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Experimental Transonic Flutter Characteristics of Two 72°-Sweep Delta-Wing Models

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SUMMARY

Transonic flutter boundaries are presented for two simple, 72°-sweep, low-aspect-ratio wing models. One model was an aspect-ratio-0.65 delta wing; the other model was an aspect-ratio-0.54 clipped-delta wing. Flutter boundaries for the delta wing are presented for the Mach number range of 0.56 to 1.22. Flutter boundaries for the clipped-delta wing are presented for the Mach number range of 0.72 to 0.95. Selected vibration characteristics of the models are also presented.

INTRODUCTION

Because highly swept, low-aspect-ratio delta-wing configurations are candidate planforms for use with hypersonic airplanes, there is considerable interest in understanding better the flutter characteristics of such configurations. A recent literature survey by Reed *et al*, reference 1, focused on the flutter characteristics of candidate hypersonic airplane configurations. This survey identified only a few papers presenting flutter data for delta wings. Interestingly, an earlier survey, reference 2, conducted about 25 years prior to the Reed survey, also found a general lack of published papers discussing delta-wing flutter. Although interest in the use of delta-wing configurations has, in general, increased over the years there apparently has not been much emphasis on flutter research for these types of configurations.

The present study, part of a much larger effort to provide a better understanding of delta-wing flutter characteristics throughout the Mach number range, was undertaken to determine the experimental transonic flutter characteristics of two simple delta-wing configurations. One was a 72°-sweep delta wing with a 3.0-percent-thick modified biconvex airfoil section. The other wing was a 72°-sweep clipped-delta wing which also had a 3.0-percent-thick modified biconvex airfoil section. Flutter data for the delta-wing model are presented for the Mach number range from 0.56 to 1.22. Flutter data for the clipped-delta-wing model are presented for the Mach number range of 0.72 to 0.95. The experimental results were obtained in the NASA Langley Research Center Transonic Dynamics Tunnel.

The information presented herein is intended to assist in the better understanding of the transonic flutter characteristics of highly swept, low-aspect-ratio configurations and to provide a data base for use in validating flutter analysis procedures applicable to such configurations. Although the content of this paper is essentially the same as that of reference 3, some additional material is included. The primary addition is some measured airfoil section contours of the wind-tunnel models.

SYMBOLS

b_r reference length, mean geometric semichord, ft

f_f flutter frequency, Hz

f_2 reference frequency, frequency of second natural mode, Hz

M Mach number

m total model mass outboard of cantilever root, slugs

q dynamic pressure, $1/2\ \rho V^2$, lb/ft^2

R_N Reynolds number, based on b_r

v reference volume, volume of circumscribed cone or conical frustum, ft^3

V flutter velocity, fps

V_I velocity index parameter, $V/(2\pi f_2 b_r \sqrt{\mu})$

μ mass-ratio parameter, $m/(\rho v)$

ρ density, $slugs/ft^3$

APPARATUS AND PROCEDURE

Wind Tunnel

The wind-tunnel tests were conducted in the Langley Transonic Dynamics Tunnel (TDT). This wind tunnel is used almost exclusively for aeroelastic testing. It is of the single return type, and its speed and stagnation pressure are continuously controllable over a range of Mach numbers from near zero to about 1.2 and a range of pressures from near vacuum to about one atmosphere. Either air or a heavy gas (R-12) can be used as the test medium. Only R-12 was used for the present study. (The test medium was actually a mixture of about 99 percent R-12 and one percent air.) The tunnel is equipped with four quick-opening bypass valves which can be operated to reduce rapidly test-section dynamic pressure and Mach number when flutter occurs.

Models

Geometry.- Two model configurations were tested. The first model was a 72°-sweep, aspect-ratio-0.65 delta wing with a nominal 3.0-percent-thick modified biconvex airfoil section. This model had a planform area of 260 in^2 and a weight of 2.43 lbs. The second model was a 72°-sweep, aspect-ratio-0.54 clipped delta wing with a nominal 3.0-percent-thick modified biconvex airfoil section. This model had a planform area of 252.6 in^2 and a weight of 2.36 lbs. A photograph of the delta-wing model is presented in figure 1. Sketches of both configurations are presented in figure 2.

Construction.- The models were constructed of an 0.051-inch-thick aluminum alloy plate (2024 T3) that was covered with balsa wood. The aluminum plate was extended four inches inboard of the model root to provide a means for clamping the model. (The clipped-delta wing was obtained by removing the outermost 2.2 inches of the span of the delta wing so there was actually only one model structure.) The balsa wood was shaped to provide the desired airfoil section. The grain of the balsa wood was oriented perpendicular to the aluminum plate to minimize the effect of the wood on the overall stiffness of the model. The aluminum plate was rounded along its edges. The balsa wood was faired into these rounded edges to provide a smooth aerodynamic contour. This rounding of the edges produced a modified biconvex airfoil section. (An unmodified biconvex airfoil section has sharp edges.) Some measurements of the upper-surface airfoil contour at three spanwise stations are presented in table I. Although they were not measured, it is believed that the contours of the lower surface were similar to the contours of the upper surface. If the contours are identical, then the total thickness would be twice the values given in table I. The measured airfoil thicknesses were larger than the theoretical thicknesses of a 3.0-percent-thick biconvex airfoil section. The measured values were typically about 0.018 in. larger.

Instrumentation.- The aluminum plate was instrumented with two four-arm resistance-wire strain gage bridges. One bridge was oriented to be primarily sensitive to strains produced by spanwise bending deflections whereas the other bridge was oriented to be primarily sensitive to strains produced by torsional, or chordwise, deformations.

Vibration Characteristics.- The first five natural frequencies and corresponding nodal patterns were measured for both models. To obtain these measurements the models were excited by using a variable frequency pulsating air jet. The nodal patterns were obtained by observing the gravitation of sand sprinkled on the surface of the vibrating models to the node lines (locus of points of no displacement). Similar node lines and frequencies for the first three modes of the delta-wing model were determined from transfer functions that were obtained by using an impact hammer, small piezoelectric accelerometers, and a digital signal analyzer. The measured node lines and natural frequencies are presented in figure 3 for the delta-wing model and in figure 4 for the clipped-delta-wing model. (There appeared to be some node lines near the apex formed by the leading edge and the root chord for some modes, but the exact locations of these lines were not obtained because the amplitude of the vibratory motion was not large enough to displace the sand.) In general, the characteristics of the modes were similar for the two models. For each configuration the first mode had a node line along the root and was primarily a spanwise bending mode, and the second mode was primarily a chordwise bending mode that had a single node line perpendicular to the root chord. The third mode for the delta-wing model was a combination of significant chordwise and spanwise bending and had a nodal pattern similar to the fourth mode for the clipped-delta-wing model. The fourth mode for the delta-wing model was primarily chordwise bending and appears to correspond to the third mode of the clipped-delta-wing model. The fifth mode for both configurations was primarily a chordwise bending mode with three node lines extending out spanwise from the root. The structural damping ratios of the various modes ranged from about 0.02 to 0.04.

