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FLIGHT FLUTTER RESULTS FOR FLAT RECTANGULAR PANELS

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FLIGHT FLUTTER RESULTS FOR FLAT RECTANGULAR PANELS[1]

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SUMMARY

Panel-flutter data obtained from several different aircraft during supersonic flight are presented and compared with a previously established flutter boundary based on results from wind-tunnel tests. The flight data were obtained for rectangular panels alined with the flow and for rectangular panels swept at 52°.

Some results of a flutter analysis of swept, flat, rectangular panels are presented and used to compare the flight results with the flutter boundary for alined panels. The flow direction was shown to have an appreciable effect on the flutter of swept rectangular panels. The results for panels alined with the flow direction were found to be in satisfactory agreement with the flutter boundary established by wind-tunnel tests.

Simple changes in panel geometry were found to be effective in eliminating flutter.

INTRODUCTION

One problem to be considered in the design of hypersonic and reentry vehicles is the aeroelastic instability of exposed skin panels. The seriousness of the problem has been established during flights of several aircraft well into the supersonic regime where extreme noise levels, cracks in surface panels, and loss of a few panels have been attributed to panel flutter. Investigations to eliminate the problem on these vehicles have resulted in a large amount of unpublished flight data on the flutter of essentially flat rectangular panels. This paper presents the panel-flutter data obtained and compares the results with a flutter boundary established by wind-tunnel tests.

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[1]This paper is based on material originally presented at the American Rocket Society Lifting Reentry Vehicles: Structures, Materials, and Design Conference held April 4 to 6, 1961, at Palm Springs, Calif.

SYMBOLS

E Young's modulus of elasticity

l panel length

M Mach number

q dynamic pressure

t panel thickness

w panel width

Λ flow angle

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2

RECTANGULAR PANELS ALINED TO THE FLOW

In order to compare the results for a variety of panels and flight conditions, it was convenient to make use of the previously established flutter boundary shown in figure 1. This boundary was presented in reference 1 and was established from wind-tunnel tests of unstiffened rectangular panels alined with the flow. The modified thickness-ratio parameter which has been shown by theory to be the primary panel-flutter parameter is shown as a function of the panel length-width ratio. The boundary curve was drawn to enclose all of the wind-tunnel test points, and the flutter region lies below the curve. The boundary was obtained for panels with length-to-width ratios from 1 to 10, which was the limit of the test data for unstiffened panels.

In figure 2 the flight results for the flutter of unstiffened rectangular panels that were alined with the flow direction are compared with the boundary of figure 1. The results shown are based on free-stream Mach number and dynamic pressure at flutter. The solid curve is the boundary from figure 1, and the dashed curve is an extension of this boundary toward the theoretical flutter value for buckled panels of infinite aspect ratio. The data for aluminum panels include unpublished data obtained from North American Aviation, Inc., Columbus Division, and McDonnell Aircraft Corp.

Figure 2 shows that many of the panels that fluttered had length-to-width ratios less than 1 and that all the data except one point fall in the flutter region established by wind-tunnel tests. The results were obtained from all areas of the exposed surface of several flight vehicles. The data have not been corrected for boundary-layer effects (ref. 2) or for other local conditions, such as differential pressure and temperature (ref. 1). The large number of data points for the start of flutter, which lies well below the boundary curve, indicates that this boundary, based on free-stream flow conditions, may be conservative for panels on some areas of the vehicle.

RECTANGULAR PANELS SWEPT TO THE FLOW

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Analytical Results

On vehicles designed for supersonic flight there are many areas such as swept wing and tail surfaces where skin panels are not alined with the flow. Flight experience has shown that these panels are susceptible to flutter; however, no research information is available on the flutter of swept panels. Attempts to obtain a simple geometric correction to the thickness-ratio parameter and the length-to-width ratio were unsuccessful. Therefore, a theoretical analysis was conducted to provide some insight into the effect of the flow direction on the flutter of rectangular panels. The analysis followed the procedure given in reference 3 for the flutter of rectangular panels and is based on simple plate theory, with aerodynamic loading given by first-order supersonic two-dimensional flow theory (Ackeret's theory). A Galerkin solution was obtained by using two natural-vibration modes in both directions for a simply supported plate. The calculated results for one length-width ratio are presented in figure 3, in which the thickness-ratio parameter at flutter is shown as a function of the flow direction. In this figure l is the panel length corresponding to $\Lambda = 0°$. The curve shows that for the example panel at a fixed Mach number the critical dynamic pressure for flutter decreases as the flow angle increases; thus, for the panel length-to-width ratio considered, the swept panel is more susceptible to flutter than the same panel alined with the flow.

