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NASA TN D-827

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TECHNICAL NOTE

D-827

SUPERSONIC PANEL FLUTTER TEST RESULTS FOR FLAT FIBER-GLASS SANDWICH PANELS WITH FOAMED CORES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON June 1961

5899S4
8p.

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SUPERSONIC PANEL FLUTTER TEST RESULTS FOR FLAT FIBER-GLASS SANDWICH PANELS WITH FOAMED CORES

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SUMMARY

Flutter tests have been made on flat panels having a 1/4-inch-thick plastic-foam core covered with thin fiber-glass laminates. The testing was done in the Langley Unitary Plan wind tunnel at Mach numbers from 1.76 to 2.87. The flutter boundary for these panels was found to be near the flutter boundary of thin metal panels when compared on the basis of an equivalent panel stiffness. The results also demonstrated that the depth of the cavity behind the panel has a pronounced influence on flutter. Changing the cavity depth from $1\frac{1}{2}$ inches to 1/2 inch reduced the dynamic pressure at start of flutter by 40 percent. No flutter was obtained when the spacers on the back of the panel were against the bottom of the cavity.

INTRODUCTION

The use of disposable heat insulation panels to protect cryogenic or solid fuels in upper stages of space vehicles has introduced another structural component to the panel flutter problem. Several types of insulation panels have been proposed. One design uses a lighweight plastic-foam material sandwiched between fiber-glass laminates. After the insulation panel has served its purpose it is jettisoned. For this reason the panels are made in two or more sections fastened together so as to permit separation and jettisoning on command.

Since insulation against heat is the only purpose of the panels, they are built as lightweight as possible and the stiffness of the panels may be dictated by panel flutter. The purpose of this investigation is to explore the flutter behavior of typical insulation panel construction in simple flat panel form and to compare the results with results for existing flat metal panels. This comparison would provide some basis for using metal panel data to predict the flutter behavior of plastic sandwich panels.

A single type of panel was tested at Mach numbers from 1.76 to 2.87. The effects of pressure differential across the panel and the depth of the cavity behind the panel were investigated. The tests were made in the Langley Unitary Plan wind tunnel.

SYMBOLS

C_p	pressure coefficient, $\dfrac{p_l - p_\infty}{q}$
EI	average flexural stiffness per inch of width, in-lb
EI_{xx},EI_{yy}	flexural stiffness per inch of width normal to x- and y-directions, respectively, in-lb
l	panel streamwise length, in.
M	Mach number
Δp	pressure difference between cavity behind panel and a static-pressure orifice located on splitter plate 9 inches ahead of panel leading edge, positive when cavity pressure is larger, lb/sq ft
p_l	local static pressure, lb/sq in.
p_∞	free-stream static pressure, lb/sq in.
q	dynamic pressure, lb/sq in.
t	panel thickness, in.
T_t	tunnel stagnation temperature, $^\circ F$
x	streamwise coordinate
y	lateral coordinate

PANELS AND INSTRUMENTATION

The panels were of sandwich-type construction. The skin on the cavity side was a 0.006-inch-thick fiber-glass polyester-resin laminate and the skin on the airstream side was a 0.010-inch-thick fiber-glass phenolic-resin laminate. The core was a sine-wave type of honeycomb with the cells filled with a foamed plastic. The honeycomb was formed from a 0.005-inch-thick fiber-glass phenolic-resin laminate with a cell size of about 3/4 inch and the foam filler weighed about 2 lb/cu ft. Balsa wood strips 0.05-inch-thick by 1/16-inch-wide were cemented to the back of the panels in the streamwise direction at $1\frac{1}{2}$-inch intervals. Figure 1 shows details of the panel construction.

Each panel was bonded to a steel frame to simulate fixed edges. (See fig. 1.) The panels had a width of 20.31 inches and a length of 33.38 inches. The framed panel was installed in the surface of a splitter plate to get the panel out of the wind-tunnel boundary layer. The cavity behind the panel was $1\frac{1}{2}$ inches deep measured from the back of the panel.

Each panel was weighed, and its stiffness EI was measured in the x- and y-directions before it was bonded to its frame. These properties are listed in table I along with the first four natural frequencies which were measured during vibration tests with the panel installed in the splitter plate.

Deflectometer coils, located as shown in figure 2, were used to detect panel motion. Because the deflectometers are insensitive to the motion of the plastic materials, 2-inch squares of aluminum foil were cemented over each deflectometer to provide sufficient material to activate the deflectometers. Continuous recording was provided by a 14-channel tape recorder, and motion pictures were taken at about 1,000 frames per second.

A photograph of a panel mounted in the splitter plate is presented in figure 3. An aluminum foil grid was cemented to the face of each panel in order to make it easier to see the motion of the panel. Figure 4 shows panel 1 after destruction and also, shows the cavity and deflectometers.

TESTS

The tests were conducted in the Langley Unitary Plan wind tunnel at Mach numbers of 1.76, 2.00, 2.14, 2.36, 2.66, and 2.87. The stagnation temperature was held at 125° F except for runs 12, 13, 14, and 17 when it was raised to 150° F. The dynamic pressures listed for runs 6 and 7 when no flutter was obtained were the maximums at which the tunnel could be operated.

