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SOME EXPERIMENTAL STUDIES OF PANEL FLUTTER AT MACH NUMBER 1.3

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SUMMARY

Experimental studies of panel flutter were conducted at a Mach number of 1.3 to verify the existence of this phenomenon and to study the effects of some structural parameters on the flutter characteristics. Thin rectangular metal plates were used in these studies and were mounted as a section of the tunnel wall. Most of the data were obtained by using aluminum-alloy panels, although a few steel, magnesium, and brass panels were also used. Different materials with various thicknesses and lengths were used to determine the effect of these parameters on panel flutter. The experimental program consisted of three phases: (1) panels clamped front and rear with tension, (2) initially buckled panels clamped front and rear, and (3) buckled panels clamped on all four edges.

Panel flutter was obtained under controlled laboratory conditions and it was found that, at the flow conditions of these tests, increasing tensile forces were effective in eliminating flutter, as were shortening the panels or increasing the bending stiffness. No apparent systematic trends in the flutter modes or frequencies could be observed, and it is significant that the panel flutter sometimes involved higher modes and frequencies. The presence of a pressure differential between the two surfaces of a panel was observed to have a stabilizing effect. Initially buckled panels were more susceptible to flutter than panels without buckling. Buckled panels with all four edges clamped were much less prone to flutter than buckled panels clamped front and rear.

INTRODUCTION

Many of the early German V-2 rockets failed during flight after entering the supersonic speed range. After 60 or 70 failures, the conclusion was finally reached that many of these failures were caused by failure of the skin covering, and, moreover, it was conjectured that the skin failures were due to a dynamic instability which was caused by the air flow. This instability has been termed "panel flutter."

*Supersedes declassified NACA Research Memorandum L52I16 by Maurice A. Sylvester and John E. Baker, 1952.

Some simplified analyses of the flutter of a panel fastened front and rear, with one surface exposed to a supersonic air stream, have been made in references 1, 2, and 3. These analyses are based on linearized two-dimensional supersonic aerodynamic forces. In reference 1, a static analysis is made to determine the condition at which static equilibrium is no longer possible. This is assumed to be the flutter condition. References 2 and 3 sought to determine the flutter condition by means of the dynamic solution on the basis of quasi-stationary aerodynamic forces; the quasi-stationary forces, in phase with the velocity, which produce either positive or negative damping, were not included in the analysis of reference 2 but were included in reference 3. In the theories of references 1, 2, and 3 buckled panels are considered, with reference 3 also including a solution for unbuckled panels. An analysis of the flutter of panels fastened on all four edges is not known to exist.

In spite of the fact, however, that these simplified theoretical treatments indicate the possibility of panel flutter and that the V-2 failures were eventually attributed to such flutter, no real proof is known to exist that flutter of this type could develop at supersonic speeds. Some experimental studies of panel flutter have therefore been conducted in the Langley supersonic flutter apparatus at a Mach number of 1.3 to (1) verify the existence of panel flutter, (2) obtain some data which may be of use to designers, and (3) provide some data for any possible correlation studies with theories. The experimental studies were conducted with panels which were mounted to form a section of the tunnel wall; therefore, only one surface of the panels was exposed to the supersonic airstream. In order to minimize the effect of a pressure differential on the flutter data, the panels were tested with the static pressure on opposite surfaces of the panels nearly equal, although some tests were made with a finite pressure differential. Since the Mach number, velocity, and fluid density were fixed, the technique employed for the tests reported was to vary panel material, thickness, and length at various conditions of tensile loading or initial buckling in order to define the flutter regions. The effects of both tensile loading and buckling were studied on panels clamped front and rear, but various amounts and kinds of buckling were studied using rectangular panels clamped on four edges as a means of estimating the status of panels for more practical installations.

This paper consists of a description of the test apparatus and experimental techniques, the presentation of the flutter data in the form of a nondimensional parameter showing the variation of the flutter regions with various tensile loads and amounts of buckling, and the presentation of the characteristics of the flutter encountered under different panel conditions.

SYMBOLS

d	maximum buckled deflection with no air flow
E	Young's modulus of elasticity
I	area moment of inertia per unit width of skin panel about the neutral axis of skin
L	length of panel in direction of flow
M	Mach number
P	panel flutter parameter, $\frac{EI\sqrt{M^2 - 1}}{\rho V^2 L^3}$
ρ	fluid mass density
V	stream velocity

APPARATUS AND PROCEDURE

A description of the panels tested and the experimental techniques used is presented as follows:

Test conditions.- The panel flutter studies were conducted at a Mach number of 1.3 in the Langley supersonic flutter apparatus (see ref. 4) which is a blowdown supersonic tunnel operating from atmospheric pressure. The flow density was 0.000918 slug per cubic foot and the velocity was 1413 feet per second. The stagnation temperature of the tunnel flow was about 160° F and the temperature in the pressure equalizing chamber was about 90° F. The tunnel-wall boundary layer at the test section was about 0.75 inch thick.

Panel models.- The panels were thin rectangular metal plates, mounted so that one surface was exposed to the air stream. The tests were divided into the following three phases:

(1) Panels clamped front and rear with tension

(2) Panels clamped front and rear with initial buckling

(3) Panels clamped on all four edges with initial buckling

In order to vary the bending stiffness, different materials and thicknesses were used; most of the data were obtained using aluminum-alloy panels, although some magnesium, steel, and brass panels were also tested; the thickness ranged from 0.010 to 0.064 inch. Specific panel dimensions and materials are listed in columns 1 to 5 of each of the three parts of table I, where these three parts refer, respectively, to the three phases of the test program. Although most of the panels were 11.62 inches long, some panels were shortened to study effects of length on the flutter characteristics. Panels clamped on four edges were 9.62 inches wide, whereas the panels clamped front and rear were 8 inches wide.

Methods for mounting panels with tension or buckling.- The panels were mounted in a side-wall plate which was located in one side of the tunnel test section. A view of this assembly as seen through an opening in the opposite side wall and showing a panel clamped on all four edges is presented as figure 1. A close up of this view, but with the panel removed, is given in figure 2 and shows the panel clamps and the induction pickups which were used to measure panel deflections. A small chamber behind the panels was provided to equalize the pressures on both sides of the panels. In order to accomplish this, the chamber was sealed from the atmosphere and vented to the tunnel by means of the holes indicated in figures 1 and 2.

The edges of the panel were securely clamped to the tunnel side-wall plate in such a way that the clamped edges were flush with the tunnel wall. For the case of panels clamped front and rear, the side edges were allowed to move as free edges; for panels clamped on all four sides, all the edges were, of course, held flush with the tunnel wall. The overall clamping arrangement is shown in figures 1 and 2, but a clearer indication of the method of clamping can be obtained from figure 3 in which the panel is viewed from the back. The edges of the panels were bent 30° and fastened to the clamping bracket by tightening screws through the beveled clamp. The clamping bracket was fastened to the tunnel side-wall plate by the screws labeled "A." The panels, which were clamped on four edges, utilized the same clamps on all edges as those shown in figure 3 with the tension springs removed.

The technique of applying tension and compression forces can also be shown with the aid of figure 3. Before setting the conditions on tension or initial buckling, the panels were first brought up to the temperature that would exist during the test runs so as to avoid temperature expansion effects. Then, for the tension tests, known amounts of tensile forces were applied to the panels by means of calibrated springs labeled "D"; for the buckled-panel studies, given amounts of buckling were introduced by means of compression screws labeled "C". In the case of panels clamped front and rear, only buckled deflections of the (1 - cosine) type could be developed; whereas, in the case of the panels clamped on all four edges, the two types of buckled shapes illustrated in figure 4 could be formed. The buckle shape shown in figure 4(a) is herein referred to as "simple" buckling, whereas the buckle shape shown in figure 4(b) is referred to as "complex" buckling.

Instrumentation.- Deflections of the panels were detected by inductance pickups, with the inductance being a function of the air-space distance between the panel surface and the pickups. Seven pickups were used for the full-length panels and they were located 0.20 inch behind the panels at intervals of 1.5 inches along the longitudinal center line (fig. 2). The pickups were particularly useful in that they indicated both static and oscillatory panel deformations.

Static pressures of the tunnel flow and chamber pressures were measured by using quick-response strain-gage type pressure cells. These pressures were used to compare the tunnel and chamber pressures, and the tunnel pressure was used to compute Mach number by using isentropic-flow theory.

The data were recorded as a function of time by a recording oscillograph.

