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SUPERSONIC JET TESTS OF MISSILE STABILIZERS

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SUMMARY

Seven stabilizers were tested at a Mach number of 2 in order to determine the effects of aerodynamic heating and loading on the structural stability of the stabilizer. The models differed in internal structure and postcure temperatures of the laminated Fiberglas skin. Tests were made at various stagnation temperatures between 440° F and 625° F. The postcure temperatures of the Fiberglas skins were found to affect significantly the ability of the model to withstand the imposed test conditions.

INTRODUCTION

The present investigation was undertaken to determine the structural stability of a proposed missile-stabilizer configuration subjected to aerodynamic heating and loading. The models employed two types of internal construction and had laminated Fiberglas covers for which the postcure temperature cycle had been varied. The stabilizers were tested at a Mach number of 2, and the stagnation temperature was varied between 440° F and 625° F. Comparisons are made of the temperature, strain, and vibration data obtained during the tests. A description of model behavior, as determined from an analysis of high-speed motion pictures taken during the test and a visual inspection of the models after the test, is presented.

DESCRIPTION OF MODELS

Model Construction

The models tested were full-size delta plan-form wings having a sweep angle of approximately 80° and a rectangular trailing-edge control surface.

The construction details of the seven stabilizers (designated FS-1 to FS-7) are shown in figure 1. All models were covered by a one-piece, four-ply, laminated Fiberglas skin of 0.045-inch thickness. On models FS-1 to FS-5, the skin was supported by a cast magnesium frame. For models FS-6 and FS-7, part of the frame members were replaced by an aluminum honeycomb core.

The procedure used to form the skin and bond it to the model frame is given in the appendix. The skins for models FS-4 and FS-6 were post-cured to 275° F. All other models had skins which were postcured to 400° F.

The exterior of each model was painted with zinc chromate primer over which an India ink grid was applied to aid in determining model motions from analysis of motion-picture film. A photograph of a model mounted on the support fixture is shown in figure 2.

Model Instrumentation

Models FS-1 to FS-5 were instrumented with 14 iron-constantan thermocouples and 7 Baldwin SR-4 type EBDF-7S minus wire strain gages located as shown in figure 3. Eight thermocouples were installed in the frame by peening each beaded junction into a hole, approximately equal in diameter and depth to the bead size, which had been drilled into the frame. The six skin thermocouples were beaded junctions which had been glued to the inside surface of the skin. Two models, FS-6 and FS-7, did not contain any instrumentation.

High-speed 16-millimeter motion pictures were taken of each test to record model behavior.

TESTS

Supersonic Jet Facility

The tests were made at the NASA Wallops Station in the preflight jet, a blowdown wind tunnel in which models are tested under simulated sea-level flight conditions in a free jet at the exit of a supersonic nozzle. A Mach number 2, 27- by 27-inch nozzle was used for these tests. A description of the jet operating characteristics is given in the appendix of reference 1.

Model Mounting

The models were mounted on a special stand which placed the base of the stabilizer about 7 inches above the lower edge of the jet and the nose of the stabilizer about 1/4-inch downstream of the nozzle-exit plane. The model was essentially cantilevered from the stand along the root chord. A photograph of a model mounted at the exit of the nozzle is shown in figure 4.

At zero angle of attack, the model and its stand were alined with the jet center line. The angle of attack was obtained by rotating the model and its stand clockwise, as viewed from overhead, about a point $28\frac{3}{4}$ inches downstream of the nozzle-exit plane. Models FS-2 and FS-5 were tested at an angle of attack of 4.1°. In addition, model FS-2 had the control surface set counterclockwise 7.5° with respect to the model. Models FS-6 and FS-7 were tested without control surfaces.

Aerodynamic Test Conditions

All test data presented herein are referenced to a zero time taken as the instant air began to flow in the nozzle as indicated by a static-pressure orifice 1 inch upstream of the nozzle-exit plane. The total duration of a test was about 14 seconds. Of this time, approximately 2 seconds were required to start the jet and another 3 seconds to shut it down. Test conditions were considered to exist whenever the stagnation pressure immediately downstream of the heat exchanger exceeded 100 psia. A plot of the variation in stagnation pressure with time for a typical test is shown in figure 5.

A summary of aerodynamic test data is given in table I. The Mach number was determined from a separate calibration test. The values of stagnation pressure and stagnation temperature were measured during each test and have been averaged for the time during which test conditions existed. The remaining items were calculated from the Mach number and the average values of stagnation temperature and pressure. A discussion of the difficulty encountered in measuring stagnation temperature is given in the appendix of reference 1. The value given in table I is an average of temperatures at seven selected thermocouples located just downstream of the heat accumulator.

TEST RESULTS

Model Behavior

The determination of the behavior of the model is based on a study of the high-speed motion-picture film and the oscillograph records. The ability of a model to withstand the imposed test conditions was established by a visual inspection of the model after the tests.

Damage to the models during the tests was confined to skin buckling, failures in the bond between the skin and the internal frame, and delamination of the skin plies. Skin delamination usually resulted in the formation of a blister between skin plies, and in the case of models FS-2 and FS-4, blisters near the rearward edge of the skin caused the outer ply of the skins to tear off in a small area. Photographs of the models after the tests are shown in figure 6. Models FS-1 to FS-5 showed evidence of skin buckling during the test; models FS-2, FS-4, and FS-5 had permanent buckles after the test. Models FS-6 and FS-7, which had a honeycomb core, did not show evidence of skin buckling during the tests. Model FS-6, however, did show some skin delaminations which are visible in figure 6(f).

Of the seven models tested, models FS-1, FS-3, and FS-7 appeared to be completely sound in all respects after the test. These models all had Fiberglas skins which had been postcured to 400° F. They were tested at stagnation temperatures of 558° F, 441° F, and 593° F, respectively. Models FS-2 and FS-5 also had Fiberglas skins which had been postcured to 400° F but were tested at stagnation temperatures of 624° F and 600° F, respectively. These two models developed some skin delaminations during the test. Models FS-2 and FS-5 were tested at an angle of attack of 4.1°, but the skin delaminations appeared to be as prevalent on the leeward side of the stabilizer as on the windward side. Models FS-4 and FS-6 had Fiberglas covers which had been postcured to only 275° F but were tested at stagnation temperatures of 573° F and 614° F, respectively. The covers of these models experienced severe delaminations.

Wire-Strain-Gage Data

The data from the wire strain gages installed in models FS-1 to FS-5 indicated sinusoidal oscillations of the skin panels during some of the tests. Generally these vibrations were not of such amplitude as to be discernible on the high-speed motion-picture film. Only for model FS-4 at about 9.2 seconds could the oscillations indicated by the oscillograph records be observed on the motion-picture film.

Plots which show the variation in indicated strain during the test for models FS-1 to FS-5 are shown in figure 7. Actual oscillograph records of the strain data were made at a paper speed of 24 inches per second. The galvanometers used to record strain had a frequency response flat to 90 cps; therefore, the recorded amplitude of the high-frequency strains is greatly attenuated. No attempt has been made to correct for this attenuation. Neither the amplitude nor the frequency of the random oscillations that occur during the starting and stopping phases of the jet has been shown on the strain plots; only the approximate mean value of strain is shown during these times. For the period during which test conditions existed, the frequencies of vibration indicated by the wire strain gages are noted on the figure. For frequencies below 100 cps, the curves shown represent the measured strains; the approximate amplitudes of vibratory strains have been indicated by a band. Vibratory strains above 100 cps are also indicated by a band, but in this case the amplitudes shown do not represent true strains because of the high attenuation of the recording system. Where a curve for a particular gage has been omitted, the gage was either inoperative or considered unreliable during the test.

The strain gages in the second bay of the stabilizer (numbered 1, 2, and 3 in fig. 3) did not show any vibrations during any of the tests. On all the models which had operative gages in the third bay (numbered 4, 5, 6, and 7 on fig. 3) oscillations were noted at some time during each test.

Model Temperatures

All model-temperature data are given in table II. The temperatures did not appear to follow a consistent pattern from thermocouple to thermocouple on the same model or for any particular thermocouple location from model to model. This is believed to be due largely to the differences in individual thermocouple installations and probably to some extent due to variations in the thermal properties of the glass laminate from model to model. As was noted previously, the thermocouples on the inner face of the Fiberglas skin were held in place by an adhesive. With this type of installation, it is difficult to obtain accurate control of the intimacy of contact between the thermocouple junction and the model. The heat sink produced by the adhesive at the junction would also affect the accuracy of temperature measurements. In the case of frame thermocouples, readings could be greatly affected by variations in the thickness of the bond between the Fiberglas skin and the frame.