The testing procedure for most of the runs was as follows: Start the flow at a very low dynamic pressure and set the Mach number; next, gradually increase the dynamic pressure until flutter occurs while maintaining $\Delta p = 0$; then, vary Δp to see if flutter can be obtained at a lower dynamic pressure and some other value of Δp.

RESULTS AND DISCUSSION

The results of the tests are presented in table II in the order in which the runs were made. Listed for each run are the tunnel conditions M and q, the number of the panel being tested, Δp, and remarks pertinent to the panel conditions and behavior. During runs 9, 10, and 11 a small-amplitude, high-frequency oscillation was detected at a q slightly less than the dynamic pressure at the start of flutter. Because of its very small amplitude, these high-frequency oscillations were considered to be an insignificant flutter mode. Once flutter had started the dynamic pressure could be reduced somewhat before flutter stopped and this dynamic pressure is given for runs 9 and 14. Several panels were destroyed because of flutter, but 10 flutter runs were made using panel 4 without damaging it.

It may be noted that Δp is defined as the pressure difference between the cavity and a static-pressure orifice located 9 inches ahead of the panel leading edge, positive when the cavity pressure is larger. The value of Δp may be considered as the pressure differential across the panel if the static-pressure distribution over the panel is uniform and equal to the reference orifice pressure. A static-pressure survey was made to establish this relationship. The results are presented for several Mach numbers in figure 5. The Δp reference orifice was located at station $x = 0$ which was about 12 inches behind the leading edge of the splitter plate and 9 inches ahead of the leading edge of the panel. For Mach numbers 2.66 and 2.87 the pressure distribution was nearly constant and equal to the reference pressure; at Mach numbers 1.76, 2.00, and 2.14 large pressure gradients existed. The effect of these pressure gradients on panel flutter is not known, and their existence means that the measured value of Δp can be considered as the pressure differential across the panel for only the highest Mach numbers.

The flutter data from table II are shown in figure 6 where the q at the start of flutter is plotted against Mach number. It is apparent that the depth of the cavity has a strong influence on the dynamic pressure at the start of flutter. Reducing the cavity depth from $1\frac{1}{2}$ inches to 1/2 inch reduced the dynamic pressure at the start of flutter by 40 percent. Figure 6 also shows that a small pressure differential across the panel can raise the dynamic pressure at the start of flutter considerably; a change in pressure differential from zero to $\Delta p = -16$ lb/sq ft increased the dynamic pressure at the start of flutter by 80 percent.

Since it was desired to compare the results from the present tests on thick, nonhomogeneous plastic panels with the results for thin metal panels presented in reference 1, and since the panel stiffness EI rather than E alone was known for the present panels, the panel flutter coefficient $\left(\frac{E\sqrt{M^2 - 1}}{q}\right)^{1/3} \frac{t}{l}$ used in reference 1 has been replaced by $\left(\frac{12EI\sqrt{M^2 - 1}}{q}\right)^{1/3} \frac{1}{l}$. This replacement is made on the basis of the assumption that the equality $Et^3 = 12EI$, which holds for metals, applies also to the over-all stiffness measurement of the present panels. In figure 7 the panel flutter coefficient boundary obtained for the plastic panels is shown as a function of Mach number for cavity depths of 1/2 inch and $1\frac{1}{2}$ inches. The flutter boundary for thin metal panels was taken from the envelope of figure 2 of reference 1 for panels with length-width ratio of 33.38/20.31 = 1.64.

In figure 7 the flutter boundary is seen to be virtually constant over the range of Mach number of the present tests which indicates that the panel flutter coefficient accounts for Mach number effects. The flutter boundary for thin metal panels from reference 1 is drawn as invariant with Mach number because no distinct variation with Mach number was determined from the experimental data given in reference 1. The boundaries for the plastic and the metal panels are sufficiently close to warrant the use of metal-panel flutter boundaries as a guide to the flutter boundary of plastic panels by using an equivalent panel stiffness.

Practical applications of heat shields will probably have the back of the panels resting on the tank that is being shielded. In order to simulate this condition, the cavity behind the panels was filled with sheets of plywood until the balsa strips on the back of the panels rested against the plywood. Runs 6 and 7 were made under this condition. No flutter was obtained up to the maximum q of the tunnel which was about twice the q at which flutter occurred with a $1\frac{1}{2}$-inch deep cavity. An effort was made to start flutter by increasing the pressure behind the panel in order to increase the distance from the back of the panel to the bottom of the cavity. At a maximum q of 13.20 at $M = 2.14$ and 10.18 at $M = 2.66$, Δp was varied from 0 to 70 lb/sq ft but no flutter occurred.

The flutter mode shape appeared to be a standing wave similar in shape to the first natural mode and no traveling wave motion was observed. The amplitude at the center of panel 4 was at least $\pm 1/4$ inch for many of the flutter runs and the panel suffered no apparent damage.

CONCLUSIONS

The following conclusions can be drawn from the results of tests conducted on flat rectangular plastic panels at Mach numbers from 1.76 to 2.87.

1. Panel flutter coefficients for metal panels may be useful to predict the flutter of plastic panels by using an equivalent panel stiffness.

