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RESEARCH MEMORANDUM

LOW-SPEED TESTS OF A MODEL SIMULATING THE PHENOMENON

OF CONTROL-SURFACE BUZZ

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SUMMARY

Low-speed tests have been made of an airfoil model with a freely hinged flap attached to spoilers which passed through slots in the airfoil ahead of the hinge line. The spoilers were intended to simulate the action of shock waves in producing flow separation. When the model was fitted with spoilers which had an initial projection of 1.7 percent chord at zero flap deflection, a continuous oscillation of the flap of about $\pm 4^{\circ}$ amplitude occurred under certain conditions. This oscillation was similar in nature to control-surface buzz. Results of tests with other spoiler arrangements are also presented.

The tests indicate that buzz is not caused simply by buffeting of a flap by separated flow. Instead, it is an oscillation involving coupling between the flap motion and the shock-wave-separation pattern. The occurrence of an oscillation similar to buzz with no associated compressibility effects indicates that flow separation may be an important factor in the conditions which produce control-surface buzz at transonic speeds.

INTRODUCTION

Previous experimental studies of control-surface buzz at transonic speeds have shown that these oscillations may occur when only one degree of freedom, that of control-surface rotation about the hinge line, is involved. The tendency for an oscillation to occur may be attributed to lag in the development of hinge moments when the control surface is oscillating. (See reference 1.) This lag has been ascribed, by previous investigators, to the effects of flow separation caused by shock waves at transonic speeds and to the time required for pressure impulses to be transmitted upstream from the flap against the air stream moving at near-sonic velocity. The time required for the transmission of these pressure impulses has been used as the basis for determining the time lag in some empirical theories of control-surface buzz.

An example of unstable single-degree-of-freedom oscillations involving flow separation and occurring at low speeds has been cited by Goethert in reference 2. In this case, an airfoil with a sharp leading edge was found to be statically stable in pitch about an axis of 25 to 30 percent of the chord. When this airfoil was free to rotate, oscillations occurred. In an oscillation of this kind, the lag in development of aerodynamic hinge moments is attributed to flow separation, inasmuch as the transmission of pressure impulses at the low speeds involved is practically instantaneous.

The oscillations of the airfoils at low airspeed involving flow separation were used in reference 2 to indicate the possible importance of flow separation in the phenomenon of aileron buzz at transonic speeds. A more direct indication of the effects of flow separation would be obtained, however, if the oscillating system more closely resembled a control surface. A brief discussion of transonic buzz is now presented to show how this phenomenon might be simulated at low airspeed.

The flow over an airfoil at Mach numbers slightly above the critical Mach number is characterized by supersonic regions on the upper and lower surfaces. These supersonic regions are terminated by shock waves. Shadowgraph pictures of these shock waves and their action during aileron buzz are given in reference 3. In the examples shown in reference 3, the shock waves were located at about 60 to 70 percent of the chord in the Mach number range where aileron buzz occurred. The shock waves cause separation of the boundary layer. Oscillation of the aileron during buzz causes a chordwise oscillation of the shock waves and, presumably, a corresponding variation in intensity of the shock waves. Thus, a downward deflection of the flap creates a larger supersonic region on the upper surface and a more intense shock wave. This more intense shock wave would be expected to increase the flow separation occurring on the upper surface, while a corresponding decrease in separation would occur on the lower surface. The changes in separation in conjunction with the flap motion are believed to be responsible for the occurrence of buzz.

It was thought that a simulation of the effects of these shock waves at low airspeed could be obtained by the use of spoilers. Chordwise motion of the spoilers to simulate the shock-wave motion did not appear to be feasible, but changes in spoiler projection to simulate changes in shock intensity could be readily obtained. This spoiler motion was produced by attaching spoilers to a flap so that, for example, downward deflection of the flap resulted in an upward projection of the spoiler; this spoiler projection simulated a shock wave of increased intensity on the upper surface.

APPARATUS AND TESTS

A drawing of the model used is given in figure 1, and a photograph of the model is given as figure 2. The model, which was constructed of mahogany, had an NACA 65-009 airfoil section, a span of 9 inches, and a chord of 6 inches. This airfoil was mounted as a semispan model simulating a wing of aspect ratio 3. The full-span radius-nose flap was hinged at the 75-percent-chord line. Arms attached to the flap carried the spoilers which moved into the air stream when the flap was deflected; these arms also carried lead weights which were used for mass balancing the flap. The moment of inertia of the flap, spoilers, and lead weights was approximately 6.0×10^{-6} slug-feet squared. The spoilers were located at 66 percent chord and were made as thin as practicable with sharpened edges in order to reduce to a minimum hinge moments on the spoilers themselves. The spoilers passed through slots in the airfoil with small clearance and were rigidly attached to the flap. The stops on the spoilers limited the flap deflections to $\pm 14^{\circ}$. The hinges consisted of thin strips of spring steel which crossed at the hinge line; this type of hinge held the flap rigid in translation while the flexibility of the springs allowed rotation with a negligible amount of friction.

