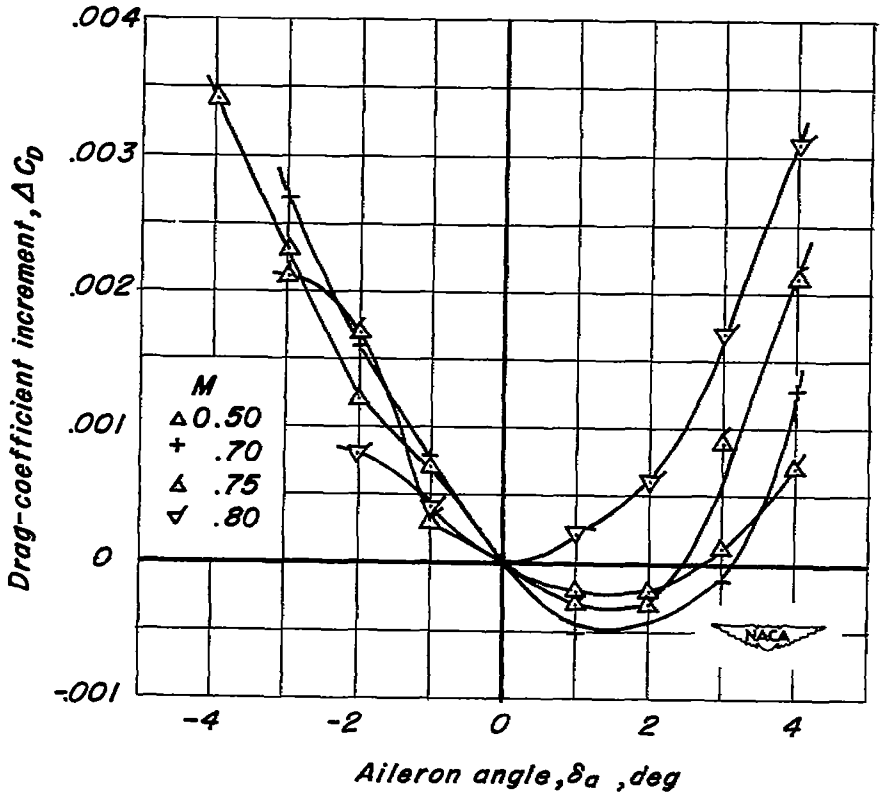
Figure 16.– Continued.

[redacted]



(d) α_u, 2°.

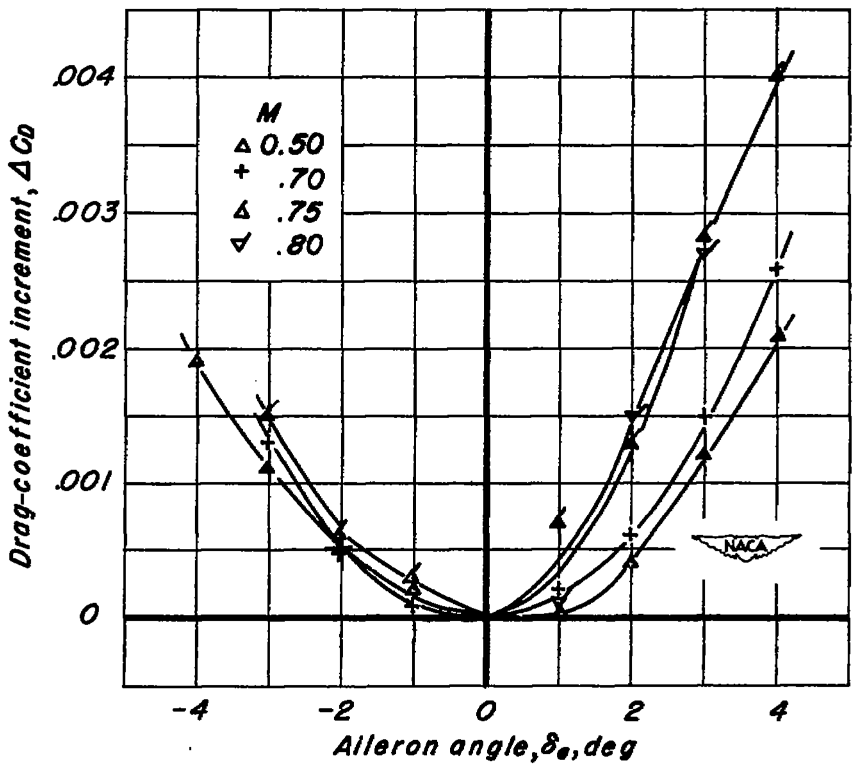
Figure 16.—Concluded.



(a) au ;-1°.

