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Influence of In-plane Support Flexibility on the Nonlinear Flutter of Loaded Plates

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ABSTRACT

Previous studies of the flutter behavior of plates exposed to a supersonic flow with concurrent transverse and/or in-plane loadings have indicated that the degree to which in-plane motions at the edges of the plate are restricted must be accounted for in order to obtain a proper representation of the flutter behavior of the plate. For loaded plates in particular this is necessary not only to determine the post-flutter motion of the plate but to determine its flutter boundaries as well.

Dowell and Ventres[1] have compared theoretical results for the flutter of a two-dimensional clamped-edge plate exposed to a constant static pressure differential with existing experimental data for a panel with a length-width ratio of 0.46. Their results indicate that relatively massive and seemingly "rigid" panel support structures can be effectively quite flexible insofar as their restraint at in-plane motions of the boundaries of the panel are concerned. They showed further that excellent correlation between theory and experiment can be obtained by assuming a suitable degree of support flexibility. The amount of flexibility present was estimated in an approximate manner.

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In the present paper similar comparisons are given using a more complete theory and a broader range of experimental data. The effects of static pressure differential and of in-plane loads due to thermal expansion of the panel with respect to its supporting framework are studied theoretically for panels having various degrees of in-plane edge restraint, and the results are compared with existing experimental data (2), (3).

The method of analysis is similar to that used in (4). Von-Karman's nonlinear plate equations are used to describe the elastic behavior of the plate, along with a quasi-steady or piston theory expression for the aerodynamic pressure on the plate. The transverse deflection w is expanded in terms of a sequence of functions appropriate for a plate clamped on all four edges. Galerkin's method is then used to obtain a set of ordinary nonlinear differential equations that can be integrated numerically to determine both the plate flutter boundaries and the character of the flutter motion.

The influence of the in-plane boundary conditions is felt through the expression for the stresses arising in the plane of the plate due to its transverse motion. Three separate methods are used to calculate these stresses. The first is similar to that used in (4), in which the in-plane boundary conditions are satisfied only in an average sense around the perimeter of the panel. Using this method, stresses are calculated for panels having no edge restraint (zero in-plane stresses at the edges), complete edge restraint (zero in-plane motion at the edges), and for any variation in-between. In order to assess the error involved in the use of stresses calculated with this approximate method, two additional solutions were obtained in which the boundary conditions for zero in-plane restraint and for complete in-plane restraint are satisfied exactly.

The equations discussed above, involving exact satisfaction of in-plane boundary conditions, and a modal expansion of w suitable for clamped three-dimensional panels, have not appeared previously in the literature.

Typical results are shown in Figures 1 and 2, in which theoretical stability boundaries for panels with zero and with complete in-plane edge restraint are compared with experimental results from Reference 2. The variables on the horizontal and vertical axes in both figures are non-dimensional dynamic pressure, and static pressure differential, respectively. In Figure 1, a third theoretical curve is shown for an intermediate value of edge restraint arrived at by a rough estimate of the flexibility of the panel support structure, using simple beam theory.

Note that the relative positions of the stability boundaries for panels with zero edge restraint and with complete edge restraint are reversed in the two figures. Therefore, whereas panels of low length-width ratio, a/b, are most strongly stabilized by a static pressure differential when they are completely restrained at the edges, just the opposite is the case for panels of high length-width ratio. An explanation of this rather surprising behavior will be offered in the paper.

Panels with in-plane loads, due either to loads applied at the edges or to uniform thermal expansion of the panel itself, have also been treated. Comparisons with experimental results from Reference 3, for panels buckled by in-plane stresses due to thermal expansion, indicate that edge support flexibility is once again important, and must be properly accounted for to achieve correlation between theory and experiment.

Some of the conclusions that will be drawn are as follows:

1. Satisfying in-plane boundary conditions "on the average" leads in some cases to improper representation of the stresses in the middle surface of the plate, and may result in the calculation of erroneous stability boundaries for loaded plates having little in-plane edge restraint. Such averaged stress solutions can also produce spurious flutter behavior for plates with complete in-plane edge restraint at large length-width ratios.

2. Zero edge restraint may be a more realistic assumption than complete edge restraint for some panel configurations (cf. Figure 2).

3. Knowledge of in-plane support flexibility is essential if accurate predictions of panel flutter behavior under in-plane loadings are to be made.

REFERENCES

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2. Dowell, E. H., and Voss, H. M., "Experimental and Theoretical Panel Flutter Studies in the Mach Number Range 1.0 to 5.0," Aeronautical Systems Division, Technical Document Rept. ASD-TDR-63-449 (June 1963).