The maximum skin temperature recorded during any of the tests was 452° F indicated by thermocouple number 1 on model FS-5. Although model FS-2 was run at a higher stagnation temperature than model FS-5, its maximum skin temperature was about 50° F less. This discrepancy is probably due to differences in thermocouple installations.

CONCLUDING REMARKS

Seven full-size missile stabilizers were tested at a Mach number of 2 under simulated sea-level flight conditions in order to determine the effects of varying the internal structure and the curing temperatures of the laminated Fiberglas skins.

The models which had cast magnesium frames showed evidence of skin buckling and panel vibrations during the tests. Models FS-2, FS-4, and FS-5 had permanent buckles after the test. The aluminum honeycomb core used on models FS-6 and FS-7 prevented the formation of skin buckles.

The postcure temperatures of the laminated Fiberglas skins were found to affect significantly the ability of the models to withstand the imposed test conditions. Skin delaminations on the model covers which were postcured to only 275° F were much more severe than on those which had been postcured to 400° F.

Temperature measurements on the models were not too reliable. This is believed to be due to variations in individual thermocouple installations.

The wire strain gages installed in models FS-1 to FS-5 indicated vibration of the skin panels in the third bay at some time during each test. The oscillations were of small amplitude and apparently had no adverse effects on the integrity of the model as a whole.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., July 15, 1959.

APPENDIX

FABRICATION AND BONDING OF FIBERGLAS SKIN

Skin Fabrication Procedure

The model skins were formed from continuous filament glass fabric having the following specifications:

Fabric no. 181

Average thickness, 0.0085 ± 0.00 in.

Average weight per square yard, 8.90 oz

Type of weave, 8-harness satin

Construction (ends per inch), 57 warp and 54 fill

Finish no. 114

The fabric was impregnated with American Reinforced Plastics Co. Type 91-LD high heat resistant phenolic resin. The impregnated glass fiber was made to conform to the following requirements:

Volatile loss (percent loss in weight of impregnated fabric when heated 10 min. at 325° F), 2.5 to 5 percent

Resin solids (percent of resin after volatile loss), 35 to 38 percent

The skins were molded from four layers of impregnated fabric. The fiber layers or plies were cut so that fabric orientation was the same for each ply (the leading edge was parallel to the warp); alternate plies then were turned over before final layup for molding. The plies were placed on a preform, held at 200° F ± 10° F for 1 hour, and then cooled to room temperature. Final molding was done on a male-female mold maintained at 315° F ± 10° F. The last inch of mold separation was closed at a rate of about 1 inch per minute to permit complete heating of the laminate and allow for adequate resin flow. Sufficient pressure to hold the mold against positive stops was maintained for a 10-minute curing cycle. The formed skin then was removed from the mold, placed on a fixture, and cooled to room temperature. Postcure was done in a circulating-air oven according to the following schedule:

Temperature, °F	Time, hr
275 ± 10	17
300 ± 10	1
325 ± 10	1
350 ± 10	1
375 ± 10	1
400 ± 10	1

The skins for models FS-4 and FS-6 were postcured only through the 275° F level. The skins for all other models received the complete postcure cycle.

Bonding Process

The adhesive used to bond the skin to the frame consisted of 100 parts by weight of Shell Chemical Corp. Epon Adhesive VIII and 6 parts by weight of Shell Curing Agent A. The Fiberglas laminate was prepared by roughening the surface to be bonded with No. 240 aluminum oxide abrasive cloth and removing all dirt, grease, or grit. The magnesium frame was chrome pickled and cleaned so as to be free from all contaminants. A layer of adhesive, 0.003- to 0.004-inch thick, was applied to both surfaces to be bonded. The parts were held together in a fixture by 2- to 6-psi contact pressure and were cured at 200° F ± 10° F for $1\frac{1}{2}$ hours. The assembled parts were cooled to room temperature before the clamping device was removed.

REFERENCE

1. Griffith, George E., Miltonberger, Georgene H., and Rosecrans, Richard: Tests of Aerodynamically Heated Multiweb Wing Structures in a Free Jet at Mach Number 2 - Two Aluminum-Alloy Models of 20-Inch Chord With 0.064- and 0.081-Inch-Thick Skin. NACA RM L55F13, 1955.

TABLE I.- AERODYNAMIC TEST DATA

Model	Model angle of attack, deg	Control-surface deflection, deg	Mach number	Velocity of sound, fps	Free-stream velocity, fps	Stagnation temperature, °F	Free-stream temperature, °F	Stagnation pressure, psia	Free-stream static pressure, psia	Barometric pressure, psia	Free-stream dynamic pressure, psi	Free-stream density, slugs/cu ft	Reynolds number per foot
FS-1	0	0	1.99	1,170	2,328	558	108	112.4	14.59	14.62	40.44	2.15×10^{-3}	12.45×10^{6}
FS-2	4.1	[a]-7.5	1.99	1,208	2,404	624	145	113.5	14.73	14.70	40.83	2.04	11.65
FS-3	0	0	1.99	1,101	2,191	441	43	112.3	14.53	14.72	40.42	2.43	14.55
FS-4	0	0	1.99	1,178	2,344	573	116	113.3	14.71	14.69	40.78	2.14	12.36
FS-5	4.1	0	1.99	1,194	2,376	600	113	113.9	14.78	14.71	40.97	2.10	12.05
FS-6	0	0	1.99	1,202	2,392	614	139	113.7	14.76	14.92	40.92	2.07	11.82
FS-7	0	0	1.99	1,191	2,370	593	128	113.9	14.78	14.73	40.97	2.11	12.11

[a]Control-surface deflection measured with respect to the model.

TABLE II.- MODEL TEMPERATURES

[Location of thermocouples shown in figure 3]