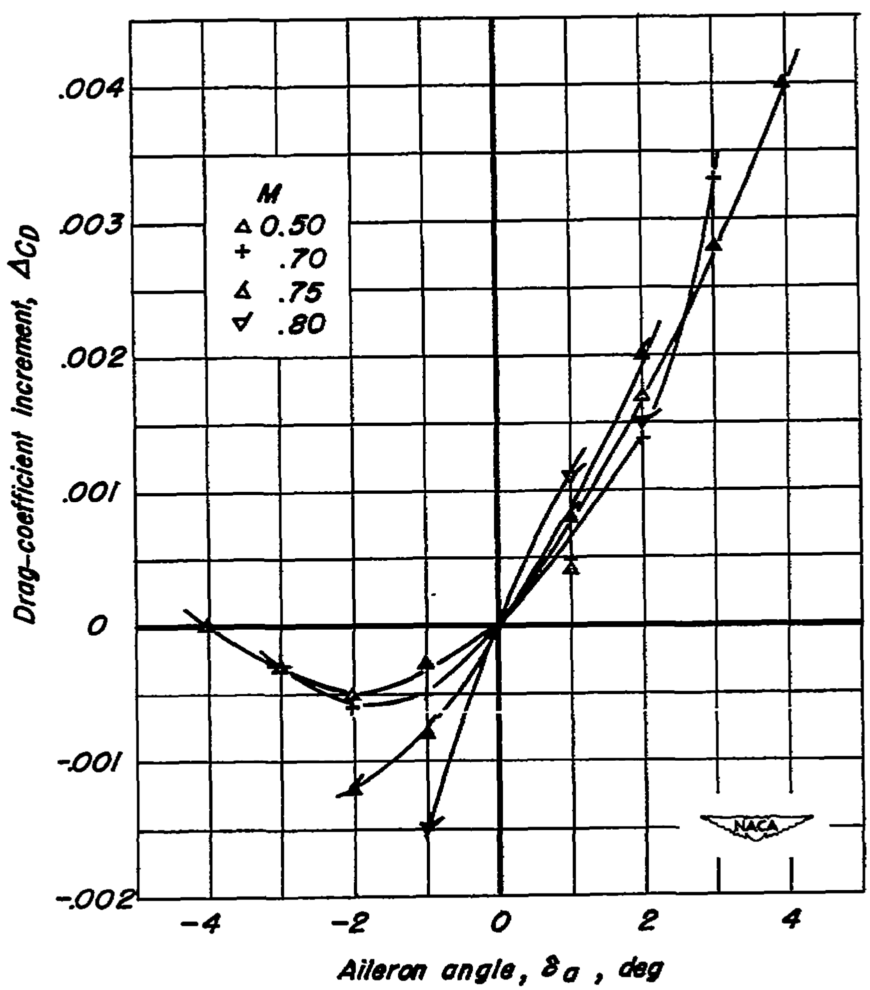
Figure 17.— Variation of drag-coefficient increment with aileron angle at several Mach numbers for the partial-span wing.

[redacted]



