Physical Research Lab

(PRD)

Flutter Survey for May 1949 Inspection

Flutter is a dynamic aeroelastic problem, which considers the interaction of aerodynamic and elastic forces, and in a certain sense it contains most of the other aeroelastic problems, as for example control reversal and wing divergence. It is concerned with a study of the circumstances whereby a component of aircraft can extract energy from the surrounding airstream to an extent causing distortion or destruction.

As representative of some of our work on flutter we will briefly mention a few items, in which we have attempted to separate and study primary parameters, and will discuss these with the aid of some charts.

Wing Flutter Trends Chart

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This chart indicates some of the trends regarding bending-torsion wing flutter in an important range of Mach numbers. The abscissa is the Mach number and the ordinate, flutter speed ratio, is the flutter speed divided by a reference speed - the reference speed being proportional to the chord and to the torsional frequency and calculated by theory for incompressible 2-dimensional flow. This part of the curve (M below .7) has been confirmed by theory and by wind-tunnel experiments. This part of the curve ($M > 1.1$) has been studied partly by theory and by experiments with freely-falling bodies and in our small supersonic tunnel. This part (near sonic) is an extrapolation of results of theory for high subsonic and for low supersonic speeds and has been largely studied experimentally with the aid of rocket-vehicles and dropped bodies.

On this chart straight lines radiating from the origin represent lines of constant torsional stiffness, the value of the stiffness being greater for the smaller slopes or angles. The intersection of such a line with the representative flutter curve shows the speed at which flutter may begin for any assumed design. For the unswept wing the slope of the line of tangency, from the origin to the black curve, represents the critical design stiffness required to avoid wing flutter, since no intersections with this curve occur for lines of still smaller slope. This work has demonstrated the existence of such design critical values for unswept wings of representative center-of-gravity locations shown.

However, there are less normal combinations of wing parameters which may put the design critical values into the supersonic speed range. For the 60° swept wing, shown on the chart in green, this is the case, for the stiffness sufficient for the 0° wing is not enough for the 60° wing and apparently the critical point of tengency is pushed well into the range of supersonic speeds. A large expenditure of research effort is still needed for these high speed-range studies.

With reference to our techniques for these studies we may mention the telemetering developments which have resulted in many excellent records of the frequency and amplitude messages of the wing as it approaches flutter. Of interest also are the techniques required for the supersonic wind-tunnel work. Our tunnel is of an intermittent type and make use of the large sphere outside this building as an evacuation chamber. The models could be inserted or withdrawn from the stream by an hydraulically operated piston, thus avoiding the transient range of tunnel speeds. Confirming the results indicated on the chart it was found necessary for the unswept wings to avoid the transient speed range, while for the 60° swept wing this was not necessary.

Pitching-Bending Flutter Chart

In our experiments on flutter with the aid of rocket vehicles we have occasioned some failures which appeared to involve a significant amount of pitching or porpoising of the whole missile and bending of the wing. It has long been suspected, without experimental substantiation, that the type of free-body (or rigid-body) modes which are employed in discussions of airplane stability may also enter significantly into flutter, interacting with modes involving structural deformations. The stability modes usually imply low frequencies, the structural modes usually high frequencies. Theoretical analysis of some of the failures experienced has confirmed our views of the possible interaction of these modes. We have had some failures which occurred in essentially the two modes pitching and bending.

The curves on the chart are calculated by analysis and the ordinates represent the flutter speed and flutter frequency for a definite body-wing configuration, and are plotted against as abscissa the nondimensional moment of inertia of the body-wing combination. The upper point represents the experimental flutter speed for one of the rocket missiles that fluttered to destruction, the abscissa of the point being at the measured value of the moment of inertia factor. The lower point (in green) is correspondingly the flutter frequency. Note from the right hand scale (where ω_h is the bending frequency) that the undamped oscillations began in this case with a frequency about $\frac{1}{4}$ the bending frequency. This work is a forerunner of other flutter research employing free-body modes, which may have special significance for swept wings, tailless designs and missile arrangements.

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Effect of Sweep Chart

Recently we have modified the theoretical analysis for oscillating wings to include aerodynamic effects of sweep. This analysis also considered some effects of structural deformations as for example, the fact that the bending deflections for swept wings enter into the angle of attack. This chart shows a comparison of the experimentally determined flutter speeds and results of calculations using the analysis. The experiments shown by points in this case were made with a rotated model of length-to-chord ratio 6. Such good agreement with calculations is gratifying, but in view of the neglect of aerodynamic effects of aspect ratio, is not to be expected in general. It should also be noted that the increase shown in the flutter speed ratio with angle of sweep is valid for certain representative ranges of the wing parameters. For other, less common ranges, for example, with the section centers-of-gravity located forward near the $\frac{1}{4}$ chord position, the flutter speed ratio may actually decrease with angle of sweep.