Mounting.- For testing, the models were clamped along the entire root chord (cantilever root condition) by using a pair of steel blocks that were in turn attached to a remotely controlled turntable in the wind-tunnel wall so that the angle of attack could be changed during testing. A splitter plate arrangement was used so that the model root chord was about eight inches off the wind-tunnel wall, thus putting the model root outside the wall boundary layer.

Test Procedure

The determination of the flutter boundary for the delta-wing model is described in the following discussion. Reference to the schematic diagrams in figure 5 will be helpful in understanding the following narrative description of the procedure.

The determination of the transonic minimum flutter point and points at lower Mach numbers is described first. This procedure is illustrated in figure 5(a). With the tunnel stagnation pressure set at a very low value the tunnel speed was increased by gradually increasing the fan rpm until the maximum Mach number available for that pressure, about M=1.2, was reached. The tunnel speed was then decreased to a subsonic value and increasing the tunnel pressure was begun by slowly adding R-12. With the pressure continuing to be increased, the speed was slowly varied over a range of Mach numbers until a flutter point was encountered. (This procedure was intended to ensure that the first flutter point obtained was, or at least was very near to, the transonic minimum point.) When this flutter point was obtained the tunnel speed was decreased to a lower value and the addition of R-12 stopped. With the tunnel at this lower speed which is a condition well removed from flutter, the tunnel pressure was increased by a prescribed amount after which the tunnel speed was slowly increased until another flutter point was obtained. The tunnel speed was again reduced, followed by an increase in pressure, and then another increase in speed until another flutter condition was encountered. This sequence of speed and pressure changes was repeated several times until the desired flutter boundary for conditions below the transonic minimum was obtained.

A somewhat similar sequence of step-like increases in speed and pressure was used to obtain the flutter points at Mach numbers above the transonic minimum value. This procedure is illustrated in figure 5(b). In these instances, the tunnel speed was held constant while the pressure was increased until a flutter condition was encountered. When flutter occurred, the tunnel speed was increased to a safe no-flutter condition after which the pressure was increased again until another flutter point occurred, and so on.

In all instances, as tunnel speed and/or pressure were being changed the model response was observed visually by the test engineer. The output of the strain gage bridges displayed on a strip chart recorder were monitored by another engineer. In addition, the mean values of the strain gage signals, proportional to static load, were displayed on a digital readout. The model was continually trimmed to the zero lift condition by adjusting the angle of the remotely controlled turntable. When the observations indicated that a flutter condition had been reached, the wind-tunnel flow conditions were recorded after which the tunnel speed was rapidly reduced. In addition, the strain gage output signals were monitored using a digital signal analyzer to obtain the frequency content of the model response as flutter was approached.

Natural frequencies of each model were checked periodically during testing to ensure that the model had not been damaged. No damage was detected.

RESULTS AND DISCUSSION

The basic experimental flutter results are presented in table II(a) and figure 6 for the delta-wing model and in table II(b) and figure 7 for the clipped-delta-wing model. The data presented in the figures are the variations with Mach number of the mass-ratio parameter μ, of the flutter-frequency ratio f_f/f_2, and of the flutter velocity index V_I. The mass-ratio parameter μ is defined as the ratio of the total model mass to the mass of a representative surrounding volume of test medium. The volume used here is that contained in the cone for the delta wing and in the conical frustum for the clipped-delta wing generated by revolving each wing chord about its midpoint. These volumes were 3.151 ft^3 (5445 in^3) for the delta wing and 3.136 ft^3 (5419 in^3) for the clipped-delta wing. The second measured natural frequency was used as the reference frequency. The mean geometric semichord was used as the reference length for each model, 0.833 ft (10.0 in.) for the delta wing and 0.975 ft (11.7 in.) for the clipped delta wing. The flutter-speed-index curves represent stability boundaries with the stable region below the curve. This parameter depends on the physical properties of the model, in particular the stiffness, and is proportional to the square root of the dynamic pressure.

No unusual trends are shown by the data presented for either configuration. The flutter results for the delta wing for which a more or less complete transonic boundary was obtained are similar to those usually observed, namely, a gradual decrease in flutter speed to a minimum value near M=1.0 as the subsonic Mach number is increased followed by an increase in flutter speed as the Mach number is increased to supersonic speeds. The transonic dip in the flutter boundary for the delta wing model is very shallow which is characteristic of the flutter behavior of low-aspect-ratio wings. Sufficient flutter data were not obtained for the clipped-delta-wing model to define the transonic minimum flutter speed nor to determine the characteristics of the supersonic increase in flutter speed. It is believed, however, that because of the test procedure followed the flutter point at M=0.95 is close to the transonic minimum condition.

A comparison of the flutter boundaries of the two configurations can be made by examining the data presented in figure 8. At the top of the figure the variation of the flutter dynamic pressure with Mach number is given. These data show that the flutter boundary for the clipped-delta-wing model is slightly higher than that for the delta wing. The data in the lower portion of the figure, variations of V_I with M, show that the flutter boundary for the clipped-delta-wing model is slightly lower than that of the delta-wing model.

A few comments about the nature of the flutter that was observed are in order. As the flutter boundary was approached the models exhibited long bursts of lowly damped oscillations. The flutter condition itself was in the nature of a limited amplitude oscillation in that it did not exhibit the characteristic rapid increase in vibration amplitude often observed when the flutter boundary is penetrated. Consequently, it was necessary to exercise extreme care in determining the flutter conditions in a consistent manner. Within the usual accuracy associated with flutter testing, it is believed that the flutter points for Mach numbers less than the transonic minimum value represent little or no penetration into the flutter region.

Furthermore, it is believed that the supersonic boundary points for the delta-wing model represent a small, consistent penetration into the flutter region. Consequently, the actual boundary is believed to be slightly below that shown in figures 6 and 8 for supersonic Mach numbers.