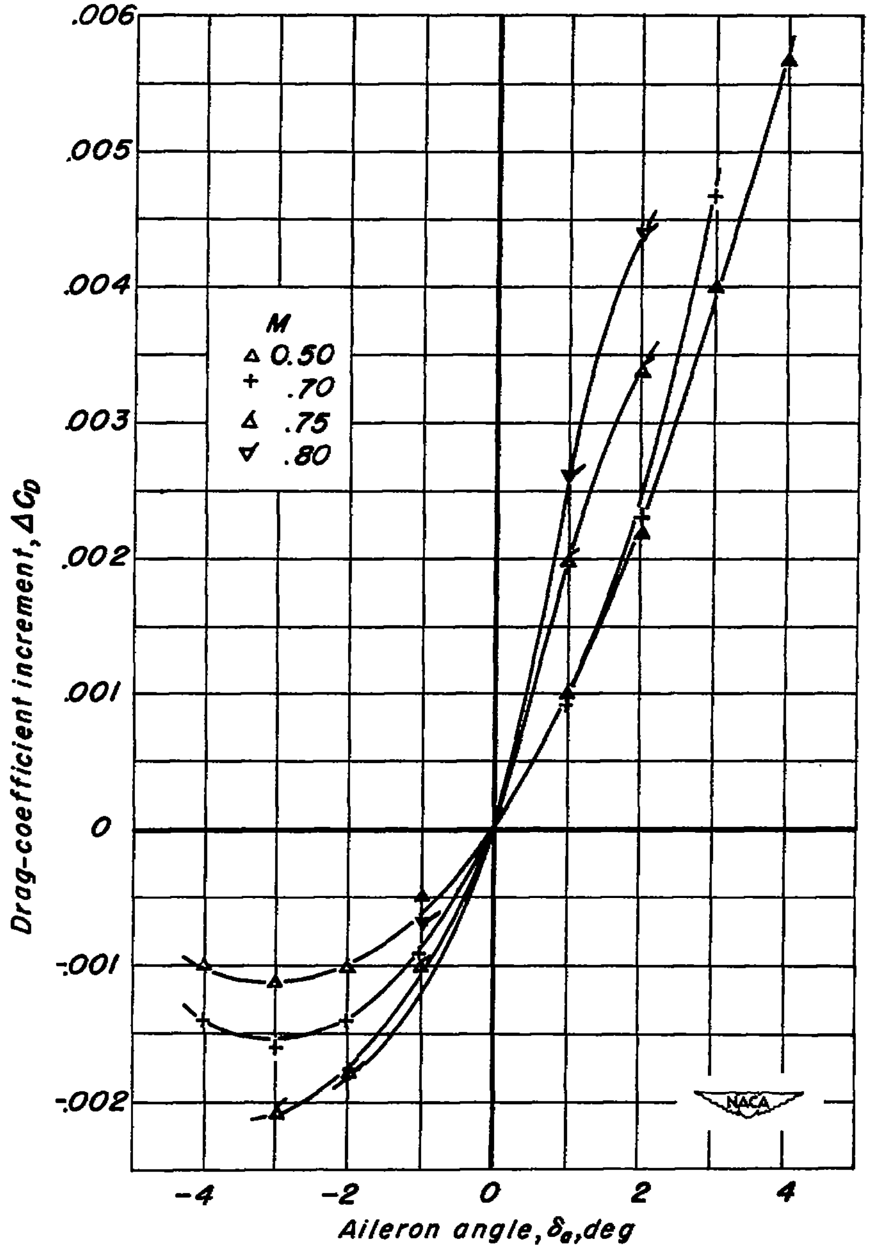
(b) α_u, 0°.

Figure 17.— Continued.



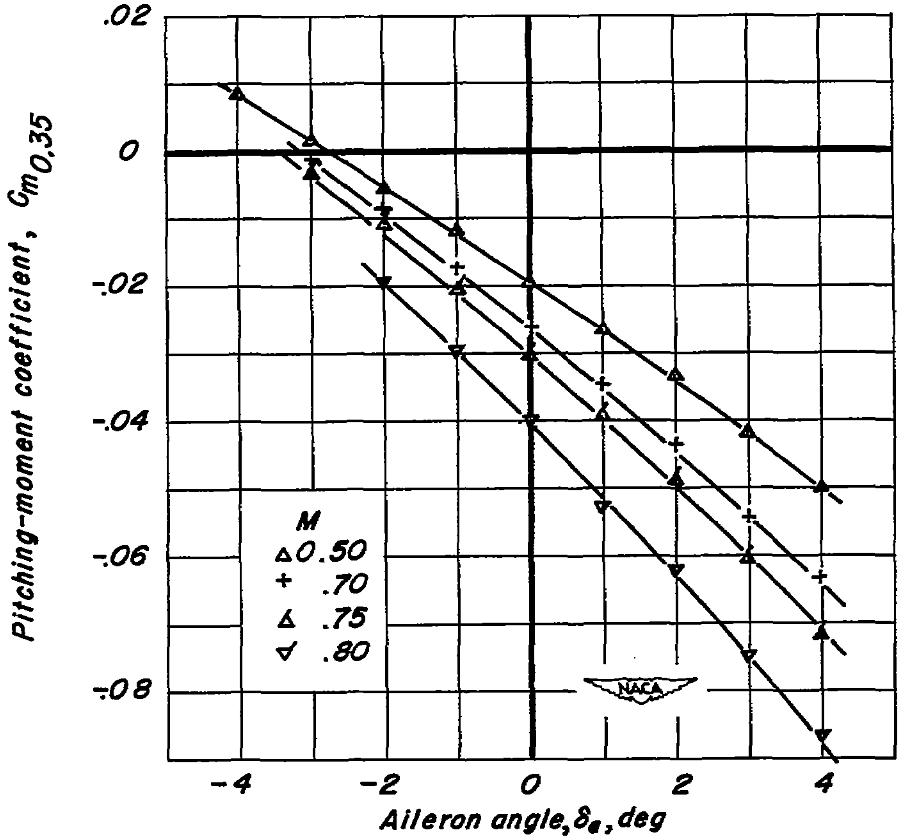
(c) a_u, 1°.

Figure 17.– Continued.