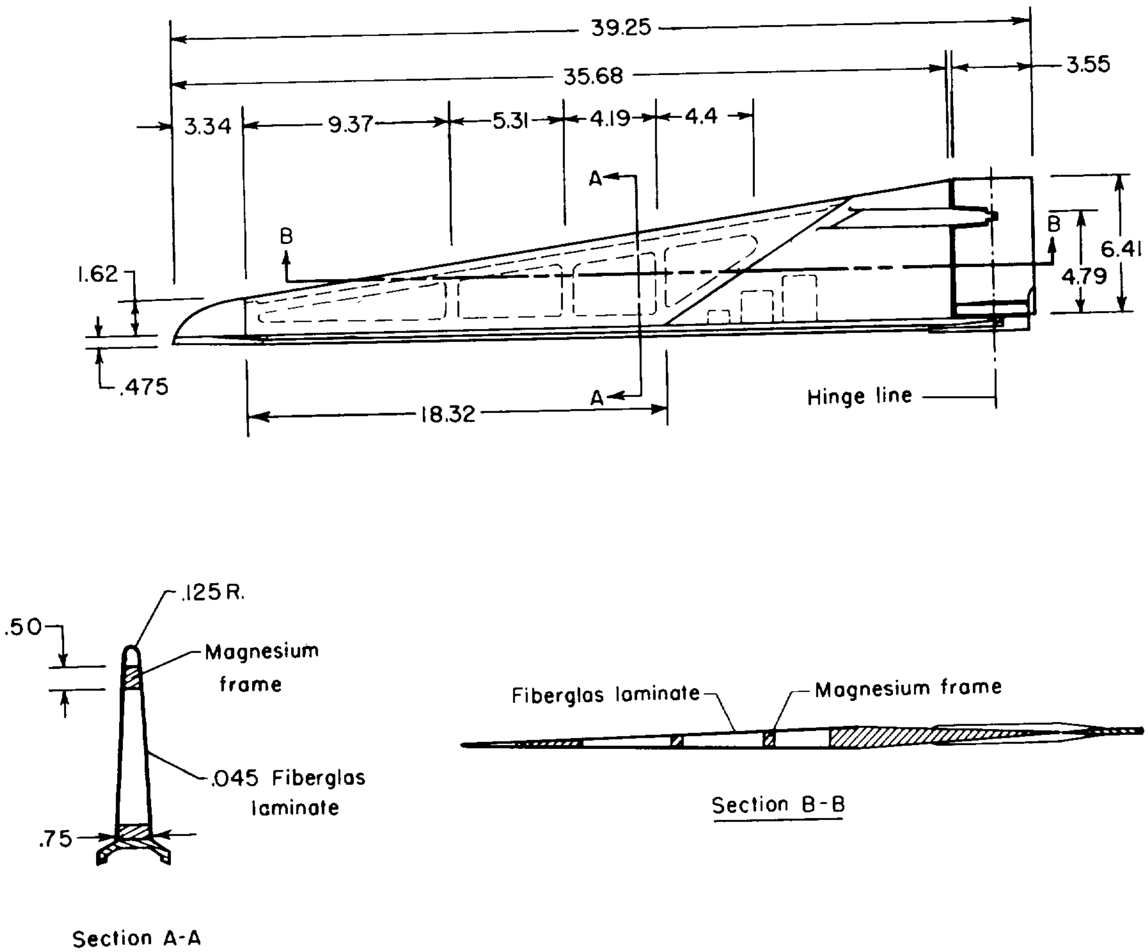
Time, sec	Temperature, °F, at thermocouple[a] -													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Model FS-1														
0	82	76	75		89	76	75	74	75	88	79	76	76	77
1	94	85	82		92	82	75	75	76	95	87	76	78	78
2	133	111	92		112	98	77	75	79	110	111	78	79	79
3	191	155	111		150	128	79	79	85	143	154	83	81	82
4	233	193	122		192	165	88	84	100	183	205	89	89	88
5	270	231	137		234	202	100	94	120	224	250	98	102	99
6	300	265	151		269	234	108	100	133	256	280	108	112	109
7	325	293	168		299	261	117	110	151	286	311	121	124	122
8	347	318	184		324	286	126	118	164	309	332	132	134	131
9	365	339	198		345	308	137	128	181	324		146	148	144
10	381	358	215		364	326	143	134	189	325		155	156	152
11	394	372	228		378	342	156	147	207	337		167	169	168
12	403	384	236		394	358	163	155	210	350		176	173	174
13	407	392	244		389	370	171	159	217	366		185	178	181
14	414	400	249		384	382	180	168	227			194	191	195
Model FS-2														
0	69	70	67	67	72	77	70	68	67	83	78	66	68	68
1	89	72	73	72	74	78	72	70	68	88	86	69	71	70
2	135	92	86	102	80	99	85	81	72	101	93	72	76	74
3	195	126	102	139	90	127	98	92	74	133	117	78	101	85
4	243	166	118	164	108	161	116	105	79	176	150	82	123	92
5	280	205	137	187	128	197	132	109	91	220	184	89	153	105
6	310	241	159	218	150	226	135	113	104	260	217	99	172	110
7	337	276	176	238	173	256	140	125	116	299	248	110	174	121
8	359	304	191	259	198	288	145	138	126	336	277	122	163	131
9	376	329	206	276	222	318	162	152	145	369	302	136	165	144
10	381	351	214	334	245	345	178	163	165	392	328	148	180	156
11	385	368	220	329	269	376	182	200	181	408	349	159	182	167
12	392	378	232	311	284	397	194	243	208	418	369	177	195	179
13	397	391	239	350	303	399	255	316	239	394	363	197	209	194
14	405	401	245	362	319	400	257	291	260	375	361	205	252	207
Model FS-3														
0	73	71	70	69	92	75	70	69	69	95	80	70		72
1	76	73	71	70	95	77	71	72	69	99	83	71		73
2	96	91	76	72	104	89	71	77	70	121	91	80		79
3	130	118	85	76	121	108	72	85	76	148	105	80		81
4	165	150	95	83	144	132	78	103	85	178	129	87		87
5	197	180	106	91	167	155	86	120	96	205	155	95		94
6	221	206	116	96	189	177	94	135	108	228	180	102		100
7	243	229	126	105	210	197	101	147	119	248	200	109		109
8	263	242	136	115	228	216	109	157	130	262	220	116		117
9	278	265	144	125	243	231	115	167	142	276	238	125		126
10	292	280	155	133	259	247	122	172	150	286	254	133		134
11	304	292	161	141	272	259	125	173	157	297	266	148		142
12	311	300	161	149	283	271	130	177	165	303	275	152		153
13	318	306	168	158	293	280	136	184	173	315	285	165		166
14	324	315	192	167	302	290	144	198	182	321	294	162		171

[a]Where data for a particular thermocouple are not given, thermocouple was not in proper working condition at time of test. Where data are listed for only part of test, values beyond those given were considered unreliable.

TABLE II.- MODEL TEMPERATURES - Concluded

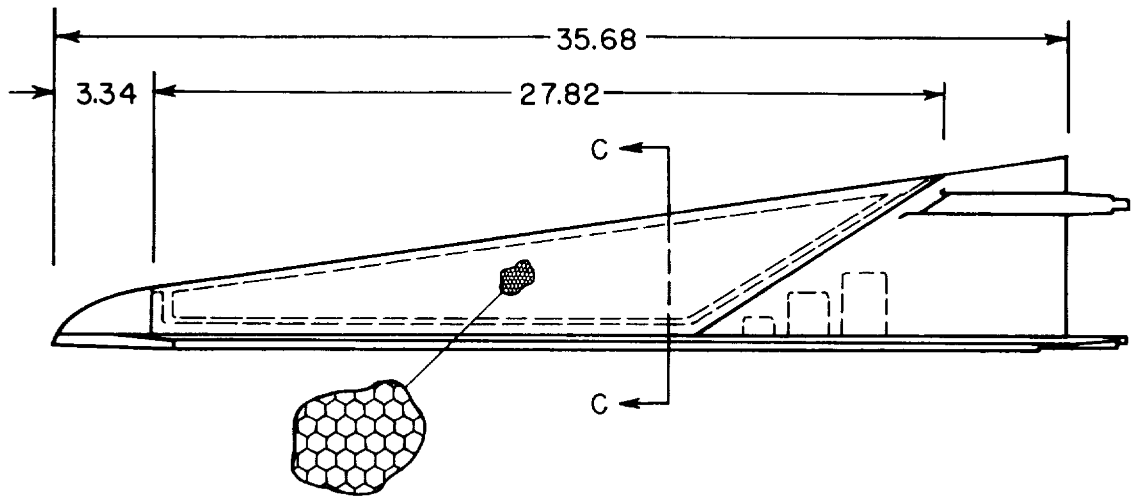
Time, sec	Temperature, °F, at thermocouple[a] -													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Model FS-4														
0	66	65	64	65	72	67	64	65	66	79	77	64	64	65
1	69	73	70	66	74	73	66	70	69	81	80	66	68	66
2	83	100	85	71	94	100	83	85	79	96	111	81	83	70
3	114	148	115	81	138	150	116	115	97		164	120	118	90
4	148	190	126	93	183	193	153	150	116			153	144	113
5	179	228	136	107	230	215	184	182	141			180	166	143
6	205	260	145	122	265		211	207	163			204	190	158
7	230	285	163	139	291		230	227	181			223	209	166
8	253	308	181	153	313		237	241	194			240	228	178
9	270	324	196	167	328		243	257	204			250	246	195
10	286	340	213	177	350		257	259	215			259	251	205
11	303	349	226	184	364		262	253	224			251	241	209
12	316	357	237	199	376		255	263	240			241	215	212
13	324	362	245	218	386		255	268	253			243	252	222
14	332	372	258	222	392		262	289	262			254	260	229
Model FS-5														
0	74	70	69	70	95	77	69	73	72	76	70	69		72
1	80	77	71	72	100	80	70	73	73	82	72	73		73
2	114	115	83	83	126	107	73	73	79	99	91	80		78
3	172	178	107	101	172	153	80	87	86	134	129	99		80
4	223	223	120	120	217	201	89	99	95	176	169	117		90
5	269	262	136	140	260	243	100	115	107	216	209	135		98
6	307	294	153	158	295	280	113	130	123	254	245	162		118
7	339	322	169	174	326	312	125	147	137	288	278	180		134
8	365	346	186	190	352	339	139	162	147	315	305	190		154
9	387	366	202	207	373	362	150	178	155	341	329	197		174
10	406	384	218	224	392	380	163	194	165	362	351	205		193
11	422	397	232	235	407	396	174	208	176	382	372	215		199
12	433	407	232	239	422	412	182	222	185	397	384	240		206
13	442	418	239	263	429	423	194	236	208	406	390	253		224
14	452	426	246	262	435	432	204	248	217	413	395	261		239

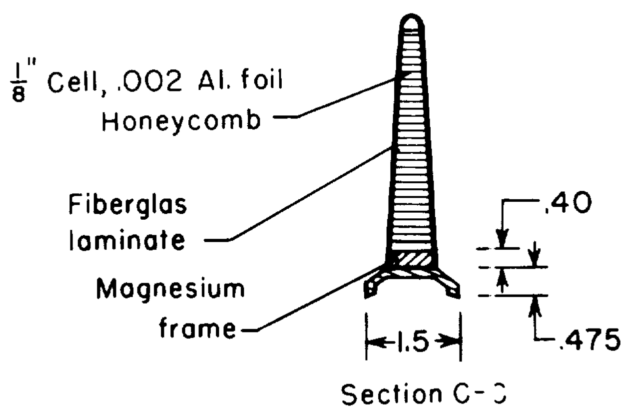
[a]Where data for a particular thermocouple are not given, thermocouple was not in proper working condition at time of test. Where data are listed for only part of test, values beyond those given were considered unreliable.



