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NASA Technical Memorandum 4274

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Determination of the Effects of Heating on Modal Characteristics of an Aluminum Plate With Application to Hypersonic Vehicles

H. Todd Snyder
Planning Research Corporation
Edwards, California

Michael W. Kehoe
Ames Research Center
Dryden Flight Research Facility
Edwards, California

National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Division

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SUMMARY

The structural integrity of proposed high-speed aircraft can be seriously affected by the extremely high surface temperatures and large temperature gradients throughout the vehicle's structure. Variations in the structure's elastic characteristics as a result of thermal effects can be seen by changes in vibration characteristics. Analysis codes that predict these changes must be correlated and verified with experimental data. This report gives analytical and experimental modal test results from uniform, nonuniform, and transient thermoelastic vibration tests of a 12- by 50- by 0.19-in. aluminum plate. The data show the effect of heat on the modal characteristics of the plate. The results showed that frequencies decreased, damping increased, and mode shapes remained unchanged as the temperature of the plate was increased. Analytical predictions provided good correlation with experimental results.

INTRODUCTION

Hypersonic flight vehicles like the national aero-space plane (NASP) will be subjected to extremely high surface temperatures and large temperature gradients. These conditions can seriously affect the structural integrity and the aeroelastic and aeroservoelastic stability of the vehicle. If analytical procedures are relied on to predict these changes in stability, then accurate determination of the modal characteristics of these structures at elevated temperatures is vital.

Prior research in thermoelastic vibration testing was conducted for hypersonic vehicle programs of the 1960's. This research documented the effects of nonuniform heating on the fundamental vibration modes of simple panels (ref. 1) and on a prototype wing for the X-15 vehicle (ref. 2). Results showed that thermal stresses could have significant effects on structural stiffness.

There is a renewed interest in thermoelastic vibration testing with the advent of the NASP program (ref. 3). Design and flight test considerations dictate that analysis methods be accurate enough to predict the structural stability of the vehicle when it is subjected to extremely high temperatures. High confidence in analytical results can only come through correlation and verification with experimental data.

A series of thermoelastic vibration tests have been conducted at the NASA Ames Research Center's Dryden Flight Research Facility (Ames-Dryden). These test results will form a foundation of experimental data which will permit correlation with computations and verification of analytical procedures. This report gives analytical predictions and experimental test results from uniform, nonuniform, and transient thermoelastic vibration testing of a 12- by 50- by 0.19-in. aluminum plate.

NOMENCLATURE

EAL	Engineering Analysis Language
g	acceleration due to gravity (32.2 ft/sec^2)
LaRC	Langley Research Center
MAC	modal assurance criterion
NASP	national aero-space plane
STARS	STructural Analysis RoutineS
VAC	volts alternating current

TEST ARTICLE SETUP

The test article was a uniform flat 7075-T6 aluminum plate 50 in. long, 12 in. wide, and 0.190 in. thick. The plate weighed 12.2 lb without the accelerometers attached. The length of the plate was divided into three zones for instrumentation and heating purposes.

Instrumentation

The plate was instrumented with 18 accelerometers and 30 thermocouples. The maximum allowable operating temperatures of the thermocouples and accelerometers were 2100 and 550°F, respectively. Each accelerometer weighed 1 oz. Each plate zone contained six accelerometers and nine thermocouples on the front side of the plate. The rear side of the plate had one thermocouple positioned in the center of each zone to measure the temperature gradient across the thickness of the plate. A sketch of the instrumented plate and its suspension is shown in figure 1.

Plate Support Fixture

The plate was supported by a combination of 0.25-in.-diameter bungee cord and steel cables to give a free-free boundary condition. The overall support fixture is shown in figure 2. The portion of the suspension cables inside the oven were made of steel to withstand the heat. This length was kept as short as possible to avoid affecting the modal characteristics of the plate. The 15-in.-long steel cables were attached to the bungee cord with a clevis. The bungee cord was attached to L-shaped brackets at the top of the fixture.

Oven Description

The oven was composed of an aluminum box containing quartz lamps to heat the front of the test plate only. The oven was divided into three heating zones that matched the dimensions of the three zones specified on the plate. A more detailed description of the oven is found in reference 4.