Testing technique.- Since the panel flutter studies were conducted with constant flow conditions, the flutter boundaries were established by varying the structural properties and test configurations of the panels. In the first phase (panels clamped front and rear with tension), the tensile stress in each panel was increased until flutter disappeared. In the second phase (buckled panels clamped front and rear), the material, thickness, length, and amount of buckling were changed to establish the flutter boundary. In the third phase (buckled panels clamped on four edges), the thickness, length, and amount of buckling were changed and, in addition, both simple and complex buckling modes were studied. In this way, the effects of these two types of buckling on the panel flutter characteristics were obtained.

RESULTS AND DISCUSSION

Interpretation of flutter records and data presentation.- Several sample oscillograph records containing pickup and pressure-cell traces are shown in figure 5. Figure 5(a) shows a sample of the transient conditions present during the latter part of the tunnel acceleration as well as immediately after the flow has reached Mach number 1.3. The records shown in figures 5(b) to 5(e) were taken after the transient condition had died out and indicate the primary types of flutter obtained. These types of flutter will be discussed individually later in the discussion.

The sudden rise of Mach number in the transonic speed range during the acceleration to Mach number 1.3 causes sudden transient forces on the panels as shown in figure 5(a) at approximately time A. The transient condition often required as much as 0.5 second to subside (for example, note the static deformation at pickups 1, 2, and 3 beyond time A), and, for the sake of consistency, the flutter data were always read after the transient condition had subsided, with only the following exception: There were some cases where most of the chamber vents were closed in order to produce greater pressures behind the panels over a longer period of time. For these tests, the transient condition was the important part of the record in order to evaluate the effects of a pressure differential on panel flutter characteristics.

Since the theory of panel flutter has not been fully developed, all the significant parameters have not been definitely established; therefore, the flutter data obtained from these tests are presented in terms of a "panel flutter parameter" defined as $P = \frac{EI\sqrt{M^2 - 1}}{\rho V^2 L^3}$. This parameter includes the more significant aerodynamic and structural variables and has been indicated in references 1, 2, and 3. It represents a nondimensional ratio of elastic to aerodynamic forces, the elastic forces being proportional to EI/L^3 and the aerodynamic forces, on the basis of linearized supersonic theory, being proportional to $\rho V^2/\sqrt{M^2 - 1}$. It is possible that further experience with panel flutter may indicate that the panel flutter parameter may be more usefully expressed by including frequency terms.

The flutter data, including this flutter parameter, are shown in columns 6 to 8 in tables I(a) and I(b) and in columns 6 to 9 of table I(c).

Panels under tension, clamped front and rear.- The results of the flutter tests on panels under tension clamped front and rear are presented in figure 6, where the panel flutter parameter is plotted against tensile stress. As the value of P is increased (increasing stiffness or decreasing length) the tensile stress necessary to stop flutter becomes less. At values of P greater than 0.0018, the panels did not flutter at zero tensile stress.

The flutter oscillations for this group of panels usually occurred in the form of a traveling wave as indicated by the fact that the maximum oscillatory deflections at consecutive stations occurred at different times (for example, note that the peak values of the consecutive pickup traces in fig. 5(b) occur at different times). The amplitude of the flutter oscillations of panels with zero tensile stress increased somewhat with decreasing values of P and, for low values of this parameter (that is, long panels or panels with low values of bending stiffness), the flutter was very severe and often irregular in mode shape and frequency (sometimes similar to the flutter in figs. 5(c), 5(d), or 5(e)). The flutter amplitude was observed to decrease as the tensile stress in a panel was increased until, near the stable boundary, flutter generally occurred as a mild, low-amplitude oscillation (fig. 5(b)). No apparent trend was observed in the flutter frequencies which ranged from 84 cps to 234 cps (table I(a), column 8). The flutter modes and the high flutter frequencies obtained from the records indicated that the panel flutter sometimes occurred in higher modes.

Buckled panels, clamped front and rear.- The results of the tests on buckled panels clamped front and rear are plotted in the right-hand part of figure 7. For comparison of panels having near zero buckling with those having tensile loads, the flutter curve of figure 6 is included on the left-hand side of this figure. Although the panels were tested under various amounts of buckling, the flutter did not appear to be a function of the amount of buckling within the limits of the tests. The flutter boundary for buckled panels clamped front and rear is therefore conservatively defined by the constant value of P which is approximately equal to 0.00420, above which no flutter was obtained. The region immediately below this critical value of P contains flutter data as well as some points showing absence of flutter.

No attempt was made to determine the compressive forces acting on panels which were in compression but which had not buckled. Therefore, in figure 7, zero buckling is taken as equivalent to zero tensile stress, and the critical value of P is the same for both cases. The experiments indicate that the critical value of P ($P = 0.0018$) necessary to prevent flutter of panels with no buckling jumps abruptly up to $P = 0.0042$ with the addition of a finite amount of buckling. Thus, panels which had values of P between 0.0018 and 0.0042 were very likely to change from a stable condition to very violent flutter with the addition of a small amount of buckling.

The three types of flutter most commonly encountered on buckled panels clamped front and rear were:

(1) A low frequency oscillation (58 to 105 cps) consisting of an "oil can" type of motion in which the movement of the front portion of the panel led that of the rear (fig. 5(c))

(2) A sinusoidal oscillation with higher frequency and with motion of the front and rear portions of the panel approximately 180° out of phase (fig. 5(d))

(3) An irregular oscillation (fig. 5(e))

Any or all of the three types of flutter listed might occur during any given flutter test (see for example, fig. 5(d)). The flutter was generally very violent and was accompanied by considerable noise. The low-frequency "oil can" type of motion essentially oscillated between the two buckled extremities and had the largest amplitude of any of the types of flutter. The flutter frequencies are listed in table I(b), column 8.

Buckled panels clamped on four edges.- The flutter results for buckled panels clamped on four edges are shown in figure 8. The flutter boundary did not appear to be a function of the amount of buckling within the limits of the tests but was affected considerably by the type of buckling. A stable region is indicated in figure 8(a) for panels buckled in a simple manner for $P > 0.00015$; whereas, figure 8(b) shows that, for the same panels buckled in a complex manner, the critical value of P is increased to approximately 0.00105. These results demonstrate that it is possible to cause some panels that were flutter free when buckled in a simple shape to flutter when buckled in a complex shape. These results should be of practical significance since, in general, an aircraft panel might not be expected to buckle in a simple shape. The flutter oscillations were generally irregular as shown in figure 5(e). The flutter frequencies are listed in table I(c), column 9.

Pressure differential.- Early in the experimental test program the panels were observed to bulge somewhat into the air stream. This indicated that there might be a small pressure differential acting on the panels, and pressure measurements confirmed this observation. (The pressure differential measured was in the order of 0.1 pound per square inch.) There is some indication that sufficient positive pressure behind the panel will stop the flutter. This result is indicated by the transient portion of many of the flutter records (for example, fig. 5(a)). The record shows that flutter did not commence until most of the excess chamber pressure was relieved. This observation is substantiated by further experiments in which the period of positive chamber pressure was prolonged. The onset of flutter was delayed for a corresponding period.

Comparison of results.- The approximate experimental flutter boundaries presented in figures 7 and 8 are reproduced in figure 9 for the purpose of comparing the results. In addition, the critical values of P, as obtained in references 1, 2, and 3, are superposed on this figure. The regions above the boundaries are stable; below, unstable. The theoretical critical value of the flutter parameter for panels with clamped edges as predicted by reference 1 is 0.00674; whereas, the experimental value for the same type of panel (buckled and clamped front and rear) is 0.00420. A reduction in the critical value of this parameter to 0.00105 occurs when panels are clamped on four edges, instead of front and rear, with the panels buckled in a complex manner. The critical value of P is still further reduced if the buckling is simple. As pointed out previously, tensile forces also have a stabilizing effect on panel flutter.

The theories of references 2 and 3 indicate that, for buckled panels pinned front and rear, the critical flutter parameter for Mach numbers above $\sqrt{2}$ is 0.00912. This value is shown, although the theory does not apply to the Mach number at which these data were obtained. Miles, in reference 3, found that, between Mach number 1 and $\sqrt{2}$, the aerodynamic damping is always negative, thereby providing the condition which makes flutter possible. This condition is similar to the findings of Garrick and Rubinow in reference 5 for one-degree-of-freedom instability of wings in this same Mach number range. The experimental results obtained at a Mach number of 1.3, however, indicate that panels with a high enough value of P can be flutter free even at supersonic Mach numbers less than $\sqrt{2}$. The theoretical value of the critical panel flutter parameter predicted by reference 3 for unbuckled, or flat, panels is shown in figure 9, although this value is applicable to Mach numbers in excess of $\sqrt{2}$.