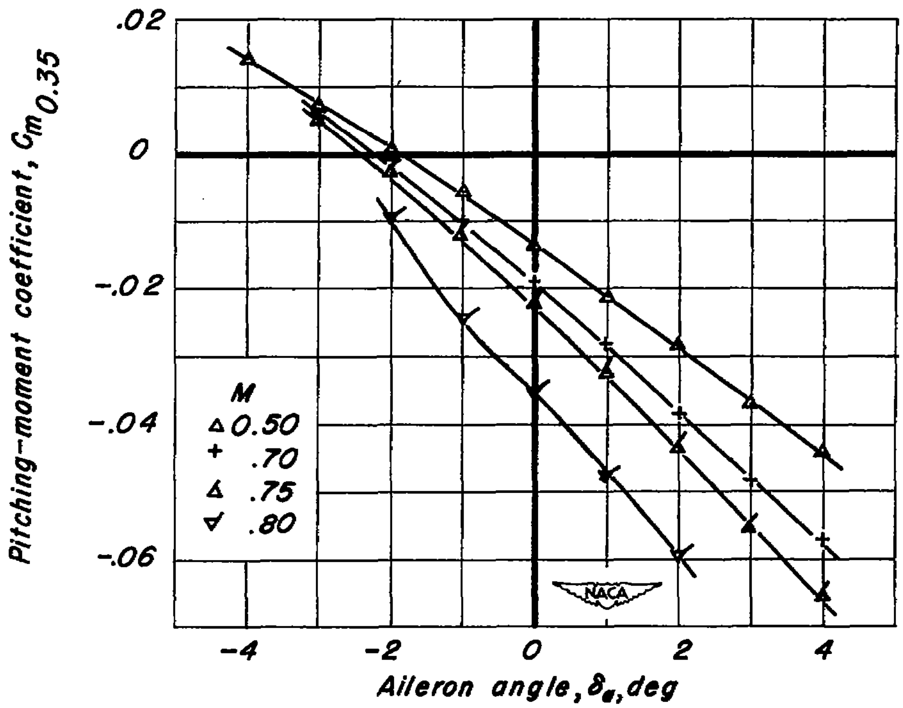
(d) a_u, 2°.

Figure 17.– Concluded.



(a) a_u, $-1°$.

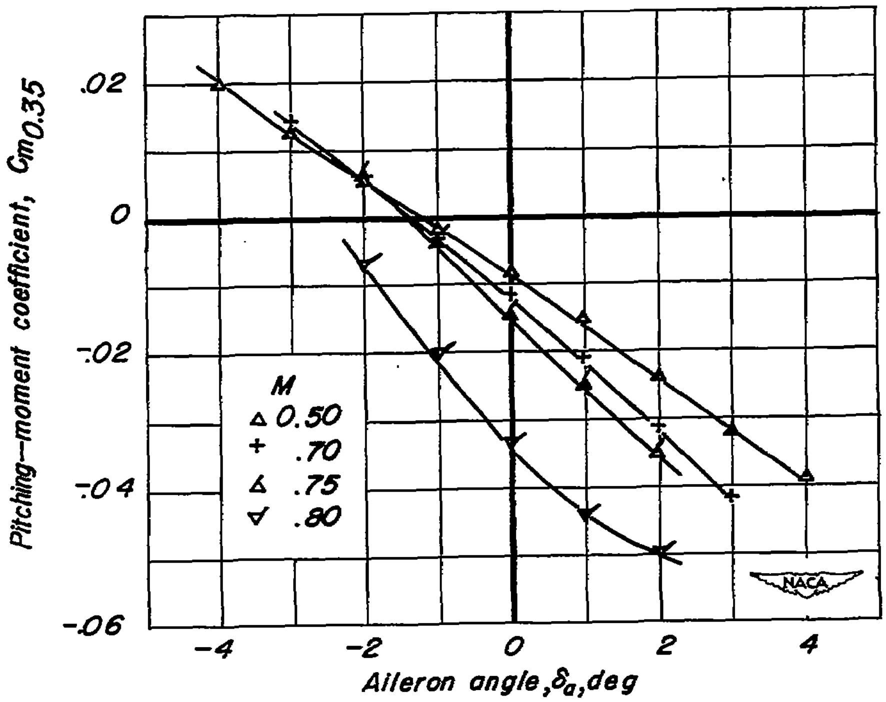
Figure 18.– Variation of pitching-moment coefficient with aileron angle at several Mach numbers for the partial-span wing.



(b) α_u, 0°.

