AEROELASTICITY AND LOADS

by

7- BY 10-FOOT WIND TUNNEL

In the past the aerodynamic and structural characteristics of an airplane have been considered more or less independently, except, of course, for the problem of determining the air loads imposed in flight. With present-day flight speeds, however, the two subjects can no longer be considered independently. The air loads associated with high speed have become so great that the resultant structural deformations seriously change the original aerodynamic characteristics of the undistorted structure. This interaction between the aerodynamic forces and structural deformations of an airplane has resulted in a field of investigation termed "aeroelasticity." As you know, certain phases of aeroelasticity such as the problems of flutter have affected airplane design for many years. Designers have also found it necessary to compensate for the loss of aileron effectiveness resulting from wing twist. However, other aeroelastic effects have not greatly influenced design procedures in the past for reasons which will now be illustrated.

Measurements have been made of the loads and structural deformations for a jet-powered bomber with a straight wing. (This model is typical of the airplane.) Measurements were made of the elevator twist and the fuselage deflection.

This chart summarizes the measurements for the airplane in steady flight and in turns. On the left the elevator twist is shown as a function of speed for two altitudes. The twist increased with speed but decreased with altitude, and never exceeded 2°.

On the right, the fuselage deflection is shown as a function of the measured tail lift for steady flight and for turning flight. Comparison of the curve for steady flight with that for turning flight where the loads were one and one-half times greater than in steady flight, indicates a downward deflection due to the centrifugal forces acting on the tail and fuselage. Neither the deflection resulting from the action of centrifugal forces nor that resulting from changes of tail lift exceeded one inch. Although these deflections caused some reduction of control effectiveness, they did not seriously impair the handling characteristics of the airplane.

Thus, for the maximum flight speeds attainable in the past, the effects of aeroelasticity have not produced serious stability changes.

The current emphasis on the problems of aeroelasticity is primarily a result of the use of wing sweep as a means for obtaining increased flight speeds. The reason for the detailed consideration of aeroelasticity for swept wings is the significant effect of bending on their aerodynamic characteristics.

Consider for a moment the two models displayed here - one with a straight wing and the other with a swept-back wing. Assume the models to be flying toward the left. If the straight wing is deflected, there is no change in the angle of attack as indicated by the pointer attached to the wing tip. If the swept wing is deflected, the pointer indicates a change, with a lift force causing a reduction of angle of attack. In addition to lift forces, the wing is also subjected to centrifugal forces in turning and maneuvering flight, due to its own weight. These act in opposition to the lift forces and tend to cause an increase in angle of attack near the tip.

For the swept wing, the lift forces are greater than the centrifugal forces and the resultant decrease of angle of attack tends to reduce the load near the tip. This redistribution of air load constitutes the primary effect of aeroelasticity on present-day swept-wing designs. The aeroelastic problems introduced by sweep would not exist, of course, if it were possible to build rigid wings. Such a solution is not practical, however, and since the trend has been toward higher and higher wing loadings, the net result has been airplanes of relatively high flexibility.

The effects of aeroelasticity on the longitudinal stability of an airplane can be illustrated with the aid of this model. If the airplane is stable, a small increase of angle of attack will produce a nose-down moment about the center of gravity tending to restore the airplane to its original angle of attack. However, as previously discussed, the effect of structural deformation of a swept wing is to reduce the air load carried by the wing near the tips. The effect of this load reduction can be simulated by the application of a down load at the wing tip which causes the model to exhibit a pitching-up tendency or a reduction of stability. The action of deformation of the horizontal tail is similar to that for the wing. Bending of a swept-back tail will cause a reduction in load on the tail. Again applying a down load as was done for the wing, it can be seen that a nose-up tendency will occur - so that the effect of tail flexibility will also be destabilizing. Consider next the action of a flexible fuselage. If the airplane is flying at a positive angle of attack, the horizontal tail will carry an up load. This tends to bend the fuselage upward, reducing the angle of attack of the tail, and hence reducing the amount of up load. The reduction of up load will result in a nose-up or destabilizing tendency. It is evident that in extreme cases where the entire airplane is quite flexible, a serious stability problem could exist because the effects of aeroelasticity on the airplane components may be additive.

The manner in which structural deformation affects the longitudinal stability of a swept-wing airplane is shown on the next chart. Here the variation of longitudinal stability with speed is shown for the ideally rigid airplane in turning flight. Also shown are the net effects caused by deformation of the structure due to air loads, and due to centrifugal loads. As can be seen, the deformation resulting from air loads has the more important influence on longitudinal stability and were it not for the alleviating effects resulting from the deformation due to centrifugal loads, the airplane would become unstable. Even so, the over-all effect of structural deformation is a serious reduction of stability at high speeds.

