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RESEARCH MEMORANDUM

SOME OBSERVATIONS ON STALL FLUTTER AND BUFFETING

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An attempt is made to describe the phenomenological differences between stall flutter and buffeting. Some experimental results are presented concerning both the boundaries at which these phenomena occur and the stresses involved.

INTRODUCTION

Manufacturers of propellers and turbines have been concerned with the problem of stall flutter for some time. Airframe manufacturers, on the other hand, have found that the vibrations associated with a related phenomena, buffeting, are of more importance in the design of wings. Recently, however, due to the trend toward thin wing sections and large masses attached to the wings, airframe designers have also become concerned about the problem of stall flutter.

DISCUSSION

Some of the concern about stall flutter arises because of the fact that stall flutter and buffeting sometimes occur under similar conditions. Both types of vibrations may occur at the same time in a manner which prevents their isolation into two separate phenomena. Usually, however, this is not the case for simple wing models and the two types of vibration can be studied more or less independently. Figure 1 has been prepared to illustrate this less complicated case. This figure shows the boundaries for stall flutter and buffeting for a simple cantilever wing model tested in the Langley 2- by 4-foot flutter research tunnel. The boundaries are shown as functions of angle of attack and Mach number. These boundaries are not necessarily general but, rather, are typical of some boundaries found for this particular wing model.

Since the wing was buffeting at all angles above the buffet boundary shown in figure 1, the question arises as to just how the stall flutter boundary was established. This may be explained by examination of figure 2. This figure shows the time histories of the bending and torsion strains for two typical conditions. The upper set of conditions apply to a case of buffeting below the stall flutter boundary. These traces indicate the type of buffeting which is most commonly encountered, that is, a more or less random bending response in the fundamental bending mode with very little excitation of the torsion. The lower set of time histories at a slightly higher angle of attack shows about the same type of bending trace but the torsion trace indicates a fairly clean sinusoidal variation at about the frequency of the fundamental torsion mode. The stall flutter boundary is defined by the conditions which first produce this steady oscillation.

In the low Mach number region (see fig. 1), where the two phenomena occurred at different angles of attack, no difficulty was experienced in distinguishing between them. In the region near $M = 0.6$, however, where the boundaries tend to coincide, it becomes more difficult to define the basic character of the vibrations.

The problem of predicting the stresses associated with these separated flow vibrations has received considerable interest. Recently, for instance, Liepmann (ref. 1) has applied the methods of power spectral analysis to a relatively simple case of buffeting, namely, the response of a tail surface subjected to the wake of a stalled wing. It is hoped that these powerful methods can be extended to the more general case of a wing excited by forces which originate because of the instability of flow on the wing itself. However, there is a need for additional knowledge of the basic nature of the forces acting on stalled wings before the response of even a simple cantilever wing can be successfully calculated; for example, the question arises as to what extent the air forces may be considered linear. Sisto (ref. 2) has concluded that a nonlinear approach is essential in order to predict the response due to stall flutter of turbine blades in cascade. It is possible that the nonlinear aspects of the problem will have to be taken into account in order to predict the loads or stresses involved in wing vibrations due to separated flows.

The problem of predicting the boundaries at which buffeting or stall flutter begins does not appear to be quite as difficult as the prediction of stresses encountered in these phenomena. For instance, the buffet boundaries for moderately thick wings have been successfully calculated empirically (refs. 3 and 4). It has been found that the buffet boundary depends almost entirely on the aerodynamics of the configuration whereas the stall flutter boundary may be altered by changes of structural parameters such as frequency or damping. This difference in behavior may serve as a general definition of buffeting and stall flutter. For the case of simple straight cantilever wings which encounter torsional stall flutter, it has been found (refs. 5 and 6) that satisfactory information concerning the stall-flutter boundary can be obtained from stability equations provided that measured values of the aerodynamic damping momemt are used.

Unfortunately, however, the aerodynamic damping moments for stalled flows depend very much on Reynolds number, Mach number, airfoil shape, mode of vibration, and other parameters so that accumulation of sufficient data to predict the boundaries for arbitrary configurations would be prohibitive. As a result, another approach has been used in order to obtain a rough idea of which configurations may be less susceptible to stall flutter than others. Although these trend studies have not been completed, some of the results of flutter tests of various simple wing models are summarized in figure 3. Most of the wings are thin, highly tapered, and of low aspect ratio in keeping with present design trends.