The restoring and friction forces provided by the flap hinges are illustrated in figure 3 by a record taken of the motion of the flap at zero airspeed. The restoring force provided by the flap hinges, which was measured to be 0.015 foot-pound per radian, was small in comparison with the aerodynamic hinge moments acting in flight as can be seen by comparing the period of the oscillation of figure 3 with those from the flight records. The friction was very small as shown by the small damping of the oscillations.

Three different combinations of spoilers and model were used. The first tests were run with 0.4-inch-wide spoilers which were flush with the surface of the airfoil when in the neutral position. For the second tests, the spoilers were enlarged to 0.6-inch width so that they extended into the air stream 1.7 percent chord when in the neutral position. A plot of spoiler projection against flap deflection for these two configurations is given in figure 4. The final test was made with these large spoilers removed from the flap arms and fixed to the airfoil so that they would not oscillate with the flap, but would remain in the neutral position. Whenever the spoilers were changed, weights were added or subtracted as necessary to maintain mass balance.

The model was mounted on a wing-flow panel of an F-51D airplane. This panel is ordinarily used for testing in the transonic speed range, but in this case it was used only to obtain a turbulence-free air stream at relatively low speeds. The records were taken during the take-off run and subsequent climb while the true airspeed at the model varied from 0 to 325 feet per second. These runs took approximately 50 seconds to complete. The change in speed during the short portions of the records reproduced in this paper is approximately 12 feet per second. The tests were limited to the maximum speed of 325 feet per second because it was estimated that the drag force on the spoilers would cause them to deflect and rub against the slot through the airfoil at higher speeds. The Reynolds number of the tests based on the mean aerodynamic chord varied from 0 to 1.16×10^6.

Flap deflections were measured by photographing a beam of light reflected from a small mirror mounted on a thin rod extending below the flap into the test panel. Airspeed of the test airplane was measured with standard NACA instruments. Airspeed at the location of the model was determined from the airplane speed and lift coefficient by means of calibrations previously made of the test panel. The angle of attack of the model, which resulted from sideslip of the F-51D airplane and sidewash over the test panel, was measured with a wedge-shaped vane mounted 22 inches outboard of the model and calibrated to give the angle of flow at the model. A simple lever system driven by an air motor was used to give the flap an intermittent mechanical disturbance during some of the flights.

RESULTS

Initial tests were made with a spoiler flush with the surface of the airfoil when the flap was at zero deflection. Copies of typical records obtained in this configuration are presented in figure 5. Values of angle of attack α and airspeed V are given in the figure. This arrangement might be considered to simulate an airfoil very near its critical Mach number, so that, for example, downward deflection of the flap would cause the formation of a shock wave on the upper surface. In the first tests, in which the flap was not given any mechanical disturbance, no oscillations occurred at any airspeed in the range tested. A typical record for this case is shown in figure 5(a). In order to determine whether the oscillation might become unstable if it had been started with an initial amplitude, the device described previously was installed to displace and release the flap periodically. This device deflected the flap about 6° at approximately 0.3-second to 0.5-second intervals. Typical records from this test are shown in figure 5(b). The flap oscillations were quickly damped throughout the speed range tested.

The next tests were made with a spoiler which projected 1.7 percent chord on both sides of the airfoil at zero flap deflection. This arrangement might be considered to simulate an airfoil above its critical Mach number, so that strong shock waves and separated flow exist on both surfaces at zero flap deflection. Deflection of the flap caused a change in the relative deflection of the spoilers on the upper and lower surfaces, this change corresponding to a change in the relative intensity of the shock waves on the two surfaces. Records obtained with the flap undisturbed are shown in figure 6(a). At values of airspeed below 250 feet per second, the flap oscillated intermittently with a double amplitude ranging from 0° to 3°. At a speed of 250 feet per second, a continuous oscillation of the flap occurred with a double amplitude of 6° or 8°. This oscillation continued as the speed increased until it abruptly stopped at a speed of 325 feet per second. The stopping of the oscillation near the maximum speed is thought to be caused by rubbing of the spoiler on the rear of the slot through the airfoil as a result of deflection under drag loads. The angle of attack of the model causes the flap to oscillate about a position other than the zero-deflection position.

Records obtained in this configuration with the flap periodically displaced are shown in figure 6(b). The oscillations at an airspeed of 146 feet per second decreased slowly from the amplitude of the initial disturbance, indicating very slight damping. Over a speed range between 146 and 250 feet per second, the damping increased somewhat. Then at a speed of 252 feet per second, a continuous oscillation occurred as before with double amplitude of 6° or 8°. This oscillation again stopped at an airspeed of 321 feet per second. The shift of the center point of the oscillations after each mechanical disturbance in figure 6(b) is caused by slipping of the shaft carrying the mirror under the torque loads imposed by the disturbing device. The actual flap angles are therefore in error, but the amplitude and frequency of the oscillations are believed to be correctly recorded.