(a) Models FS-1 to FS-5.

Figure 1.- Details of construction. All dimensions are in inches.





(b) Models FS-6 and FS-7.

Figure 1.- Concluded.

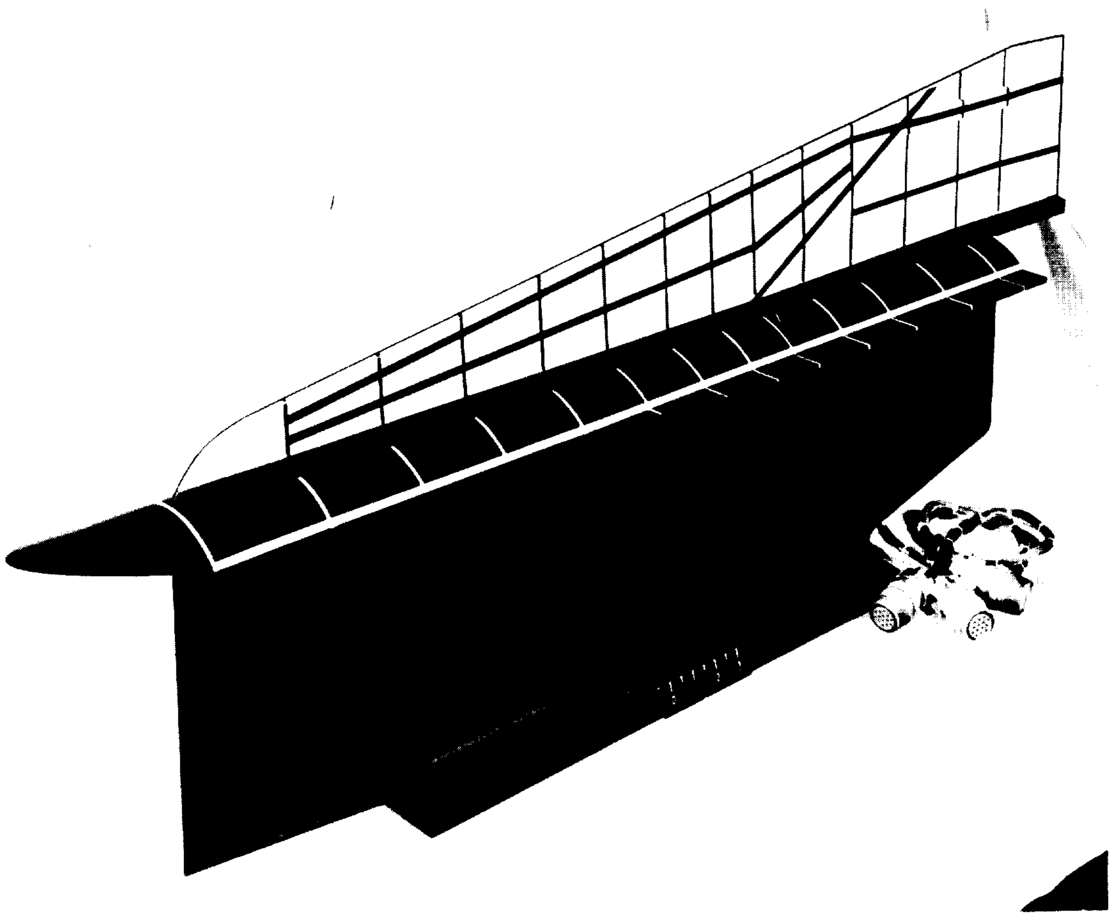


Figure 2.- Typical stabilizer assembly on support fixture. L-84208

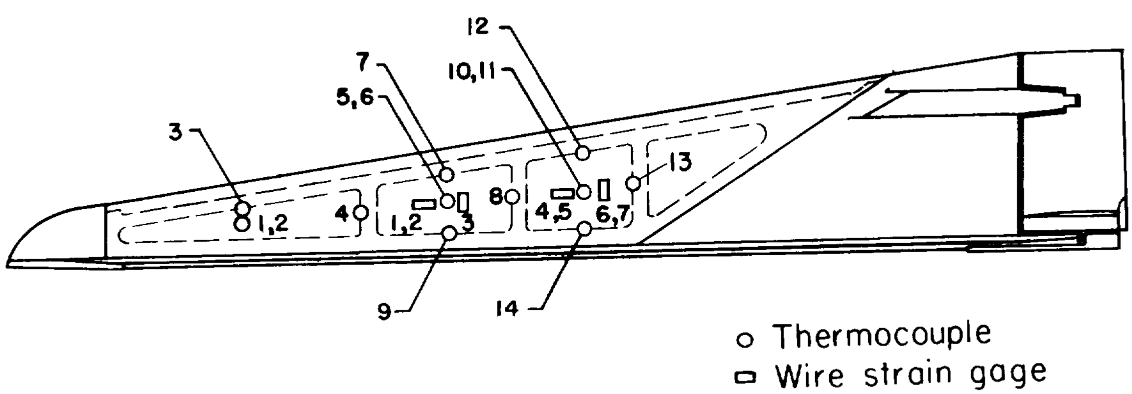


Figure 3.- Location of instrumentation. When two numbers are given, the first number represents the instrument on the near side and the second number represents the instrument on the far side.

L-84999
Figure 4.- Model mounted ready for test at exit of supersonic nozzle.