Thus far in our discussion we have concerned ourselves with longitudinal stability. Mr.___________, the next speaker, will now describe some of the effects of aeroelasticity on control.

Second Speaker

The controls normally used in flight are the rudder, elevator, and aileron. The problems associated with these devices will be discussed. In the case of directional control (i.e., control of this motion), rudder operation is actively employed only at low speeds, therefore it is doubted that this control will present a serious problem for most airplanes.

In the case of longitudinal control (control of this motion), the calculated effects of horizontal tail and fuselage flexibility are shown on this chart. Elevator effectiveness is given as a function of speed. For a rigid airplane the elevator effectiveness increases with speed. However, flexibility of the tail alone or of the tail and fuselage in combination reduces the elevator effectiveness to zero at high speeds. As yet, these effects have not become too serious since present-day flight speeds are well below the speeds at which extreme reductions of elevator effectiveness occur as a result of aeroelasticity.

A current problem is that of lateral control (control in this motion), since airplane performance has now reached the point where serious loss in aileron effectiveness can occur on wings of moderate flexibility.

One method of investigating the problem of aileron control in flight is by mounting wings on rocket-powered models. Some typical results obtained by this technique are shown on the next chart for this wing which has full-span ailerons. The curves show the variation in aileron effectiveness with Mach number for a steel wing and a more flexible dural wing. The steel wing is approximately three times as stiff as the dural wing. The reduction in aileron effectiveness due to compressibility of the air at high speeds is approximately the same for both wings. Due to aeroelasticity the more flexible wing has reduced rolling effectiveness. From this point on, the dural wing actually rolls in the wrong direction. For an airplane this situation would result in roll in a direction opposite to that desired by the pilot.

The reason for a reduction of aileron effectiveness due to structural deformation can be explained as follows. Consider an unswept wing with the ailerons deflected to produce a rolling moment. The load on the ailerons will produce a twisting moment along the wing span. This twist causes a change in load opposite to that produced by the ailerons. Therefore, this twist will reduce the rolling effectiveness of the unswept wing. Now consider a swept wing. If the aileron on the swept wing is deflected to produce a rolling moment, the wing will bend, resulting in a change in load on the wing which, together with the twist, acts in opposition to the load produced by aileron deflection. This bending load will decrease the aileron effectiveness even more.

In order to further illustrate the effect of structural deformation on aileron effectiveness of a swept wing, we have prepared a wind-tunnel demonstration. The model for this demonstration consists of a flexible swept-back wing mounted on a body which is free to rotate about its longitudinal axis.

The model is scaled not only in size but also in its flexibility characteristics to represent at these wind-tunnel speeds the action of a swept-wing airplane at high speed.

The model has two sets of ailerons. Conventional ailerons are installed near the wing tip and the second set is mounted in the position normally occupied by landing flaps. The rolling speed of the model is determined solely by the action of the ailerons which we can control from here. To begin the demonstration, the conventional ailerons will be deflected to a given position. The tunnel speed, as indicated by the dial above the window, will be increased to show the rolling effectiveness at various speeds. You will see that the rate of rotation decreases until a tunnel speed is reached at which the ailerons become completely ineffective. The wing will then rotate in the opposite direction against the action of the ailerons. The inboard ailerons will then be deflected to illustrate their effectiveness.

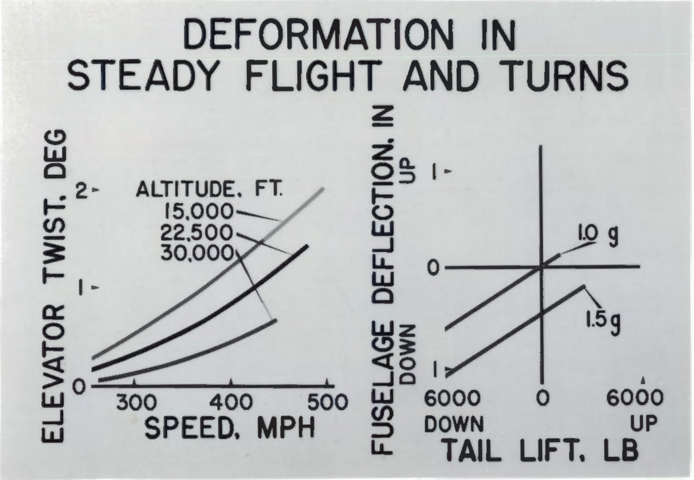
We will now begin the demonstration. Please start the wind tunnel.