A final test was made with the wide spoiler detached from the flap and fixed rigidly to the airfoil in order to determine whether the oscillations were caused by coupling between the flap and spoiler motion or simply by the action on the flap of the turbulent wake from the spoiler. A typical record for this condition is shown in figure 7. A slight irregular motion of the flap with a double amplitude of 1° occurred throughout the speed range, but no oscillations similar to those obtained with the spoiler attached to the flap occurred. A comparison of the smooth record obtained when the spoiler did not extend into the air stream (fig. 5(a)) and the record obtained with the large fixed spoiler (fig. 7) indicates that some buffeting of the flap took place with the large fixed spoilers.

DISCUSSION

The oscillations with the wide spoiler attached to the flap appear similar in nature to control-surface buzz obtained at transonic speeds. The absence of oscillations in the case of the spoiler which was flush with the surface of the airfoil at zero flap deflection is in agreement with the observation that control-surface buzz does not appear at the critical Mach number of an airfoil but appears only when the shock waves have become strong enough to produce extensive flow separation. (See references 2 and 3.)

The absence of oscillations when the large spoiler was fixed to the airfoil, compared to the oscillations obtained when the spoiler was attached to the flap, indicates that buzz is not caused simply by buffeting of the flap by the separated flow. Instead, it is an oscillation involving coupling between the flap motion and the shock-wave-separation pattern on the airfoil. This conclusion is in agreement with those of previous investigators (references 1 and 3), though a direct demonstration of this point has not been made previously.

These tests demonstrate that an oscillation similar to buzz may occur as a result of flow separation with no associated compressibility effects. This result lends support to the belief, expressed in reference 2, that the time lag in the development of hinge moments which is responsible for buzz results from the time required by the separated boundary layer to adapt itself to the changing boundary conditions. Any additional lag resulting from lag in the transmission of pressure impulses through the flow outside the boundary layer does not appear to be necessary to produce buzz and possibly is not an important factor in determining the occurrence or the characteristics of buzz.

In reference 3, an empirical theory is advanced to explain the characteristics of buzz. In this theory, the time required for the transmission of pressure impulses is used as a basis for calculating the lag in the development of hinge moments. In reference 1, the lag is determined empirically, but the time for the transmission of pressure impulses is suggested as a component of this lag. Though the present tests do not disprove the possible importance of lag in transmission of pressure impulses as a contributing factor in the buzz phenomenon, they show that an oscillation similar to buzz can occur without the existence of such lag. The occurrence of this oscillation with no associated compressibility effects indicates that flow separation may be an important factor in the conditions which produce control-surface buzz at transonic speeds.

CONCLUSIONS

Low-speed tests of a semispan model simulating the phenomenon of control-surface buzz indicate the following conclusions:

1. Buzz is not caused simply by buffeting of a flap by separated flow. Instead, it is an oscillation involving coupling between the flap motion and the shock-wave-separation pattern.

2. The time lag required for the separated boundary layer to adapt itself to the changing boundary conditions during a control-surface oscillation appears to be an important factor in producing buzz.

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3. Erickson, Albert L., and Stephenson, Jack D.: A Suggested Method of Analyzing for Transonic Flutter of Control Surfaces Based on Available Experimental Evidence. NACA RM A7F30, 1947.