CONCLUDING REMARKS

Experimental results have been presented for two simple, cantilever mounted models with leading-edge sweep of 72°. One model was an aspect-ratio-0.65 delta wing; the other model was an aspect-ratio-0.54 clipped-delta wing. No unusual trends were observed in the flutter characteristics. The observed trends of the flutter characteristics with Mach number were similar to those observed in the past for many other configurations.

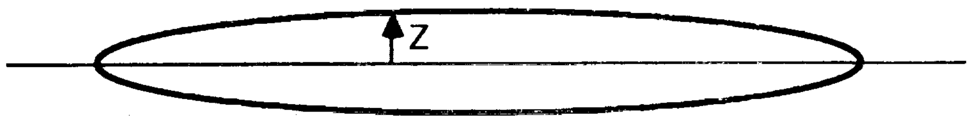
REFERENCES

1. Reed, W. H., III; Hanson, P. W.; and Alford, W. J., Jr., "Assessment of Flutter Model Testing Relating to the National Aero-Space Plane," NASP Contractor Report 1002, July 1987.

2. Harris, G., "Flutter Criteria for Preliminary Design," Bureau of Naval Weapons Contract NOw 61-1072c, Final Engineering Report 2-53450/3R467, LTV/Chance Vought Corp., Sept. 1963.

3. Doggett, Robert V., Jr.; Soistmann, David L.; Spain, Charles V.; Parker, Ellen C.; and Silva, Walter A.: Some Experimental Transonic Flutter Characteristics of Two 72°-Sweep Delta-Wing Models. NASP Technical Memorandum 1079, Aug. 1989.

TABLE I. - MEASURED AND DESIGN UPPER-SURFACE AIRFOIL CONTOURS FOR THE DELTA-WING MODEL



Fraction of local chord	Measured and (design) thickness Z in inches at fraction semispan= 0.000	0.308	0.615
0.0125	0.048 (0.030)	0.039 (0.020)	-
.0750	.187 (.167)	.135 (.115)	-
.1500	.324 (.306)	.231 (.211)	0.137 (0.118)
.2250	.438 (.419)	.306 (.290)	-
.3000	.522 (.504)	.367 (.350)	.214 (.194)
.3750	.581 (.563)	.403 (.390)	-
.4500	.613 (.594)	.426 (.411)	.243 (.228)
.5250	.619 (.599)	.434 (.415)	-
.6000	.596 (.576)	.417 (.399)	-
.6750	.546 (.527)	.381 (.365)	-
.7500	.470 (.450)	.330 (.312)	-
.8250	.365 (.347)	.260 (.240)	-
.9000	.235 (.216)	.170 (.150)	-
.9750	.079 (.059)	.060 (.040)	-
.9850	.050 (.030)	-	-

TABLE II.- FLUTTER RESULTS[1]

(a) Delta-Wing Model

M	q	V	ρ	R_N	f_f	f_f/f_2	μ	V_I
0.56	197.0	280.7	0.004873	4.35×10^6	35.7	0.781	4.91	0.529
.57	204.5	286.7	.004850	4.42×10^6	35.6	.779	4.94	.539
.70	189.2	350.5	.003030	3.38×10^6	34.0	.744	7.90	.521
.78	191.4	388.3	.002504	3.11×10^6	33.2	.726	9.56	.525
.85	199.0	423.3	.002192	2.99×10^6	32.0	.700	10.93	.535
.88	192.7	434.6	.002015	2.84×10^6	31.6	.691	11.89	.527
.89	195.8	440.9	.001991	2.82×10^6	32.4	.708	12.03	.531
.93	185.5	460.1	.001733	2.58×10^6	30.0	.656	13.82	.517
.95	174.0	-	-	-	28.8	.630	-	.498
.96	176.1	476.3	.001537	2.37×10^6	28.6	.625	15.58	.504
1.04	214.2	511.1	.001617	2.72×10^6	29.1	.637	14.81	.556
1.08	229.9	529.7	.001619	2.82×10^6	31.5	.689	14.79	.576
1.10	248.4	543.4	.001662	2.97×10^6	30.9	.676	14.41	.598
1.14	260.3	559.1	.001645	3.04×10^6	-	-	14.56	.612
1.19	277.0	585.1	.001599	3.09×10^6	32.6	.713	14.98	.632
1.22	288.6	602.6	.001572	3.12×10^6	32.9	.720	15.24	.645

[1]The values of ρ, V, and q given in the table were independently calculated using measured wind-tunnel total pressure, static pressure, total temperature, and percent of heavy gas in the heavy-gas/air mixture. Although each individual value represents the best estimate of that particular quantity, it should be noted that the values of q given are not exactly equal to the product $1/2\rho V^2$ primarily because of small errors introduced into the independent calculations by inaccuracies in determining some thermodynamic properties of the heavy-gas/air mixture. The values of V_I were calculated using the individual values of ρ and V except in the one instance for the delta wing at M=0.95 where q was used.

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TABLE II.- Concluded.

(b) Clipped-Delta-Wing Model

M	q	V	ρ	R_N	f_f	f_f/f_2	μ	V_I
0.72	225.5	360.1	0.003415	4.57×10^6	-	-	6.84	0.497
.75	221.3	377.0	.003064	4.30×10^6	-	-	7.63	.493
.85	220.8	424.9	.002413	3.85×10^6	-	-	9.69	.493
.90	214.1	447.9	.002108	3.56×10^6	30.0	0.664	11.08	.486
.95	213.9	472.1	.001896	3.40×10^6	28.7	.635	12.33	.486