Appraisal of Methods Chart

The question of margins of safety in flutter is an extremely important one. Knowledge of actual margins of safety depends greatly (among many other things) on the accuracy of the methods of analysis. An experimental flutter investigation of wings with concentrated weights furnished a basis for comparison and appraisal of some methods of analysis.

One method - a differential equation one - considers the wing as a continuous structure - with infinitely many degrees of freedom. Using theoretical two-dimensional oscillating air forces and applying this method to a uniform cantilever wing with the weight located in forward position as shown, this dashed curve is obtained where the abscissa is the spanwise location of the weight. The green points represent the experimental flutter speeds for this case. Note that no flutter is obtained in this span range where wing divergence intervened.

The differential equation method however is too tedious and difficult for an actual wing. In view of the agreement, indicating that both the structural and aerodynamic phases of the analysis are satisfactorily included, the opportunity was taken to appraise a method employing a few selected modes, a method commonly used in industry.

For locations of the weight involving small mass coupling (e.g.wt. near elastic axis) both methods and the experiment are in satisfactory agreement even employing only 2 modes. However, for larger mass coupling as in the chart 2 modes indicated no flutter at all beyond this (25%) span position. Inclusion of additional modes in the analysis improves the comparison. However, for some span positions, the result is numerically inaccurate and moreover on the dangerous, unconservative side - that is above the actual flutter speed. For large masses located behind the elastic axis, numerically inaccurate flutter speeds were calculated if only a few modes were included, but these results were on the conservative side (i.e. below experiment)

This work on appraisal of methods of analysis indicates that calculated margins of safety depend on the configurations as well as in the method of analysis and in particular care must be taken to include enough modes in the analysis especially for highly coupled masses located in forward positions.

Sweep and Weight Position Chart

The experimental part of the work just described on unswept wings was initiated about the time of our last Langley inspection (1947). We are now attempting a similar investigation including effects of sweep. The ordinate is the experimental flutter speed and the abscissa is again the spanwise position of the concentrated weight. The chart again refers to a forward location of the weight. Each curve represents one angle of sweep. Note that for the 0° angle of sweep wing-divergence again intervened for part of of the span range. Since sweepback has favorable effects on wing divergence it was possible to obtain flutter for the entire span range for the 45° and 60° angles of sweep. (Note that this filled out part of the experimental flutter curve resembles this calculated portion of the flutter curve in the preceding chart)

Variable Density and Mach Number Chart

The effect of altitude (or wing density) on the flutter speed of an airplane may be studied in a variable density wind tunnel that can also operate at high Mach numbers. Our flutter research tunnel can operate for density ratios of 30 - 1 and also approximately the choking Mach number. On this chart are shown results of fluttering a single model over a wide range of densities and Mach numbers. The abscissa is a function of density and may be considered to represent altitude (higher altitudes this way) The ordinate is the measured flutter speed. The numbers on the upper part of chart are experimental Mach numbers at flutter. The two curves are (two testing media --the upper curve (red) is for air and the lower curve for a gas having a velocity of sound about $\frac{1}{2}$ that of air.

Referring now to the lower part of the chart - by including the simple factor $(1 - M^2)^{\frac{1}{4}}$ in the ordinate (a correction similar to the Prandtl Glauert corrections, and suggested in this laboratory in 1938) the Mach number effect is extracted and the data form a single curve of flutter velocity as a function of density. Further experimental studies are required to find the ranges of parameters for which this simple Mach number correction applies. This investigation leads to the hope that existing very complicated analyses for Mach number may at times be circumvented.

Concluding Remarks

This brief survey of some of our current flutter research leaves undiscussed many other studies; for example, our initial work on the long range problem of a study of the component coefficients of the nonstationary airforces, in addition to the shorter range problems treating the integrated effects of these airforces. Also undiscussed is work on flutter wherein the potential type of flow no longer obtains, as in aileron flutter at high subsonic speeds, spoiler flutter, or in propeller stall flutter. Our aim is to contribute to the understanding and control of these various aerodynamic instabilities known as flutter.