2. The depth of the cavity behind the panel has a strong influence on panel flutter. Reducing the cavity depth from $1\frac{1}{2}$ inches to 1/2 inch reduced the dynamic pressure at flutter by 40 percent, but when the cavity depth was further decreased to the minimum possible with the bottom of the cavity resting against the balsa strips on the backs of the panels, no flutter was obtained.

3. A small pressure differential across the panel is effective in increasing the flutter dynamic pressure.

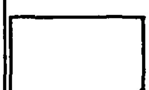
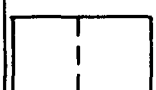
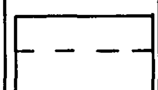
4. The panel flutter coefficient is essentially independent of Mach number from 1.76 to 2.87 which indicates that it accounts for Mach number effects in this range.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 17, 1961.

REFERENCE

1. Kordes, Eldon E., Tuovila, Weimer J., and Guy, Lawrence D.: Flutter Research on Skin Panels. NASA TN D-451, 1960.

TABLE I.- PANEL PROPERTIES

Panel	Weight, lb/sq in.	EI_{xx}, in-lb	EI_{yy}, in-lb	Natural frequencies, cps (a)			
				Mode 1	Mode 2	Mode 3	Mode 4
1	0.00208	401	409	69.3	84.5	138.8	175.0
2	.00210	398	448	65.7	85.0	131.8	156.0
3	.00222	423	474	69.0	89.0	139.0	180.0
4	.00179	383	409	70.2	89.2	140.0	173.0
				----	[b]68.5	[b]120.5	[b]150.9
Node lines							

[a]With cavity depth of $1\frac{1}{2}$ inches, except as noted.

[b]With cavity depth of 1/2 inch.

TABLE II.- TEST DATA

[Cavity depth, $1\frac{1}{2}$ inches and $T_t = 125^\circ$ F unless otherwise noted.]

Run	Panel	M	q, lb/sq in.	Δp, lb/sq ft	Remarks
1	1	2.66	4.43	11	No flutter.
2		2.66	5.89	0	Fluttered at 110 cps.
3		2.00	4.35	0	Fluttered to destruction.
4	2	2.66	3.30	0	No flutter.
5		2.66	10.17	-16	Fluttered at 193 cps to destruction.
6	3	2.14	13.20	0	No flutter. The bottom of the cavity was brought up to touch the balsa strips on the back of the panel.
7		2.66	10.18	0	No flutter.
8		2.14	5.36	14	Fluttered at 114 cps.
9	4	2.36	4.85	0	Insignificant flutter at 196 cps, very low amplitude.
		2.36	5.16	0	Flutter at 108 cps, large amplitude.
		2.36	4.93	0	Flutter stopped.
10		2.66	5.25	0	Insignificant flutter at 198 cps.
		2.66	6.05	0	Fluttered at 106 cps.
11		2.87	6.15	0	Insignificant flutter at 200 cps.
		2.87	6.95	0	Fluttered at 105 cps.
		2.87	6.50	0	Flutter stopped.
12		2.66	3.77	-8	Fluttered at 100 cps.
		2.66	3.65	-8	Flutter stopped.
13		2.87	4.26	3	Fluttered at 100 cps. Cavity depth, 1/2 inch; $T_t = 150^\circ$ F.
		2.87	4.20	3	Flutter stopped.
14		2.36	2.96	4	Fluttered at 100 cps.
		2.36	2.89	4	Flutter stopped.
15		1.76	2.14	9	Fluttered at 110 cps; cavity depth, 1/2 inch.
16		2.00	4.74	23	Fluttered at 108 cps; continued to flutter as q was reduced until at q = 1.86 and Δp = 11, the flutter finally stopped; cavity depth, 1/2 inch.
17		2.66	5.18	4	Fluttered at 98 cps; $T_t = 150^\circ$ F.
18		2.14	3.78	14	Fluttered at 108 cps.