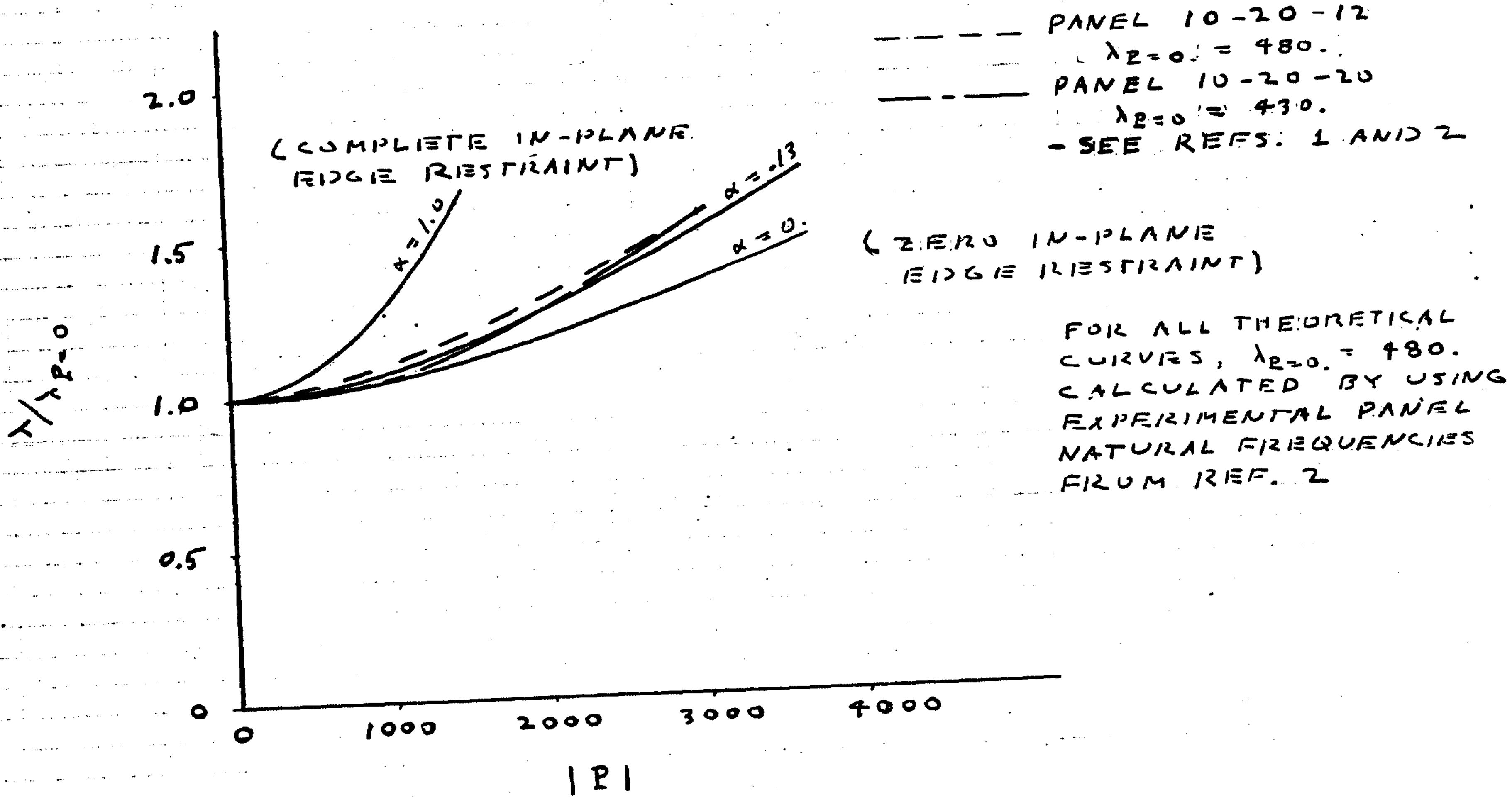
3. Schideler, J. L., Dixon, S. C., and Shore, C. P., "Flutter at Mach 3 of Thermally Stressed Panels and Comparison with Theory for Panels with Edge Rotational Restraint," NASA Langley Research Center, TND-3498 (August 1966).