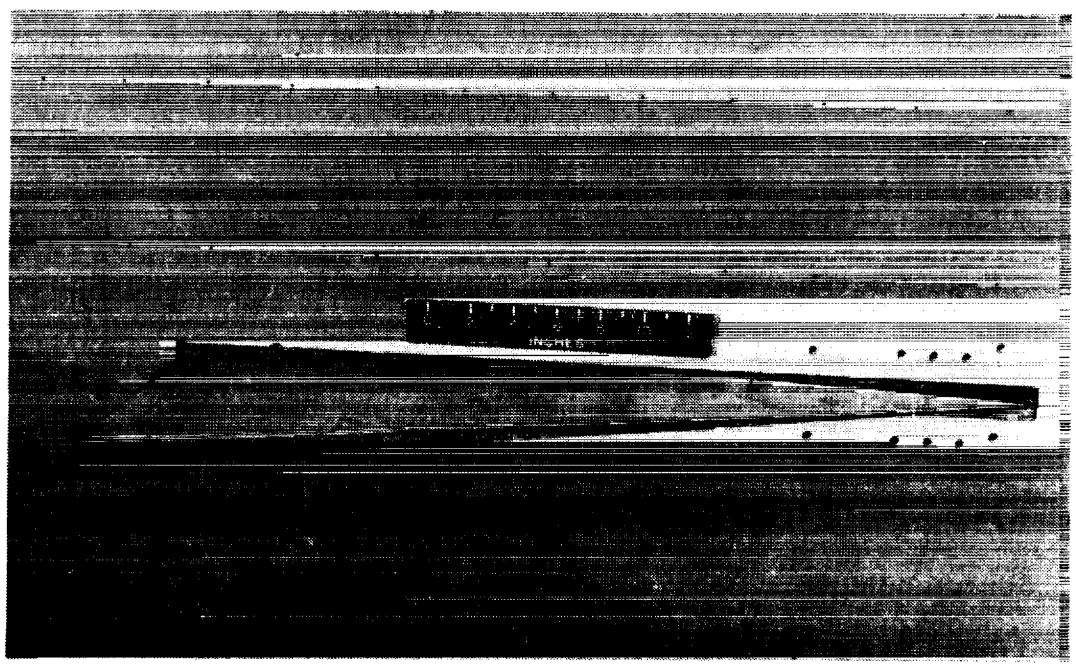


Figure 1.- Photograph of delta-wing model.

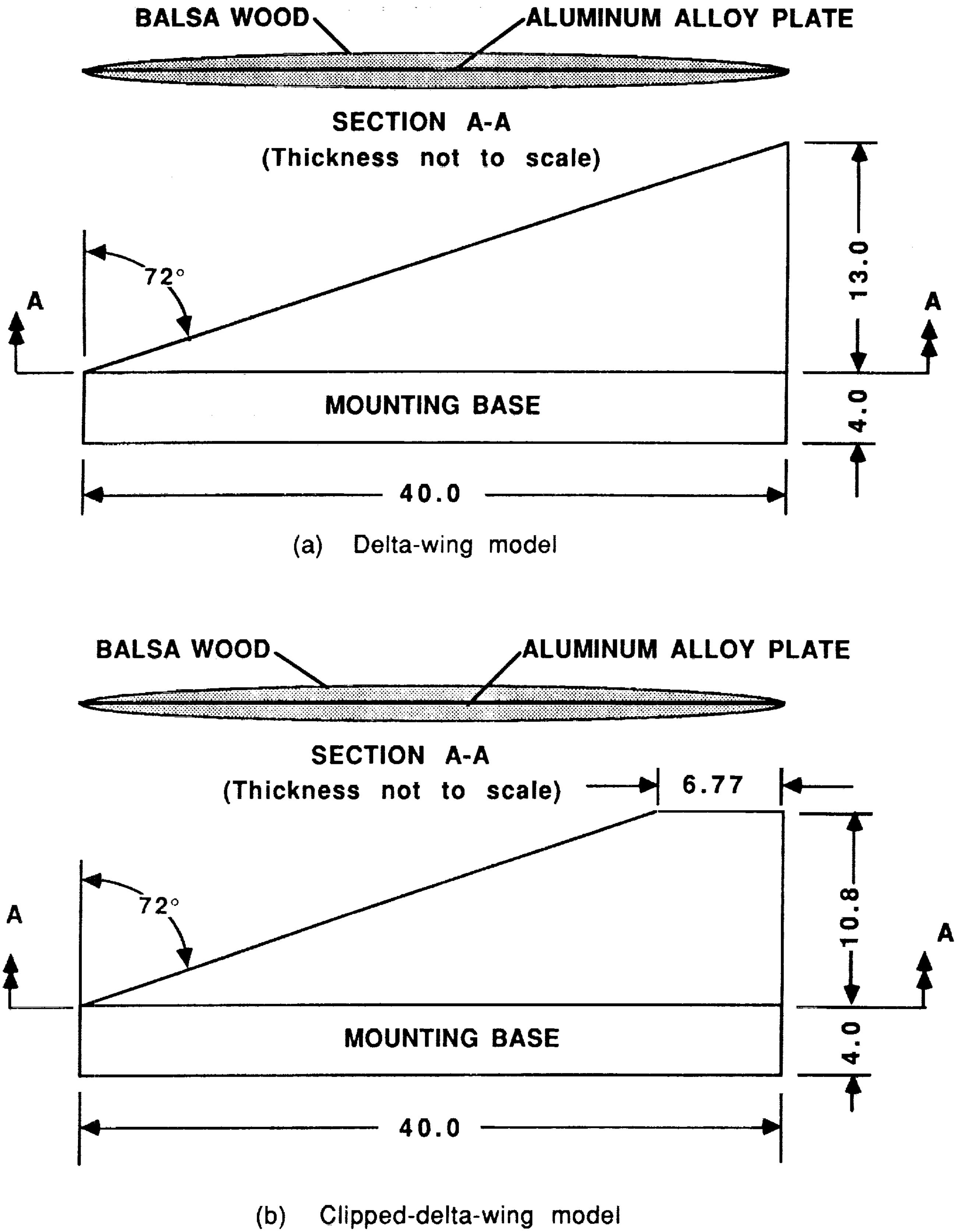


Figure 2.- Model geometry. Linear dimensions are in inches.