The column on the left in figure 3 illustrates the basic wing configurations followed by columns listing the aspect ratio, taper ratio, and airfoil thickness. The fifth column indicates the maximum Mach number of the tests and the last column indicates whether the configuration exhibited a stall-flutter region in the range of conditions over which it was tested. All the wings were tested up to angles of attack well beyond the angle of maximum lift.

The two delta wings - actually there were five structurally different models - exhibited no stall flutter until the stiffness was reduced to the point where they were more or less of academic interest because of their poor load-carrying ability.

The unswept wing had flutter characteristics similar to those reported in reference 6. The two aspect-ratio-4 swept wings did not experience stall flutter. It should be pointed out that all three of the wings of this aspect-ratio-4, taper-ratio-0.2 series were somewhat stronger than conventional design procedures would have required. Wing models of more representative stiffness properties remain to be tested.

The last configuration shown exhibited regions of stall flutter which seemed to be closely associated with the regions of leading-edge vortex flow. Some of the flutter characteristics of this configuration are illustrated in figure 4. In this figure, the stall-flutter boundaries for the 45° swept wing are shown as functions of Mach number and angle of attack. This configuration was originally a part of a general stability research program being conducted in the Langley high-speed 7- by 10-foot tunnel.

With the wing in the clean condition the large region of flutter shown in figure 4 was found. Analysis of the aerodynamic coefficients for this configuration (ref. 7) indicated that the flutter region coincided very closely with the regions in which leading-edge vortex flow existed. Consequently, the wing was equipped with a leading-edge notch; devices of this type were originated by Mr. Joseph Weil of the Langley high-speed 7- by 10-foot tunnel as a means of controlling the flow at the leading edge of the wing. The stall-flutter region was then obtained for this condition. With one leading-edge notch on each wing panel at 60 percent of the semispan, the small region of flutter shown in figure 4 was found. When the wing was equipped with an additional notch at about 80 percent of the semispan, no flutter was encountered up to the test limits of Mach number and angle of attack. The notch size is considerably exaggerated in figure 4. The actual notches used in the experiments were about 1 percent of the span in the spanwise direction and about 3 percent of the local chord in the chordwise direction.

All the preceding discussion has been concerned with separated flow vibrations which involve essentially one mode - stall flutter in the first torsion mode and buffeting in the first bending mode. These are the most common types encountered on simple wing models; however, it should not be concluded that these are the only important types of separated flow vibrations. When the effect of large external masses is considered the system cannot be regarded as a single-degree-of-freedom system, which excludes coupling effects. This point may be illustrated by examination of some data obtained on a dynamic flutter model of an unswept-wing fighter-type airplane. This model was tested in the Langley 16-foot transonic tunnel. Some of the results are illustrated in figure 5, which shows the variation of bending and torsion stresses with angle of attack at a Mach number of 0.35 for the condition of a lightly loaded tip tank. For this condition the bending and torsion frequencies were well-separated $(f_h/f_\alpha = 0.5)$ and there was little coupling between the two modes of vibration. As a result the wing responded, qualitatively, at least, in a manner which might be expected from previous observations of simpler models. That is, the maximum fluctuating peak-to-peak bending stress (referred to as Δ bending in the figure) rose gradually as the angle of attack was increased beyond the point where separation began, this point being deduced from the curve of the mean root bending stress. The peak-to-peak torsion stress (referred to as Δ torsion in the figure) rose rapidly to a high value over a narrow range of angle of attack. The time histories of the stresses indicated that the wing in the region beyond $\alpha \approx 10^\circ$ was buffeting in predominantly the first bending mode and that the large amplitudes of first-mode torsion at $\alpha \approx 9^\circ$ were due to a near approach to torsion stall flutter.

Perhaps the smallness of the range of angle of attack over which the torsion stresses were large can be better interpreted by examination of figure 6. This figure shows the contours of unstable-damping-moment coefficients as functions of angle of attack and reduced velocity. These data apply to a two-dimensional, symmetrical, 10-percent-thick airfoil oscillated in pitch about the midchord line with an amplitude of 1.2° and were obtained by a pressure-cell technique. The solid lines in figure 6 indicate the boundaries for zero aerodynamic damping and the dashed lines above the lower boundary indicate increasing values of unstable-damping-moment coefficients.

