NASA TM SX-616

TECHNICAL MEMORANDUM

SX-616

for

Bureau of Naval Weapons, Department of the Navy

TRANSONIC AND SUPERSONIC FLUTTER INVESTIGATION OF 1/2-SIZE MODELS OF ALL-MOVABLE CANARD SURFACE OF AN EXPENDABLE POWERED TARGET

TED NO. NASA AD 3164, COORD. NO. N-AM-89

By Charles L. Ruhlin and W. J. Tuovila

Langley Research Center
Langley Air Force Base, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

A transonic and a supersonic flutter investigation of 1/2-size models of the all-movable canard surface of an expendable powered target has been conducted in the Langley transonic blowdown tunnel and in the Langley 9- by 18-inch supersonic aeroelasticity tunnel, respectively. The transonic investigation covered a Mach number range from 0.7 to 1.3, and the supersonic investigation was made at Mach numbers 1.3, 2.0, and 2.55.

The effects on the flutter characteristics of the models of different levels of stiffness and of free play in the pitch control linkage were examined. The semispan models, which were tested at an angle of attack of 0°, had pitch springs with the scaled design and 1/2 the scaled design pitch stiffness and total free play in pitch ranging from 0° to 1°. An additional model configuration which had a pitch spring 1/4 the scaled design pitch stiffness and no free play in pitch was included in the supersonic tests.

All model configurations investigated were flutter free up to dynamic pressures 32 percent greater than those required for flight throughout the Mach number range. Several model configurations were tested to considerably higher dynamic pressures without obtaining flutter at both transonic and supersonic speeds.

L-1303

INTRODUCTION

At the request of the Bureau of Naval Weapons, Department of the Navy, a transonic and a supersonic flutter investigation of 1/2-size models of the all-movable canard surface of the Beech XKD2B-1 expendable powered target has been conducted in the Langley transonic blowdown tunnel and in the Langley 9- by 18-inch supersonic aeroelasticity tunnel, respectively. These flutter tests were made to determine whether adequate safety margins existed between the flight envelope of the vehicle and the flutter boundaries of the canard surface and control system and to investigate possible flutter problem areas. The transonic tests covered a Mach number range from 0.7 to 1.3, and the supersonic tests were made at Mach numbers 1.3, 2.0, and 2.55.

The effects on the flutter characteristics of different levels of stiffness and of free play in the pitch control linkage were examined. In both investigations, 1/2-size semispan models of the solid magnesium canard surface were tested with pitch springs which had the scaled design and 1/2 the scaled design pitch stiffness and with total free play in pitch ranging from 0° to 1°. The supersonic investigation also included tests of a model with a pitch spring which had 1/4 the scaled design pitch stiffness but with no free play in pitch. Presented herein are the results of these investigations.

SYMBOLS

a	speed of sound, ft/sec
b	model semichord at 3/4 exposed-panel semispan, ($b = 0.114$ ft)
c	model chord, ft
EI	bending stiffness, lb-in.^{2}
f_h	natural bending frequency of model with no free play in pitch, cps
f_i	frequency of ith natural vibration mode of model mounted to a rigidly clamped block, cps
f_α	natural torsion frequency of model with no free play in pitch, cps
g	structural damping coefficient

GJ	torsion stiffness, lb-in.^{2}
I_X,I_Y,I_Z	mass moments of inertia about X,Y,Z axes, respectively, slug-ft^2
M	Mach number
q	dynamic pressure, lb/sq ft
x	longitudinal coordinate measured from leading edge of root chord to model center of gravity, in.
x_α	coordinate measured positive rearward from pitch axis to center of gravity, in.
y	spanwise coordinate measured from leading edge of root chord to model center of gravity, in.
X,Y,Z	coordinate axes
ρ	free-stream static air density, slugs/cu ft
μ	mass ratio (ratio of mass of exposed panel of model to mass of air at free-stream density contained in a truncated cone having the root chord of the model as base diameter, the tip chord as upper diameter, and the span measured along the panel pitch axis as height)
ω_α	natural torsion frequency of model with no free play in pitch, radians per sec

MODELS

Models Used in Transonic Tests

The transonic tests employed 1/2-size semispan models of the all-movable canard surface of the expendable powered target. All models and model mounting parts were furnished by the Beech Aircraft Corporation. Six similarly constructed model panels, designated as models 1 to 6, were used in the tests. The models were of the same type of construction (solid cross section) and were made of the same material (magnesium alloy) as the full-scale canard surface. A sketch and photographs of a model are presented in figures 1 and 2, respectively, and the geometric properties and measured mass properties of the models are presented in tables I and II, respectively.

In the tests each semispan model was mounted to a steel torque shaft which was supported by ball bearings in a mounting block (fig. 2). Attached to the torque shaft was a torque arm (figs. 2(b) and 2(c)), which was restrained within the fuselage between two faces of a clamp-type stop. The gaps in the stop could be adjusted to provide desired amounts of free play in pitch to the model. Torque shafts having the scaled design and 1/2 the scaled design pitch stiffness were provided. The mass moments of inertia about the pitch axis of a typical torque shaft and its attached parts are presented in table II. Since the torque arm is attached to and moves with the torque shaft during any pitch movement within the free-play limits of a model, the moment of inertia of the torque shaft with the torque arm attached is also presented in table II. Strain gages, used to indicate the occurrence of flutter and to measure the flutter frequency, were externally mounted on the top and bottom surfaces near the model root.

The bending and torsional stiffness distribution (EI and GJ) along the maximum thickness line (43-percent chord line) measured on models 1 and 5 are presented in figure 3. The major portion of the differences between the stiffness distributions of the two models is believed to be caused by the variations in model thickness within the tolerances allowed in the model construction. The measured natural-vibration frequencies and associated node lines of each model mounted to a rigidly clamped block are presented in figure 4. The models were excited by means of an acoustic shaker.

The support stiffnesses and free play in the pitch, roll, and yaw directions and the resonant frequencies and node lines of the models tested are presented in figure 5. With the desired free play in pitch set in the model, the resonant frequencies and node lines could not be accurately measured; therefore, only the frequencies of the models with no free play in pitch are presented in figure 5. Some unintentional free play was present in the roll and yaw directions as indicated in figure 5. The stiffness in each direction (fig. 5) was obtained from the slopes of the load-deflection curves measured for this direction. The stiffnesses so measured for the pitch direction were repeatable within 5 percent or less; however, the stiffnesses in the roll and yaw degree of freedom showed scatter up to 50 percent. It is believed that the scatter in the measured stiffnesses in the roll and yaw directions may have been caused by a binding in the bearings or shifts in the alinement of the bearings in the mounting block. The addition of free play in pitch produced no measurable effect on the pitch stiffnesses of the models presented in figure 5.

Models Used in Supersonic Tests

The canard surface and support system are shown in figure 6 and their properties are included in tables I, II, and III. The models were essentially the same as those used in the transonic tests except that the models were mounted on the tunnel sidewall as shown in figure 7. The canard surface was supported by a steel shaft pivoted on two ball bearings with a third ball bearing supporting the end of the torque spring. The torque-spring clamp could be adjusted to control the free play. The ball bearings used had about ±0.0007-inch free play in translation. Because of this free play in the bearing, the first natural vibration mode was difficult to excite accurately. Strain gages were mounted on the torque spring and at the root of the model.

TEST APPARATUS AND TECHNIQUE

Transonic Tests

The transonic tests were conducted in the Langley transonic blowdown tunnel at Mach numbers from about 0.7 to 1.3. The tunnel has a slotted, octagonal test section which measures approximately 26 inches between flats. This tunnel is particularly useful for flutter investigations because Mach number and air density may be varied independently. However, the Mach number does not uniquely define the velocity in the test section since during the operation of the tunnel, as air in the reservoir is expended, the stagnation temperature constantly decreases.

For each run (defined as one operation of the tunnel from valve opening to valve closing) the mounting block with the semispan model installed was fitted into a sting in such a way as to form a cylindrical fuselage 3 inches in diameter. The fuselage sting extended upstream into the subsonic flow region of the tunnel in order to prevent the formation of bow shock waves. The sting and model weighed approximately 290 pounds, and the system had a fundamental bending frequency of about 15 cps. A sketch of a model mounted on the sting and installed in the tunnel is shown in figure 8. The model with no free play in pitch was mounted at an angle of attack of 0°. With free play in pitch incorporated in the model, the mean angular position of the model between the pitch stops was set at an angle of attack of 0°. However, the flow angle varied somewhat with the operating conditions of the tunnel so that the model was not always trimmed for zero lift throughout a given run. In addition, the tunnel stream has a certain amount of turbulence, the level of which is also a function of the tunnel operating conditions.

The technique employed in most runs was to increase the dynamic pressure gradually until either flutter occurred or a dynamic pressure

32 percent greater than that required for sea-level flight was reached. In an effort to obtain flutter, several model configurations were tested up to or near the maximum dynamic pressure available in the tunnel. During each run, the output of the strain gages on the model, the test-section stagnation temperature, and the test-section stagnation and static pressures were continuously recorded by means of a recording oscillograph. Models used in more than one run were checked for structural damage by visual inspection, and the models tested with no free play in pitch were also checked by comparing the natural frequencies measured in the tunnel before and after each run. As a check of the structural integrity of a model tested with free play in pitch, the natural frequencies of the model in the no-free-play condition were measured after the tests were completed and were compared with those measured before the tests.

Supersonic Tests

The Langley 9- by 18-inch supersonic aeroelasticity tunnel is a wind tunnel of the blowdown type operating from a high-pressure source and exhausting into a vacuum chamber. The Mach number is fixed by nozzle configuration, and for these tests Mach number 1.3, 2.0, and 2.55 nozzles were used. The useful running time was about 3 seconds.

The model was mounted from the tunnel sidewall (fig. 7) and the angle of attack was 0°. After the tunnel was closed, it was evacuated to approximately 1/4 pound per square inch absolute. The pressure valve was then opened gradually until either flutter occurred or the desired dynamic pressure was reached, and then the valve was closed quickly. A high vacuum start was used to minimize the effect of the starting transient flow. In a typical tunnel test, the dynamic pressure is continuously increased from a very low value (simulating a high altitude) to a high value (simulating a low altitude). The tunnel stagnation pressure and temperature and the outputs of the model strain gages were recorded on an oscillograph which operated continuously for the duration of a tunnel run.

RESULTS AND DISCUSSION

Presentation of Results

The flight envelope of the target is shown in figure 9, along with the approximate altitude and Mach number regions covered in the present investigations. The results of the transonic and supersonic tests are presented in table III and plots of the maximum dynamic pressure obtained against Mach number are presented in figures 10 to 13. An altitude-stiffness parameter $\frac{b\omega_\alpha\sqrt{\mu}}{a}$ is included in table III for reference purposes.

Transonic Tests

The transonic results (figs. 10 and 11) indicate that all model configurations were flutter free to dynamic pressures at least 32 percent greater than those required for sea-level flight through the transonic regime. Models having a pitch spring with the scaled design pitch stiffness were tested to considerably higher dynamic pressures without obtaining flutter (fig. 10). As an indication of the dynamic-pressure range covered by the transonic investigation, the variation of dynamic pressure with the Mach number during three typical runs in the transonic blowdown tunnel is presented in figure 12. Also presented is the dynamic pressure variation with Mach number for various altitudes in standard atmosphere (ref. 1).

The model both with and without free play in pitch was statically unstable in pitch through the Mach number range. Therefore, at the higher dynamic pressures, most of the model configurations remained at one pitch attitude for long periods or for the entire run; this was particularly true of models with free play in pitch. However, at the low dynamic pressures, the airstream turbulence was usually sufficient to "kick" or move the model from a nose-up to a nose-down pitch attitude or vice versa. A model was assumed to be adequately trimmed (table III) when the model alternated irregularly between a nose-up and nose-down angle of attack at the low dynamic pressures of a run. When a model flew constantly or predominantly at one pitch attitude for the entire run, the angle of attack of the sting was changed (the model retrimmed) in an effort to correct for this condition before the next run. Several runs were aborted at low dynamic pressures when unusually large deflections were observed. The model deflections in pitch at a Mach number of 1.3 were noticeably less than those observed for the same dynamic pressures at subsonic Mach numbers, indicating a reduction in the static moment about the pitch axis as the Mach number became supersonic.

In the course of the investigation, one panel was lost and two torque shafts deformed permanently in twist during high dynamic pressure runs at subsonic Mach numbers (table III, runs 2, 12, and 38) due to the large static aerodynamic moments. These model failures occurred at dynamic pressures much higher than those required for sea-level flight at these Mach numbers.

Supersonic Tests

No flutter was obtained during the supersonic tests (fig. 13) even at dynamic pressures well in excess of those encountered by the vehicle in its supersonic flight envelope. During the tests with free play in pitch, the model always rested against a stop indicating that the static pitching instability obtained in the transonic tests extended into the supersonic speed regime. The model was remotely moved from one stop to the other during runs with maximum free play and the very-low-amplitude oscillations that resulted from the sudden stops decayed rapidly. Some still-air damping tests were made on one model, and the results show that the damping coefficient in the first natural torsion vibration mode varied from a $g = 0.04$ at low amplitudes to a $g = 0.14$ at larger amplitudes.