EXPERIMENTAL SETUP

A schematic of the heater control, thermocouple data acquisition equipment, and the accelerometer data acquisition equipment is shown in figure 3. The remote satellite computer provided feedback control of the temperature in each plate zone. These capabilities are described in reference 5. In addition, this system acquired the thermocouple data for display and storage. The modal analysis computer system acquired the accelerometer data for display, analysis, and storage. A detailed description of the experimental setup, including the oven description used for thermoelastic vibration tests, is given in reference 4.

TEST TECHNIQUE

Excitation

Impact excitation was used to excite the plate with a rod that was attached to the plate and protruded through a hole in the oven. The location of the rod attachment point (see fig. 1) was selected to give an adequate amount of excitation for the first four structural modes. The plate and rod were threaded for connection with one another. A nut was placed on the threaded portion of the rod that extended through the plate to reduce the freeplay of the rod.

Impact excitation was given to the plate by striking the rod attached to the plate with a calibrated hammer (fig. 4). Impact excitation provided excitation to the plate in the shortest amount of time, which was essential during transient heating of the plate. Thus, impact excitation was selected to conduct the tests on the plate.

Uniform Plate Heating

Uniform plate heating was done by heating each zone of the plate to the same temperature. The thermocouple readings were monitored to ensure that the plate was uniformly heated and that there was no temperature gradient across the thickness of the plate. Once these conditions were met, the plate was excited by impact excitation. Typically, five averages of accelerometer response data were acquired by the modal analysis computer. A hard copy of the plate temperature distribution was obtained from the thermal data acquisition host computer. After accelerometer data acquisition, the frequency response functions were displayed on the modal analysis computer to verify the quality of the data. The data quality was found by examining coherence and frequency response functions. If the data quality was satisfactory, the frequency response functions were stored on the system disk for later analysis. The temperature of the oven was then increased to the next predetermined temperature and the process was repeated. Uniform heating tests were completed at temperatures of 200, 300, 350, 400 and 475°F.

Repeated heating and cooling of the plate could cause warpage. The absence of plate warpage was checked by comparing measurements of the first four fundamental plate frequencies before and after each heating test. These measurements were made at room temperature. Differences in these frequencies was an indication that the plate had permanently deformed because of the heating test.

Nonuniform Plate Heating

Nonuniform heating of the plate consisted of heating each zone of the plate to a different temperature. The plate was uniformly heated until the lowest target temperature of a particular zone was reached. At this point, the oven maintained the temperature of that zone while heating the two remaining zones to the next highest target temperature. Once reached, the oven heated the remaining zone, while attempting to maintain the temperatures of the two other zones. This heating process was typically accomplished in less than 3 min. Nonuniform heating tests were completed, with zones 1, 2, and 3 heated to 100, 200, and 400°F, and then to 200, 300, and 400°F.

The temperature distribution of each zone was closely monitored, particularly for the zones of the plate that were heated to lower temperatures. The plate was excited by impact excitation, and accelerometer responses were acquired when the highest target temperature of the plate had been reached. If the temperature of any zone varied by more than 15°F from the initial target temperatures, testing was terminated. This often resulted in less than five averages of plate impact response data, particularly at temperatures above 400°F.

After data acquisition, the frequency response functions were displayed to verify the quality of the data. If the data quality was satisfactory, the frequency response functions were stored on the system disk for later analysis. The plate was then allowed to cool to room temperature before the next test was conducted.

Plate warpage from testing was monitored as described in the Uniform Plate Heating section.

Transient Plate Heating

Transient plate heating was done by heating an end zone of the plate at different rates up to a maximum temperature of 475°F. The two different heating rates used were 3 and 7°F/sec. The plate was continually excited while it was being heated, and each plate accelerometer time history response was stored directly to the system disk. Data were also acquired while the plate cooled. In addition, the time for each impact was noted for correlation with the temperature distributions stored on the thermal control system disk. The plate was allowed to cool to room temperature before another test was attempted. The plate time history responses were recalled after each test, and frequency response functions and modal parameters for the plate were then calculated.

Plate warpage from testing was monitored as described in the Uniform Plate Heating section.

EXPERIMENTAL DATA ANALYSIS METHOD

Once data acquisition was completed for a given heating profile, frequency and damping for the first four plate modes were estimated. The technique used operated on a single frequency response function. The accelerometer at the plate corner was selected for analysis because it responded to the first four modes. Modal parameter estimates were made by fitting a second-order polynomial to each frequency peak in the function. Values of frequency, damping, phase, and amplitude were generated for each peak.