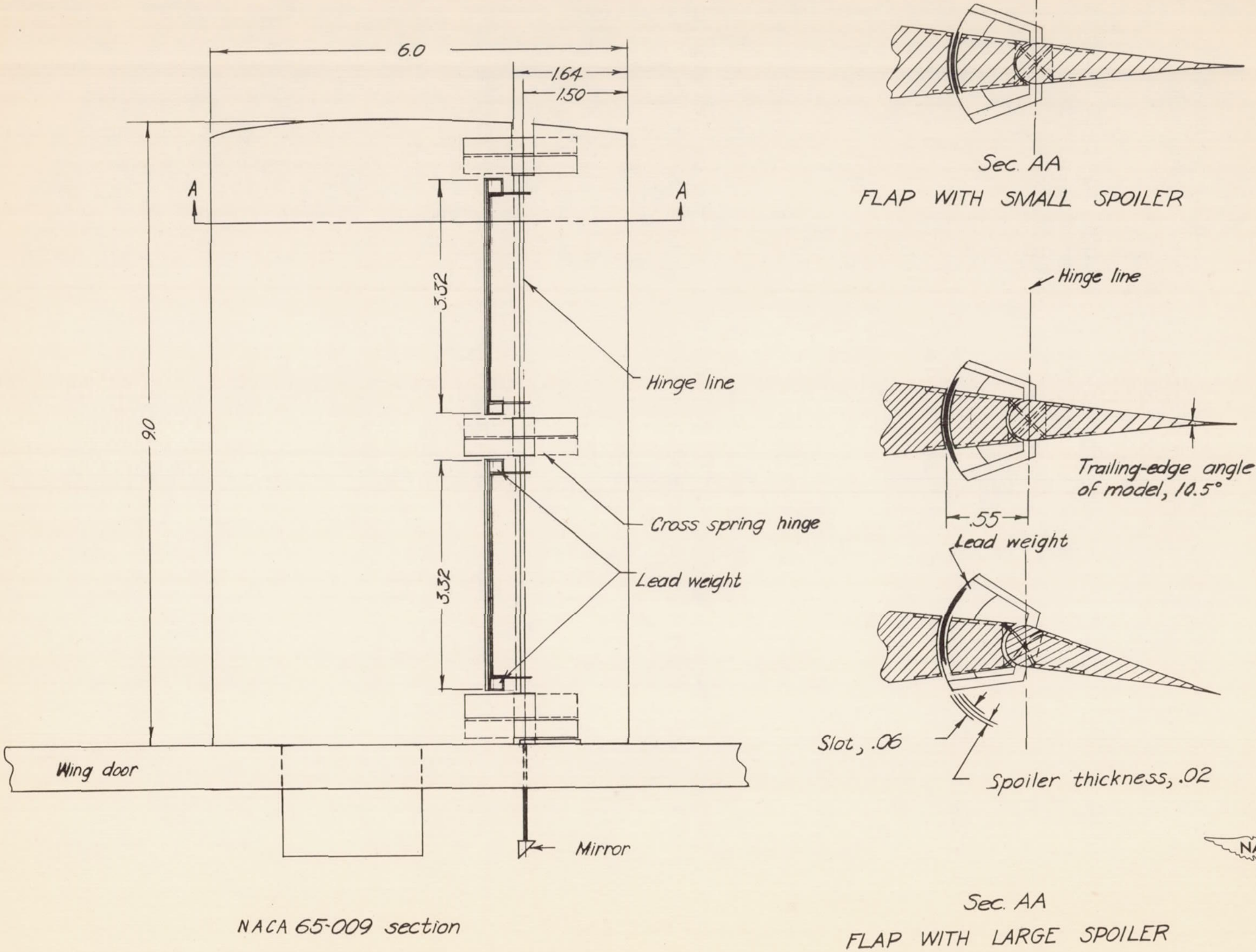


Figure 1.- Drawing of model. (All dimensions are in inches.)

