WING FLUTTER INVESTIGATION ON BRADY’S WIND TUNNEL MODEL

(AIRPLANE BRANCH)

Prepared by J. E. Younger
Matériel Division, Air Corps
Wright Field, Dayton, Ohio
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INTRODUCTION

The small flexible wing submitted to the division by the Massachusetts Institute of Technology (see figs. 1 and 2) for wing flutter observations was set up in the McCook Field 5-foot wind tunnel, and a brief investigation was made of the practicability of studying the phenomena of wing flutter by wing tunnel model tests. A number of interesting and significant points were observed in the behavior of the wing and tentative conclusions drawn therefrom concerning the nature and cause of one type of wing flutter, and a mode of procedure suggested for a systematic investigation of the problem whether by model or full scale tests.

The definite response of the model to changes of wind velocity and angle of attack, and the frequency of flutter being always the same as the natural frequency of torsional vibration of the wing, is inclined to convince one that this type of flutter is a phenomena of resonancce, and the tendency to flutter is a definite characteristic of the airfoil section. If the tendency to flutter should prove to be an aerodynamic characteristic, that is, if the frequency of aerodynamic impulses on an airfoil section is a characteristic of the section and depends on the same variables as the lift and drag, and the phenomena is one of resonance, it appears that a practical solution, qualitative at least, may be obtained.

CONSTRUCTION OF THE MODEL

The model wing was constructed by Mr. Brady, a student of Massachusetts Institute of Technology, for a study of wing flutter as the thesis requirement for a higher degree from that institution. After the completion of the study by Mr. Brady, the institute sent the wing to the division for further study.

Structurally, the model was a uniform cantilever Clark-Y airfoil, 21 inches semispan and 7 inches chord. The internal structure was a very clever duplication of the internal structure of a full scale wing. The spars and drag bracing were of steel. The ribs were cut from sheets of thin brass and spaced 1 inch apart. The covering was of parachute silk, stretched taut, glued to the trailing edge, and sewed at the ends.

MOUNTING OF THE MODEL

At the root section the spars terminated inside brass tubes 3/4 inch in diameter and 2 inches long. The remaining space around each spar in its tube was filled with lead, thus holding the spars quite rigidly in position. These two tubes were then soldered to a brass block which was mounted on the spindle of the N. P. L. balances, so as to allow the wing to set vertically in the central portion of the air stream. A glass window in the top of the tunnel allowed observations of the tip of the wing at very close range.

EXPERIMENTAL OBSERVATIONS

The study being of a preliminary nature, only qualitative observations were made. The angle of attack, the velocity, the frequency of flutter, and other data, while observed, were not taken with scientific accuracy. A very definite flutter was obtained which persisted with perfect regularity at an amplitude of about one inch of the trailing edge.

The following general observations were made:

1. The relation between the frequency of flutter and the natural frequency of vibration of the wings.
2. The effect of the magnitude, and change of magnitude, of the angle of attack.
3. The effect of the change of velocity.
4. The effect of a change in the natural frequency of the wing (change in the mass distribution).
5. The effect of a change in the shape of the airfoil.
6. The effect of turbulence in the wind tunnel.
7. The relation between bending and torsional oscillations.

The contour of the airfoil was varied by adding a trailing edge of cellulose acetate dope. To do this, the wing was laid flat on a plate of glass, and successive applications of the dope were made after a thorough drying of the previous application. In this way the streamlined contour was maintained, while an additional length of about 1 inch was added to the chord. The added trailing edge was stiff enough to hold its shape in the air stream, yet flexible and plastic enough to allow bending to any desired position.

The natural frequency of vibration of the airfoil in torsion was varied by the use of lumps of wax attached to a small strip of wood, wired to the tip of the wing parallel to the air stream. The frequency was measured by a small hand-operated stroboscope.

It was noted that:

1. The frequency of flutter was always the same as the natural frequency of torsional oscillations of the airfoil. This frequency for the natural wing was 400 complete vibrations per minute.
2. The bending oscillations appeared to depend entirely on the torsional oscillations, as they were generally of very small amplitude, and of the same frequency as the torsional oscillations, and not of the natural frequency of vibration in bending. When the natural frequency in torsion was made approximately the same as the natural frequency in bending by the use of wax as described above, excessively large oscillations were obtained which would have destroyed the model if they were allowed to persist.
3. The tendency to flutter was quite sensitive to a change in angle of attack. Half a degree change was sufficient to start or stop flutter. For instance, with an angle of attack of -2° and a wind speed of 40 miles per hour the wing fluttered. By changing the angle to -1.5°, keeping the speed constant, the flutter
was stopped. Then by increasing the velocity to 40.5 miles per hour, flutter was again started. Fifteen to twenty observations of this nature were made with the same type of result.

5. Without change in the aerodynamic characteristic of the airfoil, but with a change in the natural frequency of torsional oscillations, the airfoil would not flutter at the same combination of angle of attack and velocity. In other words, it appears that for a given angle of attack the velocity at which flutter occurs depends on the structural rigidity and distribution of mass; that is, upon the natural frequency.

6. An increase in camber, by depressing the dope trailing edge, lowered the velocity for a given angle of attack at which flutter occurred. For an angle of attack of about 0°, flutter occurred at about 30 miles per hour. By elevating the trailing edge so as to give a reverse camber, flutter could be prevented for velocities up to about 60 miles per hour at the same angle of attack. No higher velocities were tried for fear of rupturing the wing. It appears that this may have some bearing on the setting of an aliron in a wing which develops flutter.