Mode shapes were produced using a single-degree-of-freedom technique. This technique extracted amplitude and phase information from each plate frequency response function at the specified modal frequency. The information was then used for viewing animated mode shapes and producing static deformation plots.

PREDICTIVE ANALYSIS METHOD

Analytical predictions for the aluminum plate were done at NASA's Langley Research Center (LaRC) using the Engineering Analysis Language (EAL) program (ref. 6). Predictions were provided for uniform, nonuniform, and transient heating conditions.

Analytical predictions were repeated at Ames-Dryden using the STructural Analysis RoutineS (STARS) program (ref. 7). The STARS program is similar to the EAL program, but uses a different meshing technique for the finite-element modeling with fewer node points (108 nodes).

Each of these programs used finite-element modeling to determine the change in vibration frequency caused by various temperature profiles. Temperature profiles were obtained from the thermocouple data during heating tests. The temperature for each element was then used to determine the elastic modulus. The expansion coefficient was also determined from the temperature of the element. Internal forces were calculated along element edges by taking into account the effect of temperature and thermal expansion (ref. 8).

RESULTS AND DISCUSSION

Uniform Heating

As determined from test data analysis, the plate modal frequency and damping values as a function of temperature for uniform heating are presented in table 1. The uniform heating data indicate that frequency decreased and damping increased as the temperature of the plate increased.

The decrease in plate frequency was the result of the decrease in the modulus of elasticity as temperature increased. The decreased modulus of elasticity represented a decrease in plate stiffness. The plate also became more viscous as it was heated. The viscosity allowed the plate to dissipate more energy than in its cold state. This resulted in an increase in modal damping as the plate temperature increased.

Nonuniform Heating

The experimental results of two nonuniform heating tests are given in table 2. The first test consisted of heating the plate to 100, 200, and 400°F in zones 1, 2, and 3, respectively. The second test involved heating the plate to 400, 300, and 200°F in zones 1, 2, and 3, respectively. The temperature contour plot for each test is shown in figure 5.

The results show that the frequency decreased for all of the plate modes. The change in these modal characteristics are like those seen in uniform heating. The reduction in frequency is the result of a change in stiffness associated with a change in material properties brought about by (1) the increasing temperature, and (2) the thermal stress associated with the nonuniform temperature profile (ref. 8) .

The damping measured for the first plate bending and torsion modes showed a trend of increasing damping as the total overall heat energy of the plate was increased. The damping values were the highest at the maximum heat energy input, as expected, because the plate is in a more viscous state. However, the damping value of the second plate bending and torsion modes remained relatively constant in the heated condition. The cause of this condition has not been determined.

Transient Heating

Test results for two transient heating tests that were conducted at 3 and 7°F/sec are shown in table 3. The temperature contour plots are shown in figure 6.

There was a significant temperature gradient across the thickness of the plate which increased simultaneously with the heating rate. The temperature gradient was measured at the center of the heated plate zone and is shown in figure 7.

The results in table 3 show a decrease in modal frequency for each transient test. This reduction is the result of the change in effective stiffness of the plate caused by the thermal stresses of the transient heating.

The results also show that the damping for each of the plate modes did not vary much from the values at room temperature as only one third of the plate area was affected by the heat (fig. 6). Because less material was affected by the heat, only a small change in the viscous properties of the overall plate occurred which resulted in negligible plate damping changes.

Mode Shapes

The mode shapes for the first four plate modes were found for uniform, nonuniform, and transient testing. A comparison of the shapes from each type of testing was done by using the modal assurance criterion (MAC) (ref. 9). The MAC is an approximation of an orthogonality check. The MAC indicated that the mode shapes did not vary by more than one percent, regardless of the plate temperature profile.

Comparison of Experimental and Analytical Results

Analytical predictions were found using various grid patterns in the finite-element model. These patterns are shown in figure 8. The EAL coarse grid (480 nodes) was used for the uniform heating test cases in which only the moduli of elasticity were changed as a function of temperature. The EAL fine grid (960 nodes) was used for the nonuniform and transient test cases in which the moduli of elasticity were changed and the plate thermal stresses were included. The STARS grid (108 nodes) was made up of triangular elements and was used for all cases of STARS analysis.