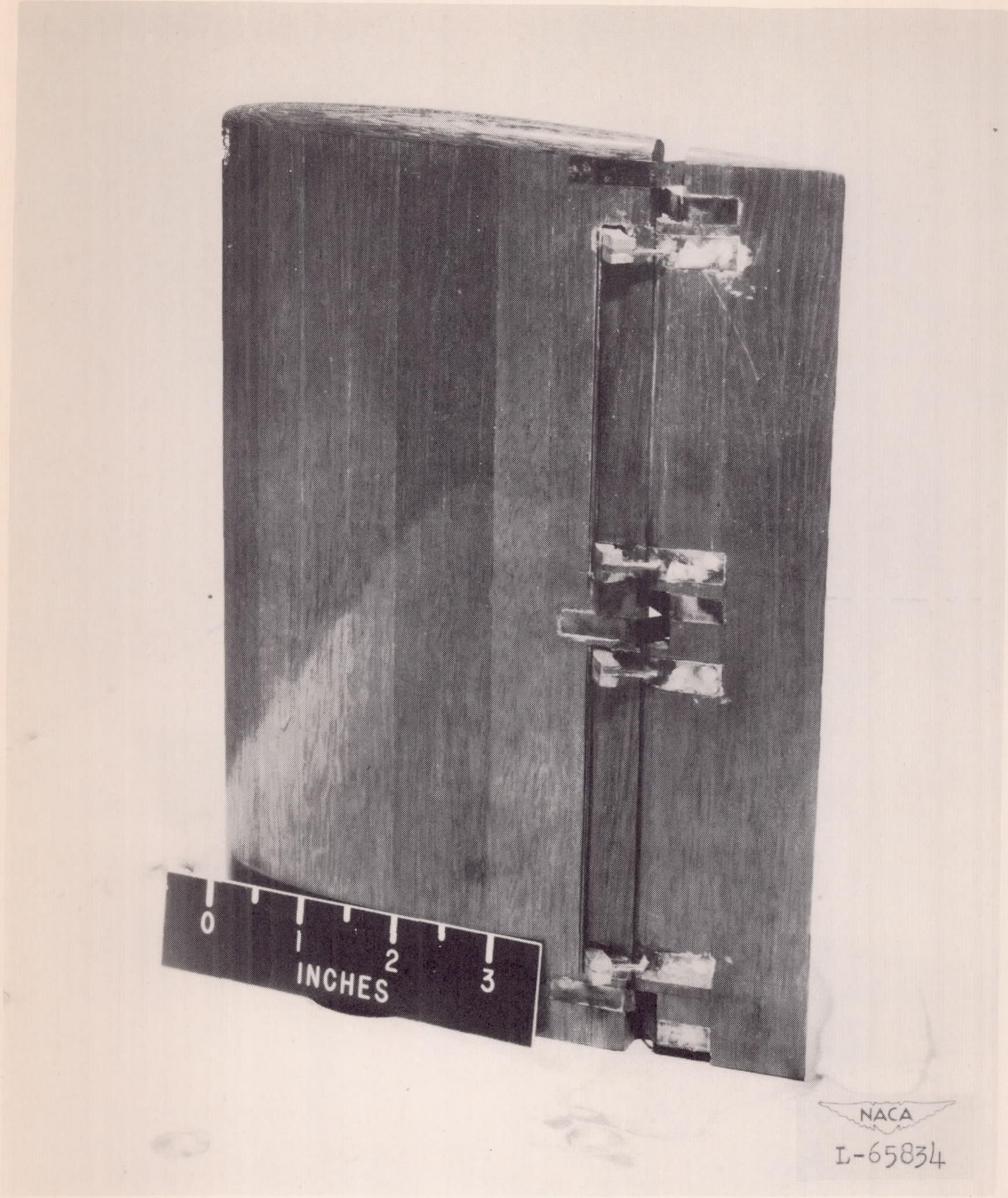


Figure 2.- Photograph of model.

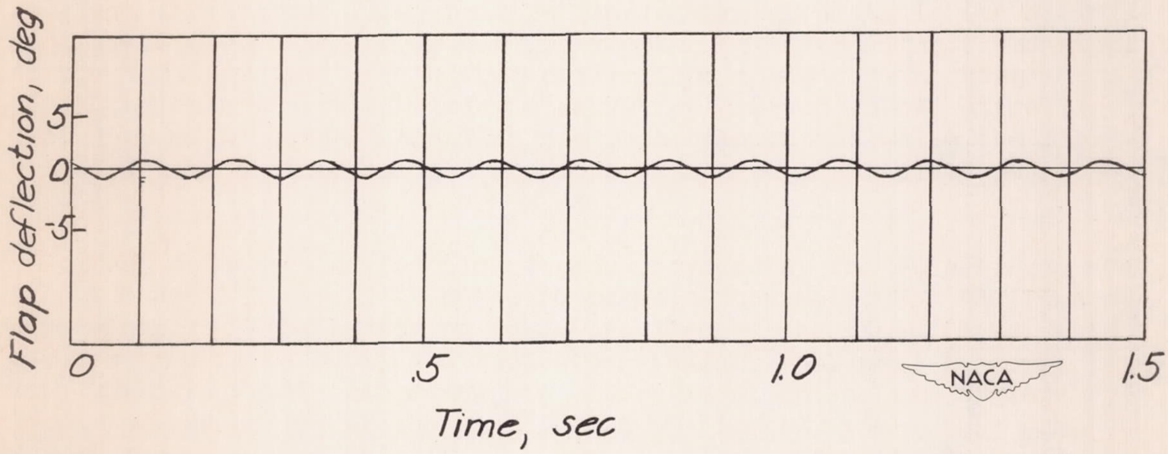


Figure 3.- Record of flap motion at zero airspeed to illustrate the small amount of friction and restoring moment existing in the flap hinges.