The effect of panel length-to-width ratio on the flutter of swept rectangular panels is shown in figure 4. The flow angle was chosen at 52°, which agreed with available flight data. The ordinate is the thickness-ratio parameter for $\Lambda = 0°$ divided by the thickness-ratio parameter for $\Lambda = 52°$, and the abscissa is the panel length-to-width ratio. These calculated results show that for panels with length-width ratios near 1 the effect of the flow angle is small; whereas, for panels with other length-width ratios the effect of the flow direction can change the thickness-ratio parameter by more than 50 percent. The curve of figure 4 shows the relationship between the critical value of the thickness-ratio parameter for a swept panel and the critical value for the same panel alined to the flow. Thus, it seems reasonable that the flutter condition of the panel alined to the flow can be predicted from the known flutter condition of the same panel swept to the flow.

Flight Results

The flight data for panels not alined to the flow direction cannot be compared directly with previously established flutter boundaries, since these boundaries do not include the effects of flow direction. In order to make a comparison, the calculated results in the previous section were used to reduce the flight results for swept panels to flutter results for the same panels alined to the flow. The flight data for a geometric flow angle of 52° were reduced by multiplying by the thickness-ratio-parameter relationship from figure 4, which corresponds to the proper value of the length-width ratio for each panel. The results are compared with the flutter boundary for alined panels in figure 5. The ordinate is the thickness-ratio parameter based on the panel thickness and the length for the panel alined to the flow, and the abscissa is the ratio of panel length to the width. The vertical bars represent data for the start of flutter obtained from panels with a given length-width ratio. Data were based on free-stream flow conditions. The numeral near each bar indicates the number of test points, and the length of the bar indicates the scatter of the results. Approximately one-half of the data lies outside the flutter region. However, if the effect of sweep were neglected entirely, all the data for panels with a length-width ratio less than 1 would fall well above the boundary curve. Some of the difference between the reduced data and the boundary curve can be attributed to the use of geometric sweep angle rather than the actual flow direction over each panel, since this flow direction was not known. Although the results shown in figure 5 are encouraging, additional research on the flutter of swept panels is necessary before the problem can be fully understood.

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FLUTTER PREVENTION

Flutter-boundary parameters depend strongly on the panel thickness, length, and width. Of the three dimensions, thickness is the most effective in preventing flutter, since an increase in thickness raises the value of the thickness-ratio parameter without changing the length-width ratio. However, from a weight standpoint, for example, an increase in thickness may not be acceptable, and other methods must be considered, such as attaching stiffeners to the panel to change the length or the width. By decreasing the panel width, the value of the length-width ratio is increased without affecting the thickness-ratio parameter (see fig. 2). This method is most effective in preventing flutter on panels with a length-width ratio between 1 and 4. A decrease in panel length affects both parameters; it decreases the panel length-width ratio and raises the value of the thickness-ratio parameter. This method is most effective for panels with length-width ratios less than 1 or greater than 4, if the stiffened panel also has a length-width ratio greater than 4.

It is of interest to examine the effectiveness of these methods in preventing flutter on a flight vehicle. Flutter has been observed in flight on the long, narrow, rectangular panels of the vertical tail of the X-15 airplane. Flutter of these panels was detected also during wind-tunnel tests. In order to eliminate flutter, the panels were stiffened by both longitudinal and transverse stiffeners, as shown in figure 6. This figure presents an internal view of a portion of the tail structure. The corrugated sheets are the streamwise ribs and the black area represents the exposed surface panels. The stiffeners divide the original panel into four panels of approximately equal size. Each panel has about the same length-width ratio as the original panel and one-half the length, thus effectively doubling the value of the thickness-ratio parameter, which removes the panel from the flutter region for the flight envelope of the vehicle. Transverse stiffeners were ineffective in preventing flutter unless they were securely attached to the internal structure at each end. Wind-tunnel tests, conducted in the Langley 9- by 6-foot thermal structures tunnel, on these modified panels failed to produce flutter within the design envelope of the X-15.