The predicted and experimentally measured frequencies for uniform plate heating are shown in table 4. Each analysis program gave similar results, and there is good agreement between the three sets of data. The largest difference is at temperatures of 400 and 475°F. The analyses predict a greater frequency change for each mode at these higher temperatures.

A comparison of the EAL-predicted and experimentally measured frequencies for nonuniform heating is shown in figures 9 and 10. The data include the heated and room temperature experimental results, the room temperature predictions, the heated plate predictions with modulus of elasticity and thermal stresses included in the analysis, and heated plate predictions with only modulus of elasticity included. The overall trend for each set of data is that the largest difference between experimental and predicted results was at the highest frequency mode (second plate torsion).

A comparison of the EAL-predicted and experimentally measured frequencies for transient heating is shown in figures 11 and 12. Overall, the trend for each data set is similar to the nonuniform heat data. The largest difference between the experimental and predicted results was at the highest plate frequency. The smallest difference was at the first plate frequency.

Another method of comparison between experimental and analytical results is in percent change in modal frequency from room temperature to the heated condition. Comparison of EAL data for uniform, nonuniform, and transient heat tests are shown in table 5. The analytical results for uniform heating show that the analysis predicted a greater frequency change from the cold state. The amount of this difference increased as temperature increased and was the largest at 475°F.

A comparison of percent frequency change for experimental and analytical nonuniform heating results indicated good agreement. The heating condition that produced the smallest temperature gradient (400, 300, 200°F) was more accurately predicted with no thermal stresses included in the analysis. Incorporating the thermal stresses in the analysis when the stresses are small gave a less accurate result. Possibly, the finite-element grid was too coarse to model the actual thermal stresses. However, for the test case with the largest temperature gradient (100, 200, 400°F), the predicted results were equally accurate with and without the thermal stresses included in the analysis. The thermal stresses were higher (see fig. 6 temperature profiles) and are increasingly more important to the analysis.

A comparison of the experimental and analytical percent change in modal frequency from room temperature to the heated condition for transient heating indicated that inclusion of the thermal stresses in the analysis gave the most accurate results. This shows the importance of including thermal stresses when predicting the change in frequency for heating where large thermal stresses exist.

CURRENT AND FUTURE PLANS

Thermoelastic vibration research is continuing with testing of a 12- by 50- by 0.19-in. composite plate. Future plans include testing a composite built-up structure consisting of two 12- by 50- by 0.19-in. composite plates connected by lengthwise Z-shaped channels. An aluminum built-up plate with a similar design will also be fabricated for testing.

CONCLUDING REMARKS

Analysis codes that predict the aeroelastic and aeroservoelastic stability of proposed hypersonic vehicles at high temperatures must be correlated and validated with experimental data. Thermoelastic vibration testing for uniform, nonuniform, and transient heating were conducted on an aluminum plate to get an experimental database for comparison with analytical predictions.

The measured modal data of a uniformly heated plate showed that frequency decreased and damping increased as the plate temperature increased.

The test results for nonuniform heating showed a decrease in modal frequency for all plate modes. The frequency change was the result of material property changes. The damping for the first two plate modes increased with temperature, while the damping for the second two modes remained constant.

The measured data obtained during transient testing showed that frequency decreased for all of the plate modes in the heated condition. The reduction in frequency was the result of an effective stiffness change caused by the thermal stresses. The modal damping did not change much in the heated condition.

A comparison of experimental and predicted frequency values showed good agreement for uniform, nonuniform, and transient tests. The transient test results showed that it was important to include the thermal stresses in the analysis for transient-type heating.