Interpretation of Results

The models used in the present investigations were of the same type of construction and were made of the same material as the full-scale canard surface, but were 1/2 of full size. For wings so constructed, at a given mass ratio and Mach number, the flutter dynamic pressure is independent of wing size. Therefore, the flutter dynamic pressure for the present model should be exactly equal to that for the full-scale vehicle at the same μ and M.

Because the temperature is not a controllable factor in the blowdown tunnels used for the present tests, at any given dynamic pressure the mass ratio of the model in the tunnel was, in general, somewhat different from that of the full-scale target at the operating condition. However, the dynamic pressures attained in the present tests far exceeded the flutter margin requirements so that the effects of the differences in the mass ratio are considered to be more than compensated for by the margin in dynamic pressure. Some quantitative indication of the effects of varying mass ratio may be found in reference 2.

CONCLUSIONS

A transonic and a supersonic flutter investigation of 1/2-size models of the all-movable canard surface of the Beech XKD2B-1 expendable powered target has been made. The transonic tests covered a Mach number range from about 0.7 to 1.3, and the supersonic tests were made at Mach numbers 1.3, 2.0, and 2.55. Models were investigated which had pitch springs with the scaled design and 1/2 the scaled design pitch stiffness and with free play in pitch ranging from 0° to 1°. Investigated only at supersonic Mach numbers was a model configuration having a pitch spring with 1/4 the scaled design pitch stiffness and with no free play in pitch. The results of the investigations have indicated the following:

1. All model configurations investigated were flutter free to dynamic pressures 32 percent greater than those required for flight throughout the Mach number range.

2. Several model configurations were tested to much higher dynamic pressures without obtaining flutter at both transonic and supersonic speeds.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., September 15, 1961.

REFERENCES

1. Ames Research Staff: Equations, Tables, and Charts for Compressible Flow. NACA Rep. 1135, 1953. (Supersedes NACA TN 1428.)

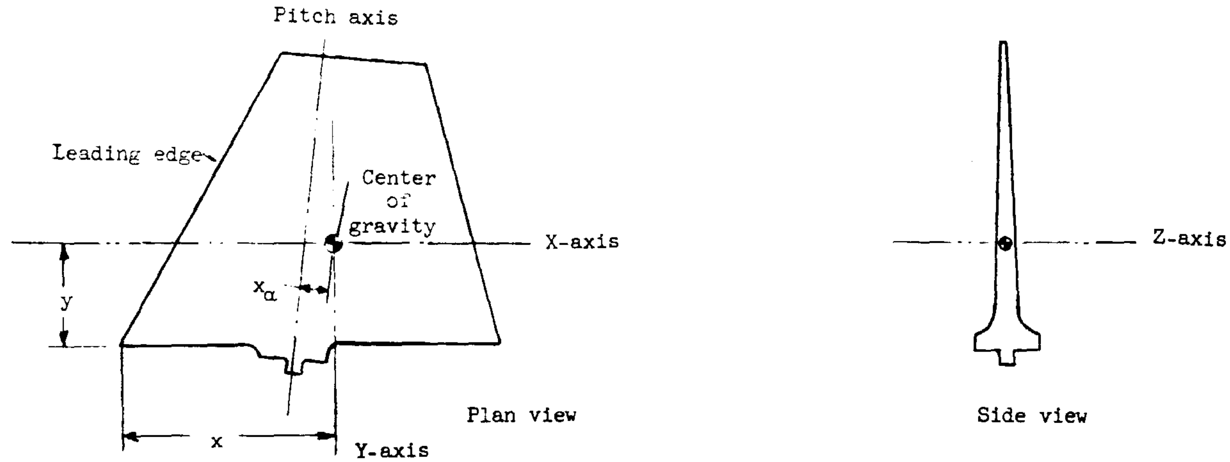
2. Yates, E. Carson, Jr.: Some Effects of Variations in Density and Aerodynamic Parameters on the Calculated Flutter Characteristics of Finite-Span Swept and Unswept Wings at Subsonic and Supersonic Speeds. NASA TM X-182, 1960.

TABLE I.- GEOMETRIC PROPERTIES OF MODELS

Airfoil:	
Section	Double wedge
Maximum thickness, percent streamwise chord:	
Root	3.7
Tip	4.6
Maximum thickness location from leading edge at tip and root, percent streamwise chord	43
Aspect ratio, (Semispan)^2/Area of semispan model:	
Planform*	1.32
Exposed panel	1.11
Sweepback angle:	
Quarter chord, deg	19
Leading edge, deg	30
Pitch axis, deg	$7\frac{1}{2}$
Pitch-axis location, percent root chord (streamwise)	45
Taper ratio:	
Planform*	0.29
Exposed panel	0.36
Chord, streamwise:	
Center line of fuselage, ft	0.545
Root of exposed panel, ft	0.433
Tip, ft	0.155
Dihedral, deg	0
Semispan:	
Planform*, ft	0.461
Exposed panel, ft	0.326

*Planform based on extension of model to fuselage-sting center line.

TABLE II.- MASS PROPERTIES OF MODELS



Model	Mass, slug	x, in.	y, in.	x_α, in.	$I_{pitch\ axis}$, slug-ft^2 (a)	I_X, slug-ft^2	I_Y, slug-ft^2	I_Z, slug-ft^2
Models used in transonic investigation								
1	30.2×10^{-4}	2.74	1.29	0.20	19.7×10^{-6}	25.6×10^{-6}	19.5×10^{-6}	44.4×10^{-6}
2	31.2	2.62	1.27	.11	19.2	25.9	19.6	45.4
3	31.1	2.74	1.27	.22	19.9	25.6	19.3	44.4
4	31.0	2.76	1.26	.20	19.7	25.5	19.8	44.6
5	32.0	2.70	1.26	.19	20.2	26.4	20.3	46.4
6	31.7	2.68	1.24	.19	20.6	26.0	20.5	46.3
Models used in supersonic investigation								
S-1	29.6×10^{-4}	2.67	1.24	0.17	17.7×10^{-6}	Not measured	Not measured	Not measured
S-2	30.8	2.65	1.28	.16	18.2			

[a] $I_{pitch\ axis}$ does not include the moment of inertia of the torque shaft, which in the transonic tests was 3.16×10^{-6} slug-ft^2 without the torque arm and 6.43×10^{-6} slug-ft^2 with the torque arm. In the supersonic tests, the moment of inertia of the torque shaft was 4.75×10^{-6} slug-ft^2 without the torque arm.

TABLE III.- COMPILATION OF EXPERIMENTAL RESULTS

(a) Transonic test results; scaled design pitch stiffness

Free play in pitch, deg	Model number	Run number	Mach number	Dynamic pressure, lb/sq ft	Velocity, ft/sec	Static temperature, °R	Static density, slug/cu ft	a, ft/sec	μ	$\frac{b\omega_\alpha\sqrt{\mu}}{a}$	Remarks
None	4	1	1.294	4,346	1,169	340	0.00635	903	20.0	0.83	Maximum q obtained without flutter. Model appeared to be trimmed adequately.
		2	1.140	3,946	1,085	377	.00669	952	19.0	.78	Maximum q, no flutter. Panel broke off from shaft at this point. Model had about 6° nose-down attitude before failure, and screws which held panel to shaft apparently failed in shear under static aerodynamic moment.
	6	12	.887	2,160	903	431	.00530	1,018	24.5	.82	Maximum q, no flutter. At this q torsion shaft deformed in twist to about 15° nose-up attitude.
0.86	2	15	0.860	1,624	890	446	0.00409	1,035	31.3	0.95	Maximum q, no flutter. Model appeared to be adequately trimmed. (runs 15 to 26)
		16	[illegible]	[illegible]	[illegible]	[illegible]	.00400	992	[illegible]	1.00	
		17	1.288	3,221	1,168	342	.00471	907	27.2	1.01	
		18	1.186	2,796	1,152	392	.00421	971	30.4	1.00	
		19	1.301	4,434	1,172	338	.00644	901	19.9	.87	
		20	.968	2,163	986	432	.00444	1,019	28.8	.93	
		21	.955	2,061	973	432	.00435	1,019	29.4	.93	
		22	.984	2,845	982	415	.00589	998	21.7	.82	
		23	.990	2,878	987	414	.00590	997	21.7	.82	
		24	.969	2,422	980	426	.00504	1,011	25.4	.88	
		25	1.098	4,039	1,024	362	.00769	933	16.6	.77	
		26	.796	2,868	795	415	.00907	999	14.1	.66	

TABLE III.- COMPILATION OF EXPERIMENTAL RESULTS - Continued

(b) Transonic test results; 1/2-scaled design pitch stiffness

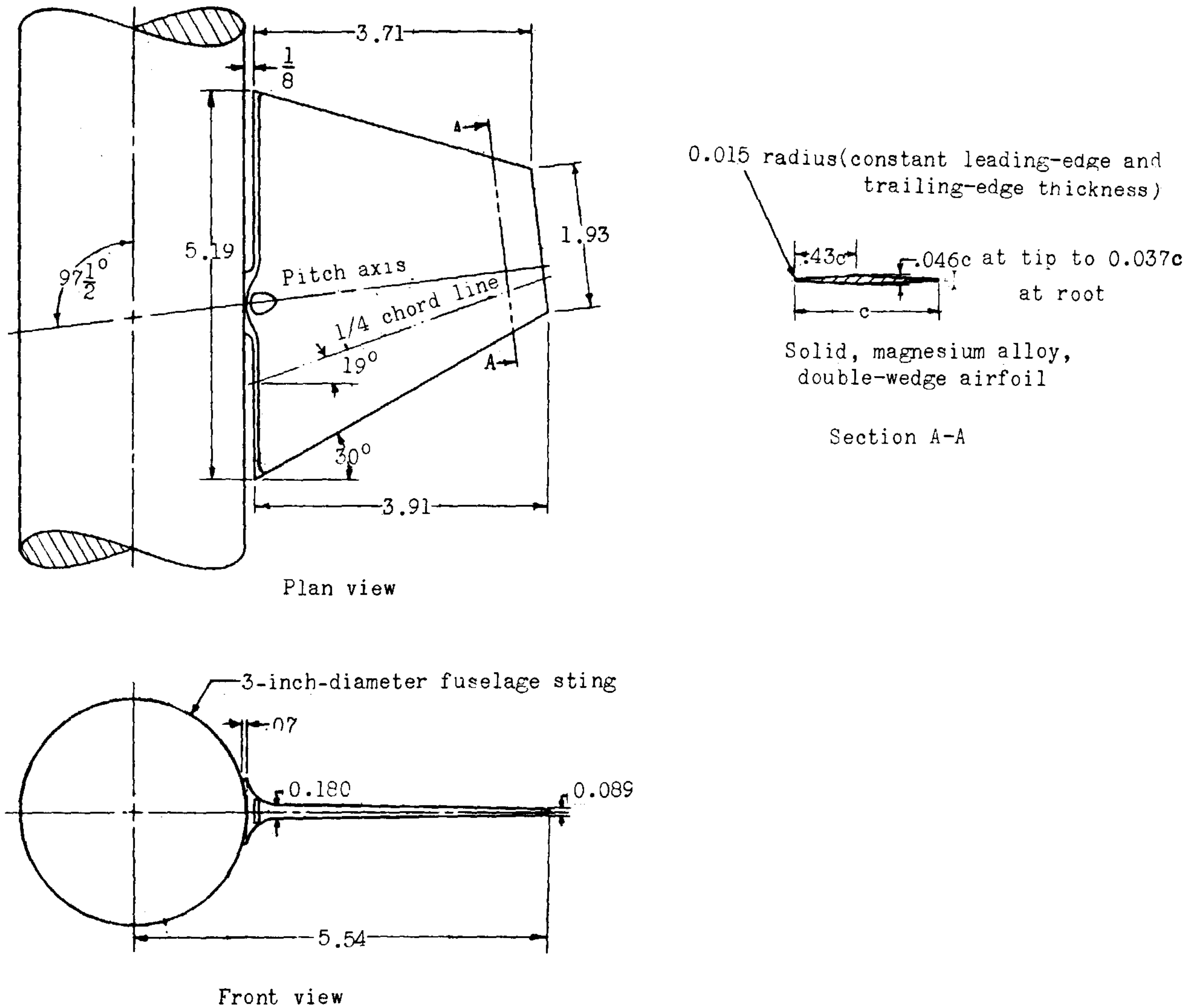
Free play in pitch, deg	Model number	Run number	Mach number	Dynamic pressure, lb/sq ft	Velocity, ft/sec	Static temperature, °R	Static density, slug/cu ft	a, ft/sec	μ	$\frac{b\omega_\alpha\sqrt{\mu}}{a}$	Remarks
None	3	3	1.300	3,236	1,227	371	0.00429	944	29.7	0.74	Maximum q, no flutter. Model appeared to be trimmed adequately. For runs 6 and 7, values of Mach number and q were estimated as pressures not recorded during these runs.
		4	.922	1,276	948	440	.00284	1,028	44.9	.84	
		5	1.061	1,892	1,055	412	.00339	994	37.6	.80	
		6	.70	778	-----	---	-------	None measured			
		7	.79	1,440	-----	---	-------				
		8	.767	1,237	798	451	.00388	1,041	32.9	.71	
		9	.850	1,574	873	439	.00413	1,027	30.9	.70	
		10	.965	1,600	979	428	.00333	1,014	38.3	.79	
		11	1.071	1,666	1,066	413	.00292	996	43.7	.86	
		13	1.056	2,249	1,058	418	.00401	1,002	31.8	.73	
		14	1.183	2,441	1,165	404	.00359	985	35.5	.78	
0.52	3	27	0.861	1,624	887	442	0.00412	1,030	30.9	0.68	Maximum q, no flutter. Model appeared to be trimmed adequately.
		28	1.289	3,504	1,195	358	.00490	927	26.0	.70	
		29	1.073	2,521	1,056	403	.00451	984	28.3	.68	
		30	.763	1,341	799	456	.00420	1,047	30.4	.67	
		31	1.022	2,131	1,028	421	.00403	1,006	31.6	.71	
1.05	1	32	0.863	1,809	897	449	0.00449	1,039	27.6	0.64	Maximum q, no flutter. Model flew nose down against stop through most of these runs.
		33	1.300	3,614	1,225	369	.00481	942	25.7	.69	
		34	1.102	2,220	1,103	417	.00365	1,001	33.9	.74	
		35	.774	1,411	815	461	.00424	1,053	29.2	.65	
		36	1.039	2,238	1,049	424	.00406	1,010	30.5	.70	
		37	-----	-----	-----	---	-------	-----	----	----	Run aborted when oscillograph recorder lamp burned out.
		38	.897	2,344	928	446	.00543	1,035	22.9	.59	Maximum q, no flutter. Sometime during run torque shaft deformed in twist to about a 4° nose-down angle.