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Panel flutter was also observed on the fuselage side fairings of the X-15. These fairings consisted of rectangular panels stiffened by corrugations across the flow directions. The flutter of these panels cannot be compared directly with the results shown for unstiffened panels because of the anisotropic nature of the stiffened panels. These panels are of interest, however, since they were designed to withstand the high temperatures of hypersonic flight. In order to prevent flutter, the panels were modified by adding a channel in the flow direction and attached to the back of the corrugations on each panel, as illustrated in figure 7.

Figure 7 shows the results of flight measurements on one of the X-15 fairing panels. The upper curve is the response for the original panel, and the lower curve is the response for the same panel with a stiffener. Oscillograph records of panel response of the original panel during flight showed a self-limiting divergent oscillation. The upper curve shows the envelope of the response, which has a sudden increase in amplitude at a dynamic pressure of 600 psf, an indication of flutter. The lower curve is the measured envelope of the response on the next flight with the stiffened panel, which shows that flutter was eliminated. Since the stiffener was attached to the corrugations only, the primary effect was to increase the panel stiffness in the flow direction and, hence, increase the effective thickness of the panel.

CONCLUDING REMARKS

Experimental panel-flutter results from flight tests at supersonic speeds have been presented for rectangular panels. These results for panels alined with the flow direction were found to be in satisfactory agreement with a flutter boundary established by wind-tunnel tests. The flow direction was shown to have an appreciable effect on the flutter of swept rectangular panels.

Simple changes in panel geometry were found to be effective in eliminating flutter.

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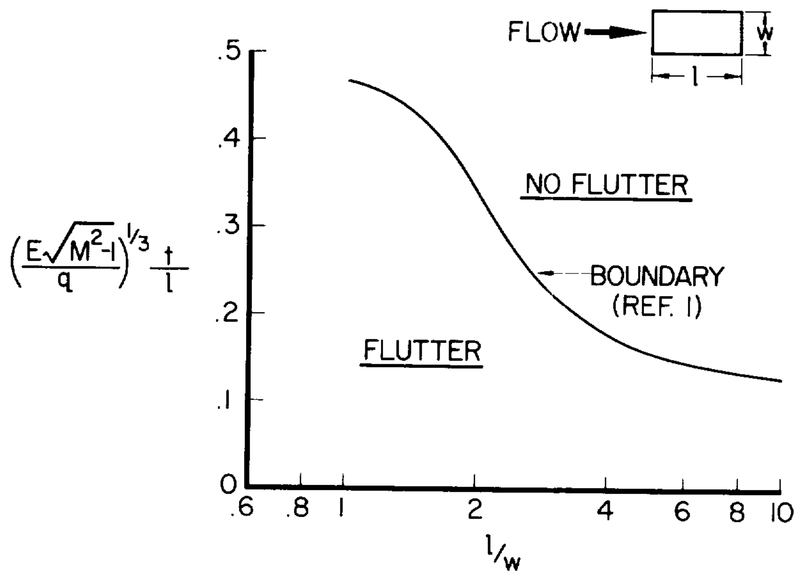

Figure 1.- Boundary curve for the flutter of flat rectangular panels.