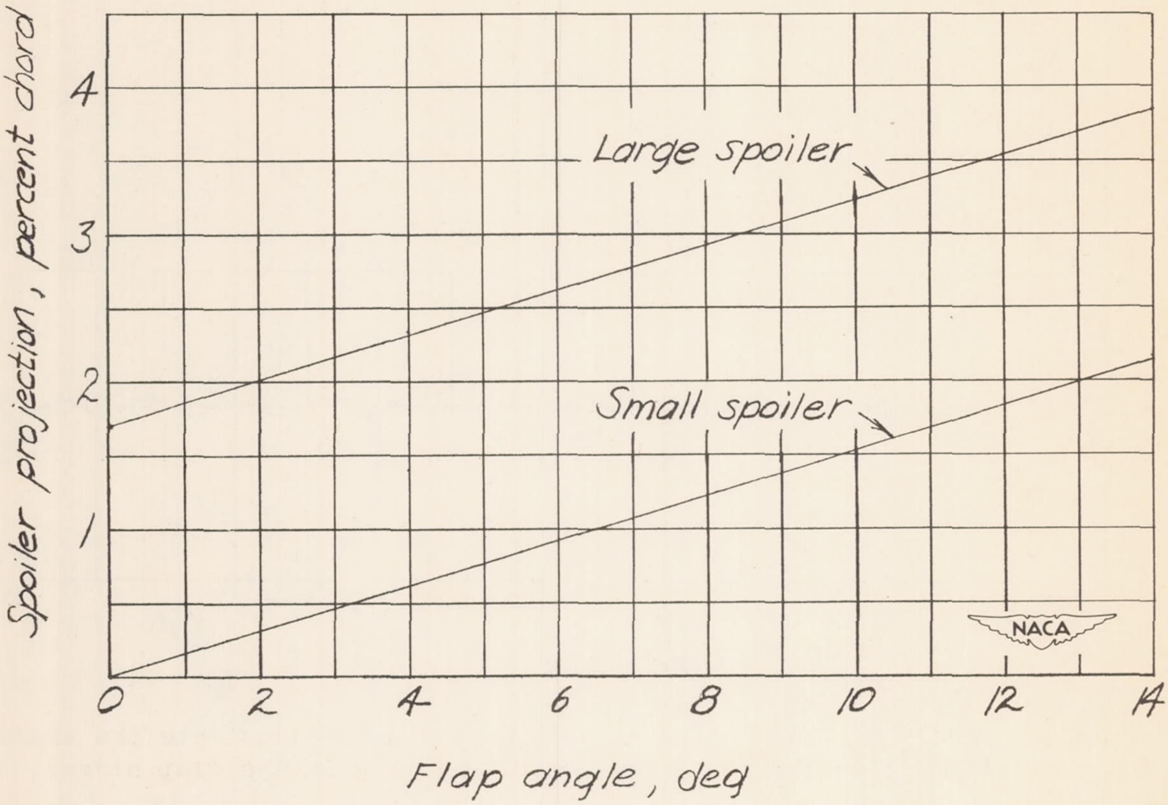


Figure 4.- Variation of spoiler projection with flap angle for two configurations tested.