TABLE III.- COMPILATION OF EXPERIMENTAL RESULTS - Concluded

(c) Supersonic test results

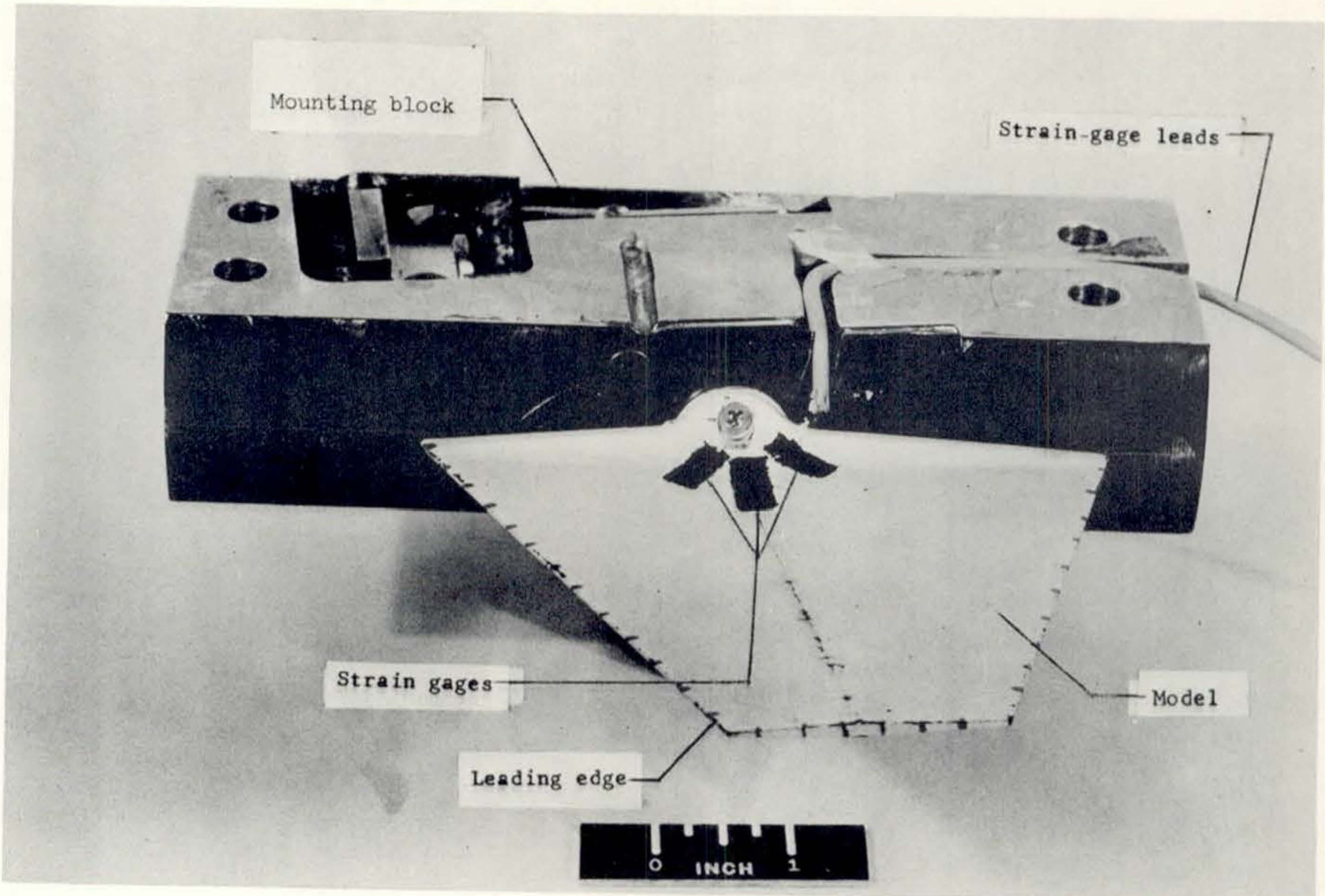
[Range of f_h, 350 to 400 cps]

Model	Free play (total), deg	Run number	M	f_α, cps	q, lb/sq ft	ρ, slug/cu ft	a, ft/sec	μ	$\frac{b\omega_\alpha\sqrt{\mu}}{a}$
Scaled design pitch stiffness; design spring stiffness = 48.2 ft-lb/radian									
S-2	0.00	1	1.30	230	2,670	0.00327	980	38.4	1.04
	.10	2							
	.32	3							
	.65	4							
	.65	5							
	.95	6							
1/2-scaled design pitch stiffness; 1/2 design spring stiffness = 29.3 ft-lb/radian									
S-2	0.00	7	1.30	180	2,670	0.00327	980	38.4	0.81
	.57	8	1.30		2,670	.00327	980	38.4	.81
	.90	9	1.30		2,670	.00327	980	38.4	.81
	.90	10	1.30		2,670	.00327	980	38.4	.81
	.00	11	2.00		2,630	.00190	830	65.2	1.25
	.00	12	2.00		3,255	.00230	840	54.0	1.13
	.56	13	2.00		3,355	.00236	840	52.5	1.11
	.90	14	2.00		3,363	.00240	835	51.5	1.11
	.00	15	2.55		2,660	.00144	760	85.8	1.43
	.60	16	2.55		2,660	.00144	760	85.8	1.43
	.90	17	2.55		2,660	.00144	760	85.8	1.43
1/4-scaled design pitch stiffness; 1/4 design spring stiffness = 9.1 ft-lb/radian									
S-1	0.00	18	1.30	100	1,230	0.00149	980	88.5	0.685
	.00	19	1.30	100	2,100	.00254	980	52.0	.526
	.00	20	1.30	100	2,580	.00311	980	42.4	.474



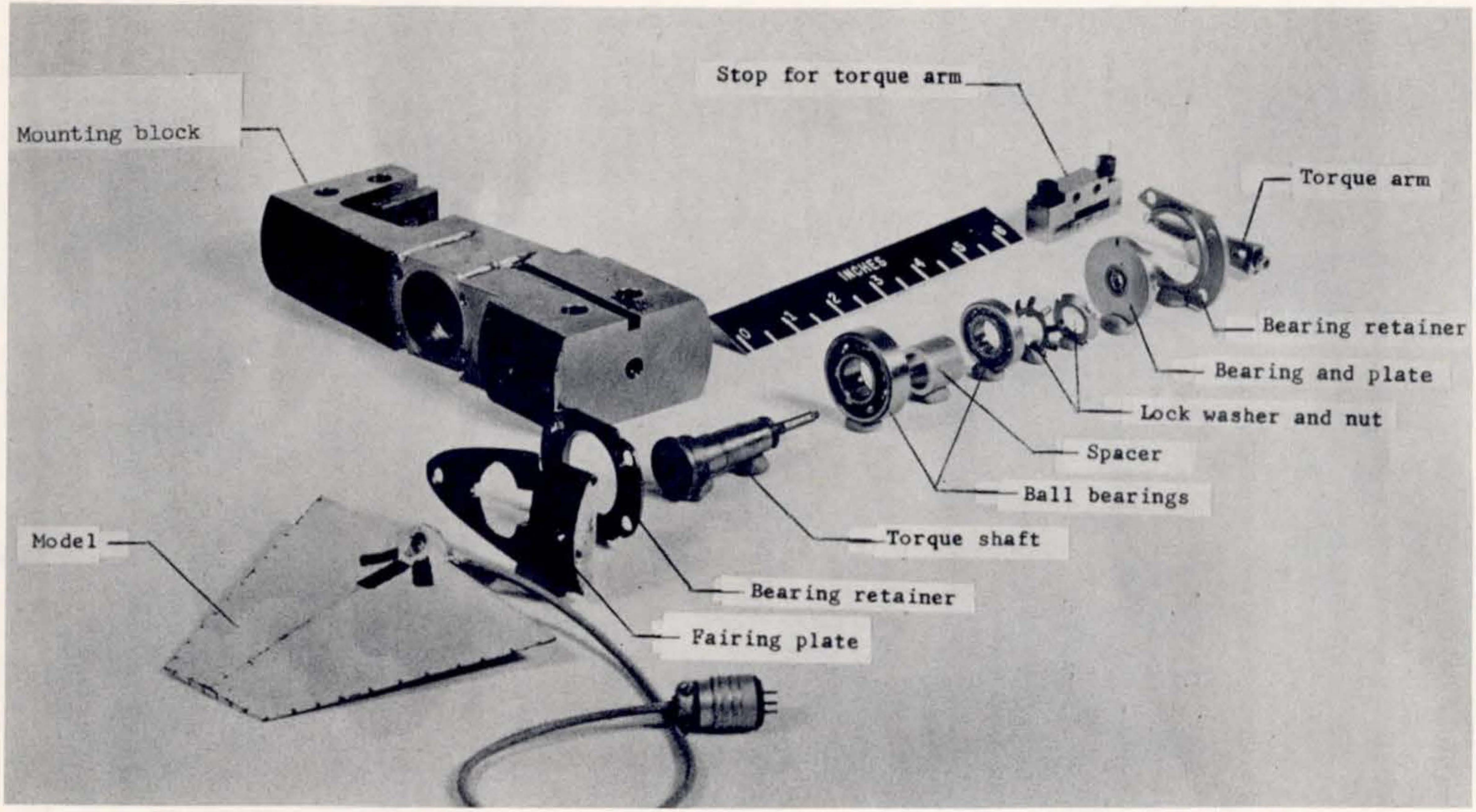
Note: 3-inch-diameter fuselage sting was used only for the transonic tests.

Figure 1.- Sketch of model. All dimensions are in inches unless otherwise specified.



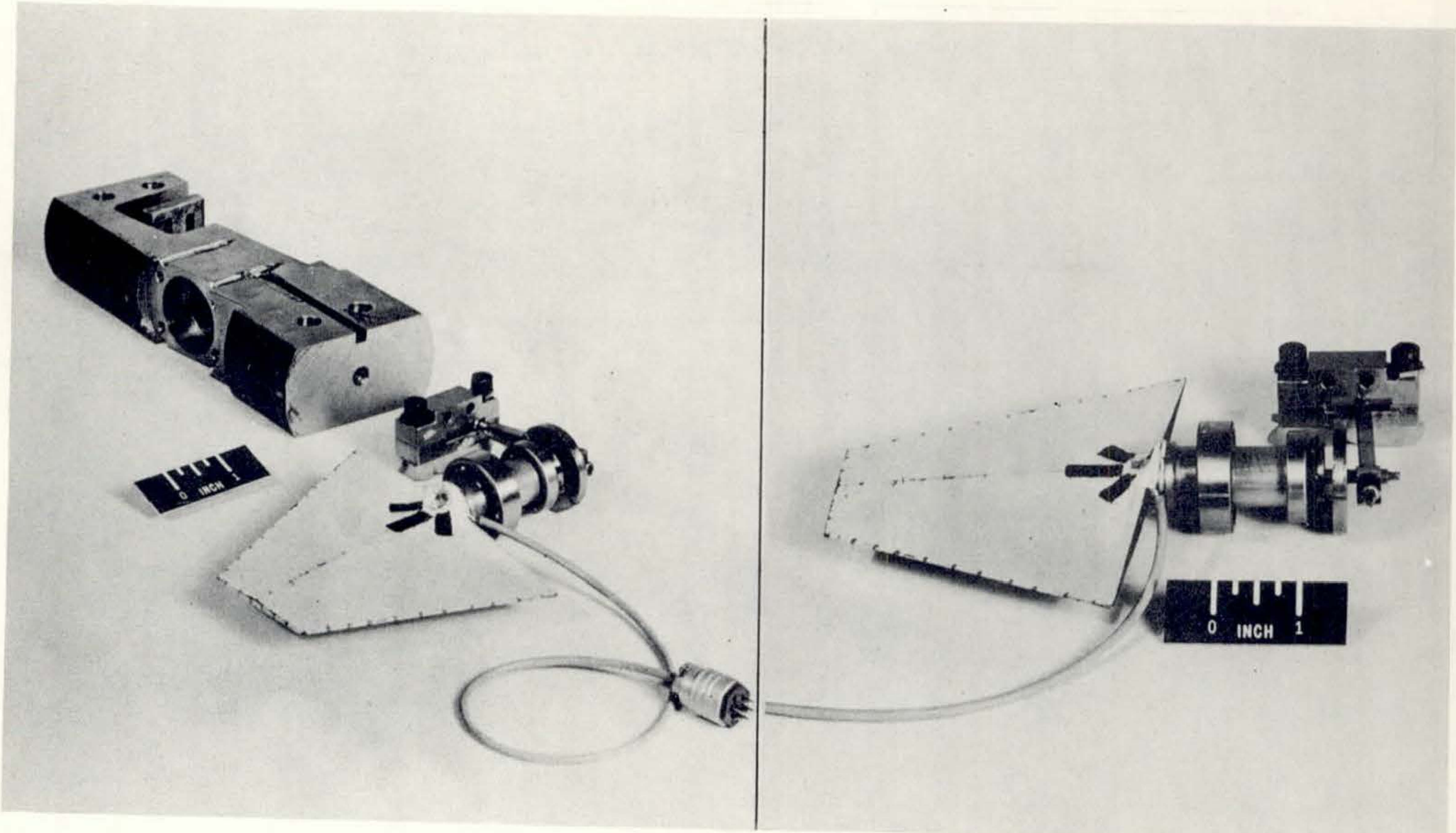
(a) Model assembled in mounting block. L-60-426.1

Figure 2.- Photographs of models and support used in transonic investigation.