The flutter boundaries in figure 9 are compared with theoretical values although the Mach number at which the data were obtained is outside of the range for which the theories are valid. Some possible reasons for these differences between theory and experiment are as follows:

(1) The two-dimensional air forces, which were used in the theoretical analyses, may not be adequate when applied to the panels of finite aspect ratio which were tested.

(2) The experimental flutter frequencies were generally above the range of frequencies for which the analyses may be valid.

(3) The boundary layer present during the tests may alter the flutter characteristics from those predicted by theory which neglects boundary layer.

(4) The effect of the pressure differential, which was present during the tests, is not included in the theories.

CONCLUSIONS

The results of this panel flutter investigation at a Mach number of 1.3 are presented for panels with clamped edges. The panels were studied in three phases: (1) panels clamped front and rear with tension,

(2) initially buckled panels clamped front and rear, and (3) buckled panels with all four edges clamped. These results indicate the following conclusions:

1. Panel flutter has been obtained at a Mach number of 1.3 under controlled laboratory conditions. It was found that for panels with tension, the flutter could be eliminated by applying sufficient tensile loads to the panel, decreasing the length, or increasing the bending stiffness. For buckled panels, the flutter could be eliminated by decreasing the length or increasing the bending stiffness.

2. No apparent systematic trends in the flutter modes or frequencies could be observed, and it is significant that the panel flutter sometimes involved higher modes and frequencies.

3. The presence of a pressure differential between the two surfaces of a panel has a stabilizing effect on the flutter tendencies.

4. Initial buckling in panels has an adverse effect on panel flutter by causing the flutter of some panels which would otherwise be stable; the amount of buckling, however, does not appear to be significant.

5. Buckled panels with four edges clamped are much less prone to flutter than buckled panels clamped front and rear.

6. Panels with all four edges clamped having simple buckling (one hump) are much less prone to flutter than panels having complex buckling.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 18, 1952.

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TABLE I.- EXPERIMENTAL PANEL FLUTTER DATA AT A MACH NUMBER OF 1.3

(a) Panels with tension, clamped front and rear

1	2	3	4	5	6	7	8
Material	Length, in.	Width, in.	Thickness, in.	Bending Stiffness, lb-in.^{2}/in.	Panel flutter parameter, P	Tensile stress, lb/in.^{2}	Flutter frequency, cps
Aluminum alloy	11.62	8	0.011	1.11	4.71×10^{-5}	0	192
	11.62	8	.011	1.11	4.71	2290	156, 114
	11.62	8	.011	1.11	4.71	4580	210
	11.62	8	.011	1.11	4.71	5730	No flutter
	11.62	8	.016	3.40	14.7	0	156
	11.62	8	.016	3.40	14.7	1574	150
	11.62	8	.016	3.40	14.7	3150	168
	11.62	8	.016	3.40	14.7	3930	No flutter
	11.62	8	.018	4.87	21.1	0	165
	11.62	8	.018	4.87	21.1	700	165
	11.62	8	.018	4.87	21.1	1400	153
	11.62	8	.018	4.87	21.1	2100	No flutter
	11.62	8	.031	24.7	107.5	0	174
	11.62	8	.031	24.7	107.5	406	No flutter
	11.62	8	.039	49.6	215.0	0	No flutter
Steel	11.62	8	.010	2.5	10.8	0	234
	11.62	8	.017	12.6	54.8	0	174, 84
	11.62	8	.017	12.6	54.8	740	No flutter
	11.62	8	.031	23.2	293.0	0	No flutter
Magnesium	11.62	8	.032	17.7	76.8	0	170
	11.62	8	.032	17.7	76.8	393	No flutter
Brass	11.62	8	.032	36.5	186.0	0	No flutter

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TABLE I.- EXPERIMENTAL PANEL FLUTTER DATA AT A MACH NUMBER OF 1.3 - Continued

(b) Buckled panels, clamped front and rear

1	2	3	4	5	6	7	8
Material	Length, in.	Width, in.	Thickness, in.	Bending stiffness, lb-in.^{2}/in.	Panel flutter parameter, P	Buckled depth, d/L	Flutter frequency, cps
Aluminum alloy	11.62	8	0.031	24.7	107.5×10^{-5}	0	174
	11.62	8	.031	24.7	107.5	.004	86
	11.62	8	.031	24.7	107.5	.010	86, 252
	11.62	8	.031	24.7	107.5	.016	86, 243
	9.81	8	.031	24.7	178.0	.007	98
	8.81	8	.031	24.7	246.0	.009	58
	7.81	8	.031	24.7	351.0	.006	75
	6.81	8	.031	24.7	532.0	.004	No flutter
	6.81	8	.031	24.7	532.0	.007	No flutter
	6.81	8	.031	24.7	532.0	.015	No flutter
	11.62	8	.039	49.6	215.0	0	No flutter
	11.62	8	.039	49.6	215.0	.004	72
	9.22	8	.039	49.6	430.0	.002	No flutter
	9.22	8	.039	49.6	430.0	.009	No flutter
	9.22	8	.039	49.6	430.0	.013	No flutter
	11.62	8	.062	198.0	864.0	.003	No flutter
	11.62	8	.062	198.0	864.0	.007	No flutter
Steel	11.62	8	.017	12.6	54.8	0	174, 84
	11.62	8	.017	12.6	54.8	.004	98, 180
	11.62	8	.017	12.6	54.8	.009	105
	11.62	8	.031	67.6	293.0	0	No flutter
	11.62	8	.031	67.6	293.0	.004	No flutter
	11.62	8	.031	67.6	293.0	.017	No flutter
Magnesium	11.62	8	.032	17.7	76.8	0	170
	11.62	8	.032	17.7	76.8	.004	95
	11.62	8	.032	17.7	76.8	.009	No flutter
	11.62	8	.032	17.7	76.8	.016	96, 246
	11.62	8	.064	142.0	615.0	.004	No flutter
	11.62	8	.064	142.0	615.0	.009	No flutter
	11.62	8	.064	142.0	615.0	.016	No flutter
Brass	11.62	8	.032	43.6	186.0	0	No flutter
	11.62	8	.032	43.6	186.0	.003	135
	11.62	8	.032	43.6	186.0	.004	No flutter
	11.62	8	.032	43.6	186.0	.009	174
	11.62	8	.032	43.6	186.0	.017	No flutter
	9.81	8	.032	43.6	310.0	.002	No flutter
	9.81	8	.032	43.6	310.0	.005	No flutter
	9.81	8	.032	43.6	310.0	.008	No flutter

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TABLE I.- EXPERIMENTAL PANEL FLUTTER DATA AT A MACH NUMBER OF 1.3 - Concluded

(c) Buckled panels, clamped on four edges

1	2	3	4	5	6	7	8	9
Material	Length, in.	Width, in.	Thickness, in.	Bending stiffness, lb-in.^{2}/in.	Panel flutter parameter, P	Buckled depth, d/L	Type of buckling	Flutter frequency, cps
Aluminum alloy	11.62	9.62	0.011	1.11	4.71×10^{-5}	0.009	Uniform	204
	10.62	9.62	.011	1.11	6.25	.009		195
	9.72	9.62	.011	1.11	8.15	.005		174
	4.72	9.62	.011	1.11	71.3	.005		No flutter
	11.62	9.62	.016	3.40	14.7	.004		175
	11.62	9.62	.016	3.40	14.7	.004		No flutter
	11.62	9.62	.016	3.40	14.7	.009		No flutter
	9.72	9.62	.016	3.40	25.2	.005		No flutter
	11.62	9.62	.018	4.87	21.1	.004		No flutter
	11.62	9.62	.031	24.7	107.5	.009		No flutter
Aluminum alloy	4.72	9.62	.011	1.11	71.3	.005	Non-uniform	252
	9.72	9.62	.016	3.40	25.2	.005		210
	11.62	9.62	.018	4.87	21.1	.004		136
	11.62	9.62	.031	24.70	107.5	.004		No flutter