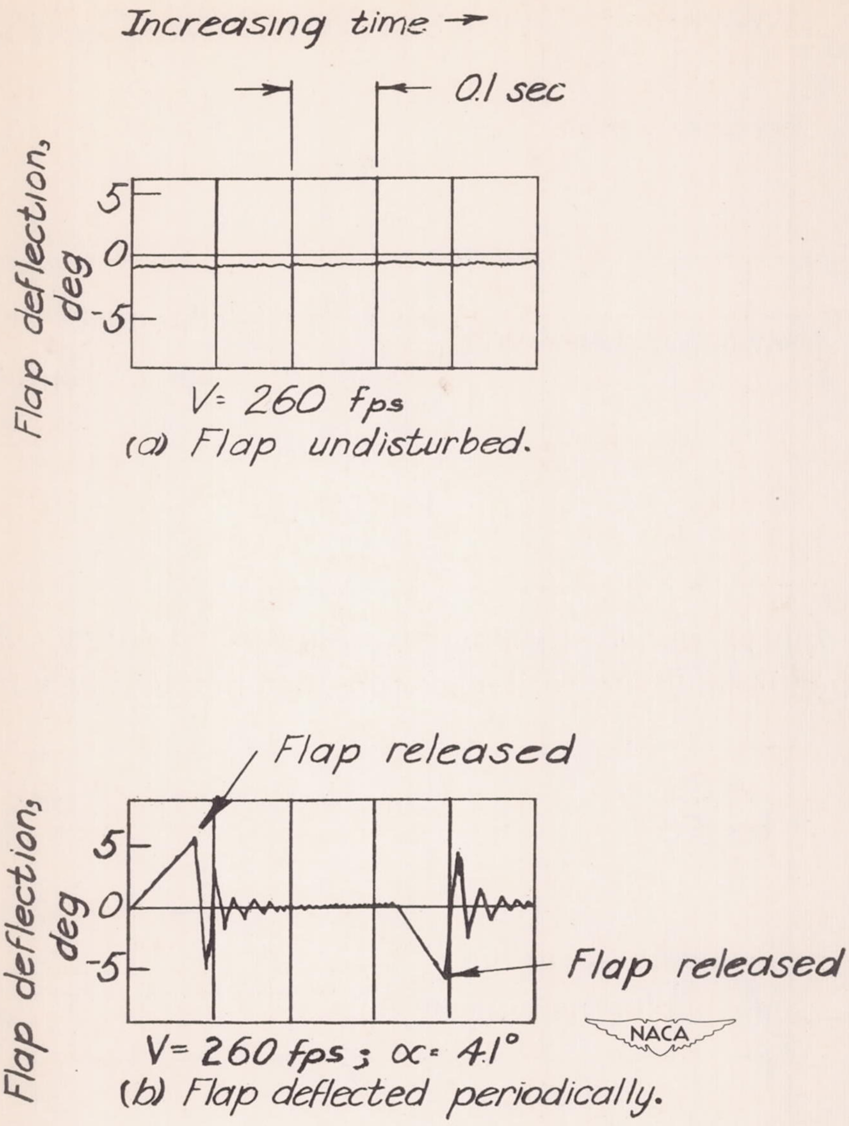
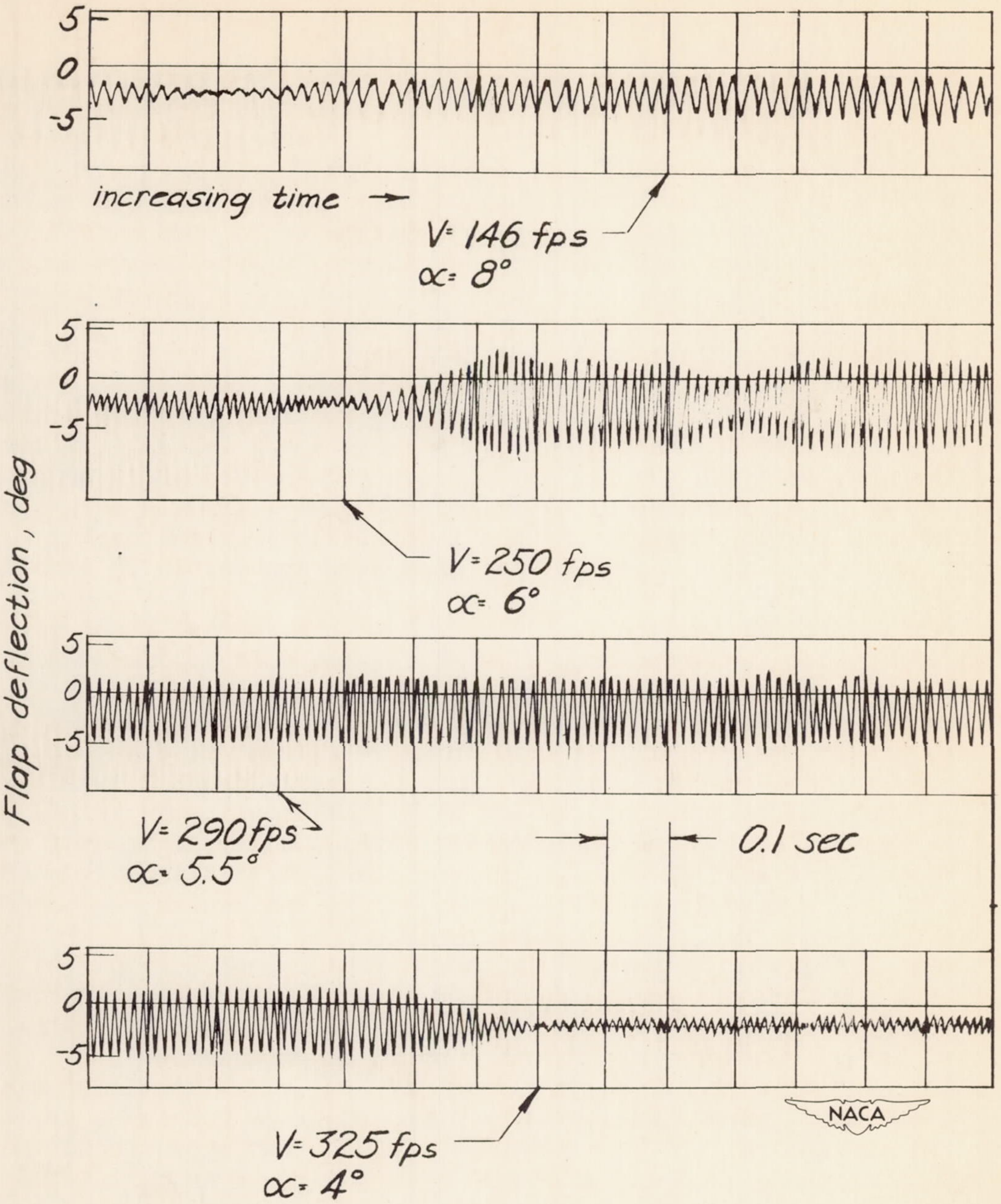
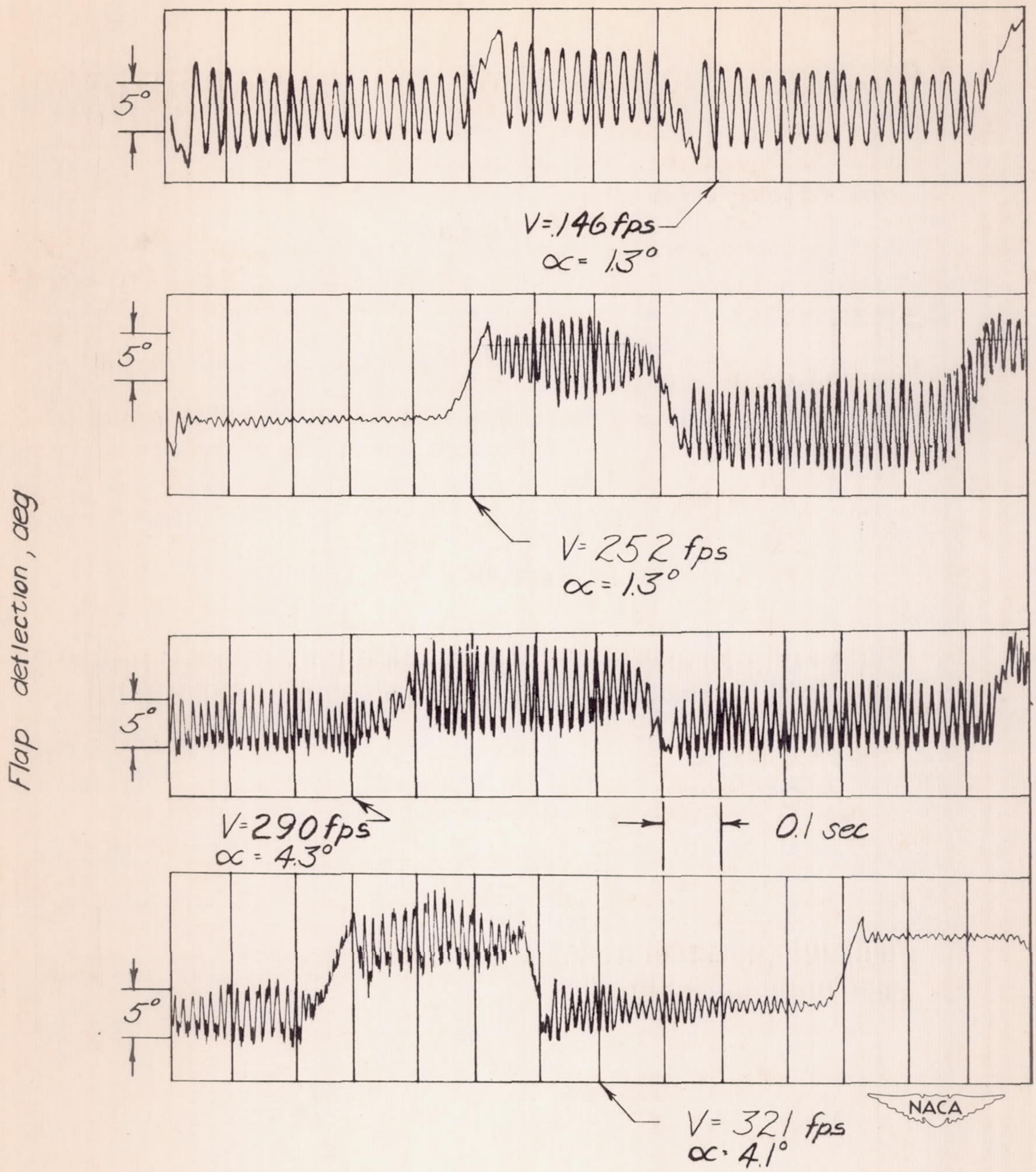