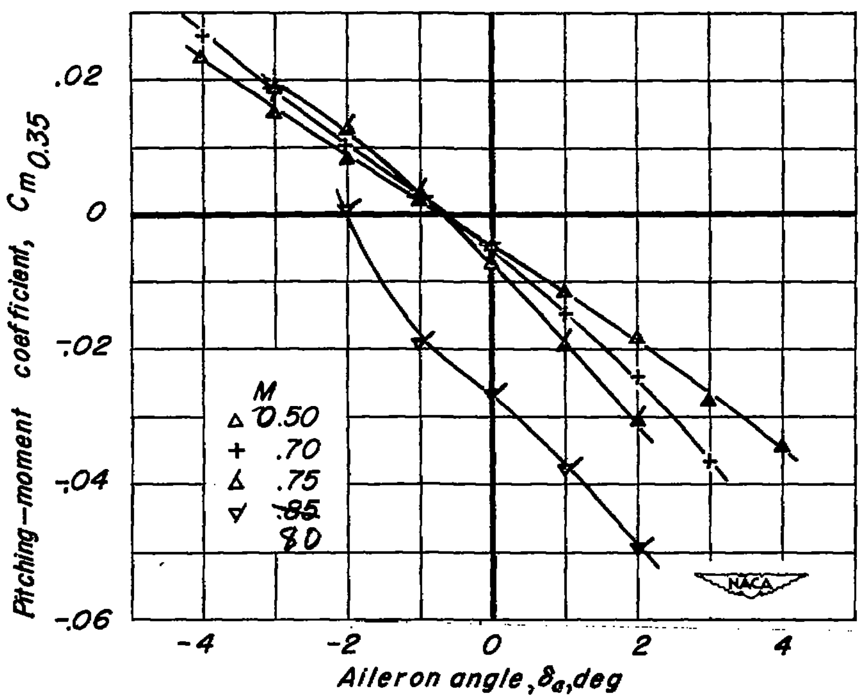
Figure 18.- Continued.

[redacted]



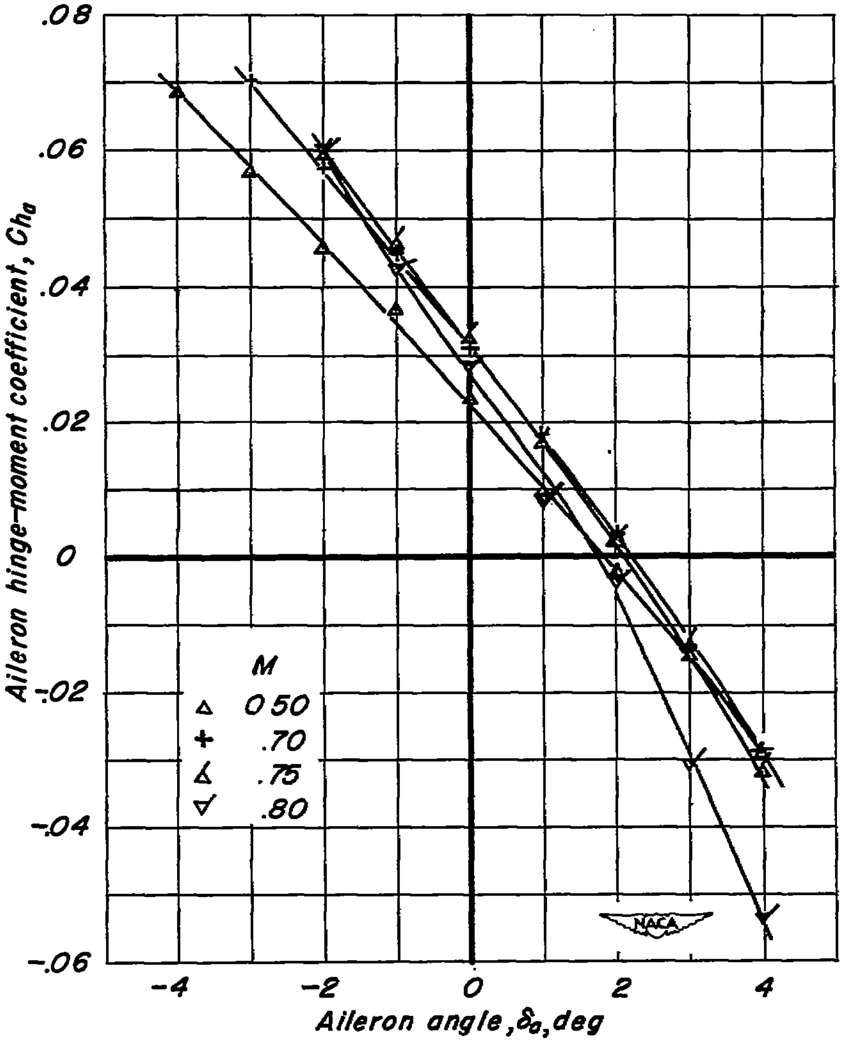
(c) α_u, 1°.

Figure 18.– Continued.