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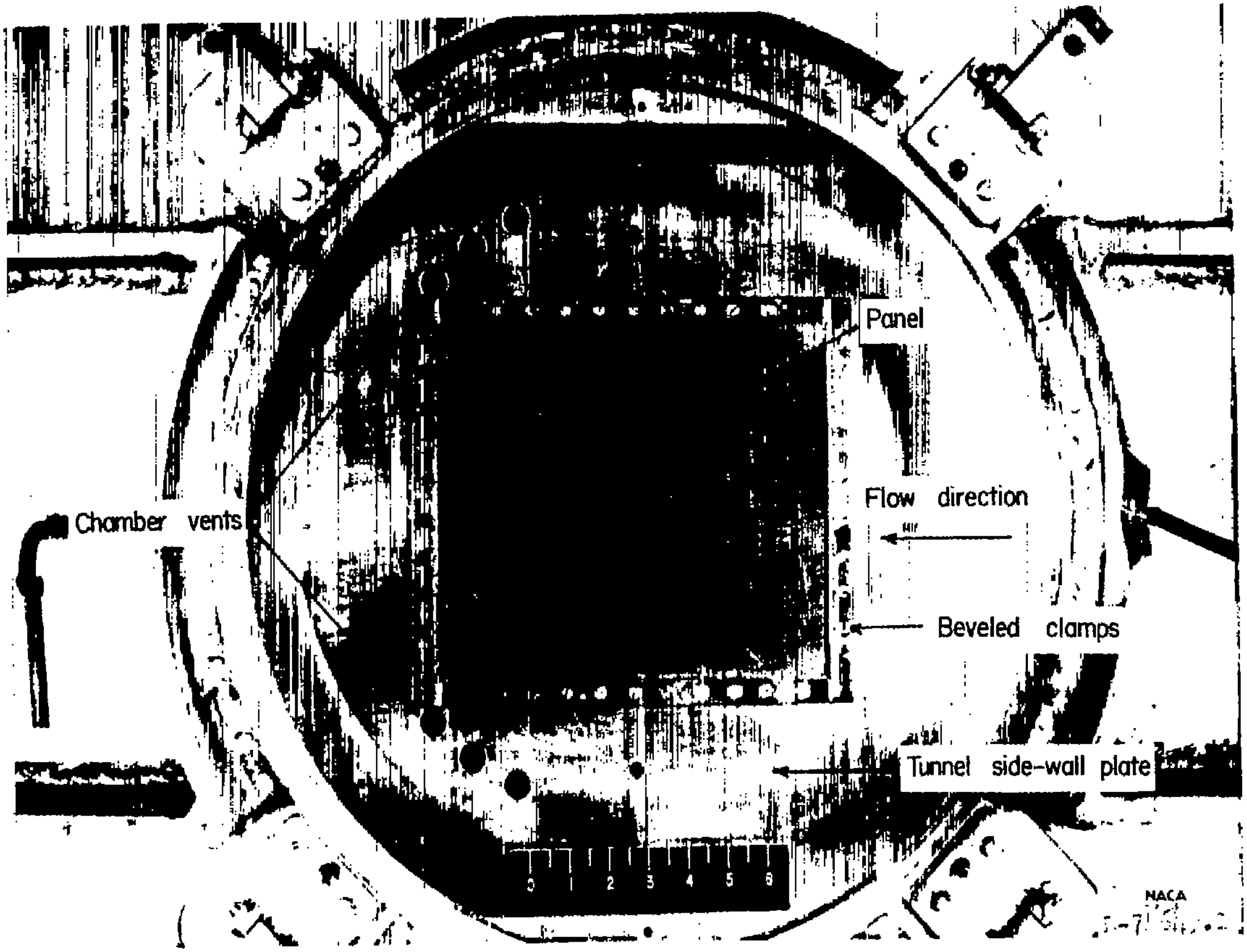


Figure 1.- Tunnel test section showing panel installed in the side-wall plate as seen through an opening in the opposite side wall.

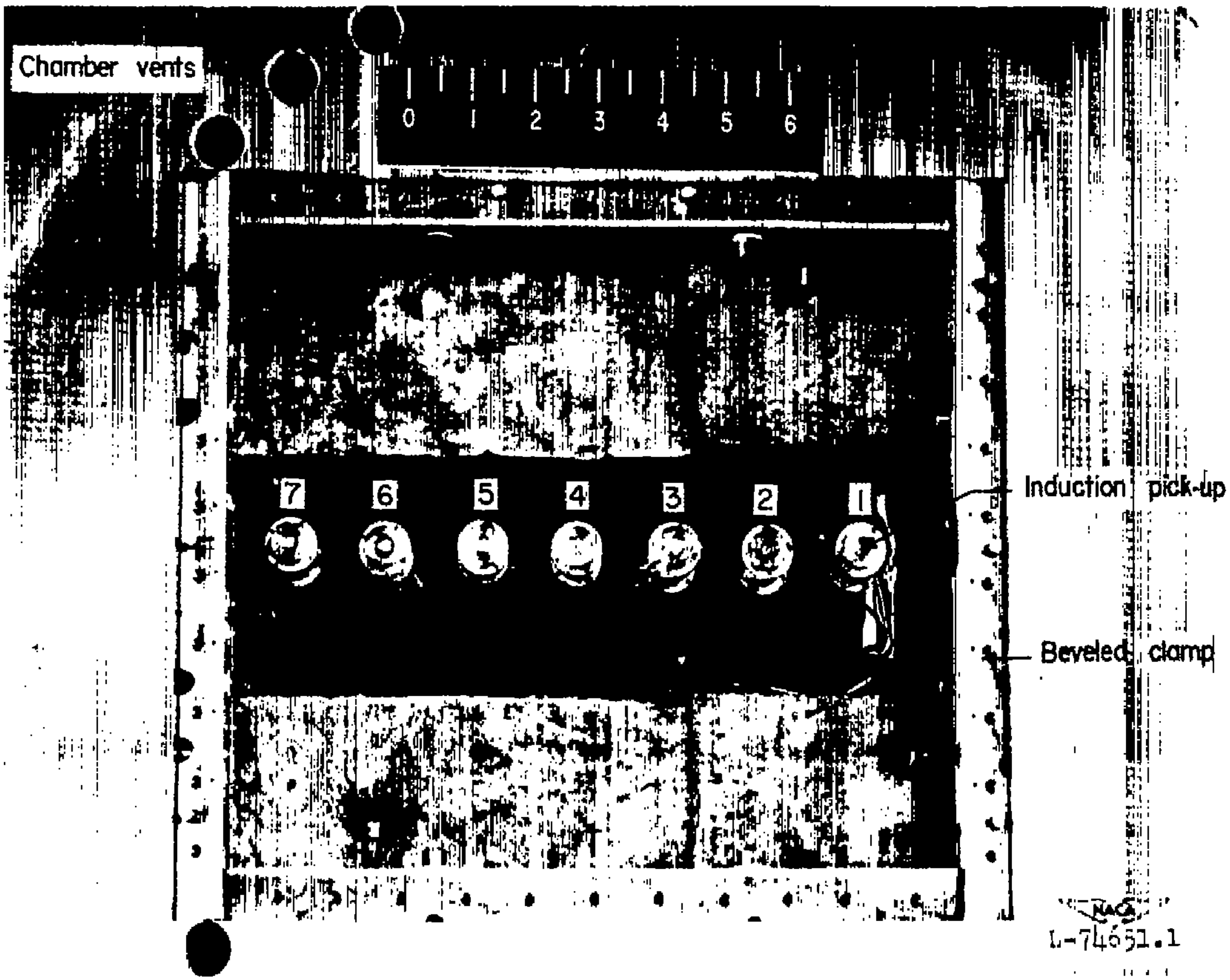


Figure 2.- Closeup view of the side-wall plate showing location of induction pickups and beveled clamps.