Figure 5.- Typical records of flap motion in flight with spoilers coupled to flap. Zero initial spoiler extension.



(a) Flap undisturbed.

Figure 6.- Records of flap motion in flight with spoilers coupled to flap. Initial spoiler extension of 1.7 percent chord.



(b) Flap deflected periodically.

Figure 6.- Concluded.

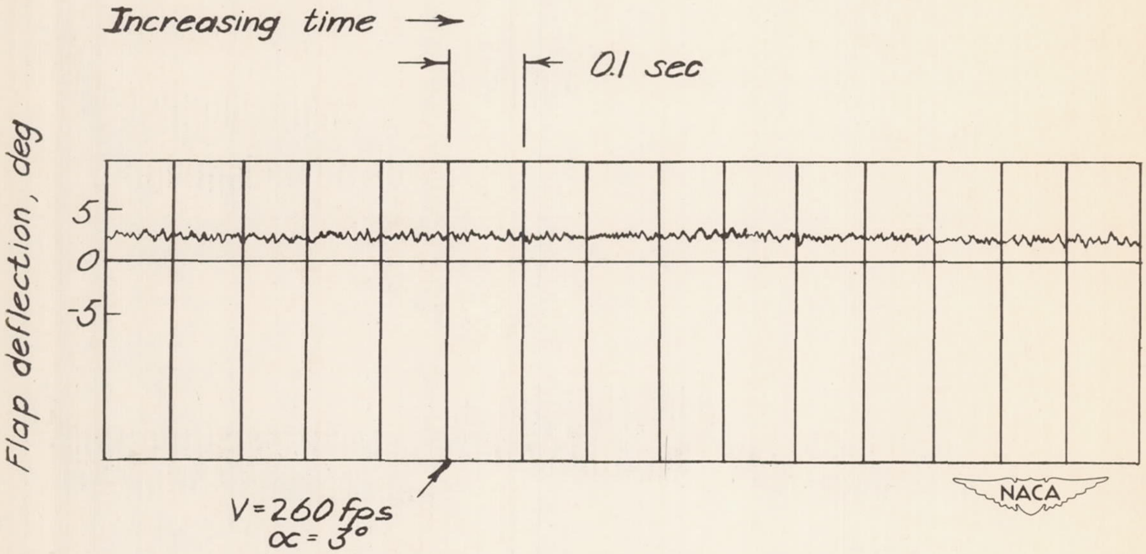


Figure 7.- Typical record of flap motion in flight with fixed spoiler. Spoiler extension of 1.7 percent chord.