Ames Research Center
Dryden Flight Research Facility
National Aeronautics and Space Administration
Edwards, California, January 8, 1991

REFERENCES

1. Vosteen, Louis F., and Kenneth E. Fuller, *Behavior of a Cantilever Plate Under Rapid-Heating Conditions*, NACA RM-L55E20c, 1955.
2. McWithey, Robert R., and Louis F. Vosteen, *Effects of Transient Heating on the Vibration Frequencies of a Prototype of the X-15 Wing*, NASA TND-362, 1960.
3. Barthelemy, Robert, "Recent Progress in the National Aerospace Plane Program," *Proceedings of the First International Conference on Hypersonic Flight in the 21st Century*, Grand Forks, ND, Sept. 1988, p. 28.
4. Kehoe, Michael W., and H. Todd Snyder, "Thermoelastic Vibration Test Techniques," presented at the Ninth Annual International Modal Analysis Conference, Florence, Italy, Apr. 1991.
5. Zamanzadeh, Behzad, William F. Trover, and Karl F. Anderson, "DACS II—A Distributed Thermal/Mechanical Loads Data Acquisition and Control System," *Proceedings of the 1987 International Telemetering Conference*, San Diego, CA, vol. 13, Oct. 1987, p. 737.
6. Whetstone, W., *EISI-EAL Engineering Analysis Language Reference Manual*, Engineering Information Systems, Inc., San Jose, CA, 1983.
7. Gupta, K.K., *STARS—An Integrated General-Purpose Finite Element Structural, Aeroelastic, and Aeroservoelastic Analysis Computer Program*, NASA TM-101709, 1990.
8. Przemieniecki, J.S., *Theory of Matrix Structural Analysis*, McGraw-Hill, New York, NY, 1968.
9. *User Guide for I-DEAS Level 4*, vol. 2, Structural Dynamics Research Corp., Milford, OH, 1988.

Table 1. Experimental plate modal data for uniform heating.

Description	Frequency, Hz	Damping, g
Mode 1, first plate bending,°F		
75	14.375	0.009
202	14.063	0.009
306	13.875	0.014
339	13.750	0.018
400	13.563	0.023
474	13.250	0.033
Mode 2, first plate torsion, °F		
75	36.000	0.010
202	35.125	0.016
306	34.875	0.014
339	34.688	0.023
400	34.313	0.024
474	34.000	0.022
Mode 3, second plate bending, °F		
75	41.438	0.006
202	40.625	0.009
306	40.063	0.008
339	39.875	0.011
400	39.313	0.014
474	38.500	0.021
Mode 4, second plate torsion, °F		
75	73.813	0.007
202	71.875	0.021
306	71.188	0.011
339	70.875	0.017
400	69.875	0.022
474	68.625	0.021

Table 2. Experimental plate modal data for nonuniform heating profile.

Description	Frequency, Hz	Damping, *g*
Mode 1, first plate bending		
Condition 1*	14.375	0.0090
Condition 2†	13.895	0.0122
Condition 3‡	13.853	0.0300
Mode 2, first plate torsion		
Condition 1	36.000	0.0100
Condition 2	34.699	0.0180
Condition 3	34.698	0.0250
Mode 3, second plate bending		
Condition 1	41.438	0.0060
Condition 2	40.261	0.0062
Condition 3	39.994	0.0078
Mode 4, second plate torsion		
Condition 1	73.813	0.0070
Condition 2	71.246	0.0114
Condition 3	71.056	0.0088

Zones 1, 2, and 3 at

*75, 75, 75°F

†100, 200, 400°F

‡400, 300, 200°F

Table 3. Experimental plate modal data for transient heating profile.

Description	Frequency, Hz	Damping, g
Mode 1, first plate bending:		
Room temperature values at 75°F	14.375	0.0090
3 deg/sec transient maximum temperature of zone 3 at 483°F	13.332	0.0106
7 deg/sec transient maximum temperature of zone 3 at 446°F	13.508	0.0092
Mode 2, first plate torsion:		
Room temperature values at 75°F	36.000	0.0100
3 deg/sec transient maximum temperature of zone 3 at 483°F	32.051	0.0218
7 deg/sec transient maximum temperature of zone 3 at 446°F	32.345	0.0135
Mode 3, second plate bending:		
Room temperature values at 75°F	41.438	0.0060
3 deg/sec transient maximum temperature of zone 3 at 483°F	39.651	0.0074
7 deg/sec transient maximum temperature of zone 3 at 446°F	39.727	0.0065
Mode 4, second plate torsion:		
Room temperature values at 75°F	73.813	0.0070
3 deg/sec transient maximum temperature of zone 3 at 483°F	68.980	0.0108
7 deg/sec transient maximum temperature of zone 3 at 446°F	69.148	0.0063

Table 4. Experimental and analytical data for uniform heating.