A Clamping bracket screws
B Tension screws
C Compression screws
D Tension screws with calibrated springs

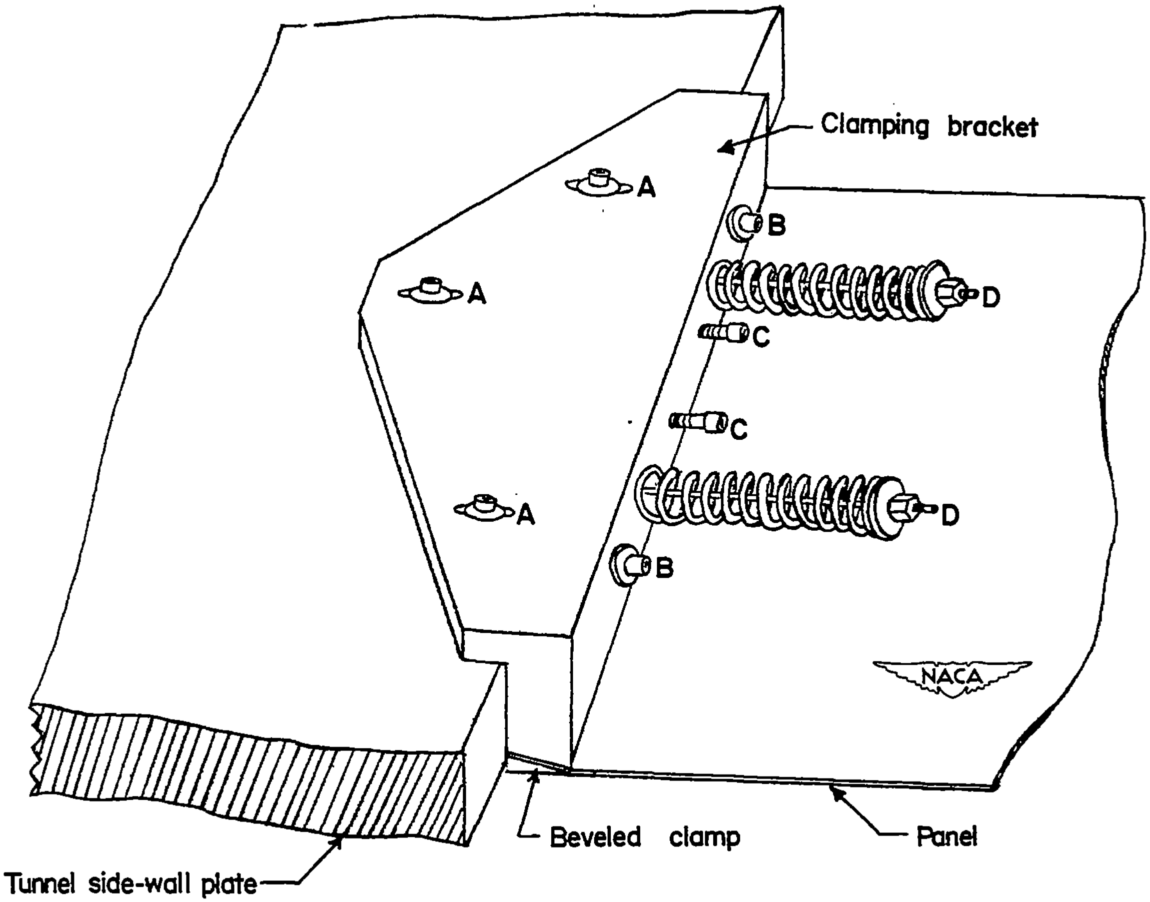
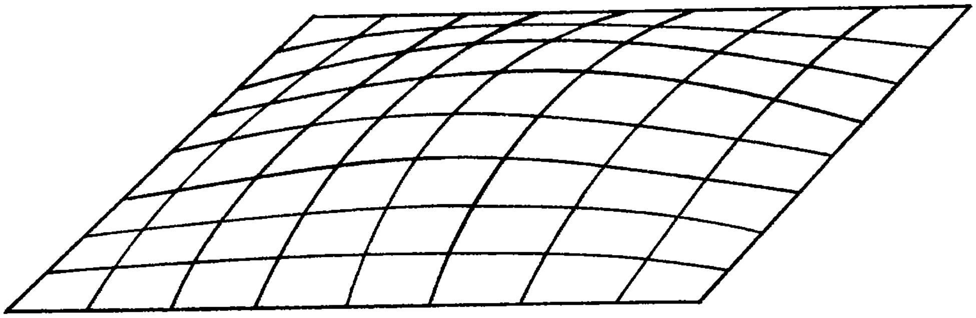
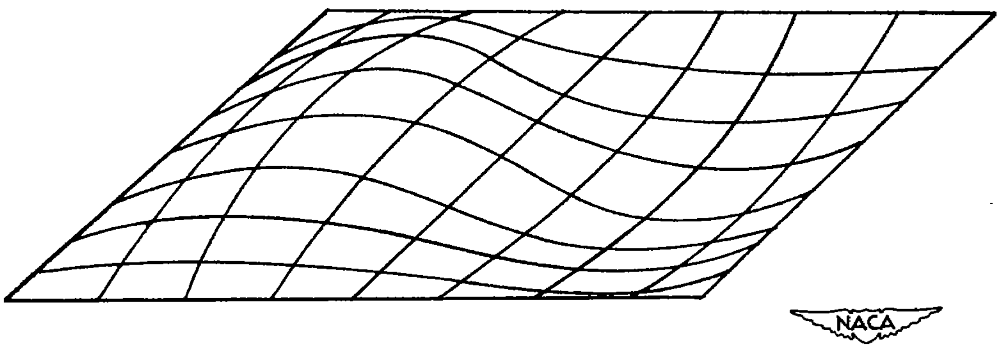


Figure 3.- Detail of the panel clamping arrangement.

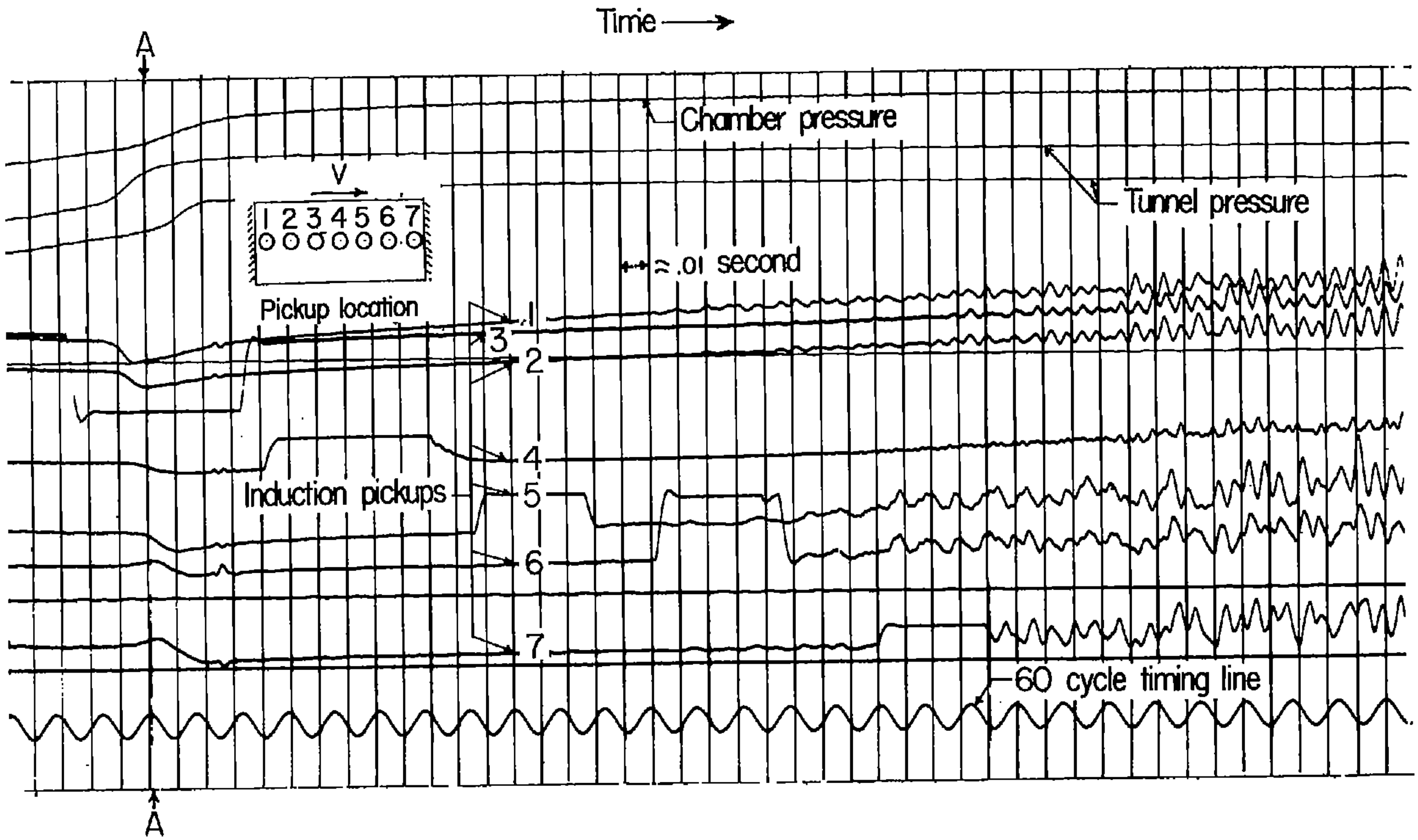


(a) Simple.