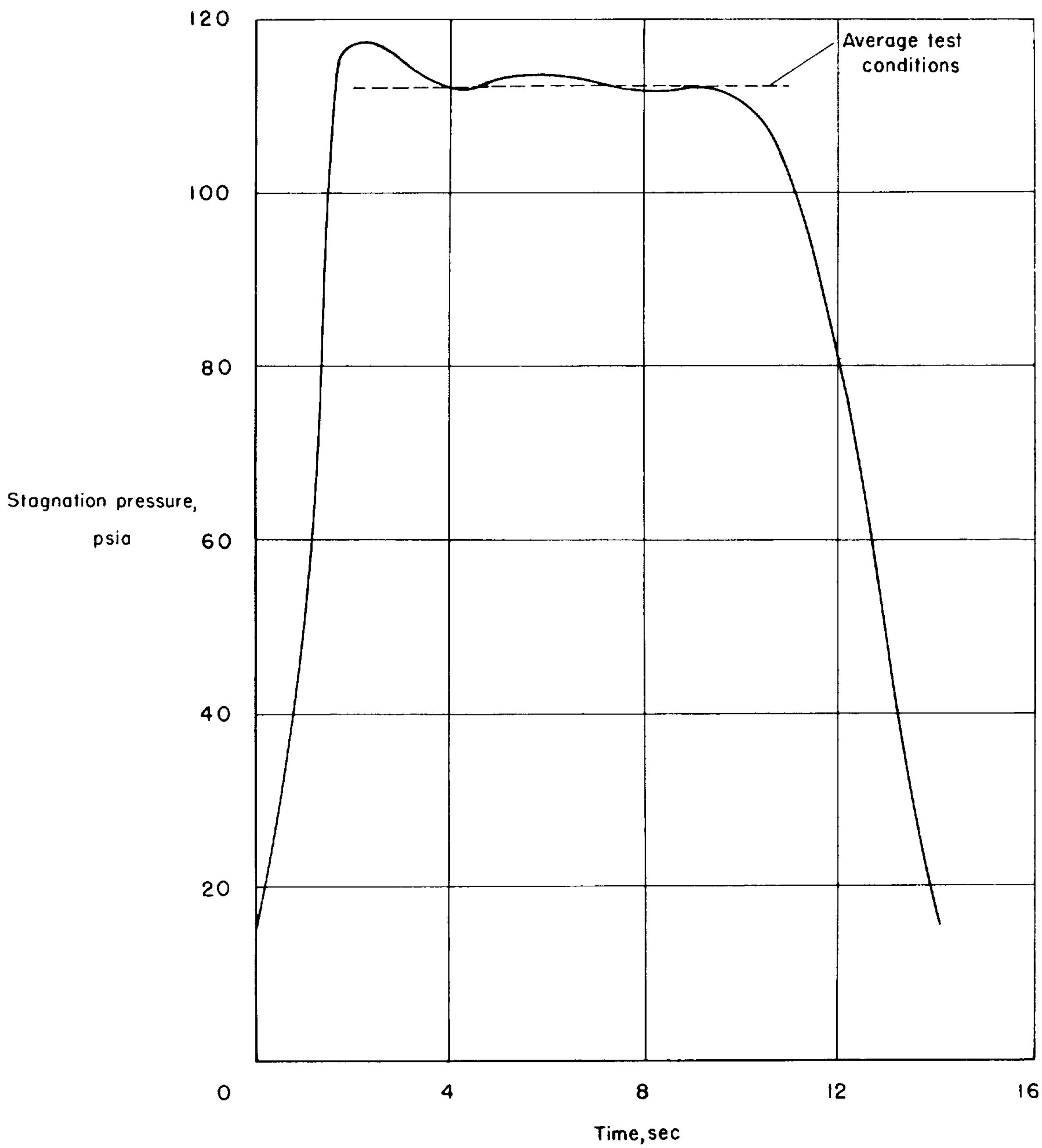
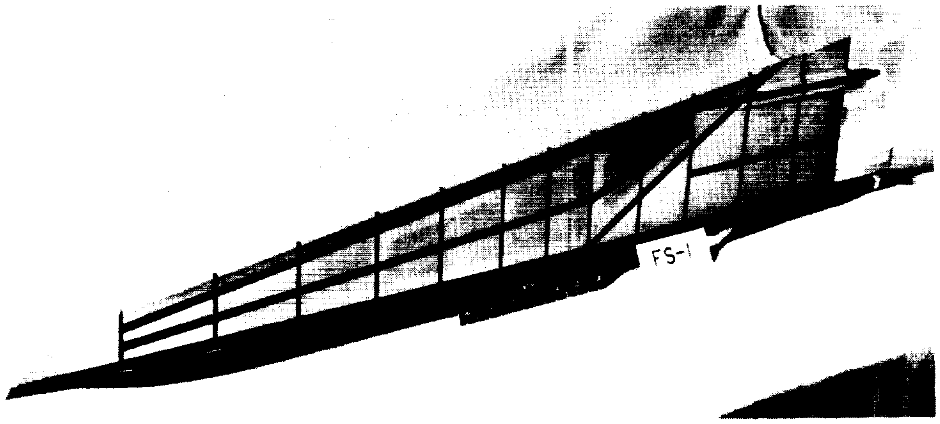
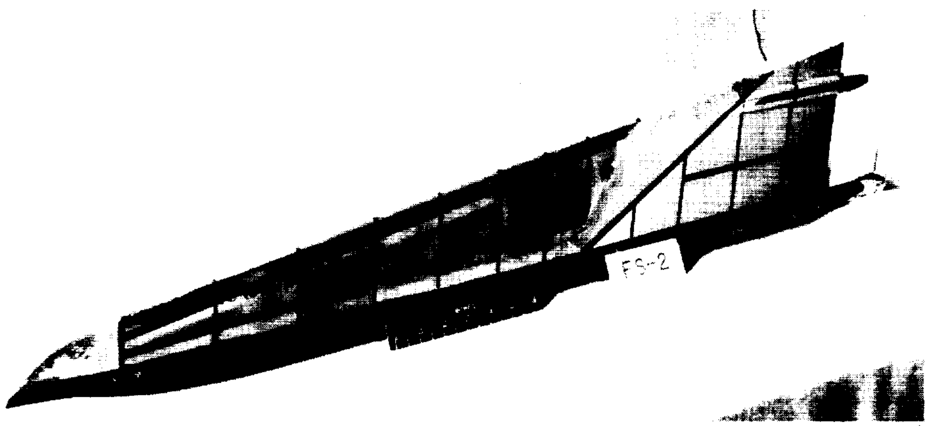


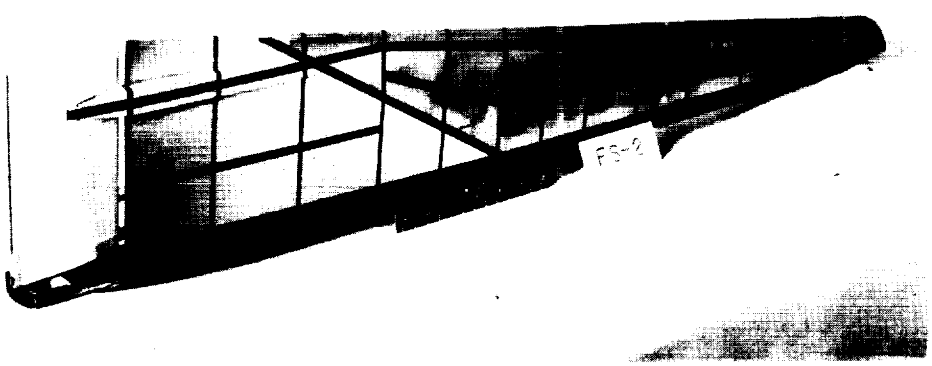
Figure 5.- Variation of tunnel stagnation pressure with time for typical test.



(a) Model FS-1. L-85080

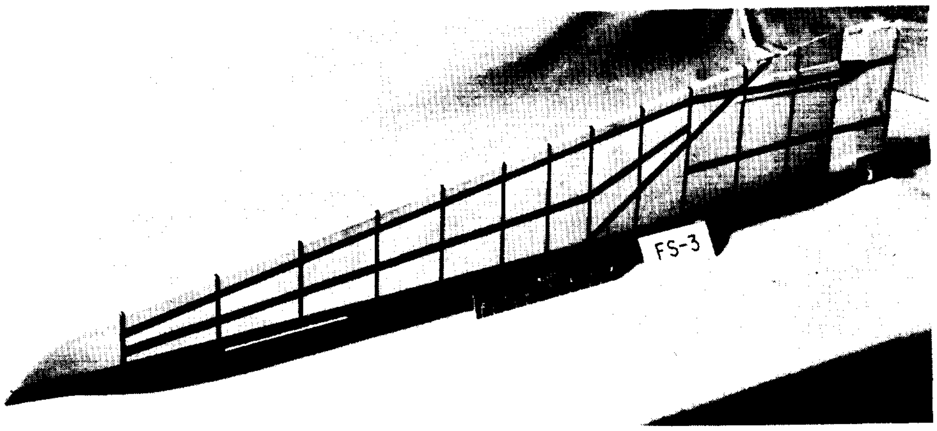


L-85081

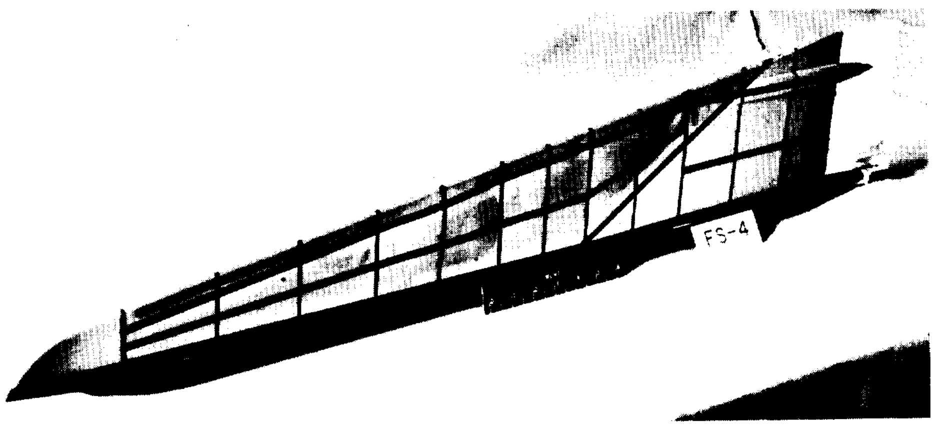


(b) Model FS-2. L-85082

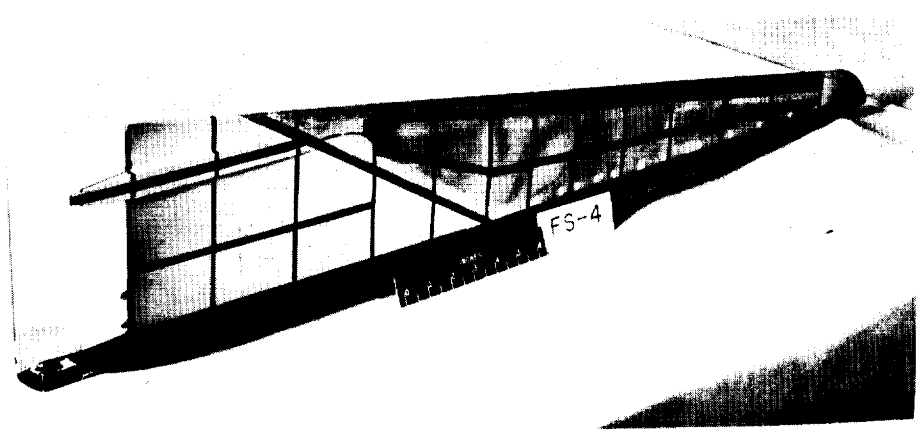
Figure 6.- Photographs of models after tests.