(b) Exploded view of model and support. L-60-427.1

Figure 2.- Continued.



(c) Two views of model on torque shaft outside of mounting block. L-61-5093

Figure 2.- Concluded.

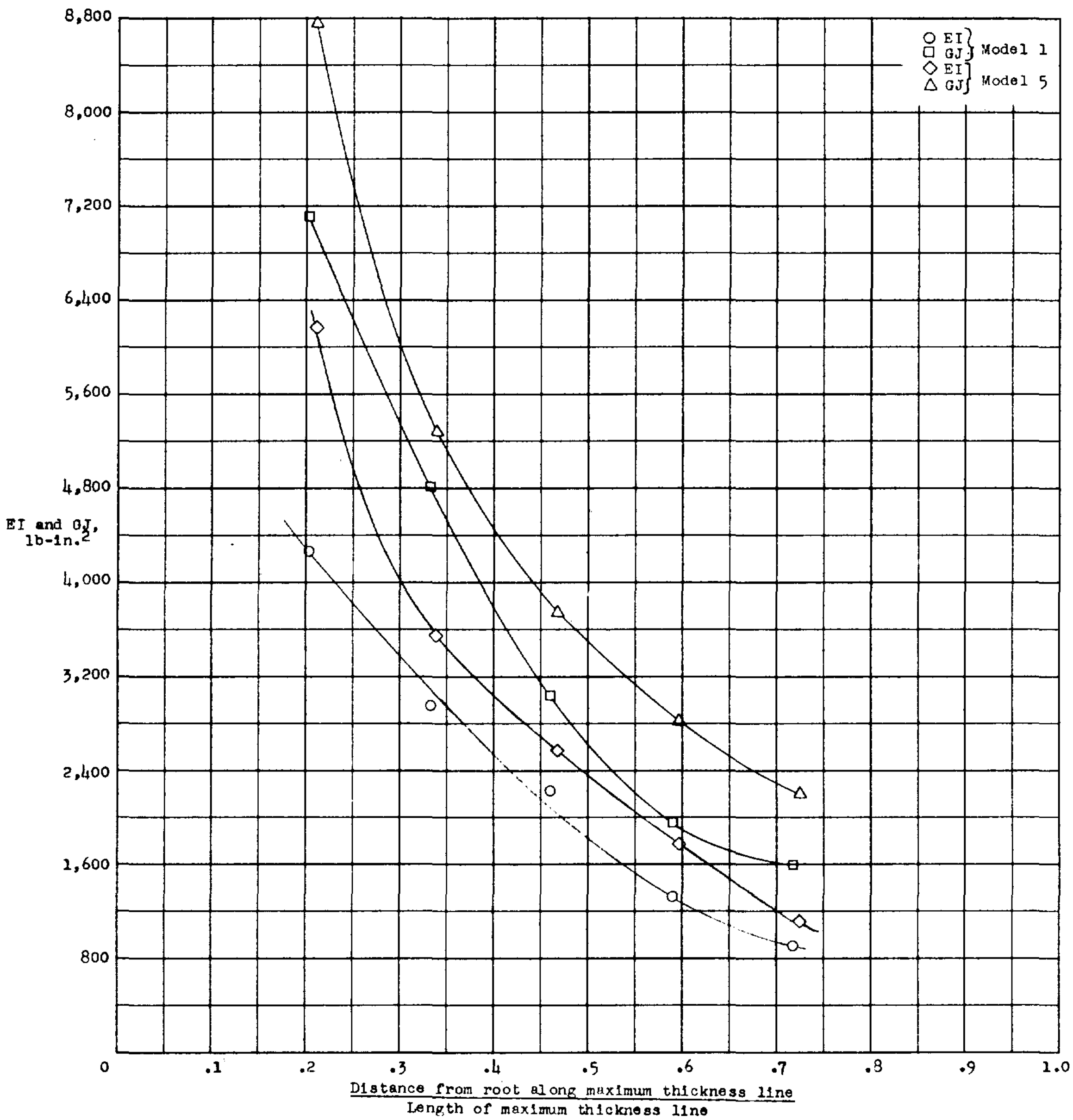
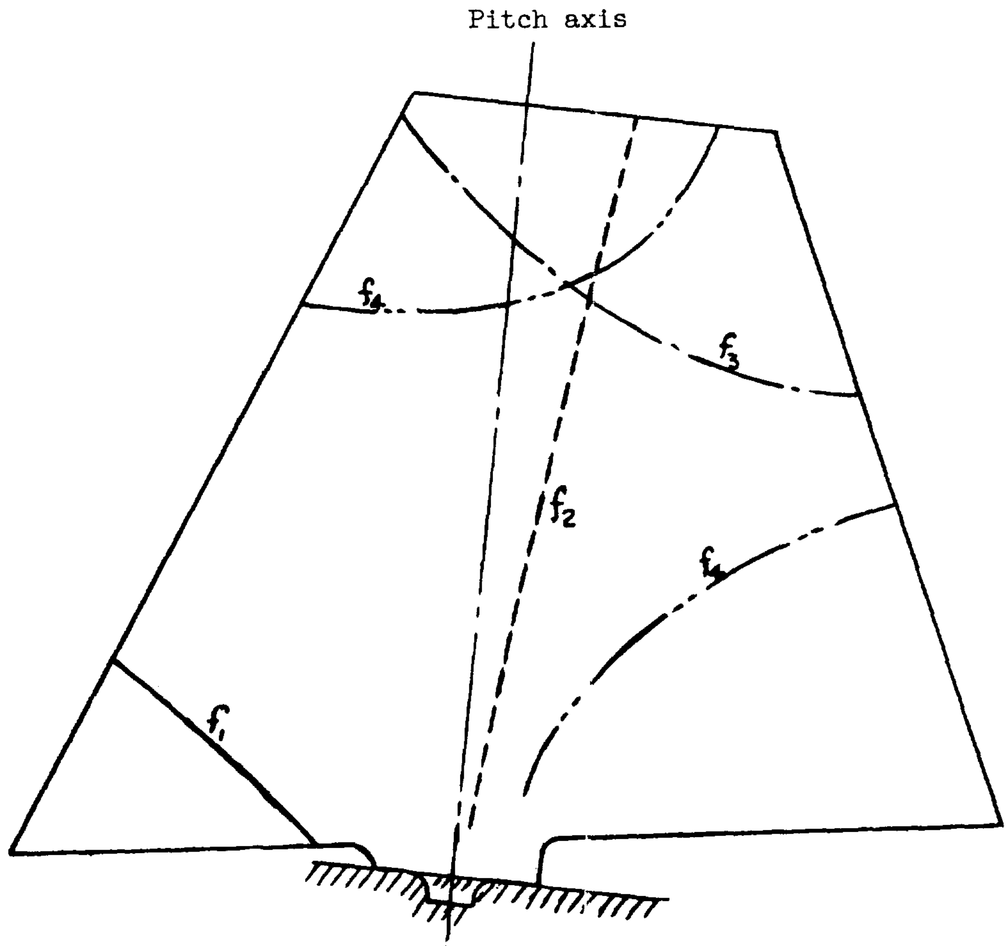
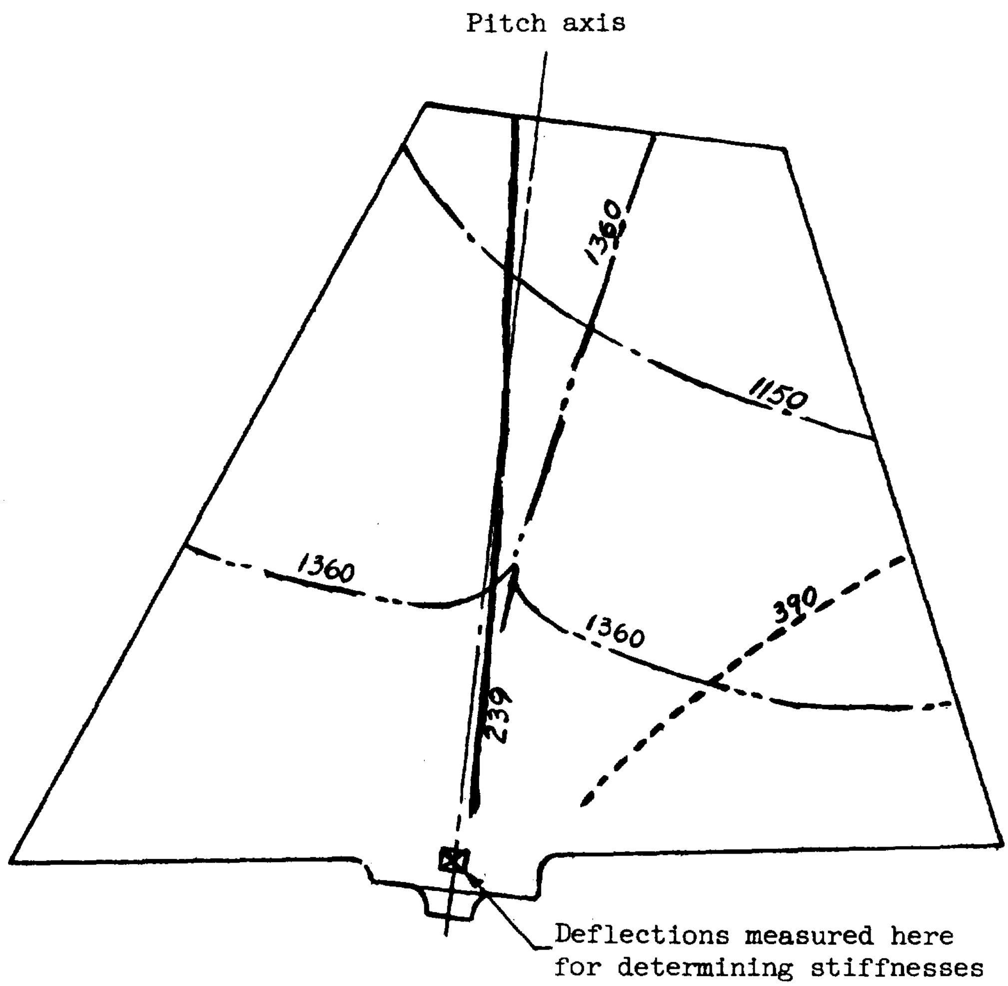


Figure 3.- Measured bending- and torsional-stiffness distribution along maximum thickness line of models 1 and 5.