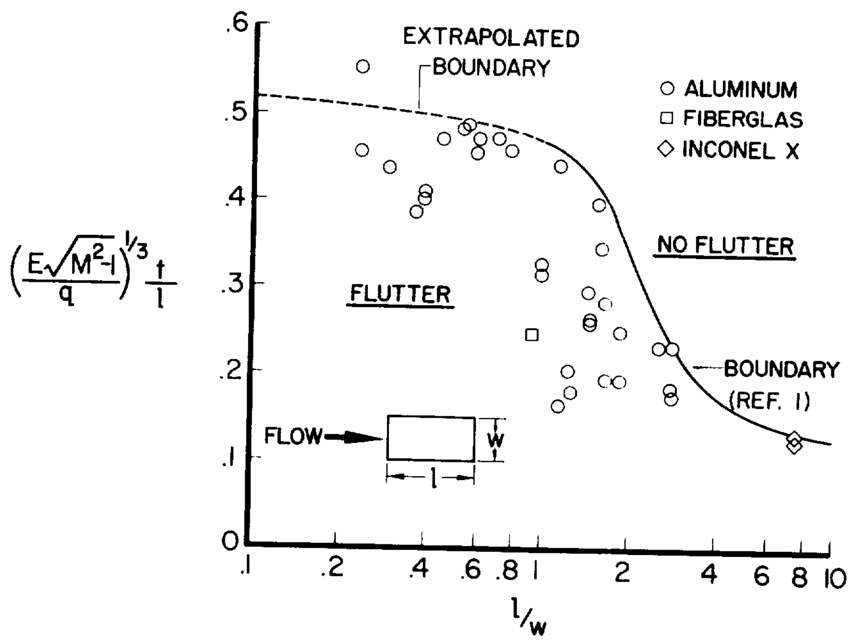

Figure 2.- Flight data for the flutter of rectangular panels alined to the flow. Data points indicate start of flutter.

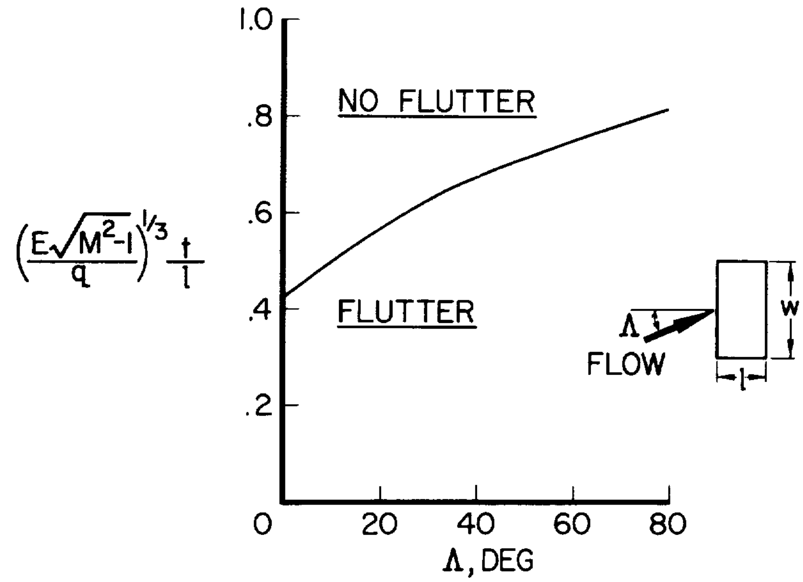

Figure 3.- Calculated results for the effect of flow angle on flutter of rectangular panels. $l/w = 1/3$.

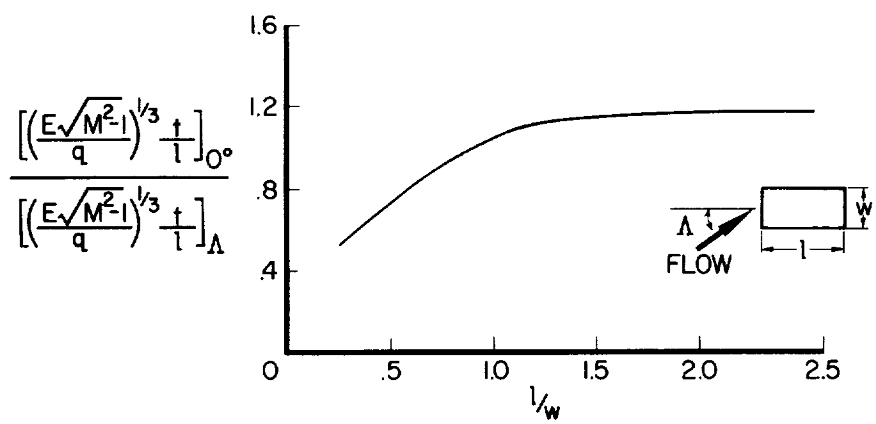

Figure 4.- Variation of ratio of calculated thickness-ratio parameters with length-to-width ratio for a flow angle of 52°.