(c) Model FS-3. L-85083

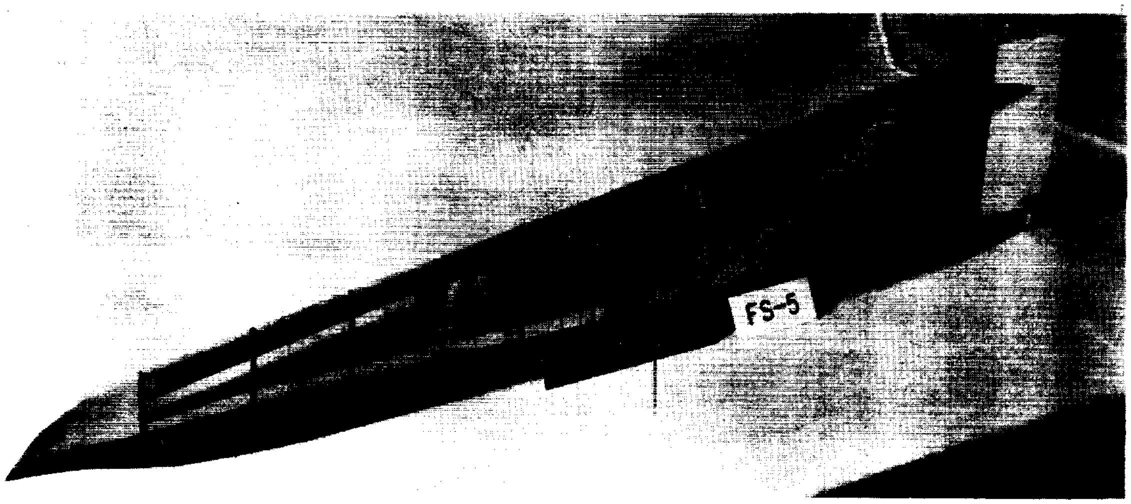


L-85085

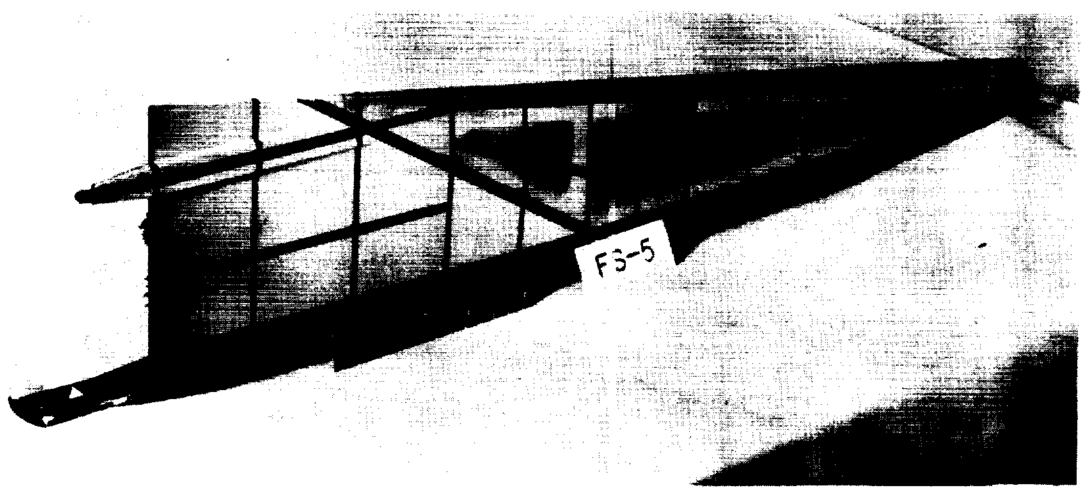


(d) Model FS-4. L-85084

Figure 6.- Continued.

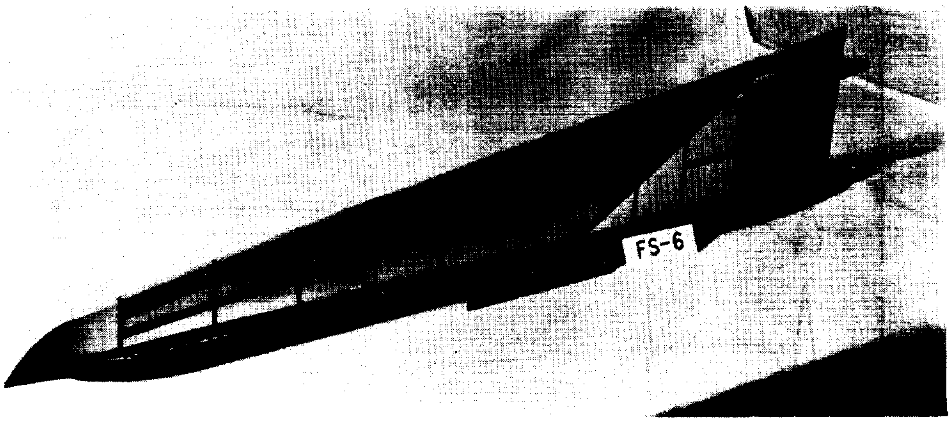


L-85086

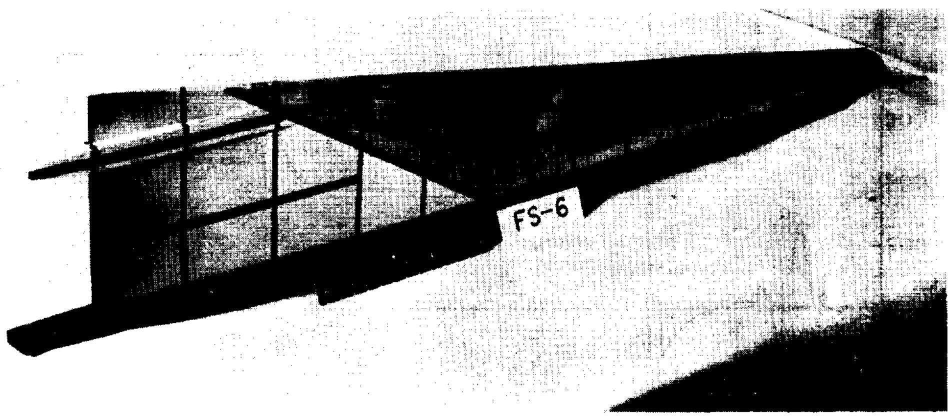


(e) Model FS-5.　　L-85087

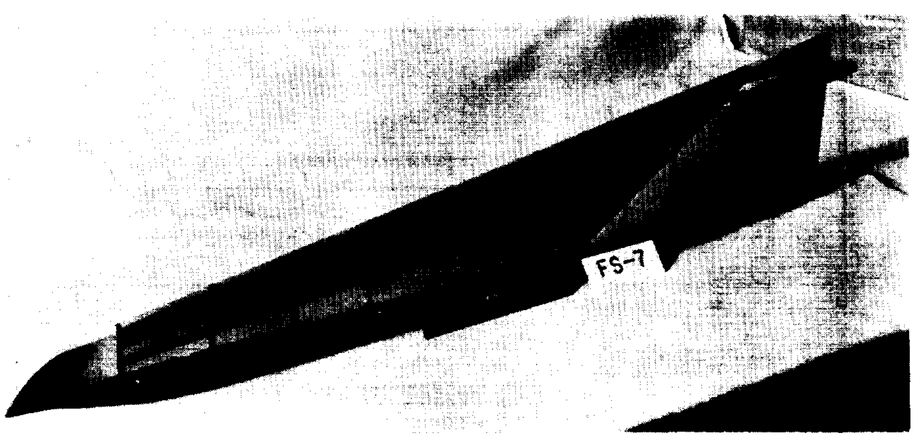
Figure 6.- Continued.



