Design Procedures for Flutter-Free Surface Panels

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Nomenclature

a,b	= panel length in x and y directions, respectively
D_1,D_2,D_{12}	= orthotropic panel stiffness parameters
$f(M)$	= Mach number correction factor
FP	= flutter parameter
GP	= geometry parameter
$\bar{K}_S$	= nondimensional edge support stiffness
N_1	= inplane load in x direction
N_{CR}	= buckling load in x direction
P_{CR}	= buckling load ratio
q	= freestream dynamic pressure
λ	= flow parameter
Λ	= flow angle

Abstract

HIGH velocity cruise aircraft and reusable entry vehicles must cope with environments which place severe thermal and structural demands on external surfaces. Prevention of panel flutter in these external surfaces is one of many problems which designers must face. Traditionally, external panels have been designed by strength, buckling, and fatigue considerations and then checked for panel flutter performance. Such a procedure often leads to flutter fixes, which result in the addition of weight for panel flutter prevention. To permit consideration of panel flutter early in the design process, design procedures have been developed in a format useful to designers with limited panel flutter experience.[1]

Interest in the establishment of panel flutter design procedures has been high for a number of years. In an initial attempt to define such procedures, a panel flutter design boundary was defined which enveloped existing experimental data from both unstiffened and corrugation-stiffened panels.[2] References 3 and 4 give modifications and refinements to this data-envelope design approach. In 1964, and later in a revised form in 1972, NASA issued a formal design monograph[5] as a guide for formulation of design requirements and specifications dealing with panel flutter. Reference 5 gives a design process philosophy rather than a detailed design procedure. Reference 6 gives simplified criteria in graphical form, for many of the pertinent panel flutter parameters; however, effects of several significant parameters were not included. The panel flutter design procedures presented in Ref. 1 are extensions of the previously mentioned design approaches, in which additional parameters such as panel orthotropy, edge support flexibility, flow angularity, and damping, as understood in the current state of the art, are included in a graphical format.

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Contents

A wealth of theoretical and experimental panel flutter data exists in the literature. Theoretical approaches were employed to establish trends and relationships required to define the panel flutter design procedures for the panel configuration shown in Fig. 1. Experimental flutter data were then used to verify the design criteria which are presented as flutter-free panel design boundaries in terms of a nondimensional panel geometry parameter GP and a nondimensional flutter parameter FP. Effects of interacting parameters such as panel size, panel stiffness characteristics, and panel support conditions are included in the geometry parameter. The flutter parameter contains the effects of freestream dynamic pressure and Mach number.

The initial definition of the geometry and flutter parameters was based on a two-mode solution for flutter of simply supported orthotropic panels, assuming two-dimensional static aerodynamics. From such a solution

$$\lambda = \frac{3\pi^4}{16}\left[15 + 6\left(\frac{D_{12}}{D_1}\right)\left(\frac{a}{b}\right)^2\right] \tag{1}$$

In Eq. (1), the flow parameter λ is expressed as

$$\lambda = \frac{2qa^3}{D_1 f(M)} \tag{2}$$

where the Mach number correction factor $f(M)$ is defined in Ref. 1. The geometry and flutter parameters are arbitrarily defined as

$$GP = \frac{a}{b}\sqrt{\frac{D_{12}}{D_1}} \tag{3}$$

and

$$FP = \frac{D_1 f(M)}{qa^3} = \frac{2}{\lambda} \tag{4}$$

Substitution of the expressions from Eqs. (3) and (4) into Eq. (1) yields the following relationship between GP and FP for simply supported panels:

$$FP = 0.0365/[5 + 2(GP)^2] \tag{5}$$

Although the two-mode solution predicts the correct trend of the relation between FP and GP, such an approximate solution is insufficient for design purposes. Therefore, existing analytical results from closed-form and modal

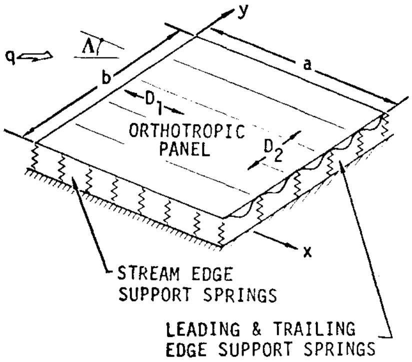

Fig. 1 Surface panel configuration.