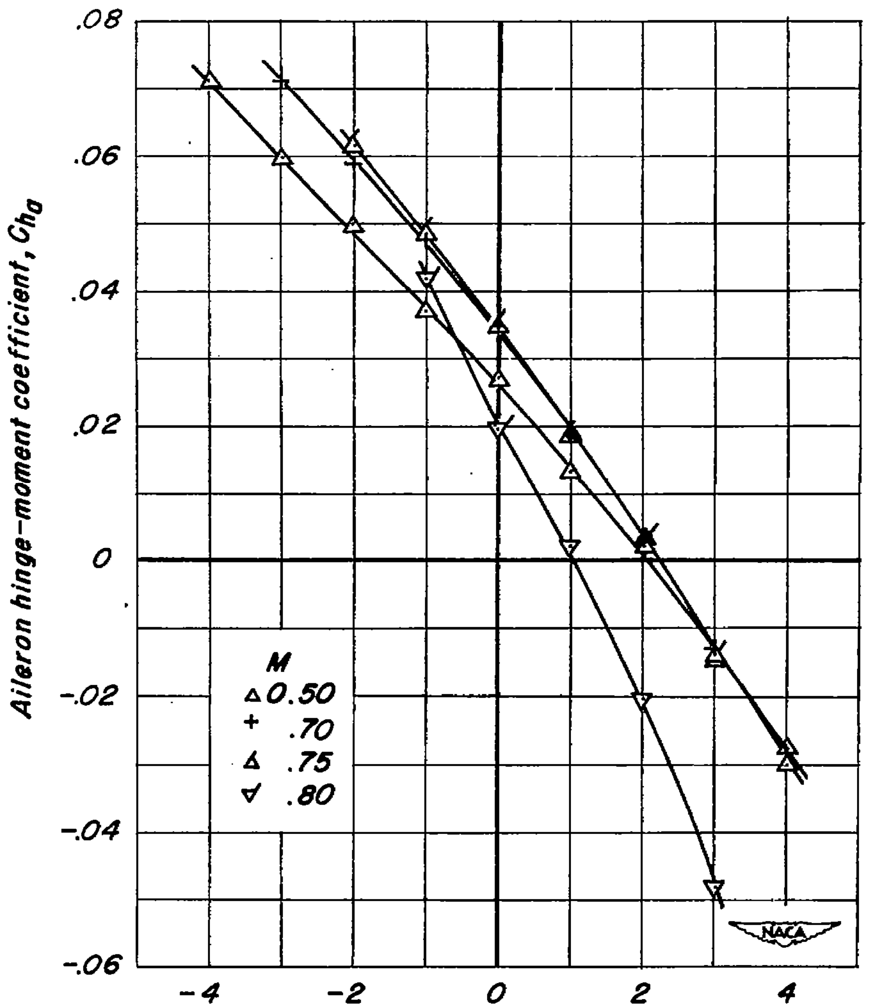
(d) α_u, 2°.

Figure 18.— Concluded.



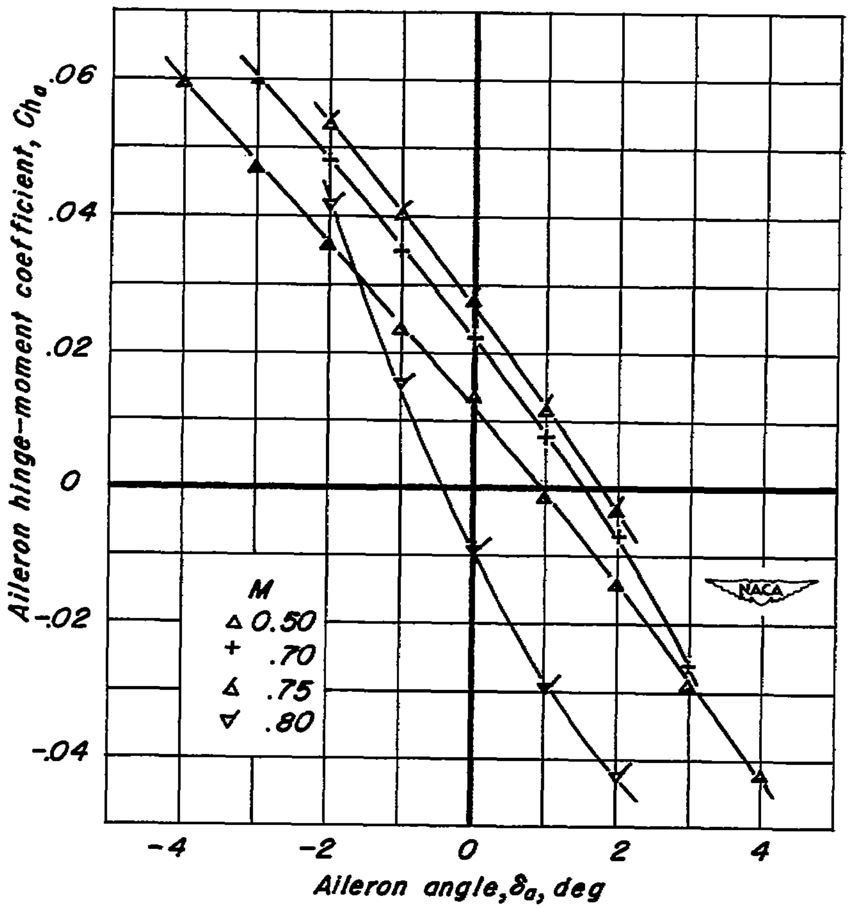
(a) α_u, $-1°$.