L-85088

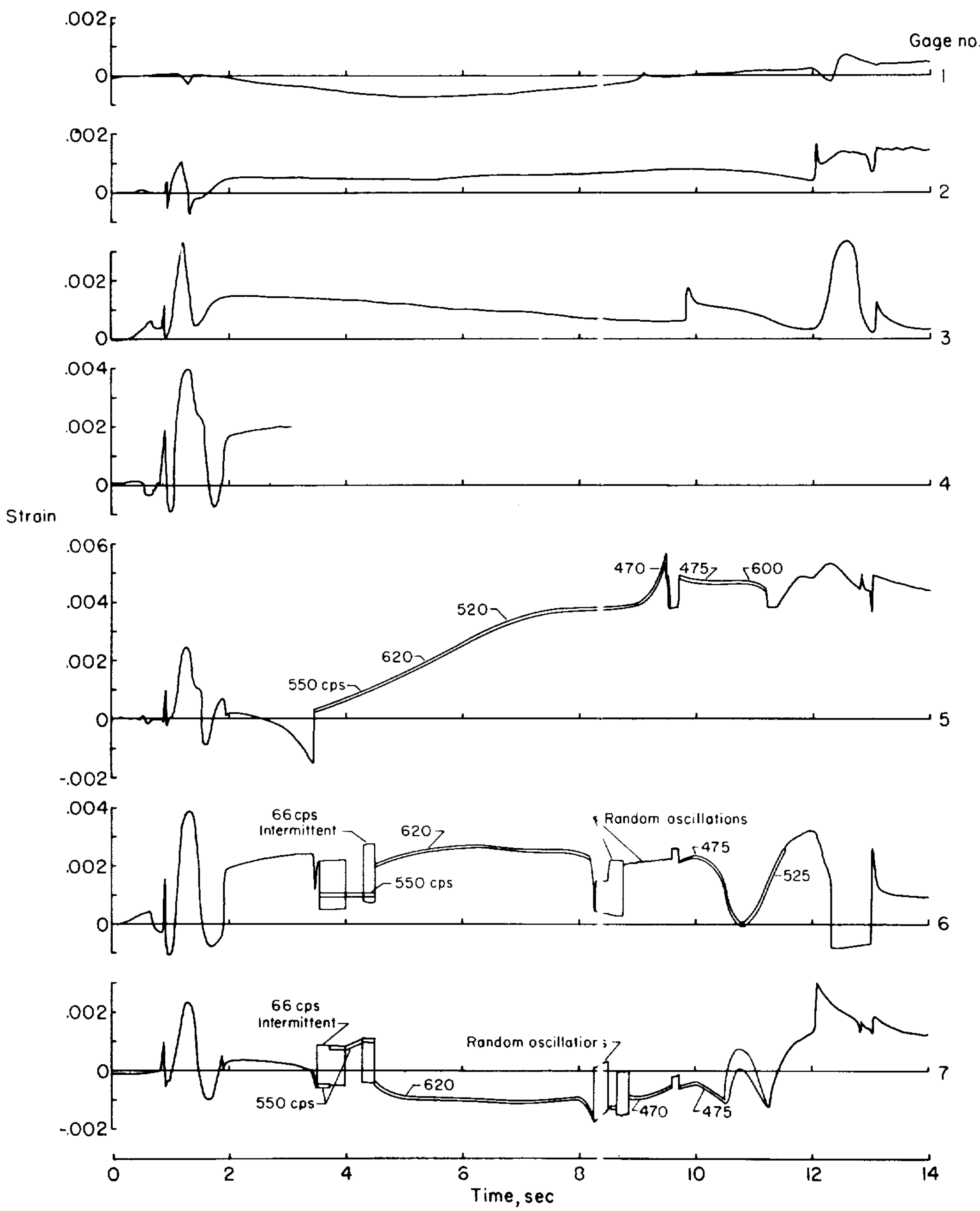


(f) Model FS-6. L-85089



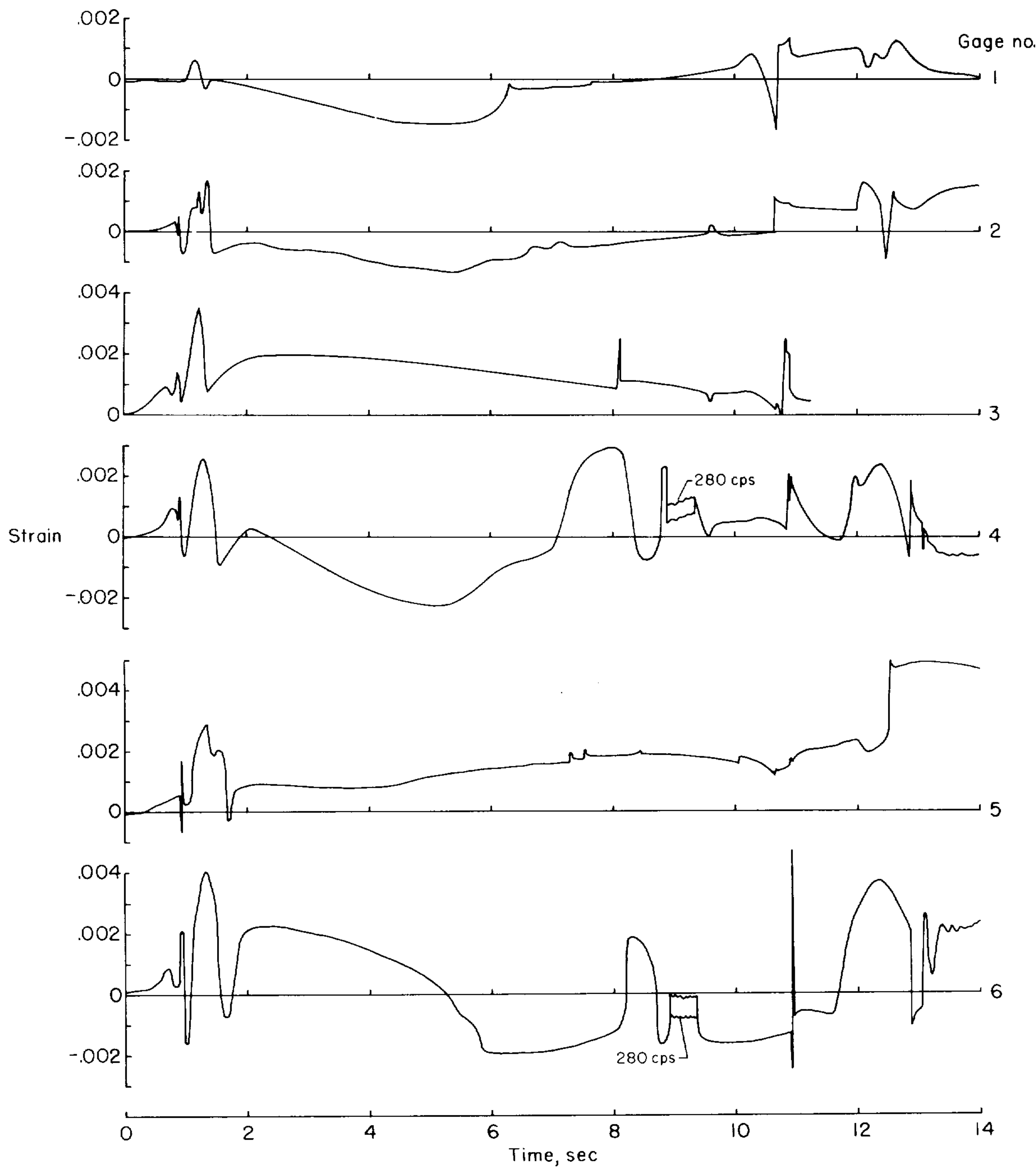
(g) Model FS-7. L-85090

Figure 6.- Concluded.