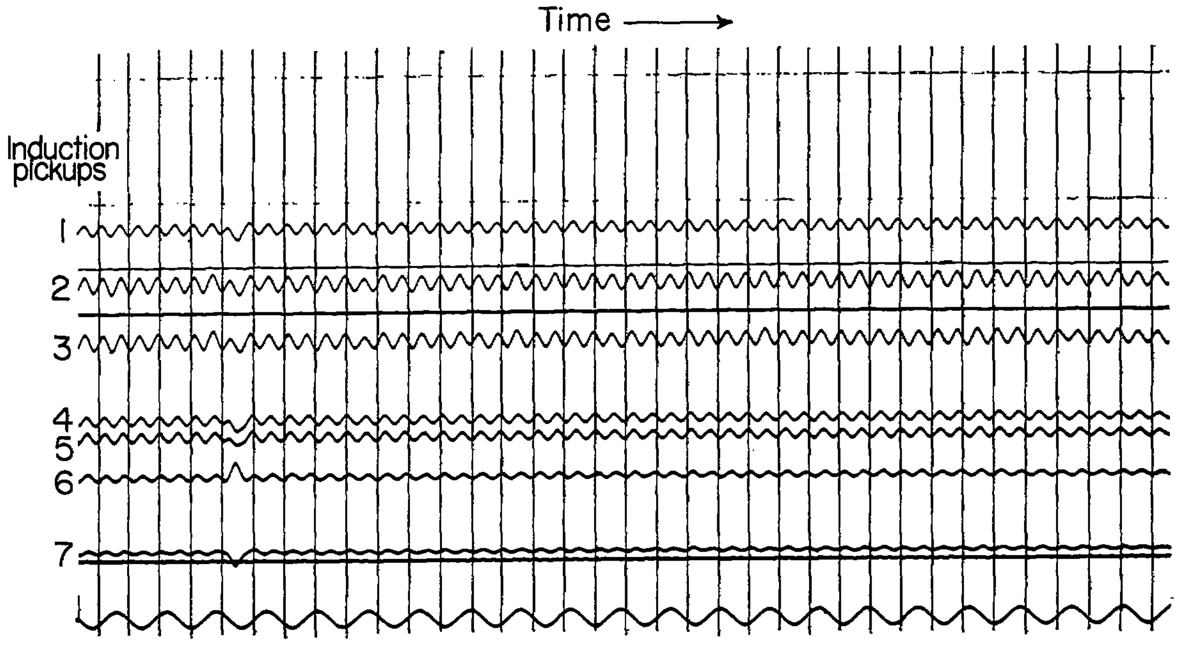
(b) Complex

Figure 4.- Illustration of simple and complex buckling of a panel fastened on four edges.

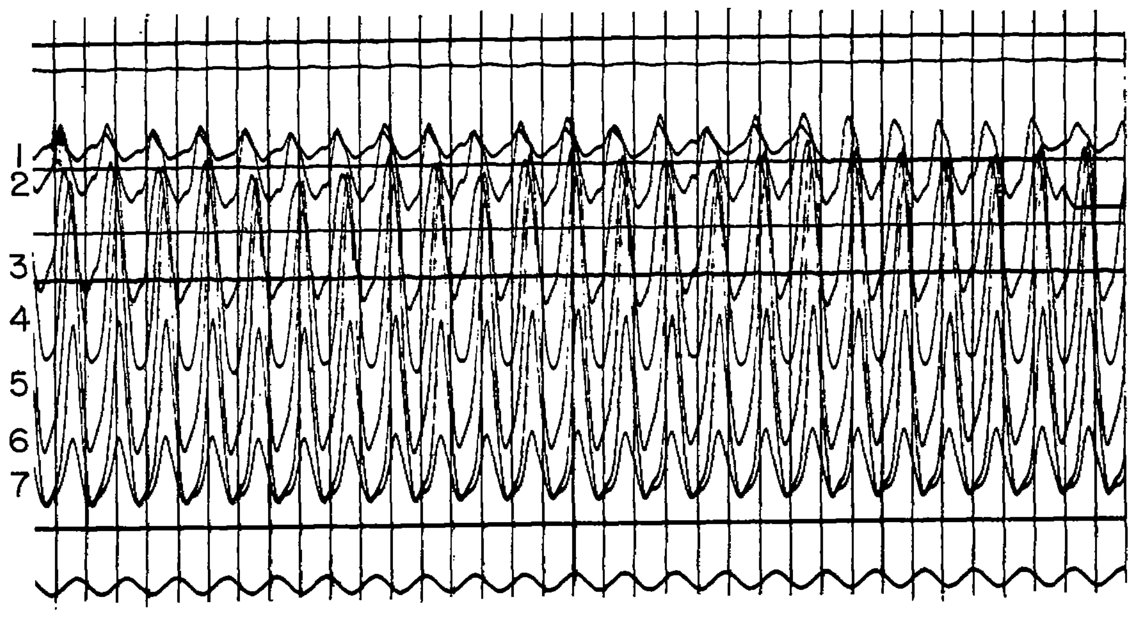


(a) Transient condition.

Figure 5.- Sample flutter records showing some of the various types of flutter modes obtained.

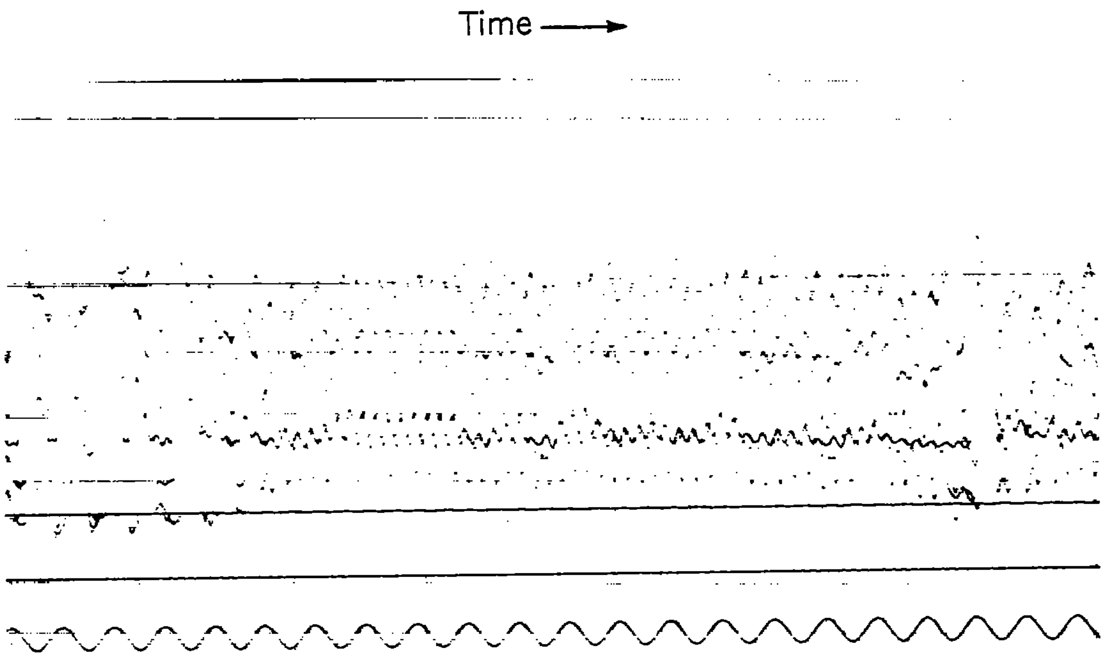


(b) Sinusoidal traveling wave.

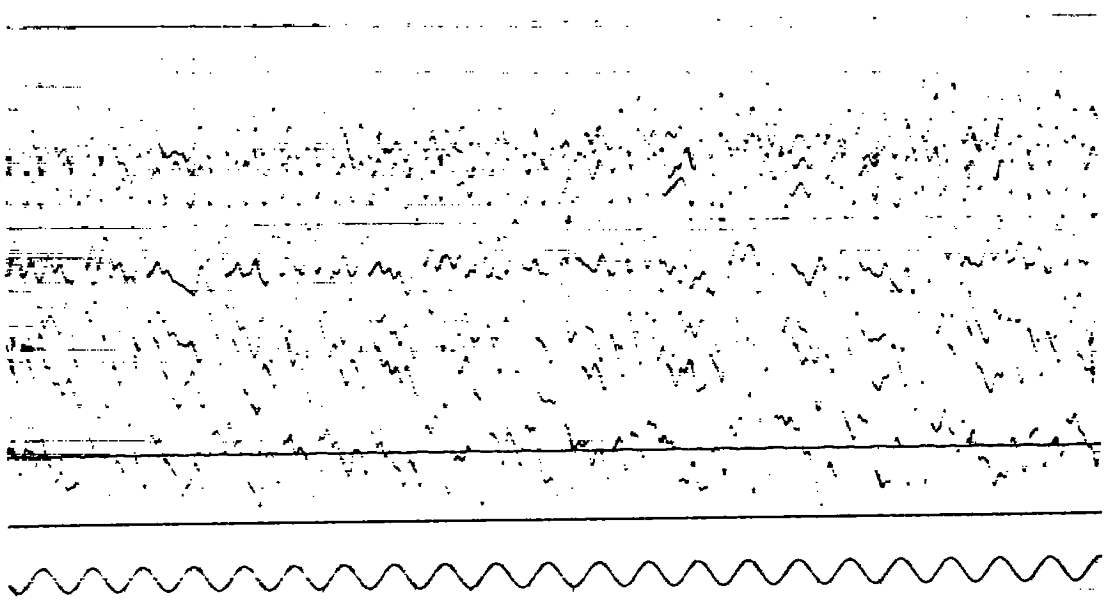


(c) "Oil can" type of oscillation.