Item	Model number					
	1	2	3	4	5	6
f_1, cps	420	438	425	436	440	440
f_2, cps	995	1040	1045	1060	1060	1040
f_3, cps	1450	1540	1480	1520	1540	1490
f_4, cps	1825	1910	1900	1900	1950	1870

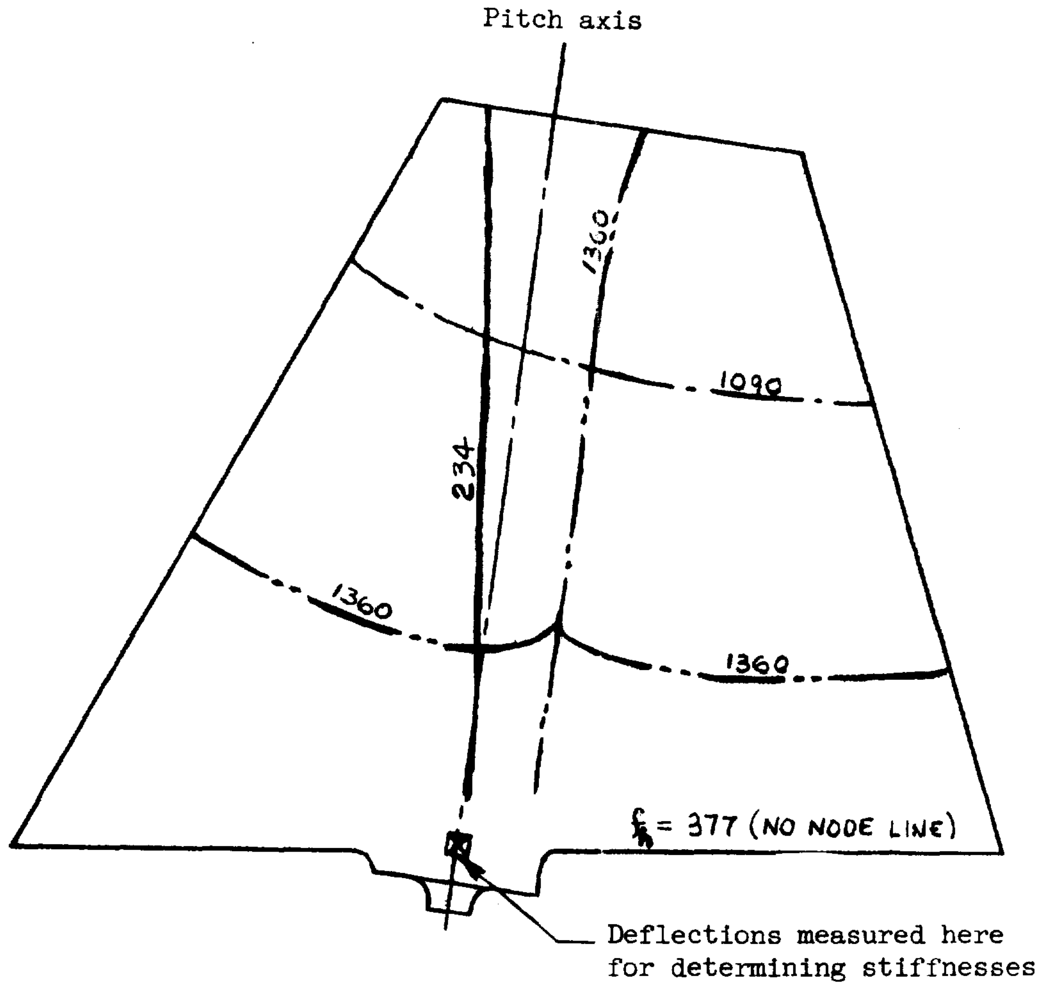
Figure 4.- Measured natural vibration frequencies and associated node lines of models mounted to a rigidly clamped block.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	55.4 ± 1%	None
Roll	1,660 ± 20%	0.006
Yaw	914 ± 50%	.006

(a) Model 4; design scaled pitch stiffness; no free play in pitch; runs 1 and 2.

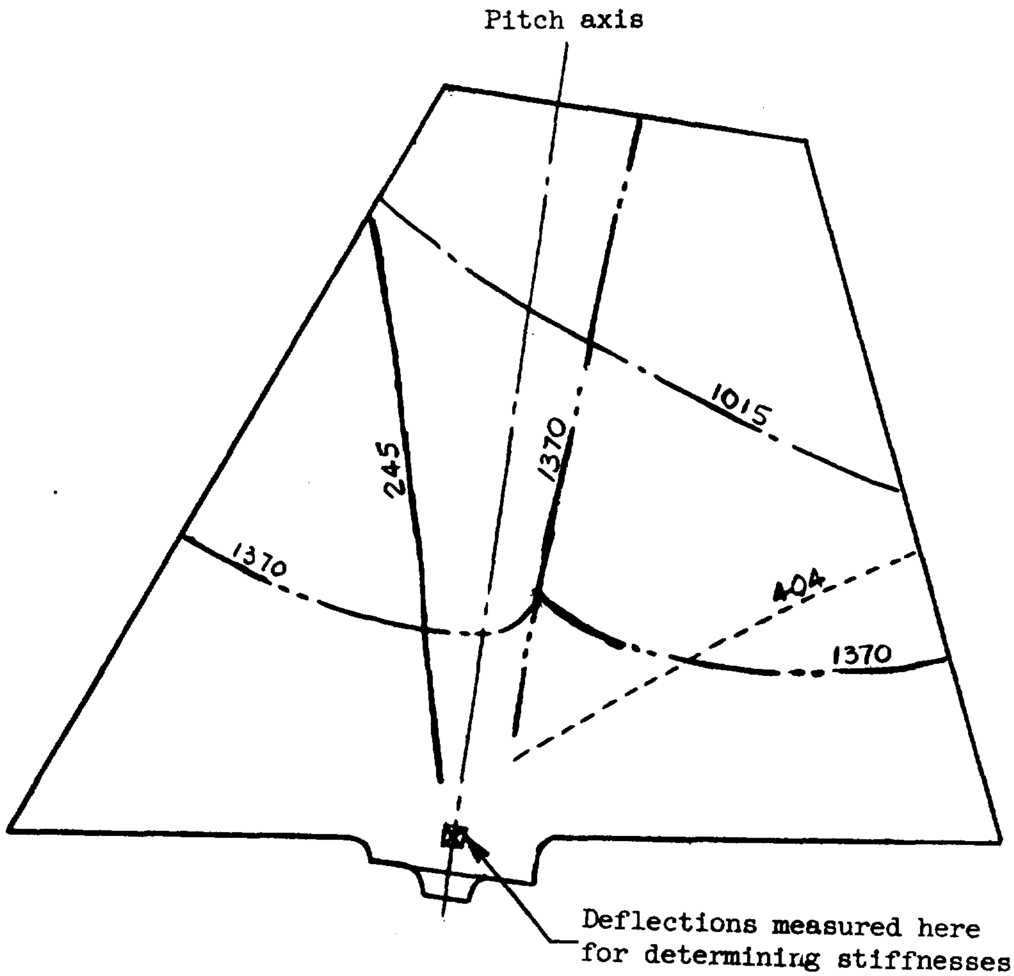
Figure 5.- Measured stiffnesses, free play, resonant frequencies, and associated node lines of models used in transonic tests. The number with each node line gives the associated frequency in cycles per second.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	53.9 ± 1%	None
Roll	1,660 ± 20%	0.006
Yaw	914 ± 50%	.006

(b) Model 6; design scaled pitch stiffness; no free play in pitch; run 12.

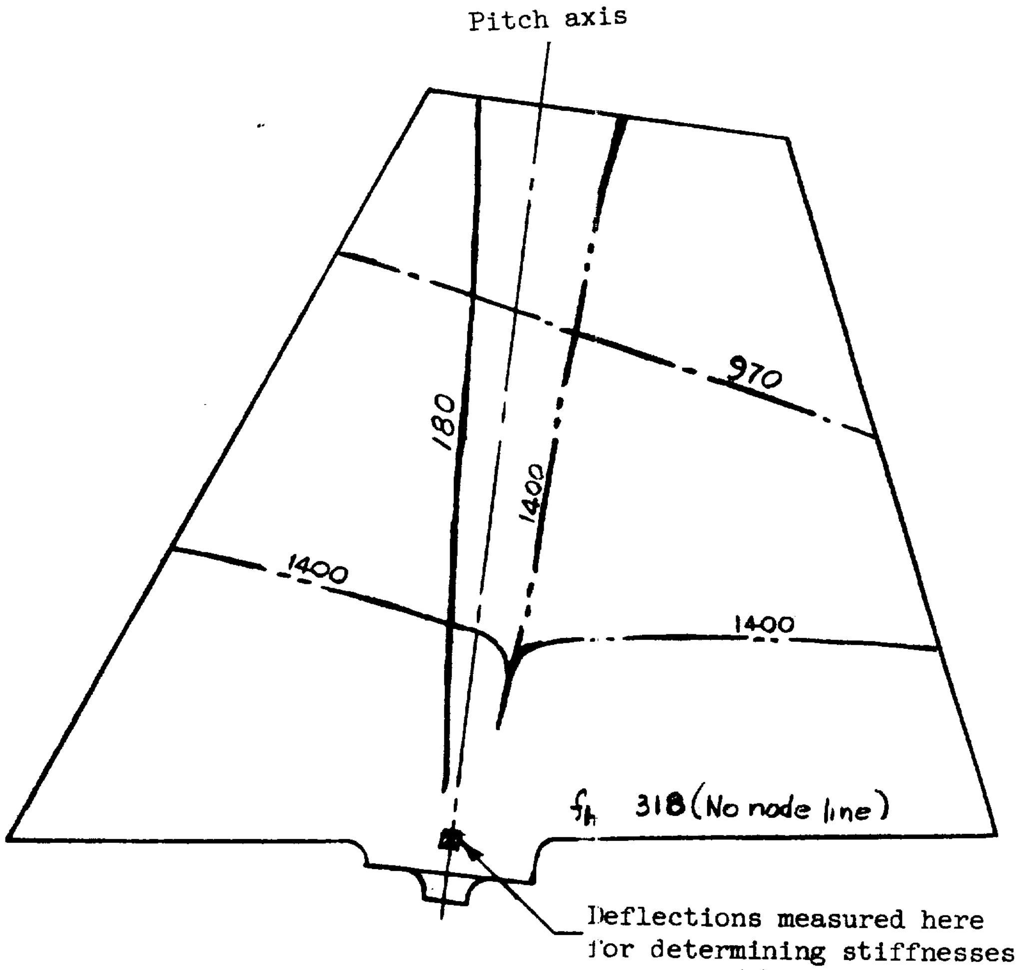
Figure 5.- Continued.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	58.3 ± 5%	None
Roll	1,590 ± 5%	0.007
Yaw	1,220 ± 4%	.008

(c) Model 2; design scaled pitch stiffness; tested with 0.86° free play in pitch; runs 15 to 26. (Note: Frequencies and node lines are presented for the model with no free play in pitch. When free play in pitch was permitted in the model, frequencies and node lines could not be measured accurately.)

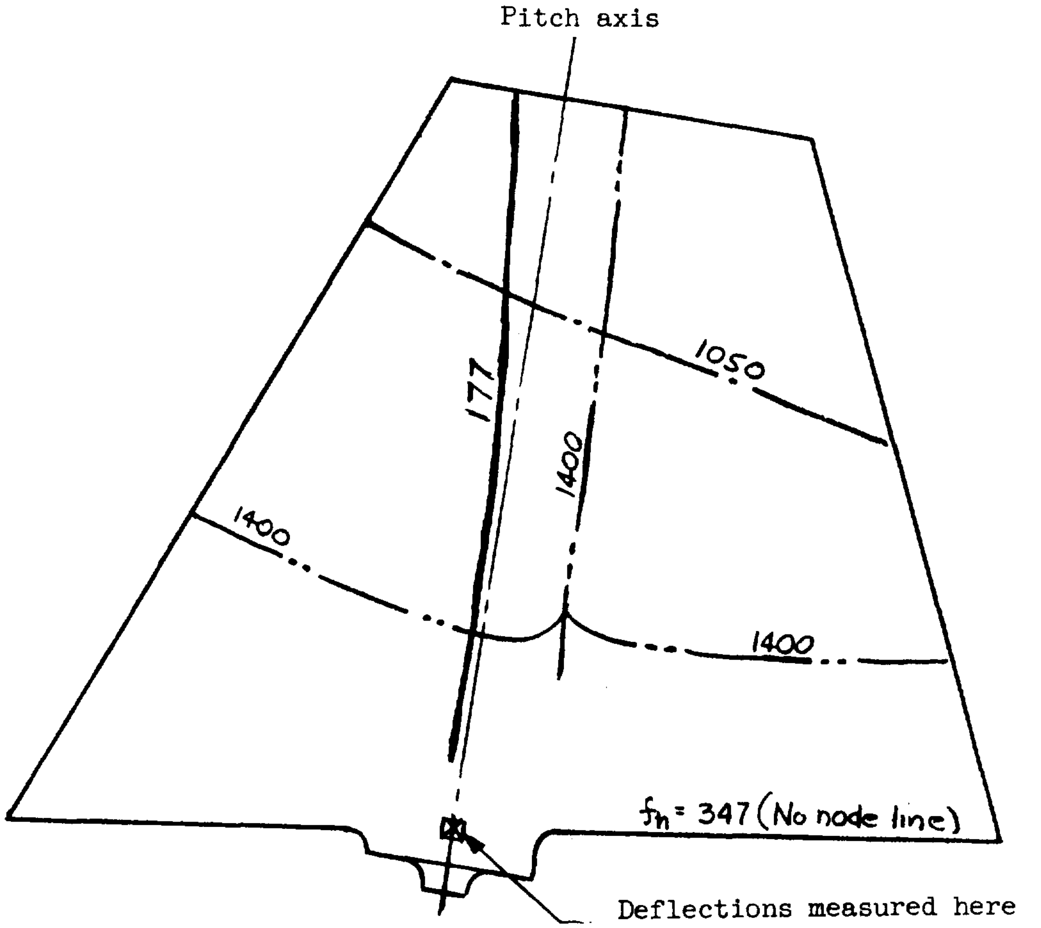
Figure 5.- Continued.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	28.3 ± 2%	None
Roll	1,730 ± 2%	0.010
Yaw	2,320 ± 12%	.010

(d) Model 3; 1/2 design scaled pitch stiffness; no free play in pitch; runs 3 to 11, 13 and 14.