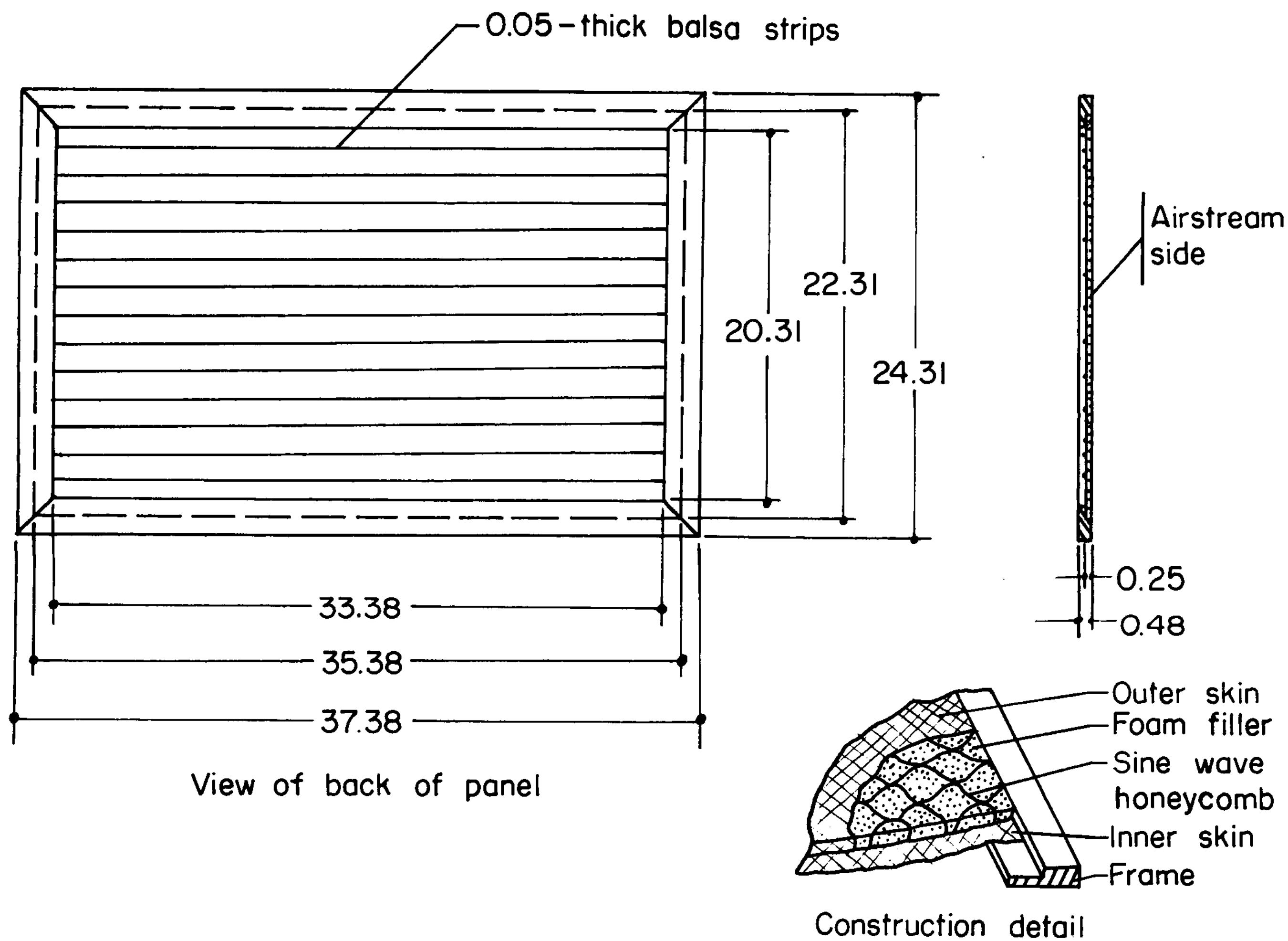


Figure 1.- Sketch of panel and frame. All dimensions are in inches.