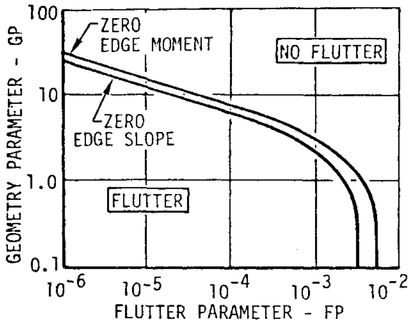

Fig. 2 Flutter-free panel design boundaries.

solutions, which employed many more modes to achieve converged results, were used to empirically refine the basic relationship between the flutter and geometry parameters. Thus, the final design boundaries shown in Fig. 2 are based entirely on analytical panel flutter results. The width of the band between the two curves shows the effect that the degree of rotational restraint of the panel boundaries has on panel flutter response.

As the effects of different parameters such as inplane loading, flow angularity, and support flexibility were considered, the geometry and flutter parameters were modified to maintain the relationship between them given by the flutter-free panel design boundaries shown in Fig. 2. For example, to include effects of inplane loading on a panel with flexible supports along the panel stream edges, the geometry parameter and flutter parameter become

$$GP=\frac{a}{b}\sqrt{\frac{D_{12}}{D_1}\,\frac{1-P_{CR}}{1+C^2/\bar{K}_S}} \tag{6}$$

and

$$FP=\frac{D_1 f(M)}{qa^3}\left[\frac{1}{1+(P_{CR})^{2b/a}(D_1/D_2)(2\pi b/a)^2}\right] \tag{7}$$

where

$$C=\sqrt{D_{12}^2/D_1D_2} \tag{8}$$

and

$$P_{CR}=N_1/N_{CR} \tag{9}$$

The nondimensional deflection edge support stiffness $\bar{K}_S$ is defined in Ref. 1. The form of GP is based on a two-mode flutter solution for a panel with inplane loads and the expression for FP was obtained by empirically matching experimental flutter data for panels with inplane loads.

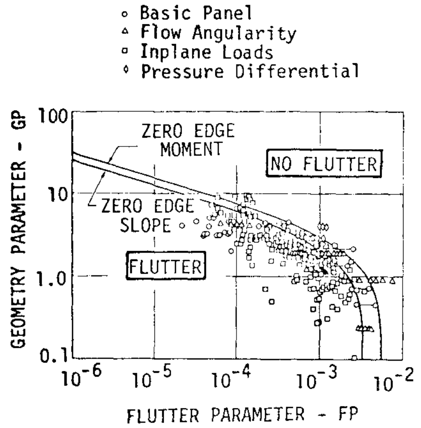

Fig. 3 Comparison of design boundary and experimental flutter data.

Details of the modifications required to include effects of flow angularity, differential pressure, Mach number, and damping in the design procedure are given in Ref. 1. To assist designers with little panel flutter experience, a step by step procedure for implementing the design boundaries in a panel design process is also given in Ref. 1.

The validity of the design curves for various panel configurations is demonstrated in Ref. 1 by comparison with existing experimental data. Also, for parameters where little or no experimental data exists to define their effects, comparisons are made with detailed theoretical analyses.

Examples of these comparisons are shown in Fig. 3 for flutter points obtained for a wide range of panel configurations, both isotropic and orthotropic, including effects of parameters such as support flexibility, flow angularity, inplane loads, and pressure differential. In Fig. 3, "basic" panel refers to isotropic or orthotropic panels with either complete edge deflectional restraint or edge support flexibility effects. The design curves are conservative for most of the data and, thus, will permit rapid prediction of flutter capability for a given panel and enable designers to consider panel flutter effects early in the design process. However, it should emphasized that although these design curves are useful in preliminary design, detailed flutter analysis and/or tests may be necessary to verify the final design of critical panel configurations.

Acknowledgment

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References

[1] Laurenson, R. M. and McPherson, J. I., "Design Procedures for Flutter-Free Surface Panels," NASA CR-2801, March 1977.

[2] Kordes, E. E., Tuovila, W. J., and Guy, L. D., "Flutter Research on Skin Panels," NASA TN D-451, 1960.

[3] Mirowitz, L. I., Zimmerman, N. H., and Schweiker, J. W., "Panel Flutter Survey and Design Criteria," Aerospace Industries Association Report, ARTC-32, 1962.

[4] Kordes, E. and Noll, Richard B., "Theoretical Flutter Analysis of Flat Rectangular Panels in Uniform Coplanar Flow with Arbitrary Direction," NASA TN D-1156, 1962.

[5] "Panel Flutter: NASA Space Vehicle Design Criteria (Structures)," NASA SP-8004, 1964, revised 1972.

[6] Lemley, C. E., "Design Criteria for the Prevention of Panel Flutter," Vols. I and II, Air Force Flight Dynamics Lab., Report TR 67-140, Aug. 1968.