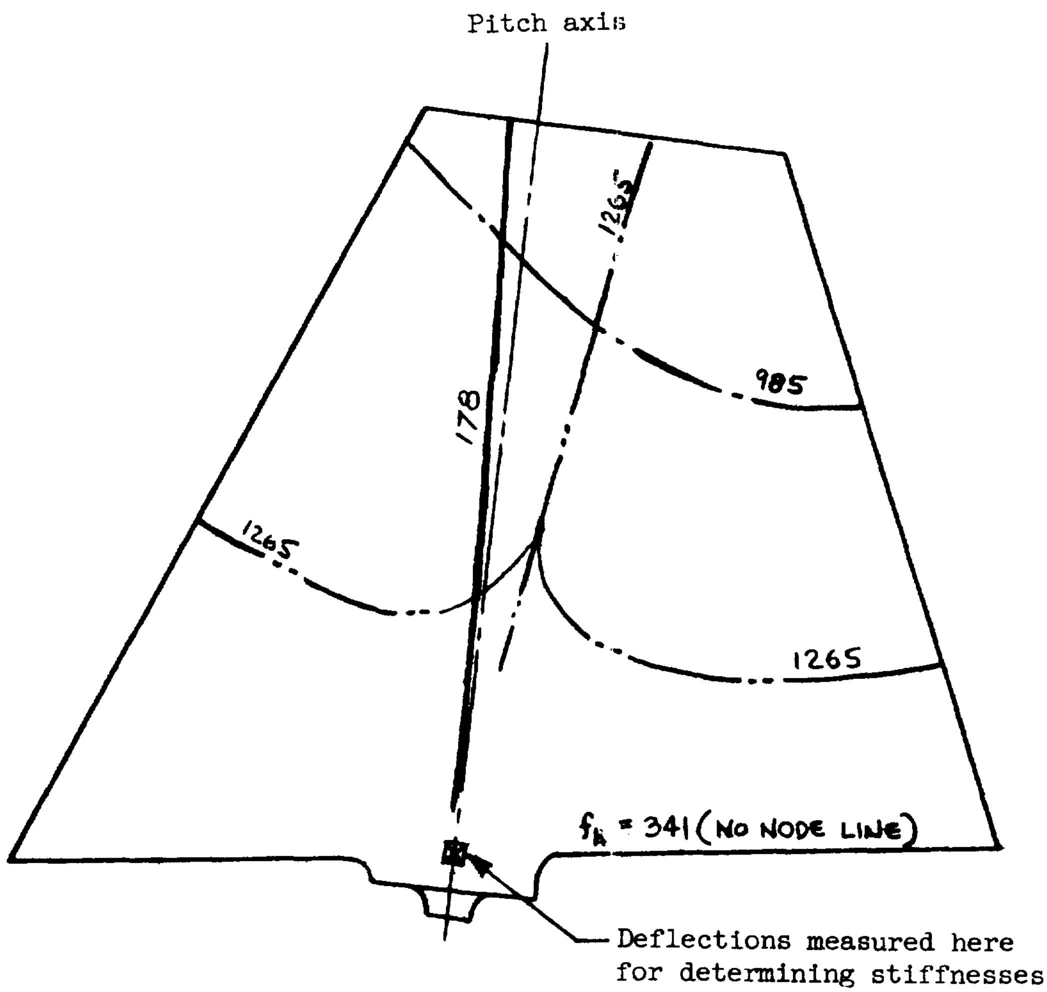
Figure 5.- Continued.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	28.1 ± 1%	None
Roll	1,500 ± 6%	0.005
Yaw	Not measured	

(e) Model 3; 1/2 design scaled pitch stiffness; tested with 0.52° free play in pitch; runs 27 to 31. (Note: Frequencies and node lines are presented for the model with no free play in pitch. When free play in pitch was permitted in the model, frequencies and node lines could not be measured accurately.)

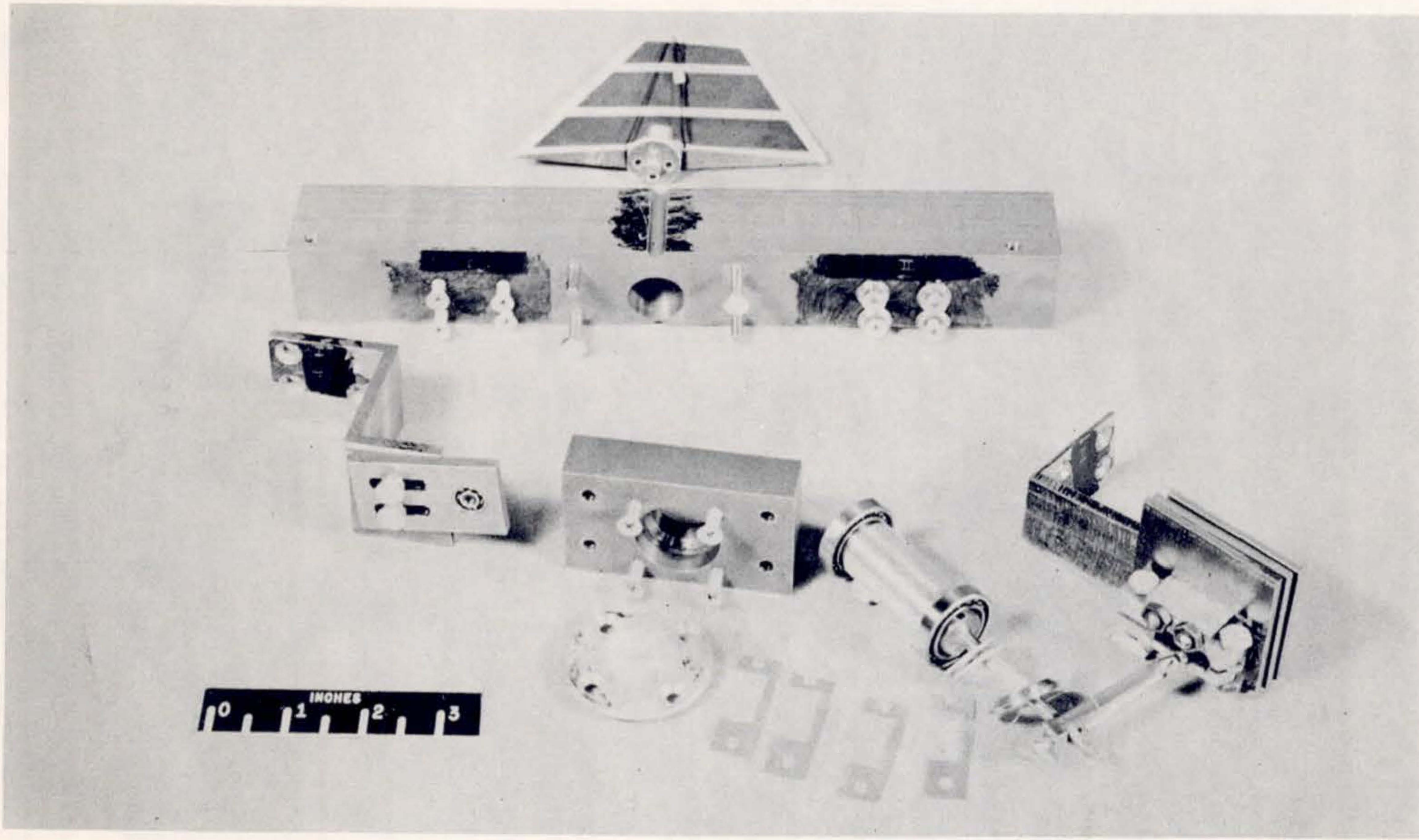
Figure 5.- Continued.



Degree of freedom	Stiffness, ft-lb/radian	Free play at tip of model, in.
Pitch	27.2 ± 1%	None
Roll	1,530 ± 5%	0.007
Yaw	Not measured	

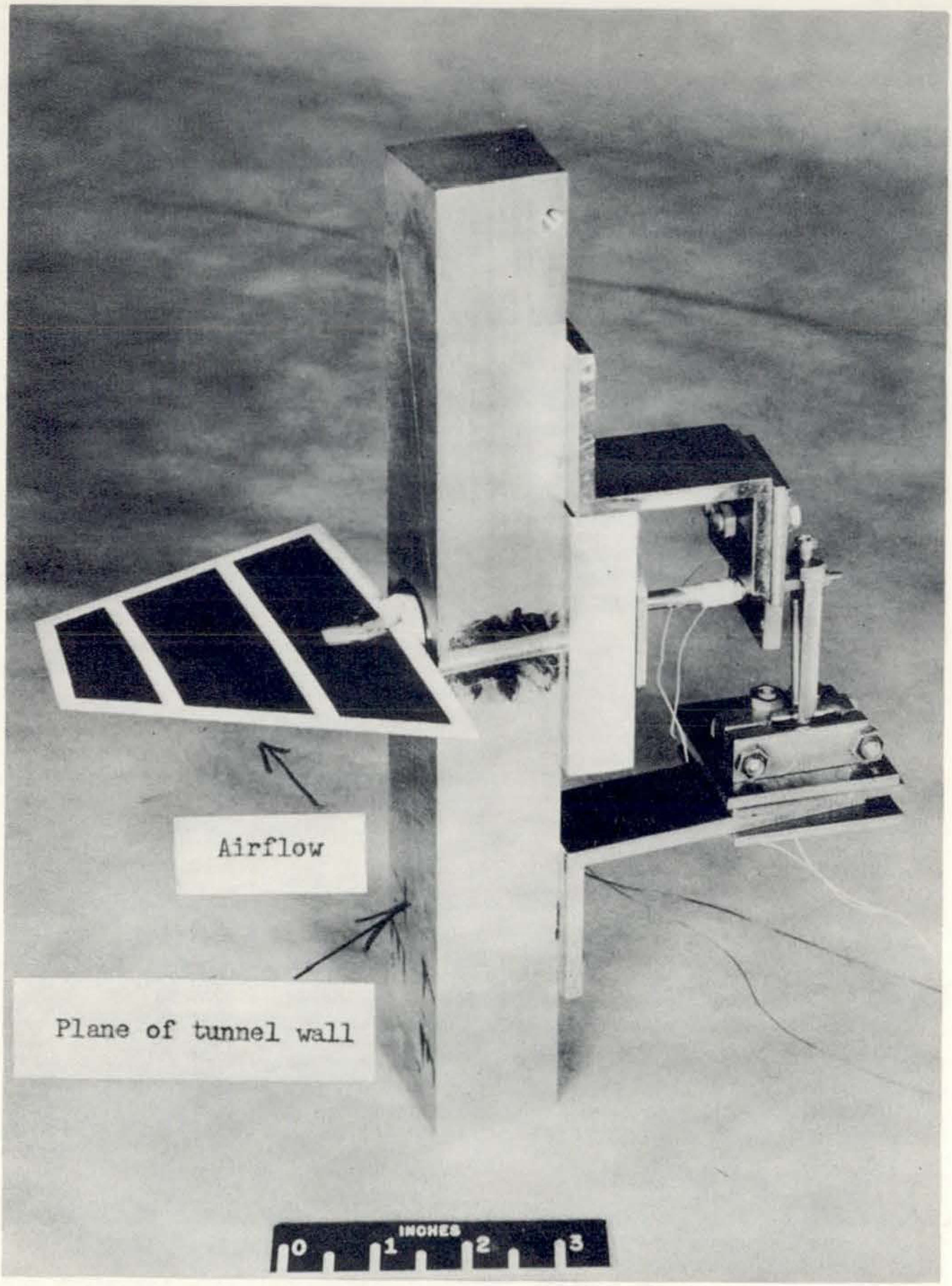
(f) Model 1; 1/2 design scaled pitch stiffness; tested with 1.06° free play in pitch; runs 32 to 38. (Note: Frequencies and node lines are presented for the model with no free play in pitch. When free play in pitch was permitted in the model, frequencies and node lines could not be measured accurately.)

Figure 5.- Concluded.



(a) Breakdown of parts. L-59-8324.1

Figure 6.- Supersonic model.



(b) Assembly. L-59-8322.1

Figure 6.- Concluded.