Although the conditions applying to these damping measurements are not sufficiently similar to those applying to the flexible model to allow reliable quantitative calculations of the torsion response, certain qualitative features can be obtained by comparison. If the dynamic model had zero structural damping it would have been expected to experience torsion flutter over a wide range of angle of attack and velocity. Inasmuch as the model had some damping, the stall-flutter boundary might resemble one of the closed contours shown in figure 6. As the angle of attack increased at a substantially constant value of reduced velocity, the flexible wing model to which figure 5 pertains is believed to have passed near or through the left boundary of a contour similar to those shown in figure 6. Over the small angle-of-attack range near $\alpha = 9^{\circ}$, the total damping in the torsion mode must have been very near zero, so that a large torsional response was obtained. Apparently, the damping in the first bending mode remained moderate so that only a moderate amount of bending response was excited by the flow separation.

When the mass in the tank was increased to the equivalent of 66 percent full, the response characteristics were changed appreciably and are illustrated in figure 7. The data on the left side of the figure refer to the condition of the center of gravity of the tip tank at the elastic axis of the wing. This condition has been labeled "neutral c.g. location" and applies to the lightweight condition of figure 5 as well. The data on the right refer to a center-of-gravity position somewhat forward of the elastic axis.

For the neutral c.g. case, the addition of the mass to the tank increased the fluctuating bending stresses while the torsional stresses were reduced. Presumably, this was caused by the changes in effective damping in the two modes associated with the reduction in frequencies. When the center of gravity was shifted forward, causing a large mass unbalance, both the torsion and bending stresses were increased appreciably, and in the range of angle of attack near $\alpha = 10.5^{\circ}$, there were short periods when the bending and torsion time histories indicated a coupled-flutter condition. It may be recalled that normally a forward movement of the center of gravity produces a stabilizing effect. However, it appears that for this case of separated flows this type of coupling created an instability. This possibility is discussed qualitatively by Schallenkamp (ref. 8).

Again, the question arises as to whether these vibrations should be called buffet or stall flutter. In the light of the preceding discussion the following definitions suggest themselves:

When the point is reached where the boundary-layer separation becomes unstable there is a continuous excitation of the structure by the aerodynamic forces caused by this separation. The amount the structure responds to this continuous excitation is determined primarily by the damping forces or moments acting on the system. If this damping is very near zero or negative, so that very large and fairly steady responses are obtained, then the vibration may be referred to as stall flutter. If the damping remains positive so that intermittent and somewhat random responses are encountered, then the vibration may be called buffeting.

It would have been desirable to obtain similar information at higher Mach numbers; however, this was not possible because of the stress limitations in the model. Tests were conducted up to a lift coefficient of about 0.2 over a Mach number range from 0.7 to 0.85. The results obtained indicated just the opposite trend from that shown in figures 5 and 7. There was a slight decrease in stresses with increased mass in the tip tank and there was virtually no effect observed when the mass was shifted to the forward position.

CONCLUDING REMARKS

In this paper an attempt has been made to describe the phenomenological differences between stall flutter and buffeting. Some experimental results have been presented concerning both the boundaries at which these phenomena occur and the stresses involved. These results demonstrate the difficulties that may be encountered in attempting to draw conclusions concerning structural vibrations associated with separated flow on the basis of insufficient information.

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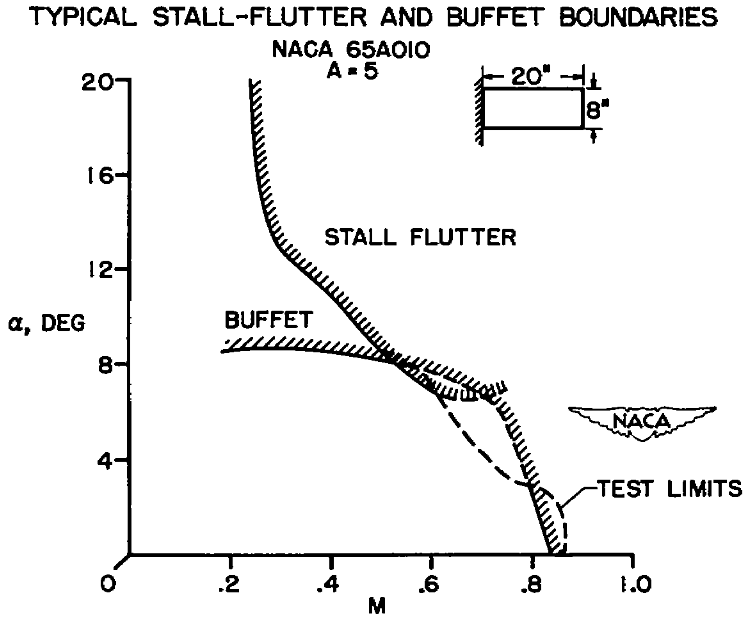

Figure 1.