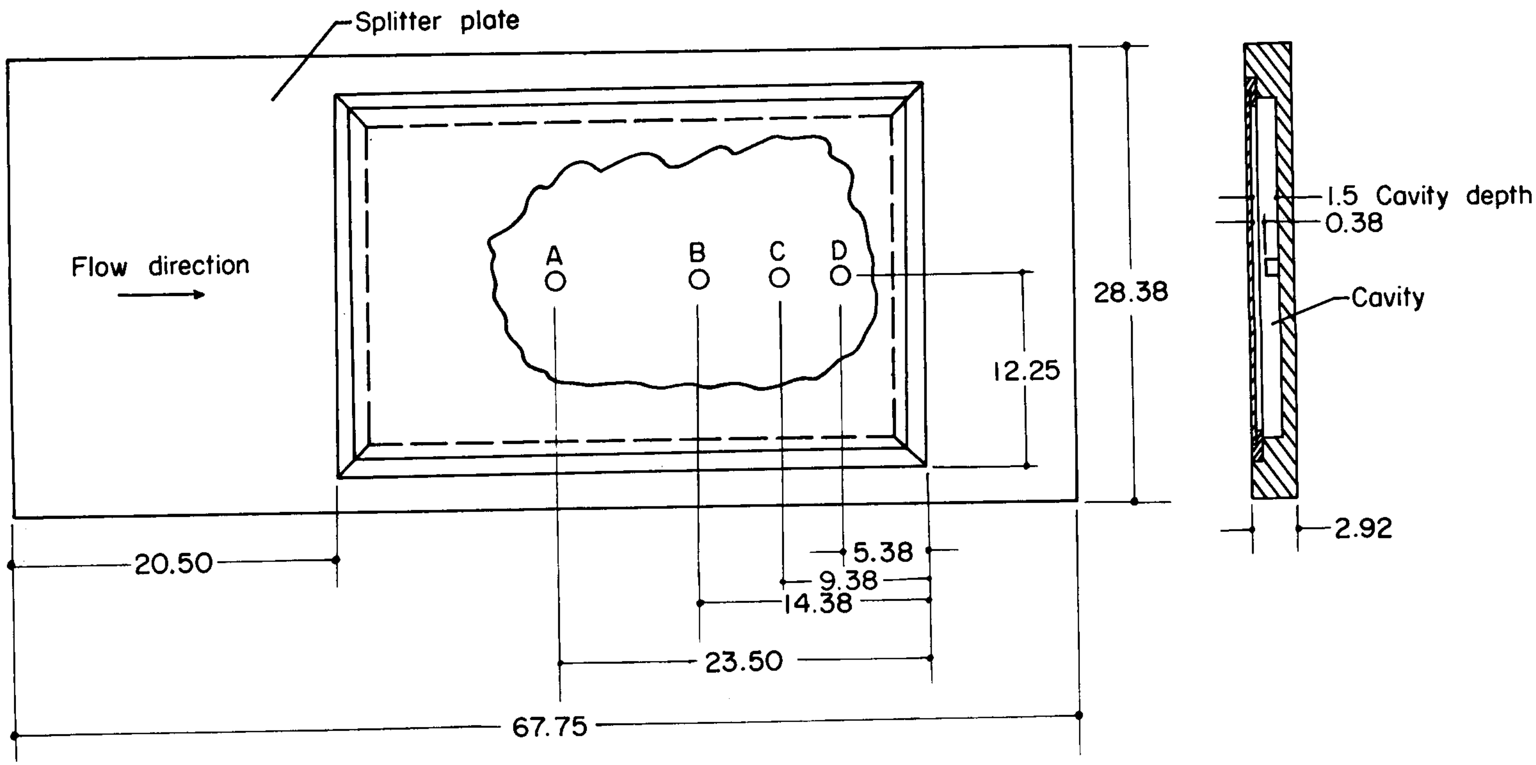


Figure 2.- Deflectometer coil locations. All dimensions are in inches.