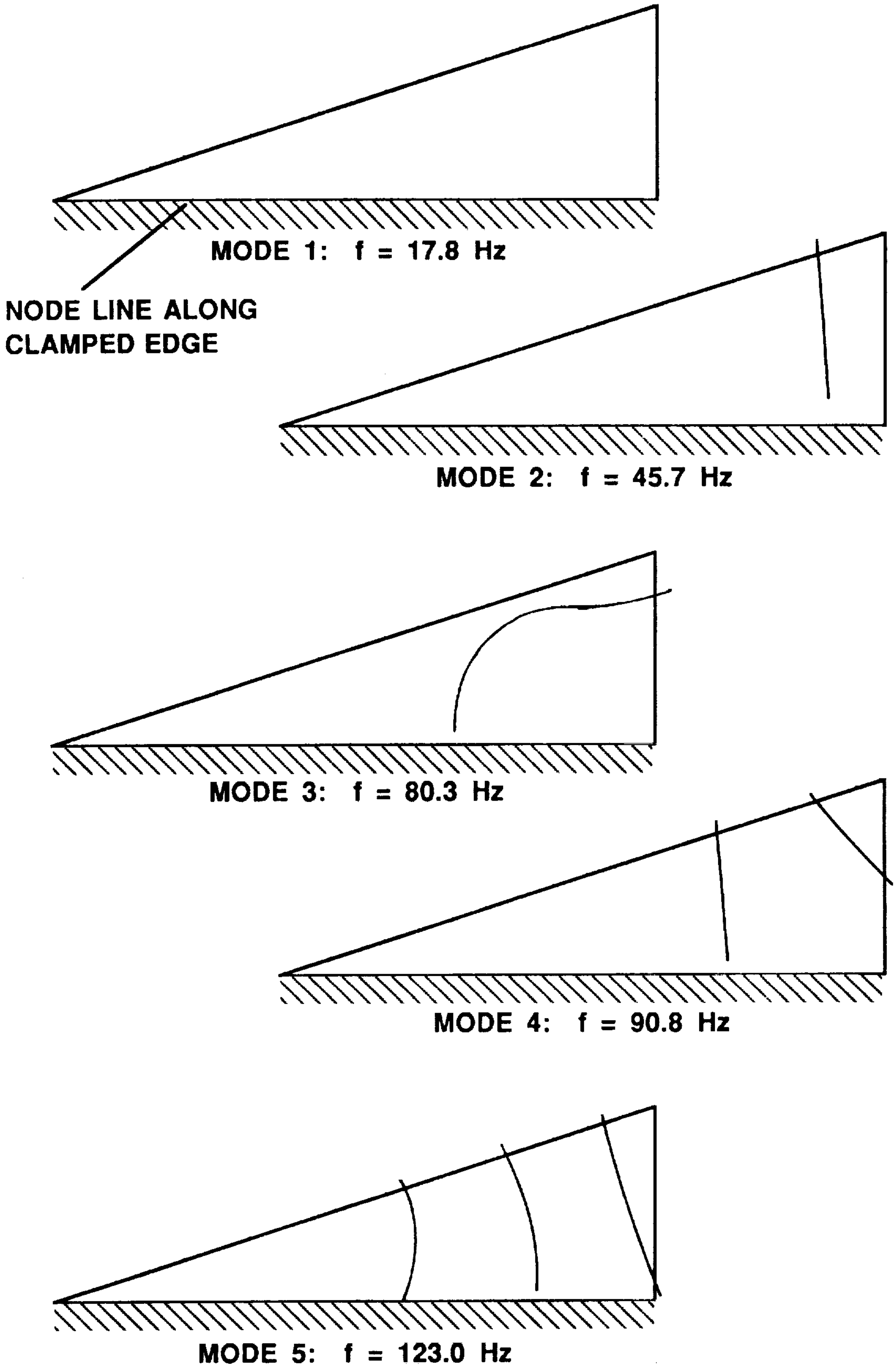


Figure 3.- Natural frequencies and node lines for delta-wing model.