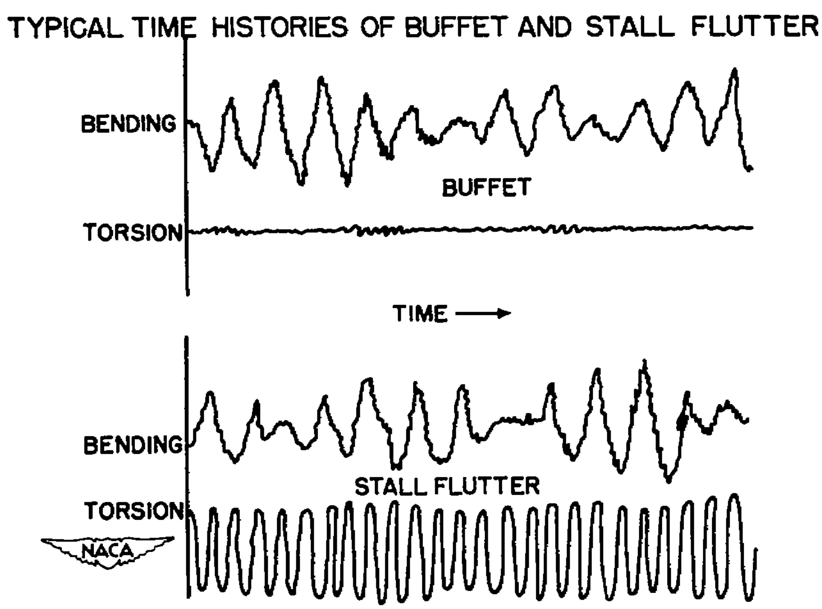

Figure 2.

SUMMARY OF STALL-FLUTTER TREND STUDIES

CONFIGURATION	ASPECT RATIO	TAPER RATIO	THICKNESS RATIO	M_{MAX}	STALL FLUTTER?
45° DELTA	4	0	0.04	0.7	NO
60° DELTA	2.3	0	.04	.7	NO
$\Lambda = 0°$	4	.2	.04	.7	YES
$\Lambda = 45°$	4	.2	.04	.7	NO
$\Lambda = 60°$	4	.2	.04	.7	NO
$\Lambda = 45°$	6	.6	.06	.93	YES

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Figure 3.

STALL-FLUTTER BOUNDARIES FOR 45° SWEPT WING

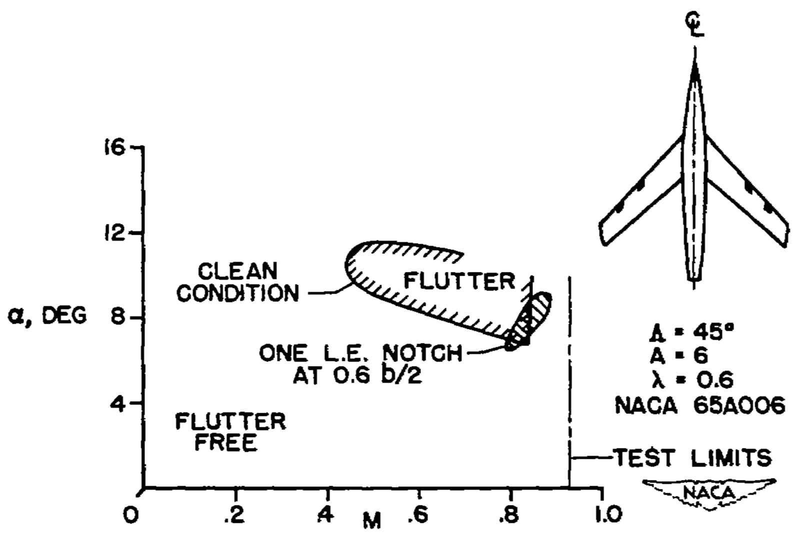

Figure 4.