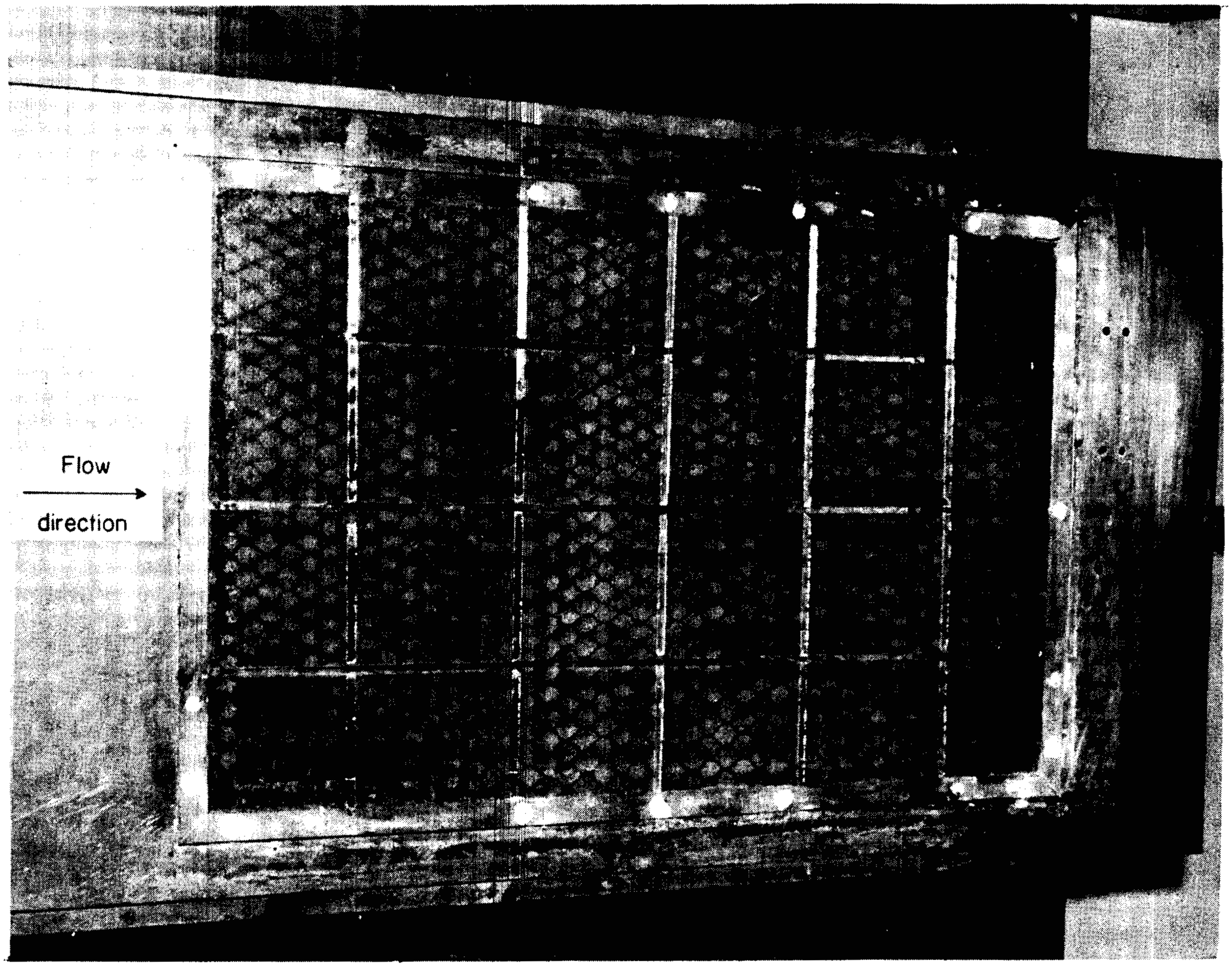


Figure 3.- Typical panel mounted in splitter plate. L-60-4249.1

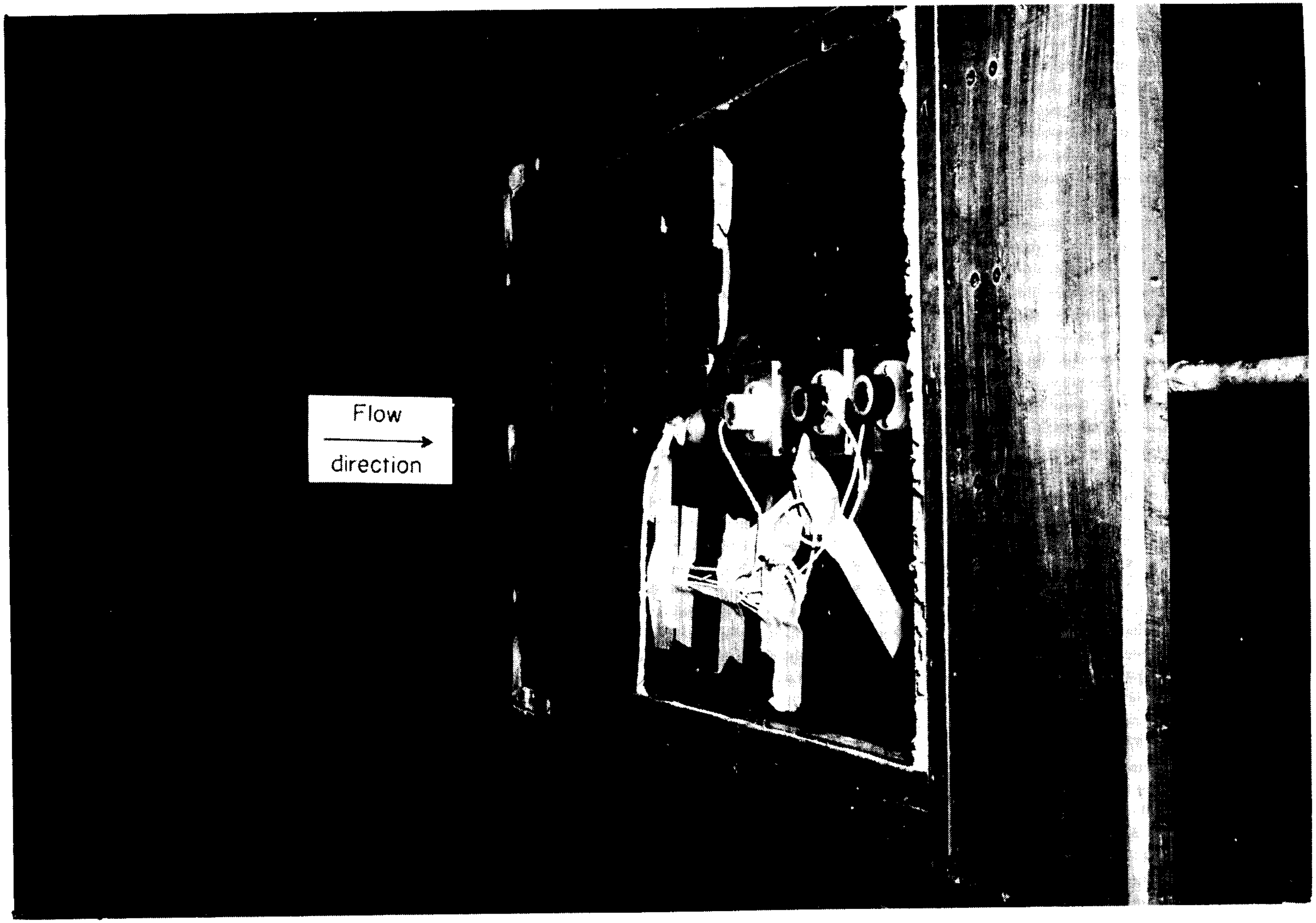