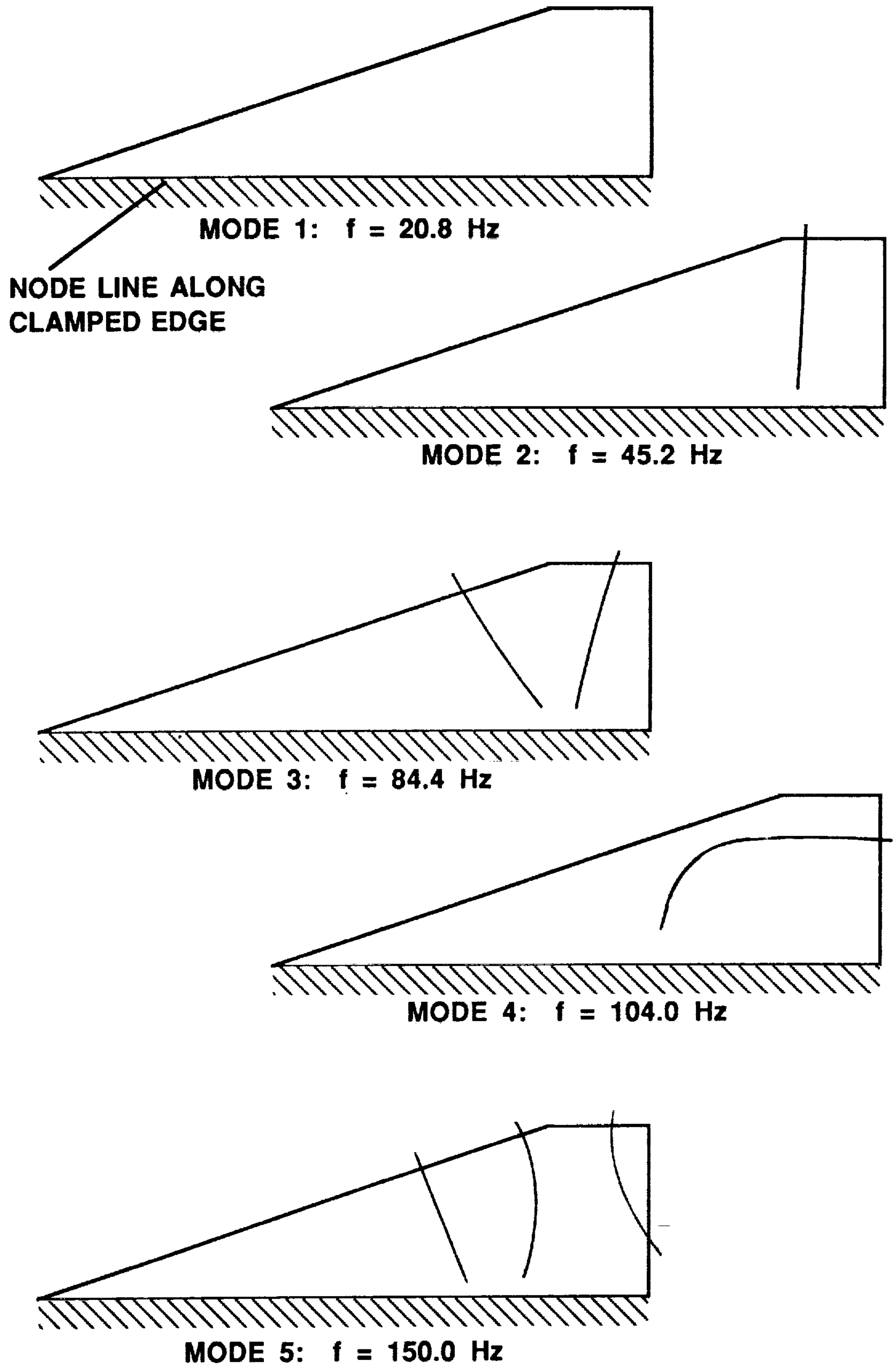
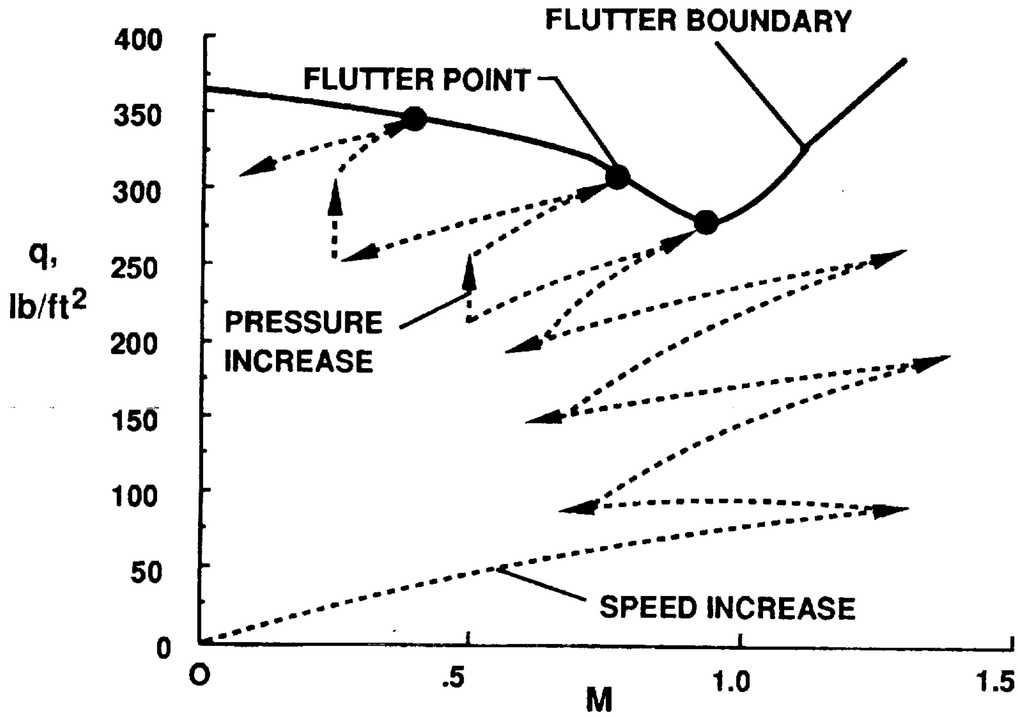
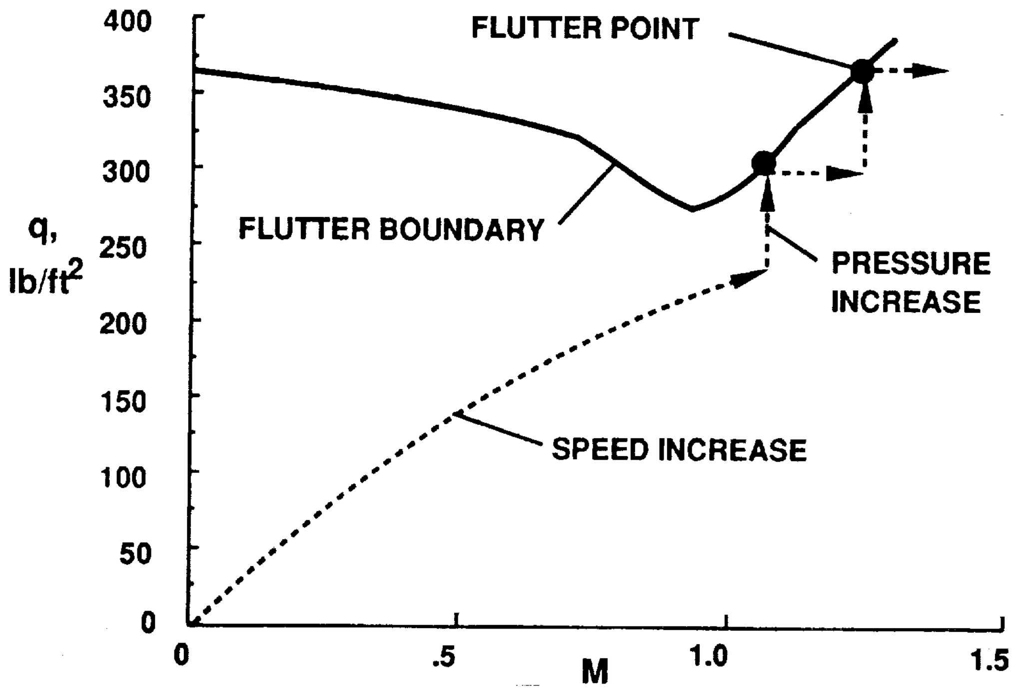


Figure 4.- Natural frequencies and node lines for clipped-delta-wing model.