Figure 5.- Continued.



(d) Erratic changes of mode shape.



(e) Irregular vibration.

Figure 5.- Concluded.

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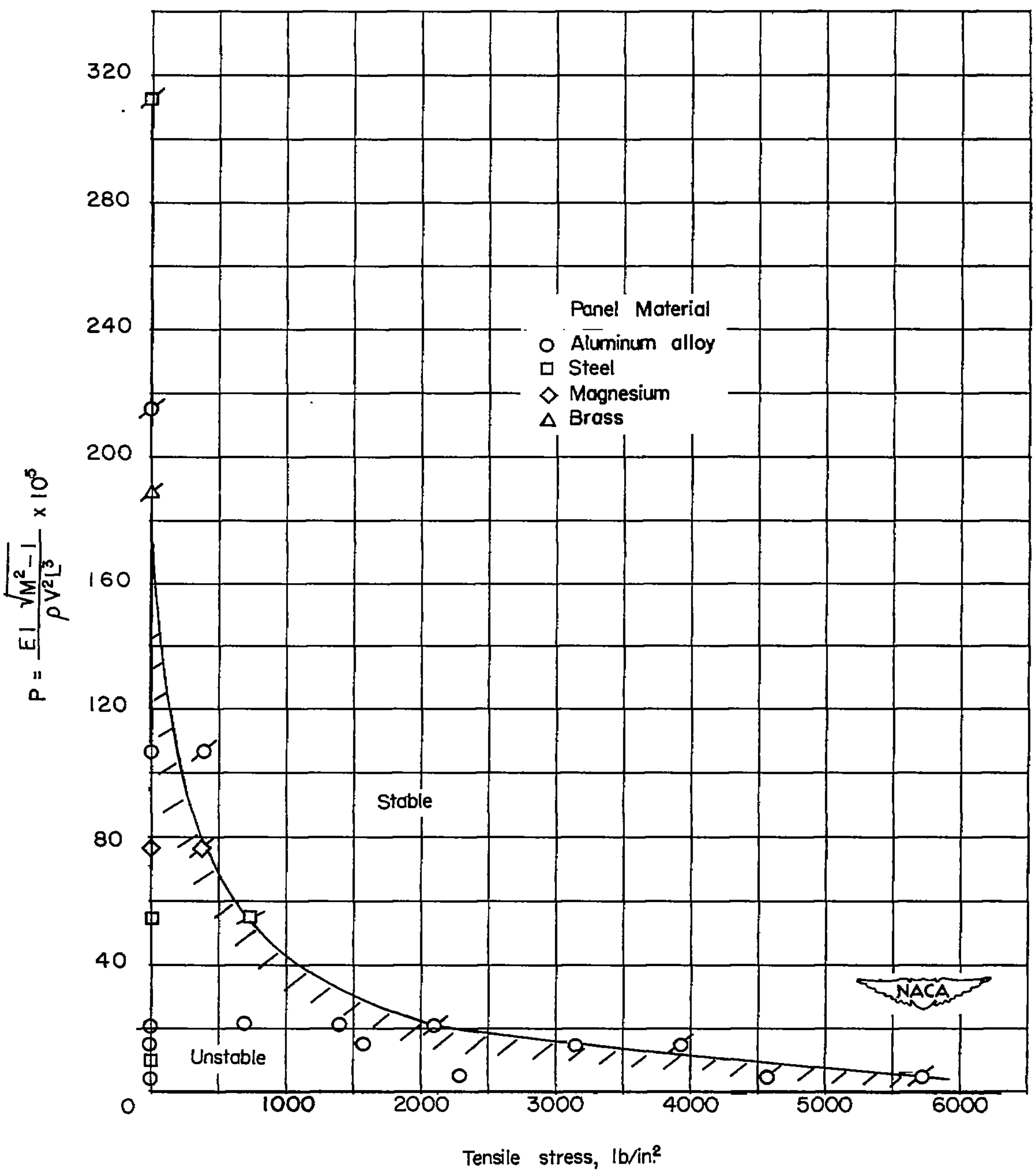


Figure 6.- Effect of tensile stress on the flutter of panels clamped front and rear. Symbols with flags indicate no flutter.