Figure 19.– Variation of aileron hinge-moment coefficient with aileron angle at several Mach numbers for the partial-span wing.



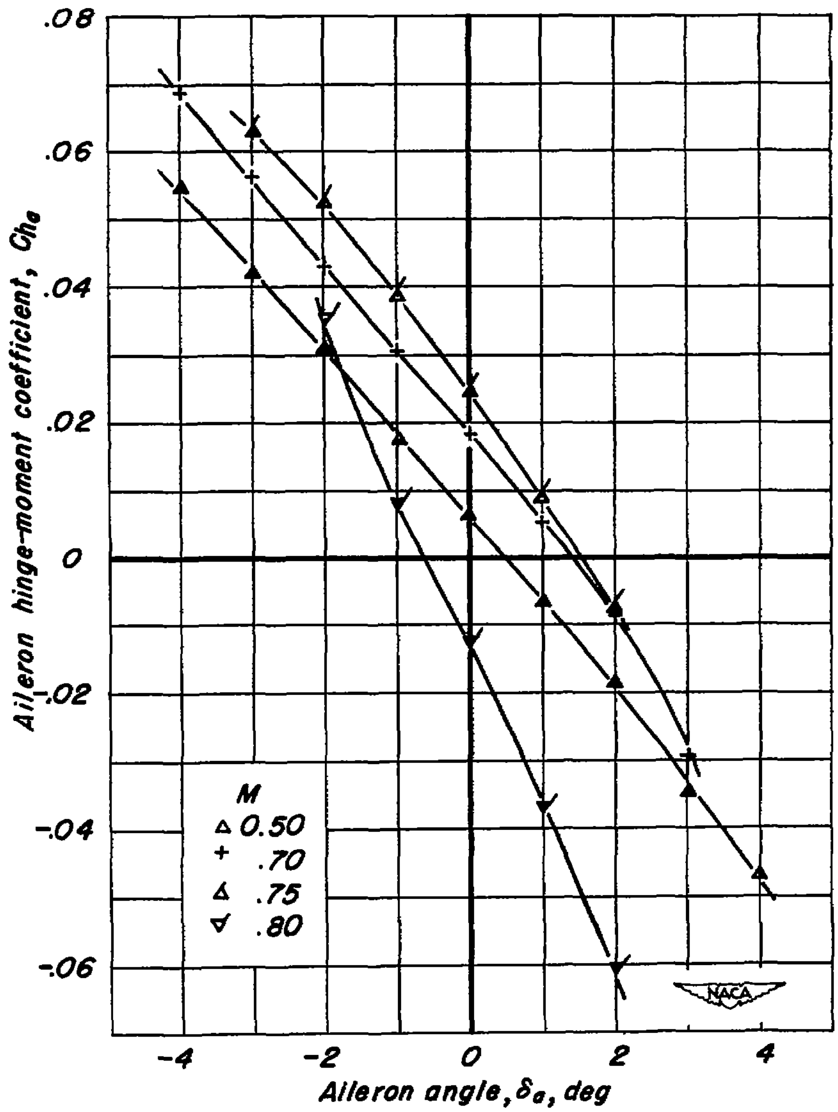
(b) α_u, 0°.

Figure 19.– Continued.



(c) a_u, 1°.

Figure 19.– Continued.



(d) α_u, 2°.

Figure 19.- Concluded.