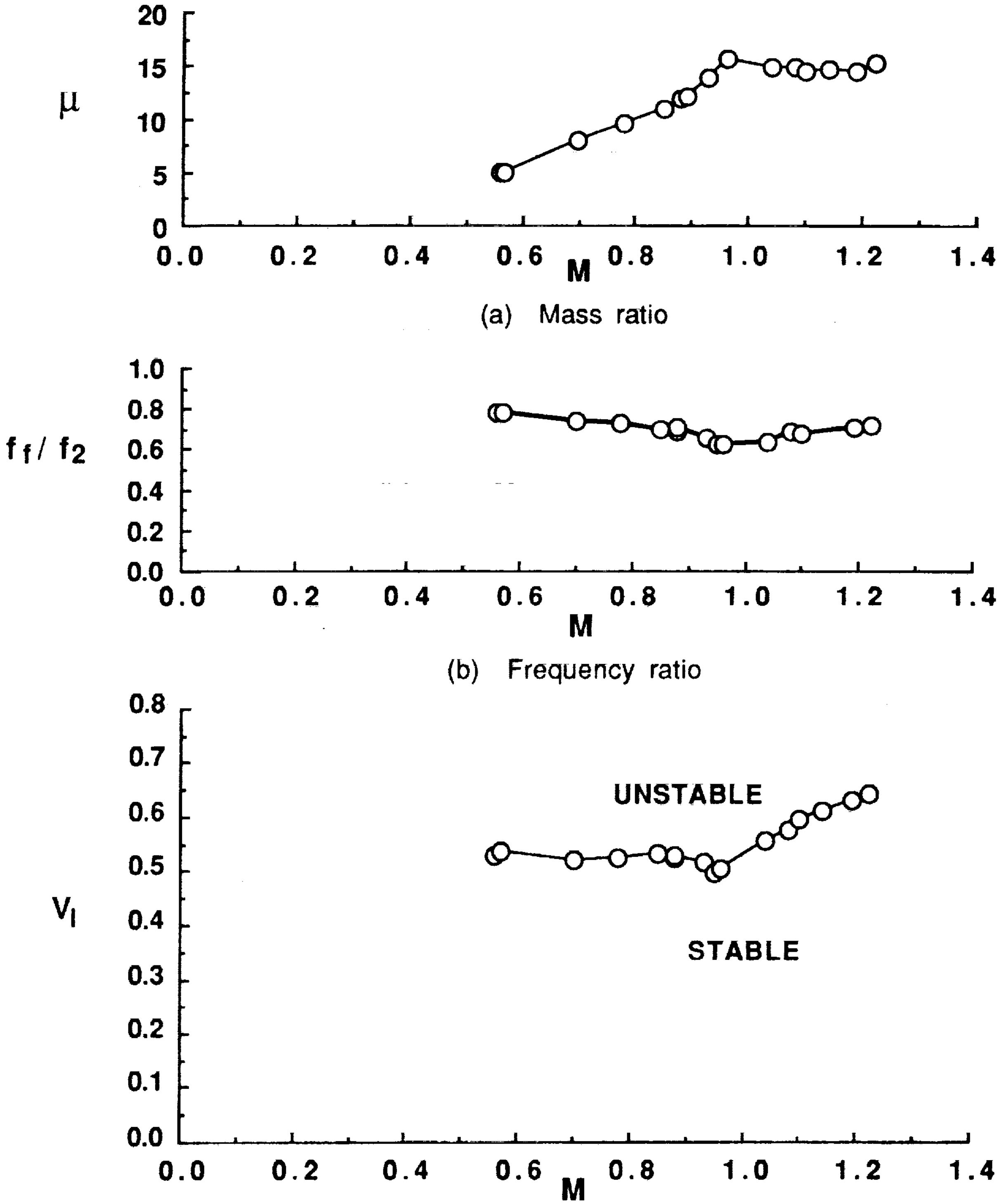


(a) Transonic minimum and lower Mach number points.



(b) Points at Mach numbers above transonic minimum.

Figure 5.- Schematic diagrams of flutter test procedure.



(a) Mass ratio

(b) Frequency ratio

(c) Velocity index

Figure 6.- Flutter results for delta-wing model.