Figure 4.- Panel 1 after destructive flutter. L-60-4251.1

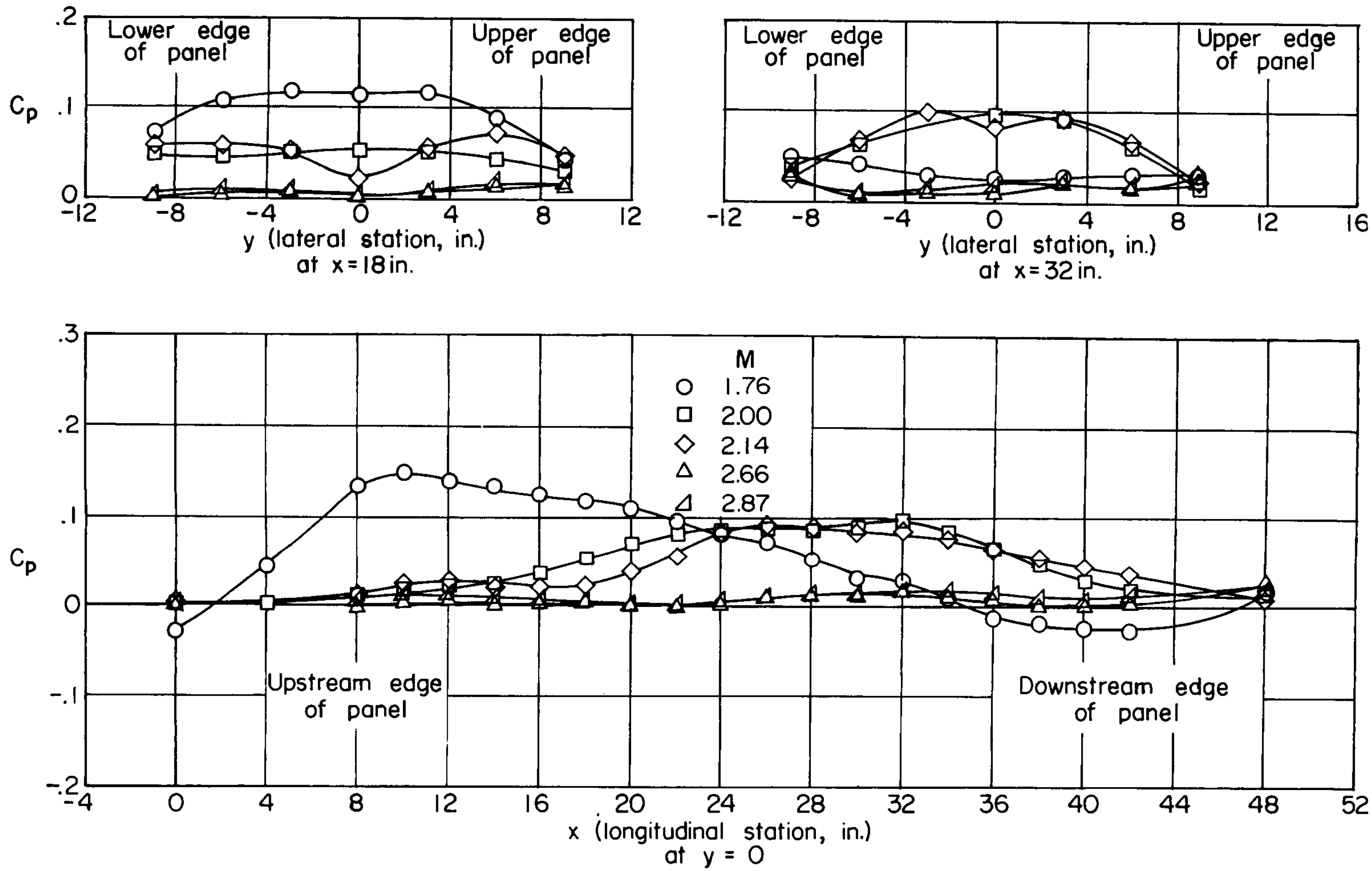


Figure 5.- Pressure distribution over a flat plate mounted in the panel support.