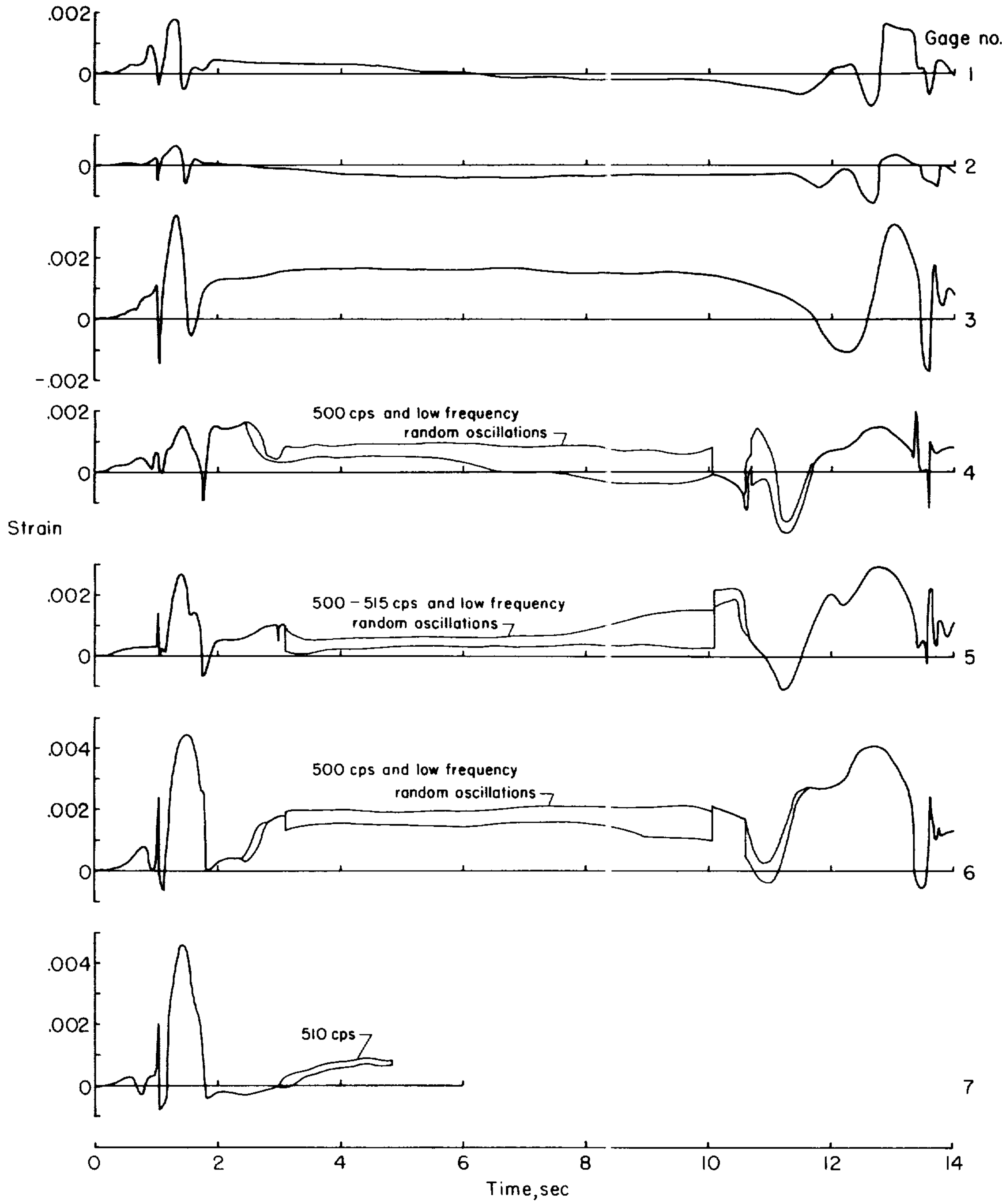
(a) Model FS-1.

Figure 7.- Variation of indicated strain with time for tests of models FS-1 to FS-5.



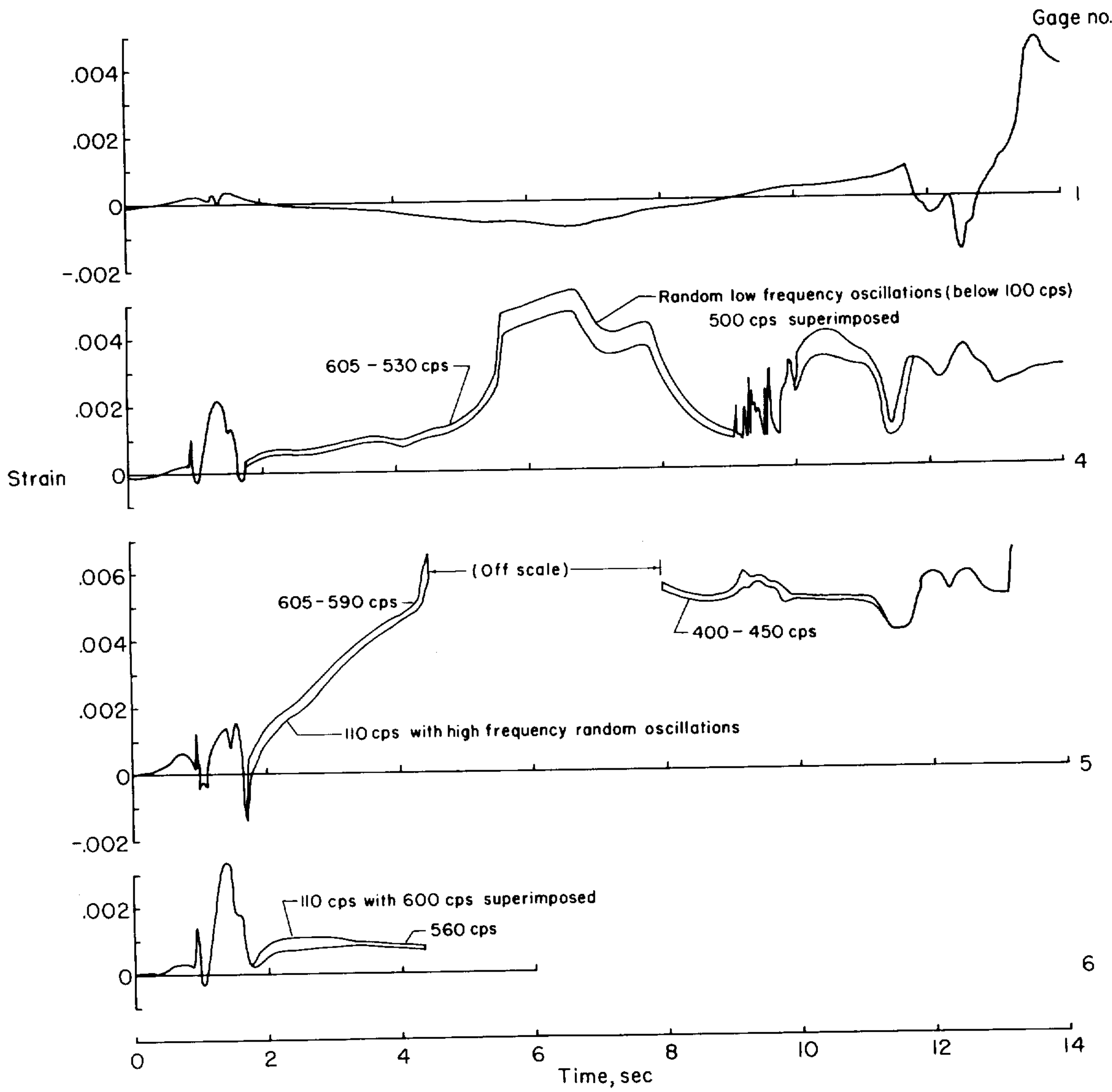
(b) Model FS-2.

Figure 7.- Continued.



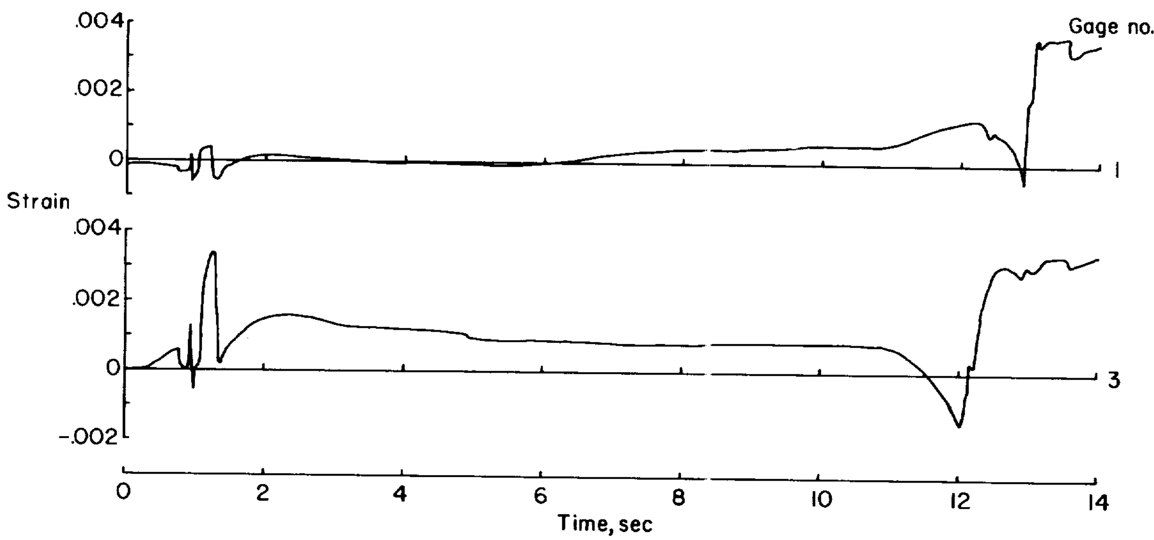
(c) Model FS-3.

Figure 7.- Continued.



(d) Model FS-4.

Figure 7.- Continued.



(e) Model FS-5.

Figure 7.- Concluded.