Description	Temperature, °F					
	75	200	300	350	400	475
Mode 1:						
Experimental	14.30	13.90	13.80	13.80	13.50	13.20
EAL predicted	14.00	13.70	13.00	13.00	12.50	11.70
STARS predicted	14.46	14.20	13.62	13.30	12.91	12.09
Mode 2:						
Experimental	35.00	34.50	34.50	34.00	34.00	33.50
EAL predicted	34.00	33.00	32.50	32.00	30.50	29.00
STARS predicted	34.56	33.69	32.61	31.66	30.92	28.91
Mode 3:						
Experimental	37.00	36.80	36.00	35.30	34.00	32.00
EAL predicted	41.50	40.50	40.00	39.70	39.30	38.30
STARS predicted	39.87	38.71	37.59	36.57	35.65	33.36
Mode 4:						
Experimental	73.80	72.00	71.50	71.00	70.00	68.70
EAL predicted	71.80	70.30	68.00	66.70	64.50	60.50
STARS predicted	71.03	69.23	67.00	65.11	63.53	59.41

Table 5. Experimental and EAL-predicted percent change in vibration frequencies.

Description	Frequency change from cold		
		EAL analytical, percent	
	Experimental, percent	Modulus change only	Modulus change and thermal stresses
Temperatures, zones 1, 2, and 3 at 400, 300, and 200°F:			
Mode 1	2.80	4.30	5.90
Mode 2	2.70	4.60	7.50
Mode 3	2.70	4.80	6.00
Mode 4	2.70	5.40	6.80
Temperatures, zones 1, 2, and 3 at 100, 200, and 400°F:			
Mode 1	3.10	2.00	3.10
Mode 2	2.80	2.40	4.10
Mode 3	3.30	2.90	3.00
Mode 4	3.00	3.40	2.90
Transient heating, 3 deg/sec:			
Mode 1	6.70	0.25	6.90
Mode 2	10.10	1.40	11.80
Mode 3	4.10	2.50	4.90
Mode 4	5.80	4.40	5.60
Transient heating, 7deg/sec:			
Mode 1	5.50	0.40	7.20
Mode 2	9.30	0.50	11.80
Mode 3	3.90	1.40	4.50
Mode 4	5.50	2.90	4.60

Table 5. Continued.

Description	Frequency change from cold		
		EAL analytical, percent	
	Experimental, percent	Modulus change only	Modulus change and thermal stresses
Uniform heating, 200°F:			
Mode 1	2.80	2.10	---
Mode 2	1.40	2.90	---
Mode 3	2.40	0.50	---
Mode 4	2.40	2.10	---
Uniform heating, 300°F:			
Mode 1	3.50	7.10	---
Mode 2	1.40	4.40	---
Mode 3	3.60	2.70	---
Mode 4	3.10	5.30	---
Uniform heating, 350°F:			
Mode 1	3.50	7.10	---
Mode 2	2.90	5.90	---
Mode 3	4.30	4.60	---
Mode 4	3.80	7.10	---
Uniform heating, 400°F:			
Mode 1	5.60	10.70	---
Mode 2	2.90	10.30	---
Mode 3	5.30	8.20	---
Mode 4	5.10	10.20	---
Uniform heating, 475°F:			
Mode 1	7.70	16.40	---
Mode 2	4.30	14.70	---
Mode 3	7.70	13.50	---
Mode 4	6.90	15.70	---