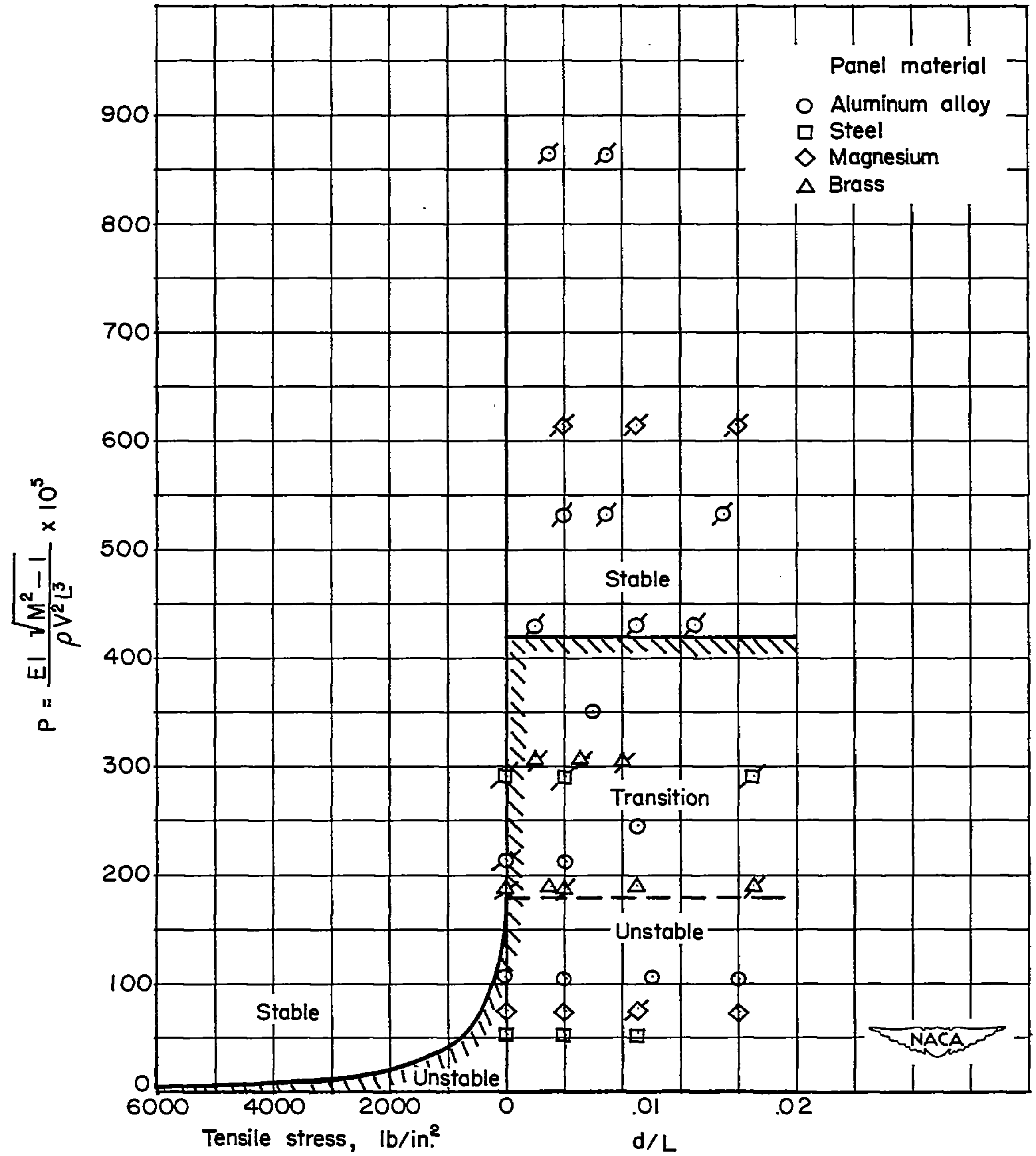
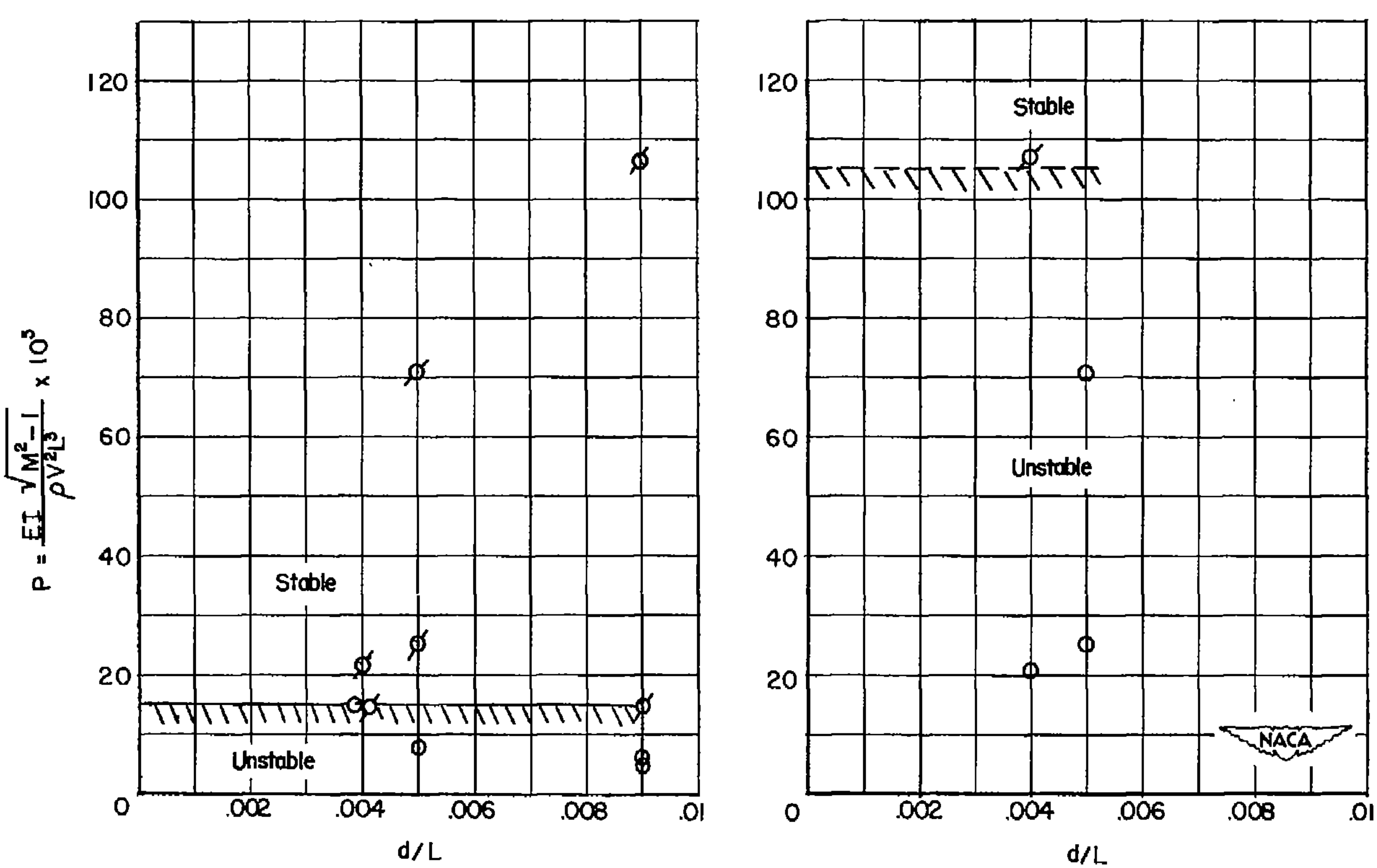


Figure 7.- Flutter results of buckled panels clamped front and rear. Symbols with flags indicate no flutter.



(a) Simple buckling.

(b) Complex buckling.

Figure 8.- Flutter results of buckled aluminum-alloy panels with four edges clamped. Symbols with flags indicate no flutter.

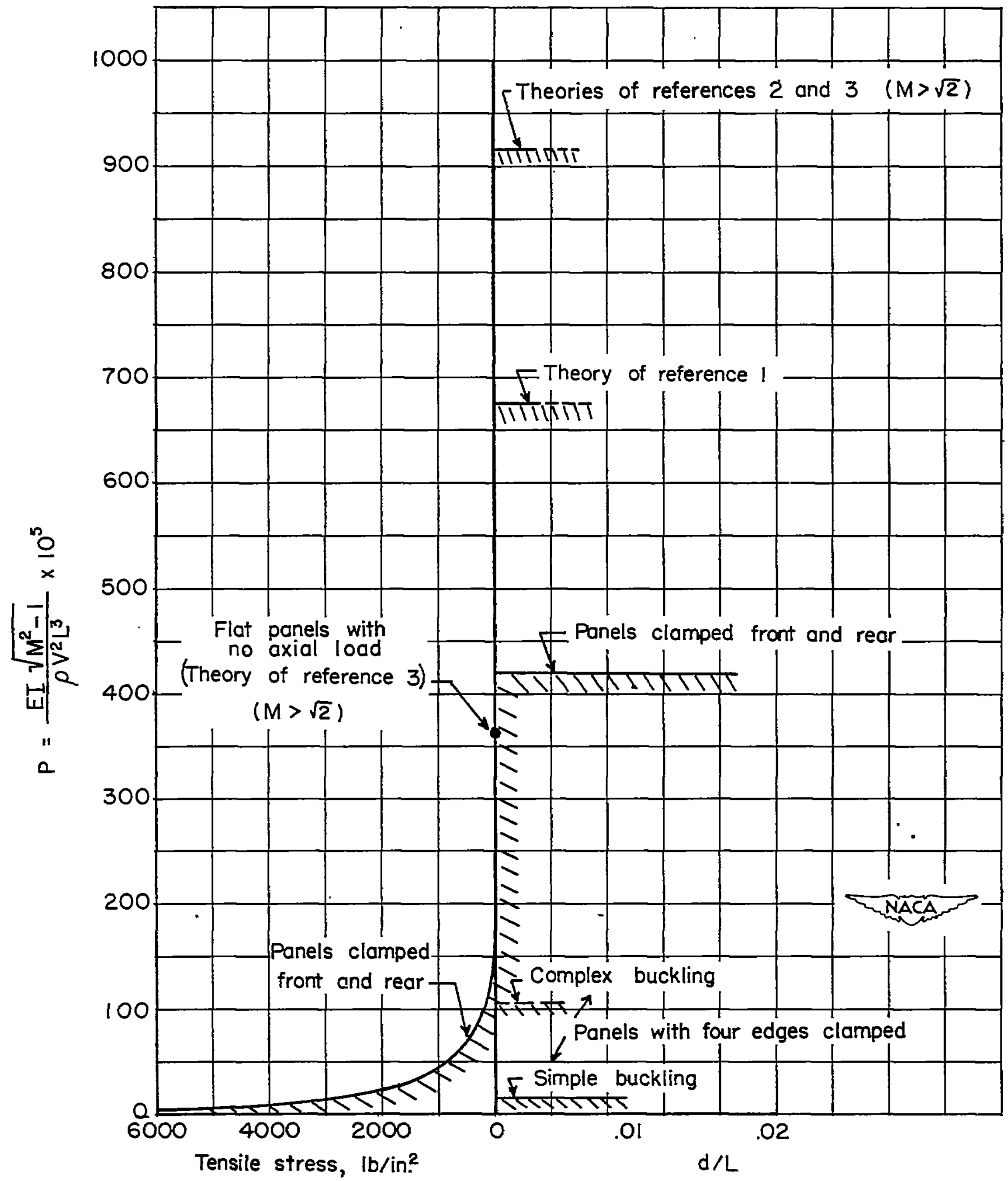


Figure 9.- Comparison of the critical values of the panel flutter parameter at M = 1.3.

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