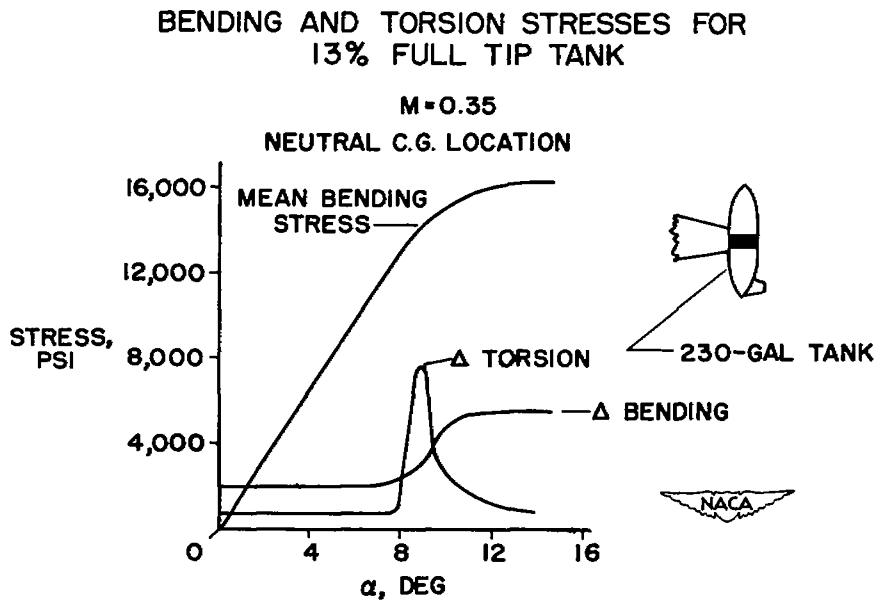

Figure 5.

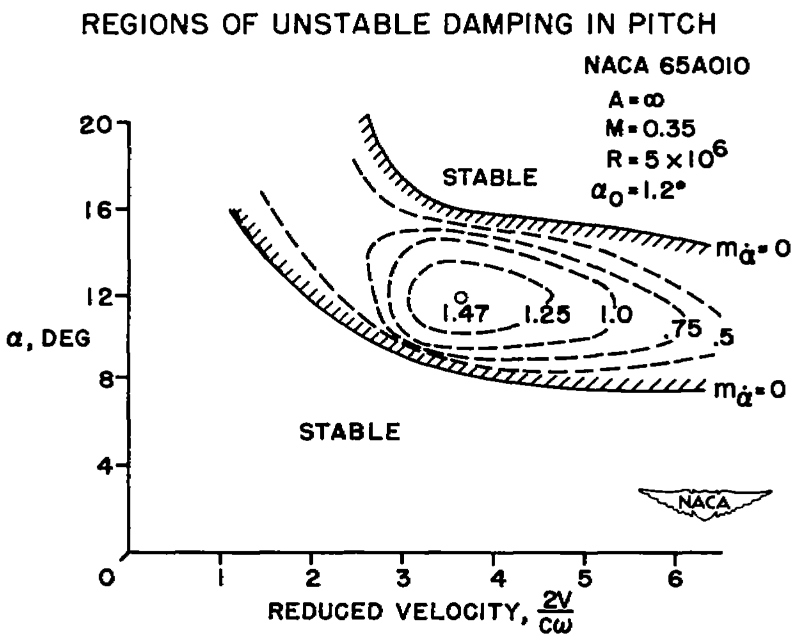

Figure 6.

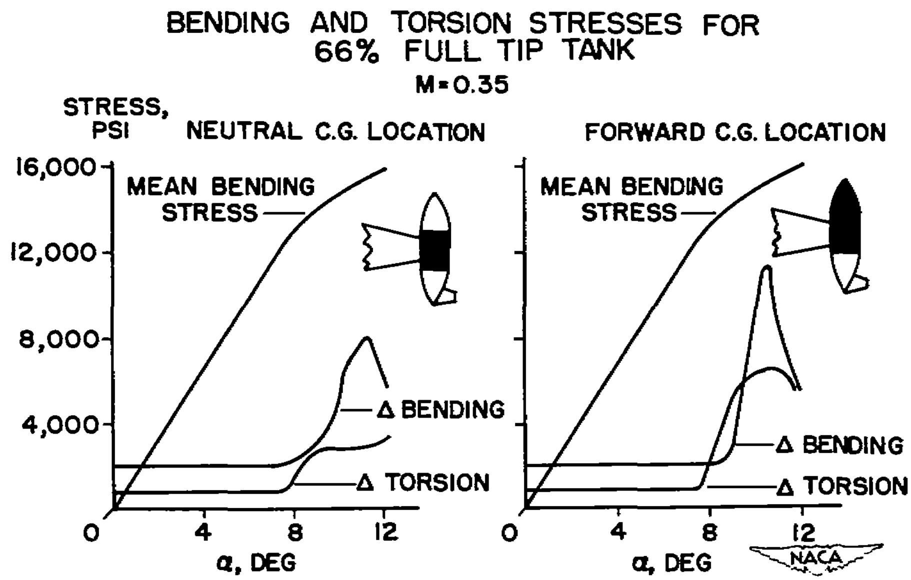

Figure 7.

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