We have attempted to show a few of the reasons for the importance of the problems of aeroelasticity in relation to the stability and control of the airplane. An immediate problem is concerned with the aeroelastic effects on lateral control. Inboard ailerons, spoilers, and other controls are currently being investigated by the NACA to minimize the effects of wing flexibility on lateral control. The results of this investigation, used in conjunction with other NACA research results, will provide information from which the designer can choose the most appropriate solution to his particular aircraft design problem.

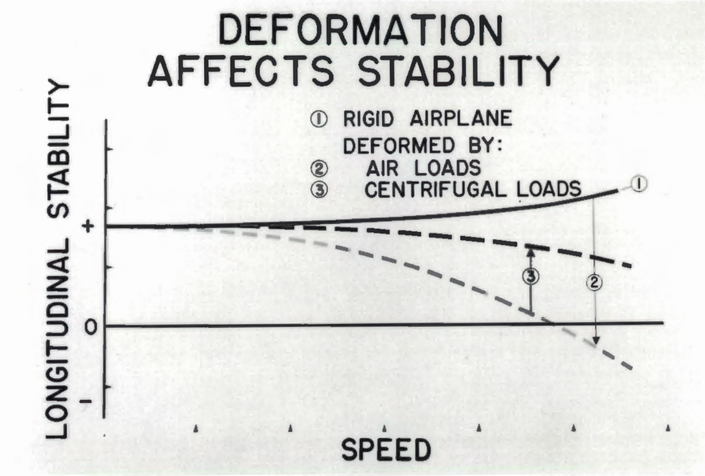
This concludes the presentation at this stop in your tour. I will now turn you over to your group leader.

Display for Presentation of "Aeroelasticity and Loads"
by the 7- by 10-Foot Wind Tunnel

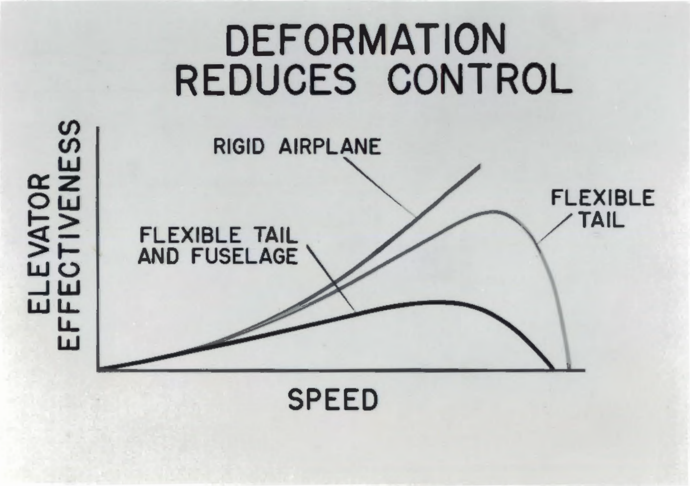
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF.


DEFORMATION IN STEADY FLIGHT AND TURNS

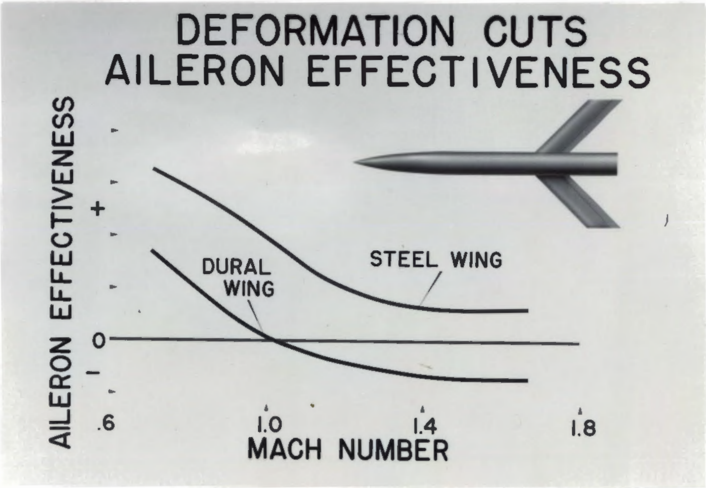
NACA
A-15205-A


DEFORMATION AFFECTS STABILITY

NACA
A-15205-B


DEFORMATION REDUCES CONTROL

NACA
A-15205-C


DEFORMATION CUTS AILERON EFFECTIVENESS

NACA
A-15205-D

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AMES AERONAUTICAL LABORATORY, MOFFETT FIELD, CALIF.