4. Dowell, E. H., "Nonlinear Oscillations of a Fluttering Plate," AIAA Journal 4, 1267-1275 (July 1966).

FLUTTER DYNAMIC PRESSURE
VS.
STATIC PRESSURE DIFFERENTIAL:

COMPARISON OF THEORY AND EXPERIMENT

$a/b = 0.46$



FOR ALL THEORETICAL CURVES, $\lambda_{P=0} = 480.$ CALCULATED BY USING EXPERIMENTAL PANEL NATURAL FREQUENCIES FROM REF. 2

FIG. 1

FLUTTER DYNAMIC PRESSURE
VS.
STATIC PRESSURE DIFFERENTIAL:
COMPARISON OF THEORY AND EXPERIMENT

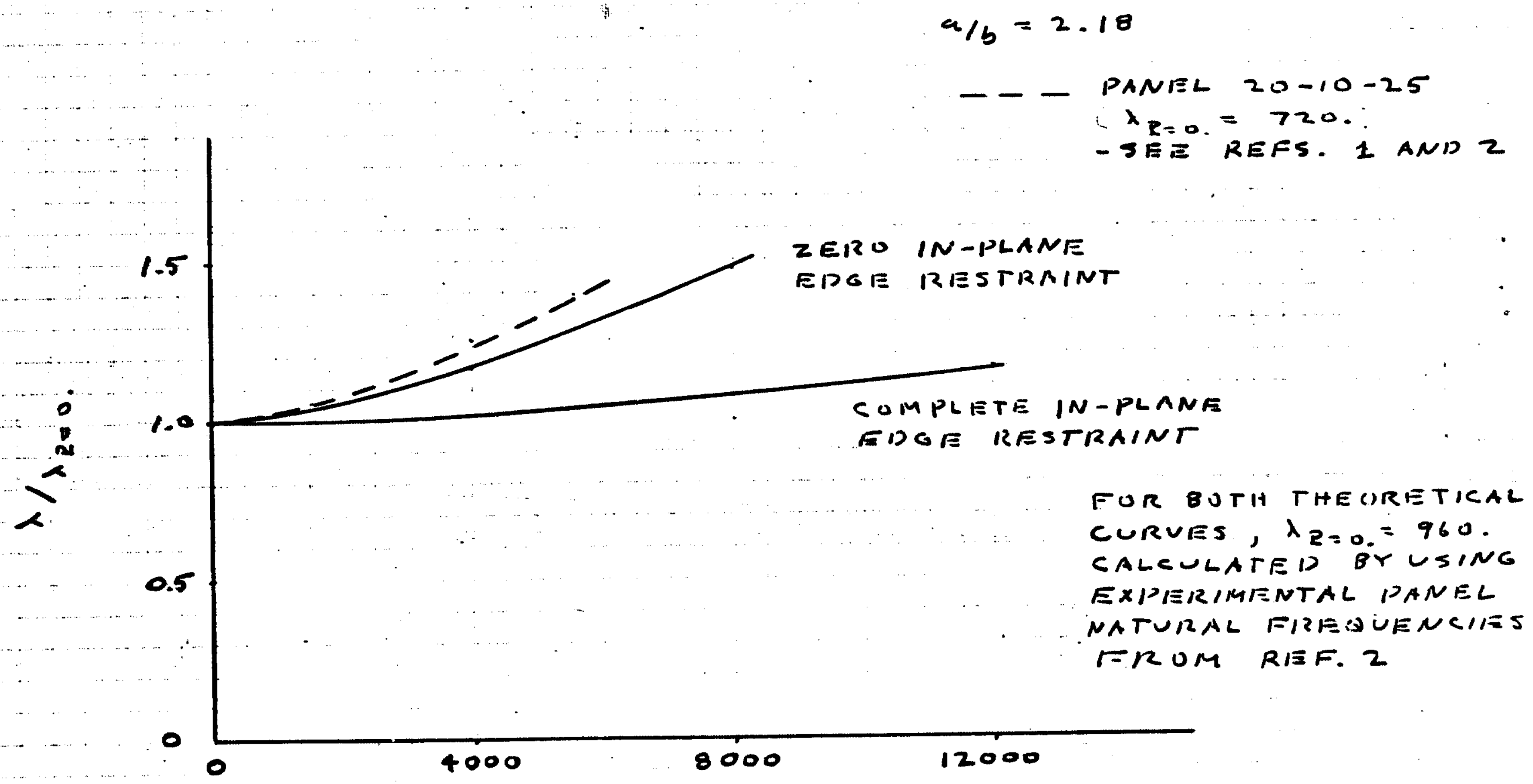


FIG. 2

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