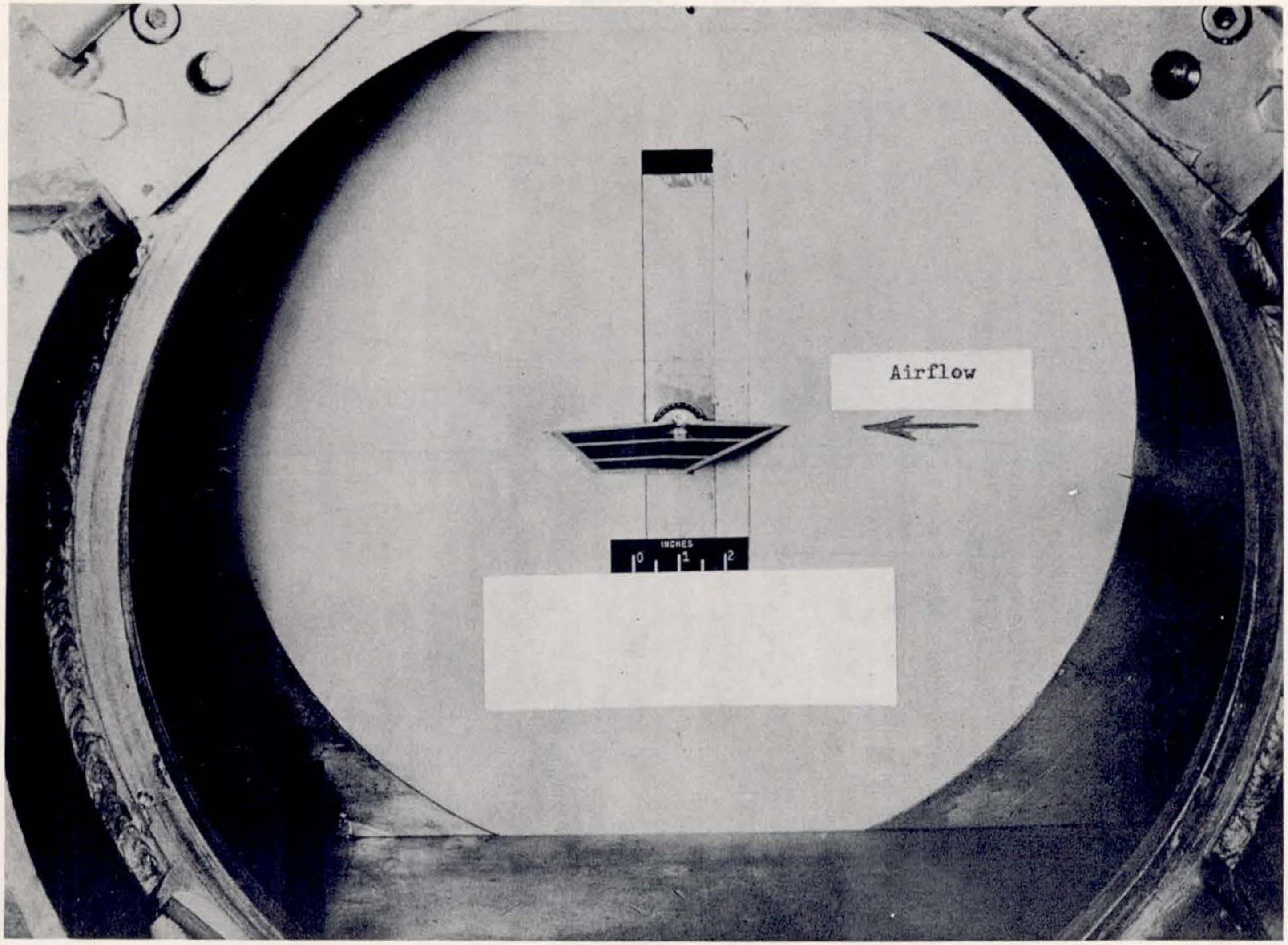


Figure 7.- Model mounted in supersonic tunnel. L-60-342.1

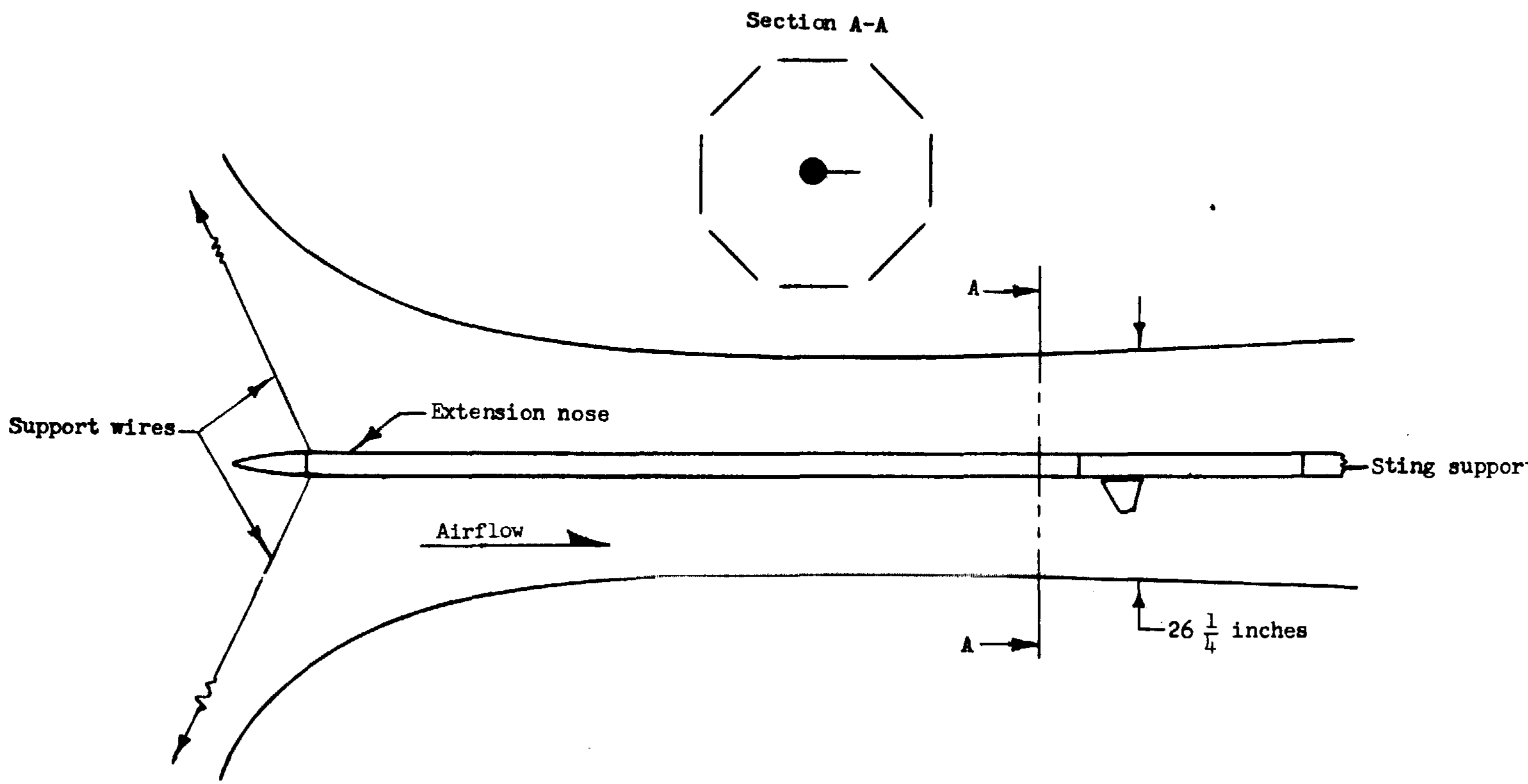


Figure 8.- Plan view of Langley transonic blowndown tunnel showing model installed.

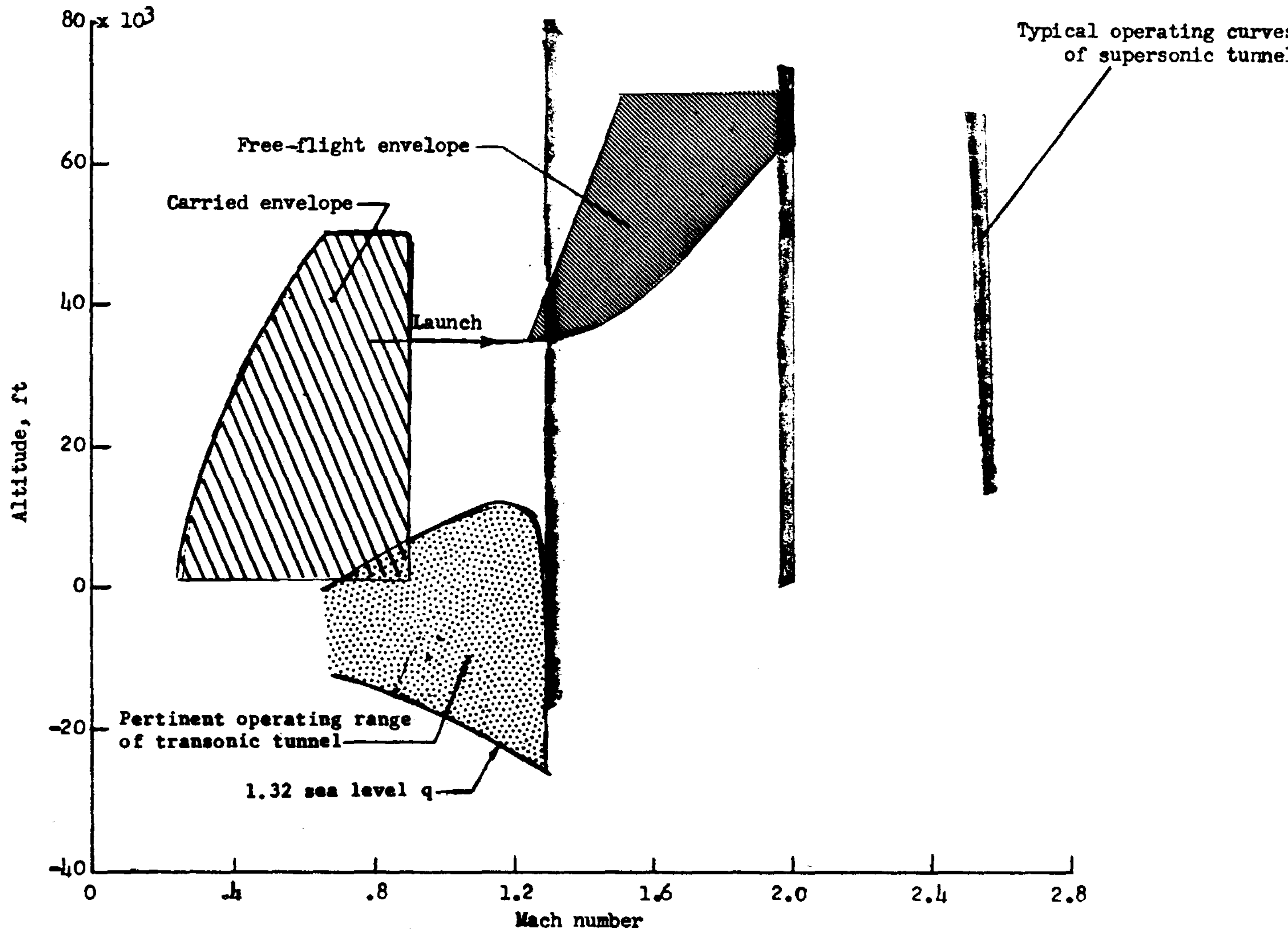
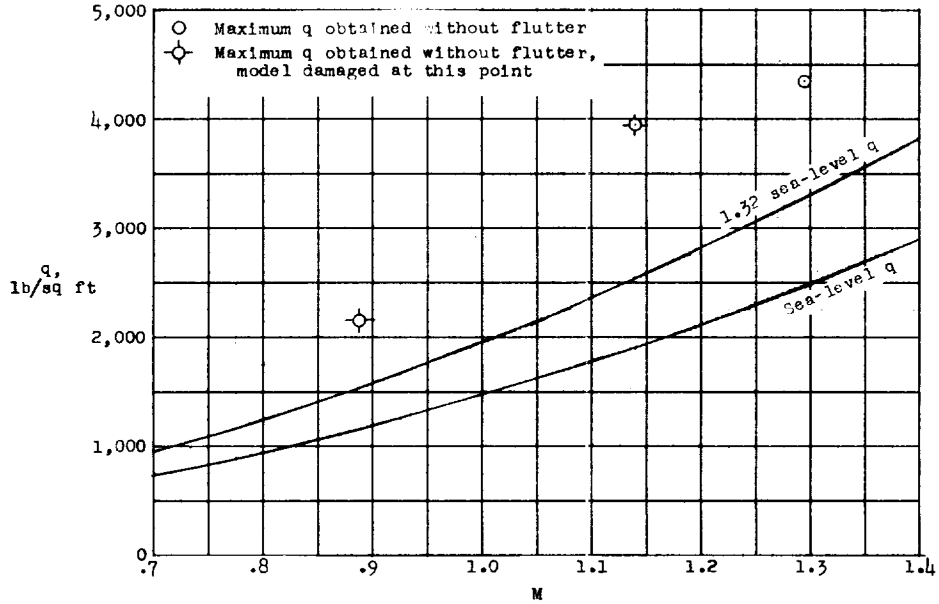
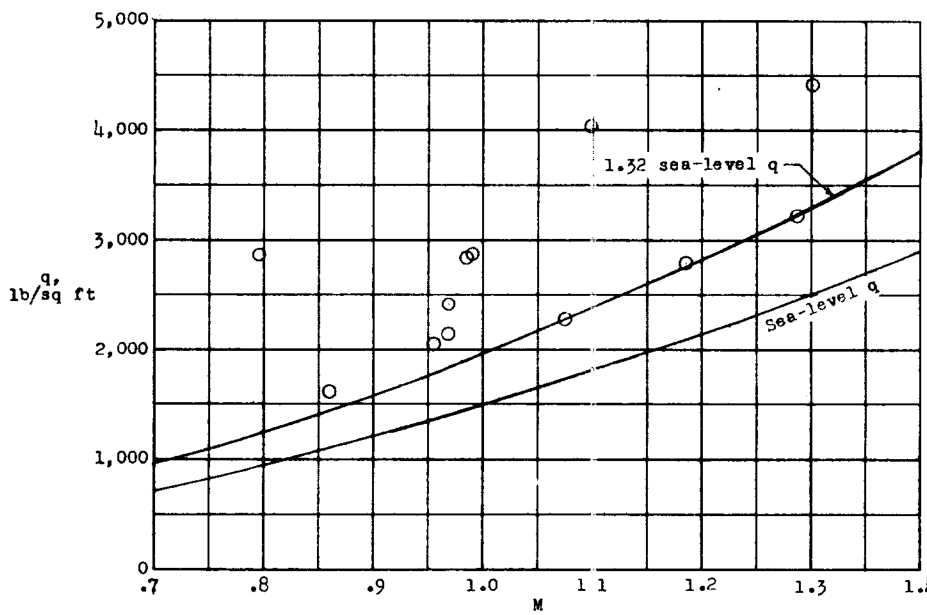


Figure 9.- Altitude and Mach number flight envelope of target and operating ranges of Langley transonic blowdown tunnel and Langley 9- by 18-inch supersonic aeroelasticity tunnel.