7. The twist of the wing, tending to decrease the angle of attack, due to the torsional moment obviously lowered the velocity at which flutter occurred. In fact, it appeared that the tip of the airfoil always twisted to the angle of zero lift before flutter started, but it appears from later observations described in (5) above, that the tip would twist to no definite angle to start flutter.

8. It was thought that the instability of the center of pressure at small angles may be responsible for the flutter, but since for any angle of attack at which instability occurs, by simply changing the mass or structural rigidity of the wing, the apparent instability could be eliminated, it appears that the center of pressure travel does not, at least, control the flutter to any great extent.

DISCUSSION

It is not an advisable policy to draw conclusions from so meager a set of data, but the fact that flutter always occurred in the same natural frequency of torsional oscillations of the airfoil and that a change of natural frequency changed the velocity at which flutter occurred for a given angle of attack, together with the fact that flutter could be started or stopped at will by a change of the velocity or angle, makes it appear that this type of wing flutter is a phenomena of resonance between the natural frequency of torsional oscillations and aerodynamic impulses, the frequency of which is a characteristic of the airfoil section.

While certain mathematical analyses have served to point out the salient features of wing flutter, one is inclined to inquire whether, like the original problem of lift and drag, and later the problems of torsional moment and travel of the center of pressure, the solution may not be found in the systematic tabulation of data. The later attempts at the solution from a mathematical standpoint involve the use of tabulated data in the form of characteristic airfoil curves. It will be recalled that these solutions, in general, involve two major characteristics in setting up the differential equations, that of the structural rigidity and that of aerodynamic forces. The fundamental operation involved is that of determining the criteria for flutter, the criteria being certain relations between structural and aerodynamic quantities which augment the amplitude of vibrations. One is inclined to inquire, since the aerodynamic impulse terms are taken from the characteristic curves, why they could not be determined directly from experiments on the same lift and drag model. In other words, if the frequency of aerodynamic impulses is a function of the angle of attack, the velocity and other quantities on which the lift and drag depend, it appears that we should be able to determine this characteristic directly from experiments on the lift and drag model and the results plotted against angle of attack.

In the same manner that the fundamental resistance equation,

\[ R = K \sqrt{\frac{\rho A V^2}{\mu}} \left( \frac{\rho VL}{\mu} \right) \]

is derived by the principle of fundamental dimensions, it can be shown that

\[ F = \left( K_L \right) \left( \frac{\rho VL}{\mu} \right) \]

in which \( F \) is the frequency of aerodynamic impulses and \( f \left( \frac{\rho VL}{\mu} \right) \) is the Reynold's number. While this derivation is open to criticism, it may, at least, afford a starting point for systematic investigation, just as did the general resistance equation afford a starting point for the systematic investigation of the chief characteristics of airfoils.

The principle of resonance could be made use of in measuring the frequency of aerodynamic impulses. The original lift and drag model mounted on a rod of variable torsional stiffness, and properly calibrated for natural frequencies would detect the slightest periodic impulses.

The application and limitation of the equation need not be discussed, since they are the same as for the general resistance equation. Bearing in mind, however, that the problem of flutter probably involves the frequency of formation of tip vortices, trailing edge vortices, and other disturbances due largely to viscosity, it would not be surprising if data of this nature taken from wind tunnel experiments be found more unreliable than the standard data of lift and drag found from model experiments. If qualitative observations only are made, it is quite probable that all that can be accomplished is to confirm data already obtained, that is, that the tendency to flutter (in standard air) depends on:

(a) The velocity.
(b) The angle of attack. A decrease in angle of attack tends to make the airfoil flutter at a lower velocity.
(c) A change in airfoil section, such as the change in camber. From a standpoint of efficiency it probably would not be practical to change the airfoil section sufficiently to materially alter the tendency to flutter. In general, it appears that an increase in camber tends to lower the velocity at which flutter occurs.
(d) The tendency of the wing to twist due to the aerodynamic moment decreasing the angle of attack has a decided effect in lowering the velocity at which
flutter occurs. This phase of the problem will require considerable attention before design prediction can be made.

From a structural standpoint it is fairly obvious that:
(a) An increase in rigidity of the structure increases the velocity required to start flutter.
(b) A large moment of inertia of wing section decreases the velocity required to start flutter.
(c) The location of the elastic axis to coincide with the center of gravity of the section minimizes flutter.

Thus, if resonance is the criterion for flutter, a development of wing flutter would indicate one or more of the following:
(a) A change in airfoil section, such as a readjustment of the setting of the aileron, intentionally or due to a strain, so as to effectively increase the camber.
(b) A decrease in the rigidity of the structure, such as involves the breakage of a member in the wing itself, the fuselage, or the opposite wing.
(c) A decrease in the effective angular setting of the wing tip due to aerodynamic torsion, breakage of a member, or a particular maneuver involving a disadvantageous setting of the aileron.

CONCLUSIONS

It appears that the fundamental underlying causes, not only of the type herein discussed, but also of other types, should receive a more thorough investigation both theoretically and experimentally. Particularly the phenomena of resonance as involves the periodic impulses of the engine, propeller, machine gun, tip vortices, trailing edge vortices, and other impulses known to exist or which may be found to exist, should be studied. With the fundamental principles well understood, a program of systematic investigation of the factors involved by any means available, would be in order.