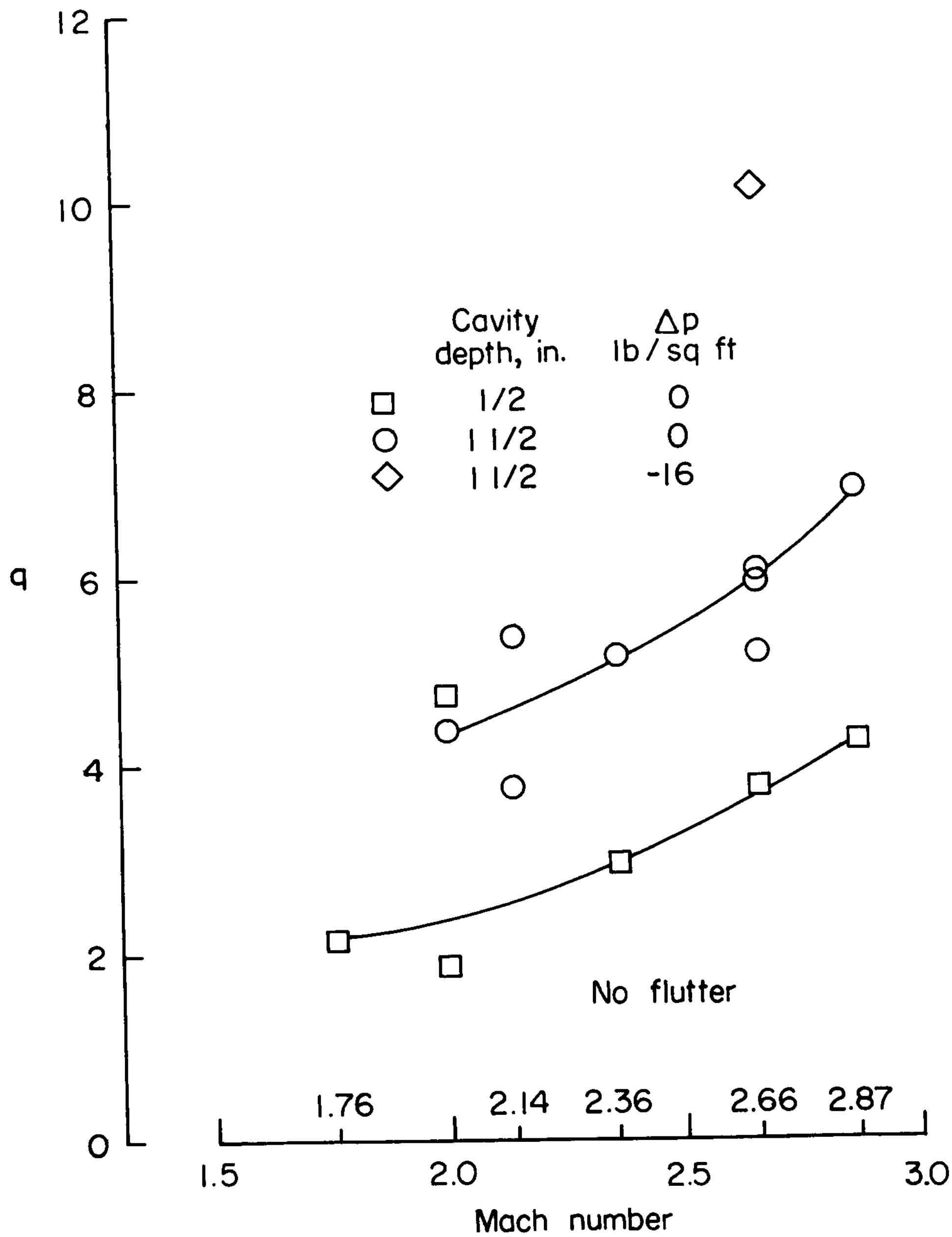


Figure 6.- Effect of Mach number, cavity depth, and pressure differential on the dynamic pressure needed to start flutter.

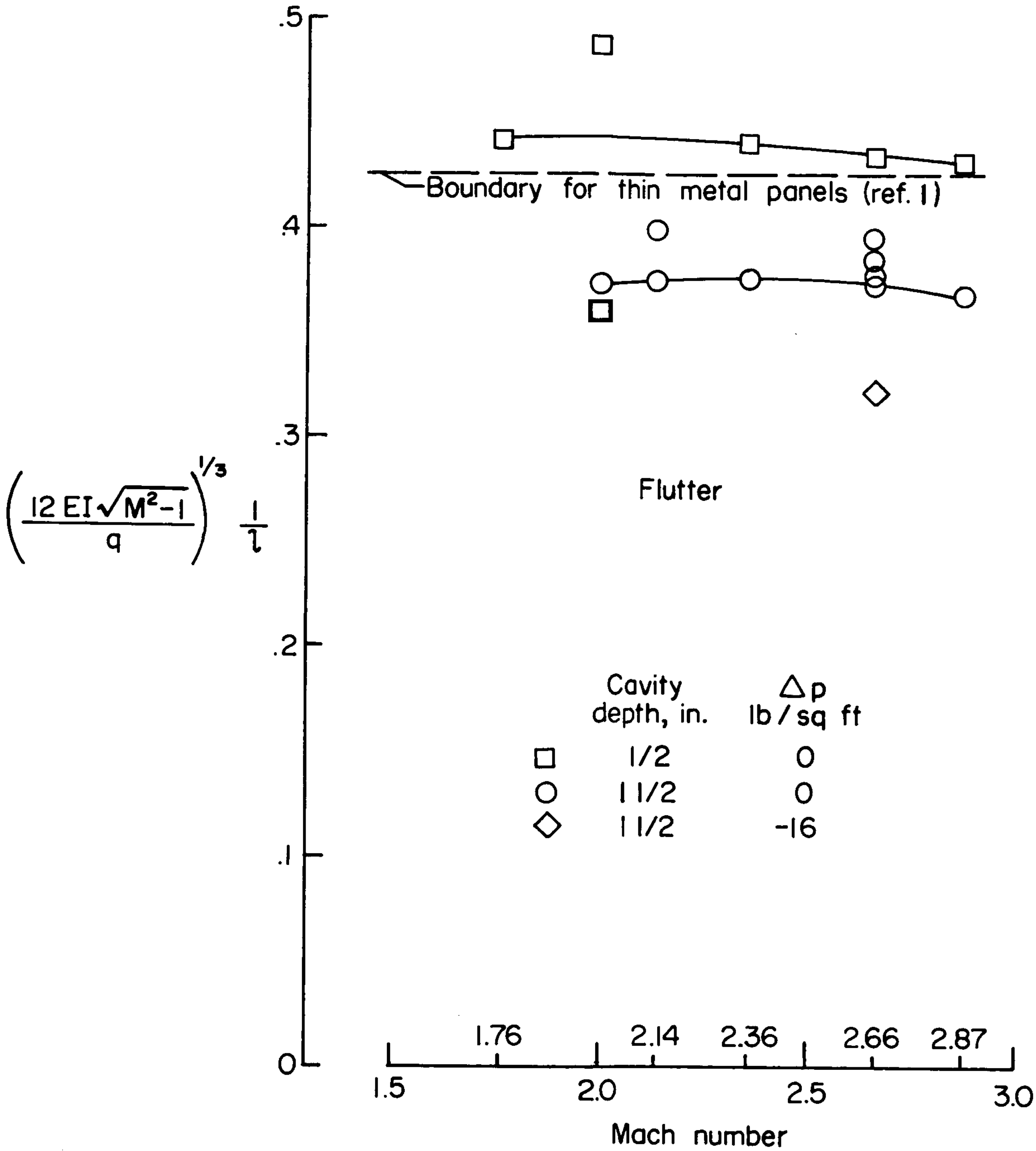


Figure 7.- Test results from figure 6 in terms of nondimensional panel-flutter parameter.