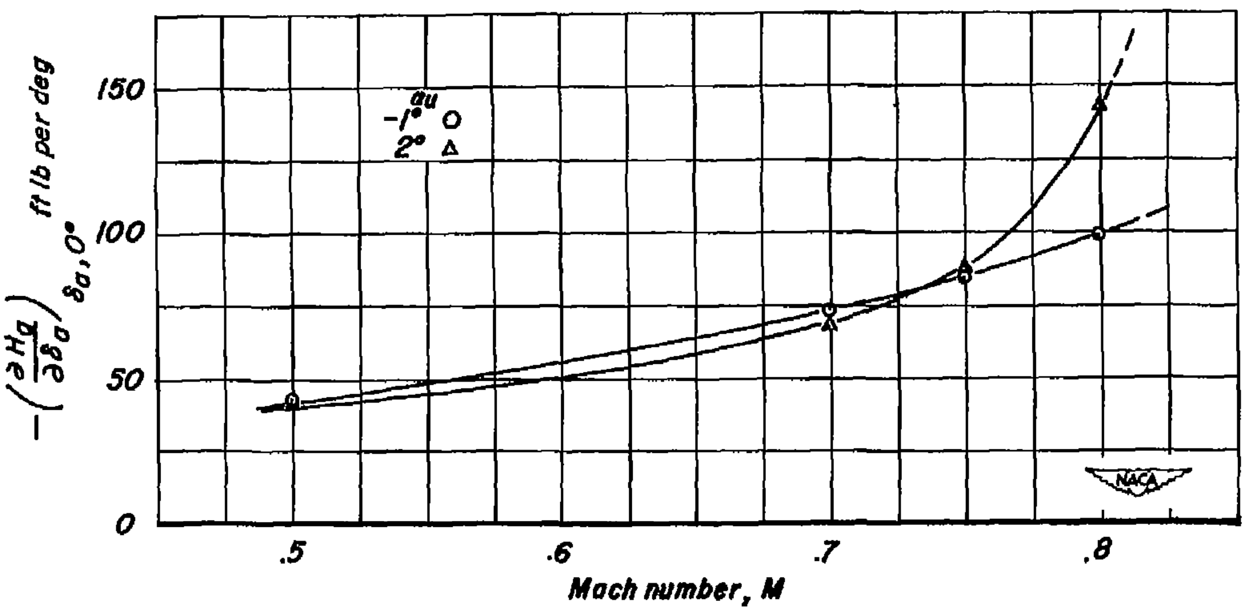


Figure 20.- Variation of aileron hinge-moment slope with Mach number at two angles of attack for the partial-span wing. $\delta_a, 0°$.

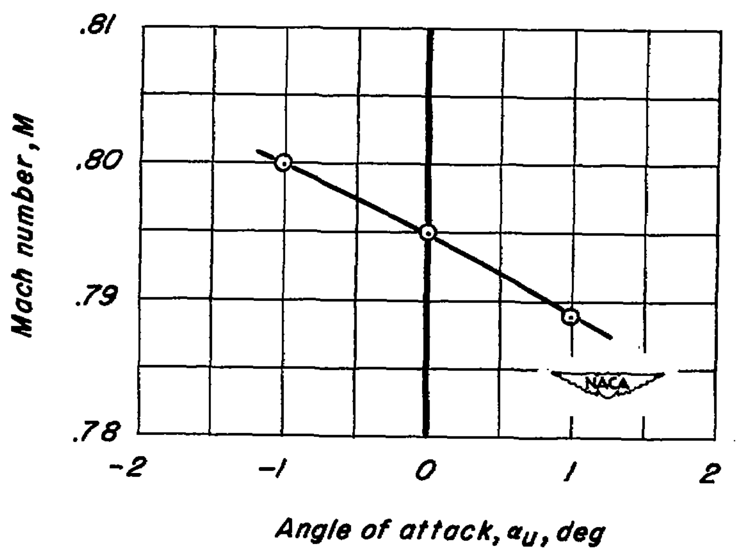
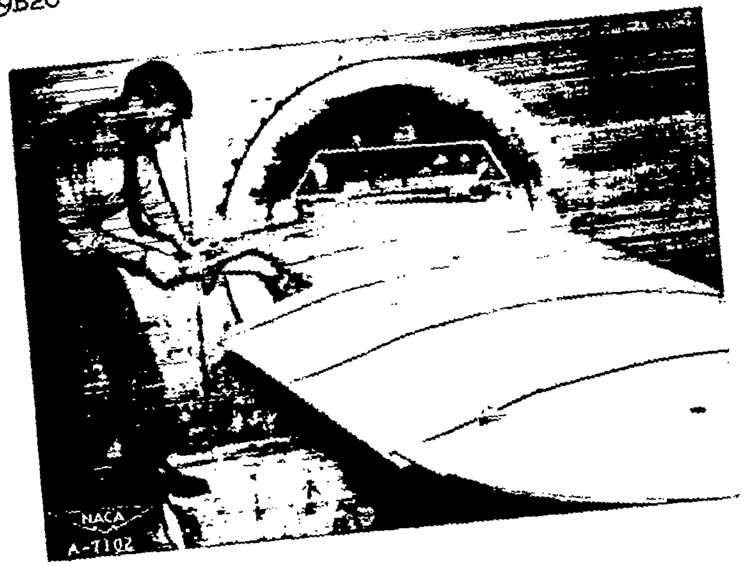


Figure 21.– Angles of attack and Mach numbers at which flutter occurred during tests of the partial-span wing with the aileron free.

[redacted]



(a) Upper surface.

(b) Lower surface.

Figure 22.- Failure of the inboard end of the aileron on the partial-span wing.

[redacted]

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