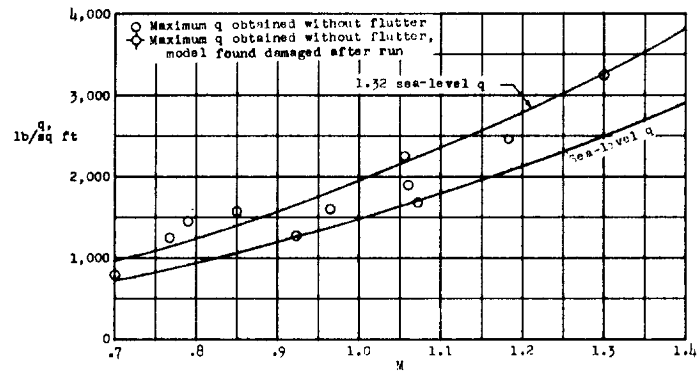


(a) Model with no free play in pitch.

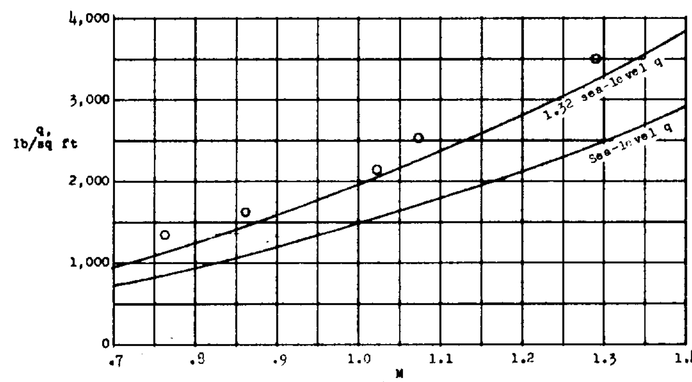


(b) Model with 0.86° free play in pitch.

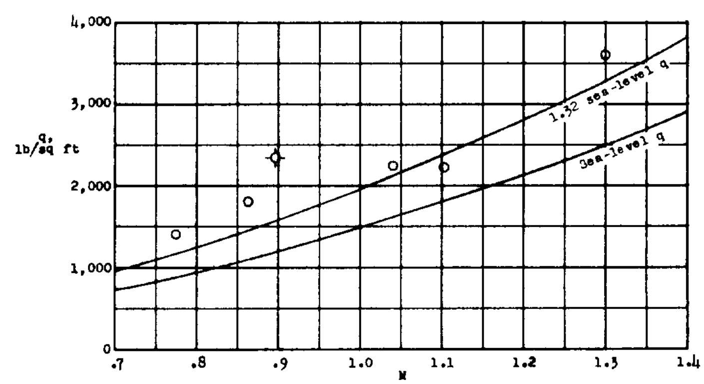
Figure 10.- Maximum dynamic pressure obtained without flutter at various Mach numbers for models having scaled design pitch stiffness.



(a) Model with no free play in pitch.



(b) Model with 0.52° free play in pitch.



(c) Model with 1.05° free play in pitch.

Figure 11.- Maximum dynamic pressure obtained without flutter at various Mach numbers for model with 1/2 scaled design pitch stiffness.

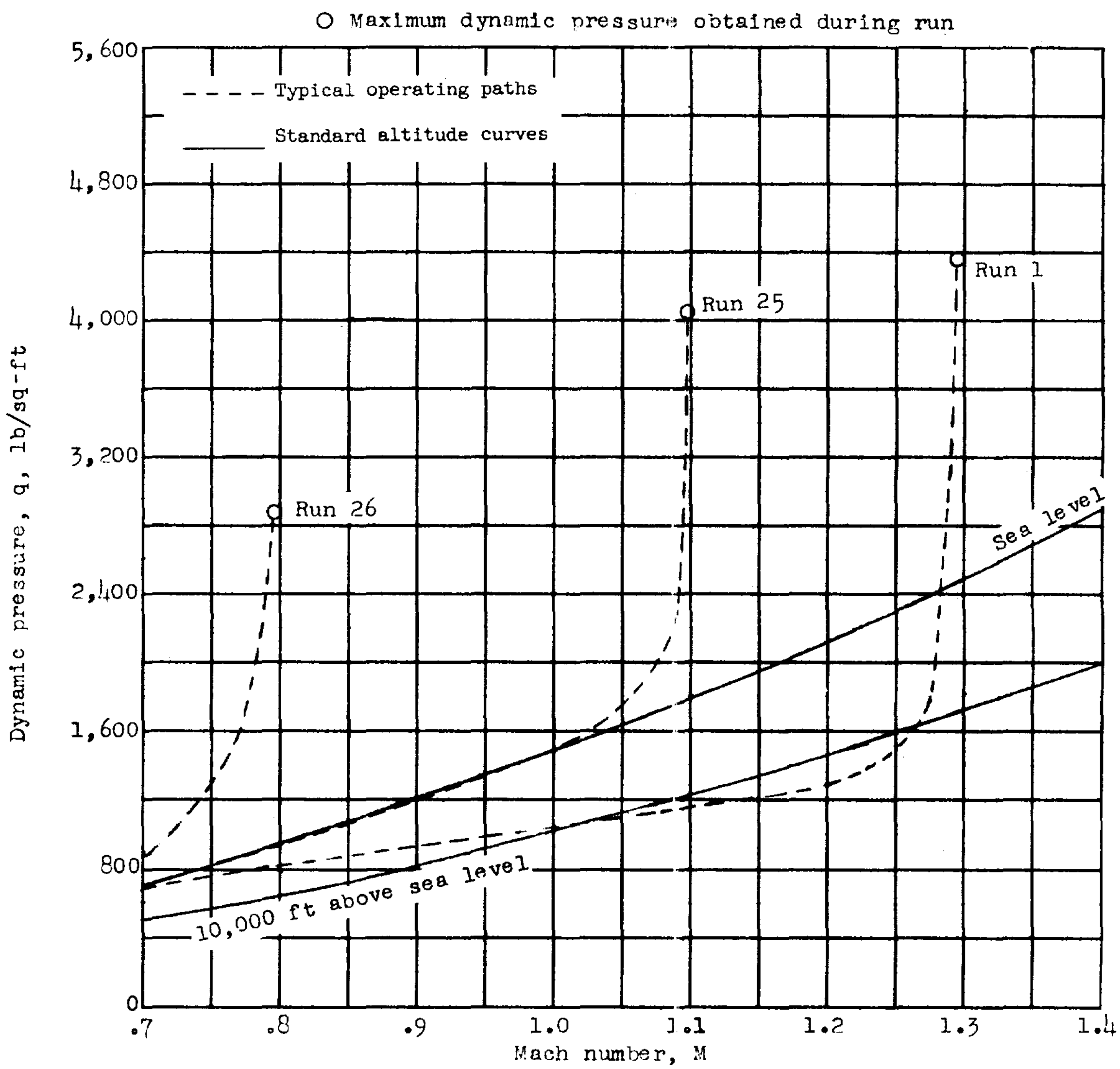


Figure 12.- Variation of dynamic pressure with Mach number during three typical runs in the Langley transonic blowdown tunnel.

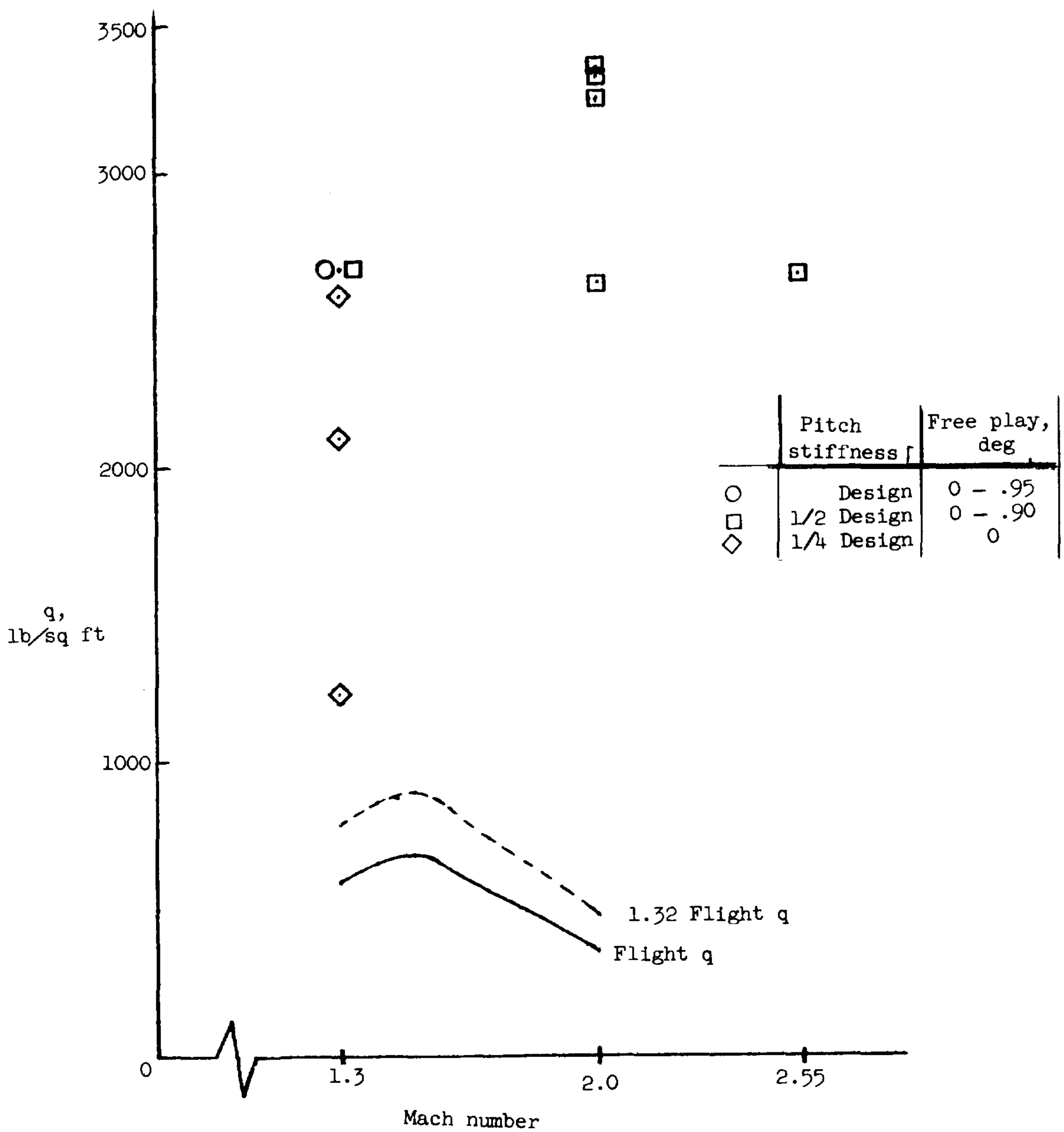


Figure 13.- Maximum dynamic pressure obtained without flutter at various Mach numbers and expected flight dynamic pressure in supersonic range.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM SX-616

for

Bureau of Naval Weapons, Department of the Navy

TRANSONIC AND SUPERSONIC FLUTTER INVESTIGATION OF 1/2-SIZE MODELS OF ALL-MOVABLE CANARD SURFACE OF AN EXPENDABLE POWERED TARGET

TED NO. NASA AD 3164, COORD. NO. N-AM-89

By Charles L. Ruhlin and W. J. Tuovila

ABSTRACT

The experimental investigations covered a Mach number range from 0.7 to 2.55. The semispan models were tested at 0° angle of attack with three pitch spring stiffnesses and with free play in pitch ranging from 0° to 1°. All model configurations investigated were flutter free to dynamic pressures 32 percent greater than those required for flight throughout the Mach number range. No flutter could be obtained although several model configurations were tested to considerably higher dynamic pressures.