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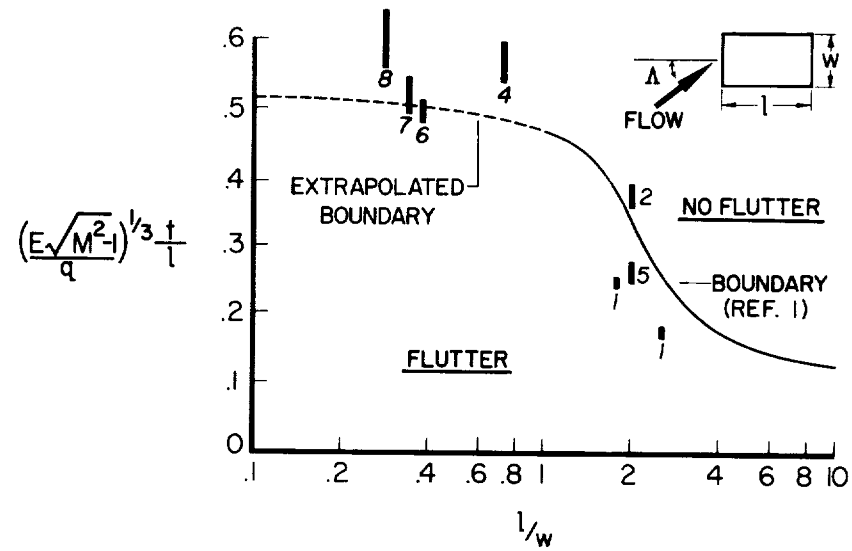

Figure 5.- Flight data for the flutter of rectangular panels at a flow angle of 52°. Bars indicate data for the start of flutter. The numeral at each bar represents the number of data points.

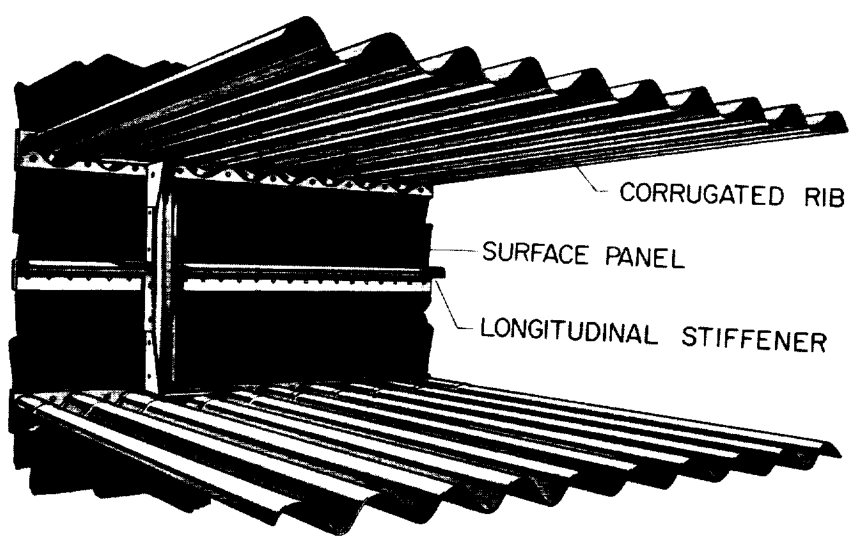

Figure 6.- Internal view of X-15 vertical-tail structure.

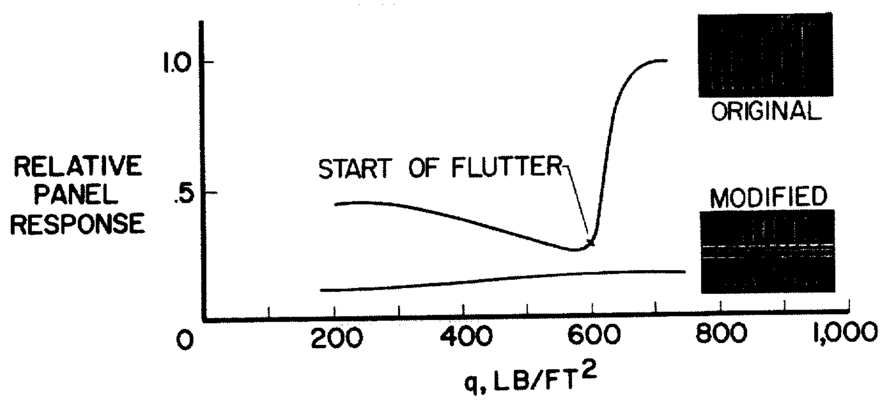

Figure 7.- Variation of panel-response envelope with dynamic pressure obtained from flight measurements on an X-15 side-fairing panel.