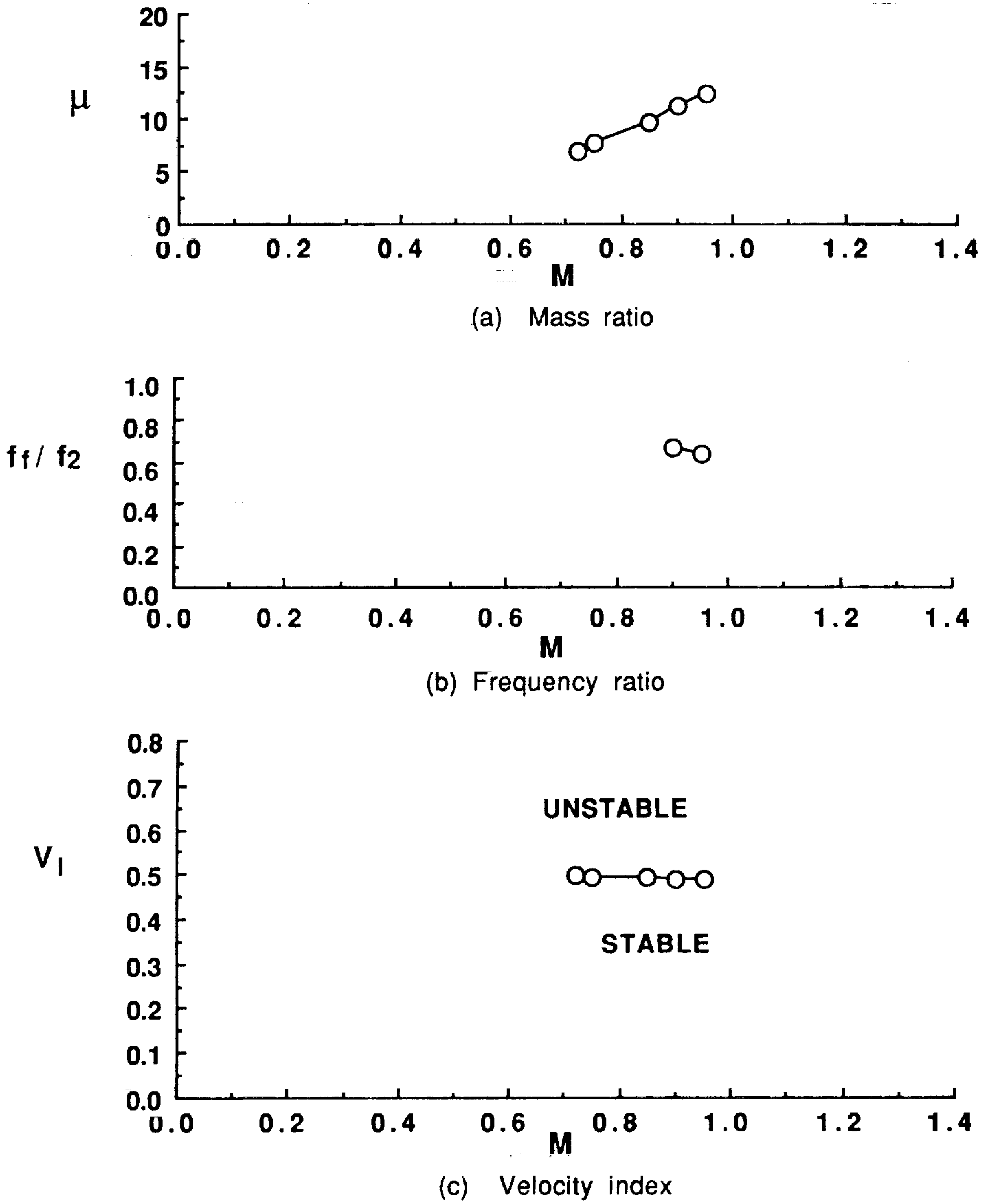
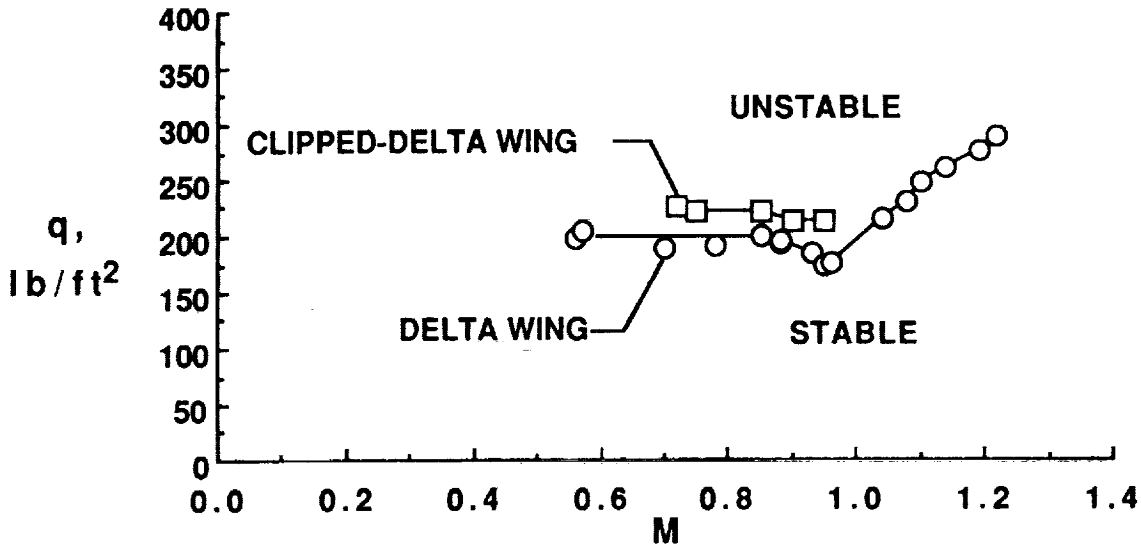
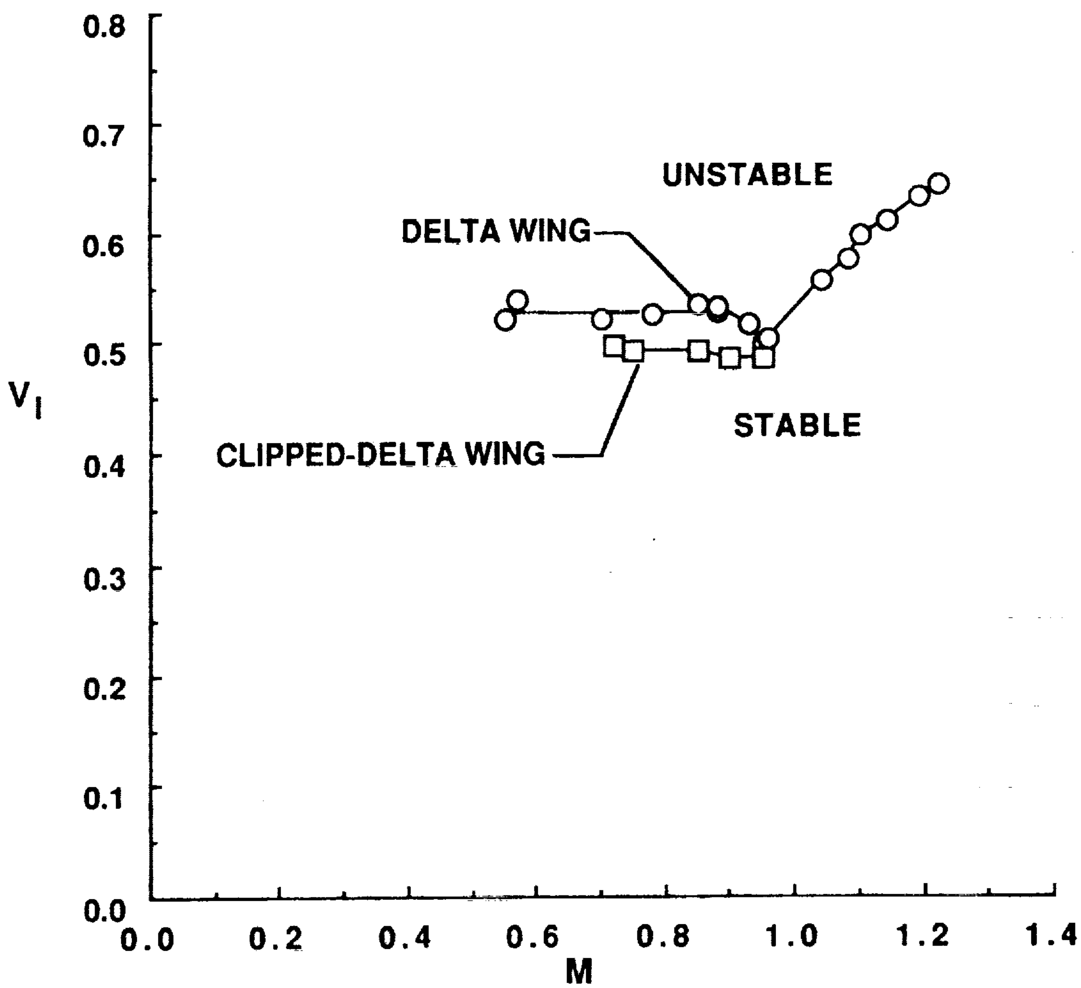


Figure 7.- Flutter results for clipped-delta-wing model.



(a) Dynamic pressure



(b) Velocity index.

Figure 8.- Comparison of flutter results for two models.

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15. Supplementary Notes

This report is similar to NASP Technical Memorandum 1079. The major difference is the inclusion of some additional information describing the airfoil section. The report is reissued in the present form to provide a broader dissemination of the infomation. David L. Soistmann, Charles V. Spain, Ellen C. Parker, and Walter A. Silva are employees of Planning Research Corporation, Hampton, VA.

16. Abstract

Transonic flutter boundaries are presented for two simple, 72°-sweep, low-aspect-ratio wing models. One model was an aspect-ratio-0.65 delta wing; the other model was an aspect-ratio-0.54 clipped-delta wing. Flutter boundaries for the delta wing are presented for the Mach number range of 0.56 to 1.22. Flutter boundaries for the clipped-delta wing are presented for the Mach number range of 0.72 to 0.95. Selected vibration characteristics of the models are also presented.

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