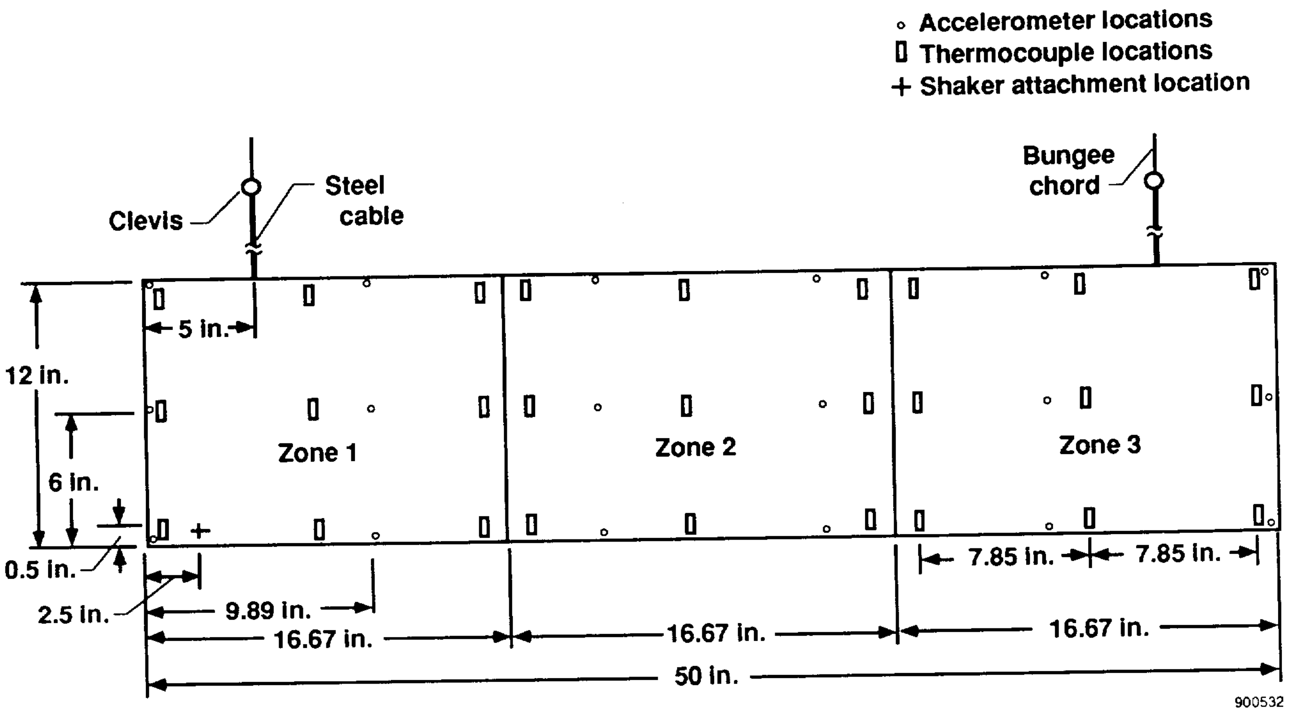

Figure 1. Test plate heating zones and instrumentation locations.

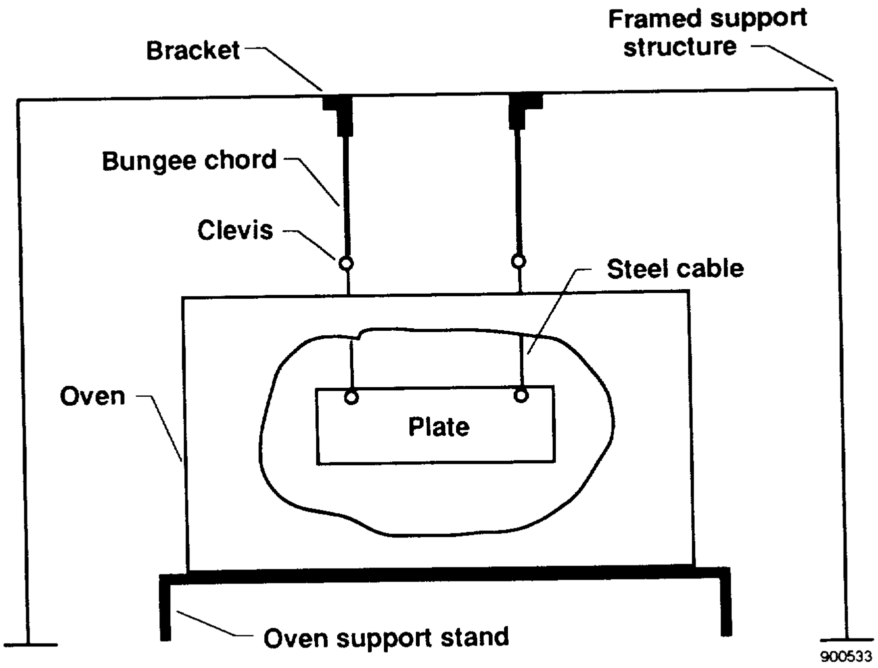

Figure 2. Plate support fixture.

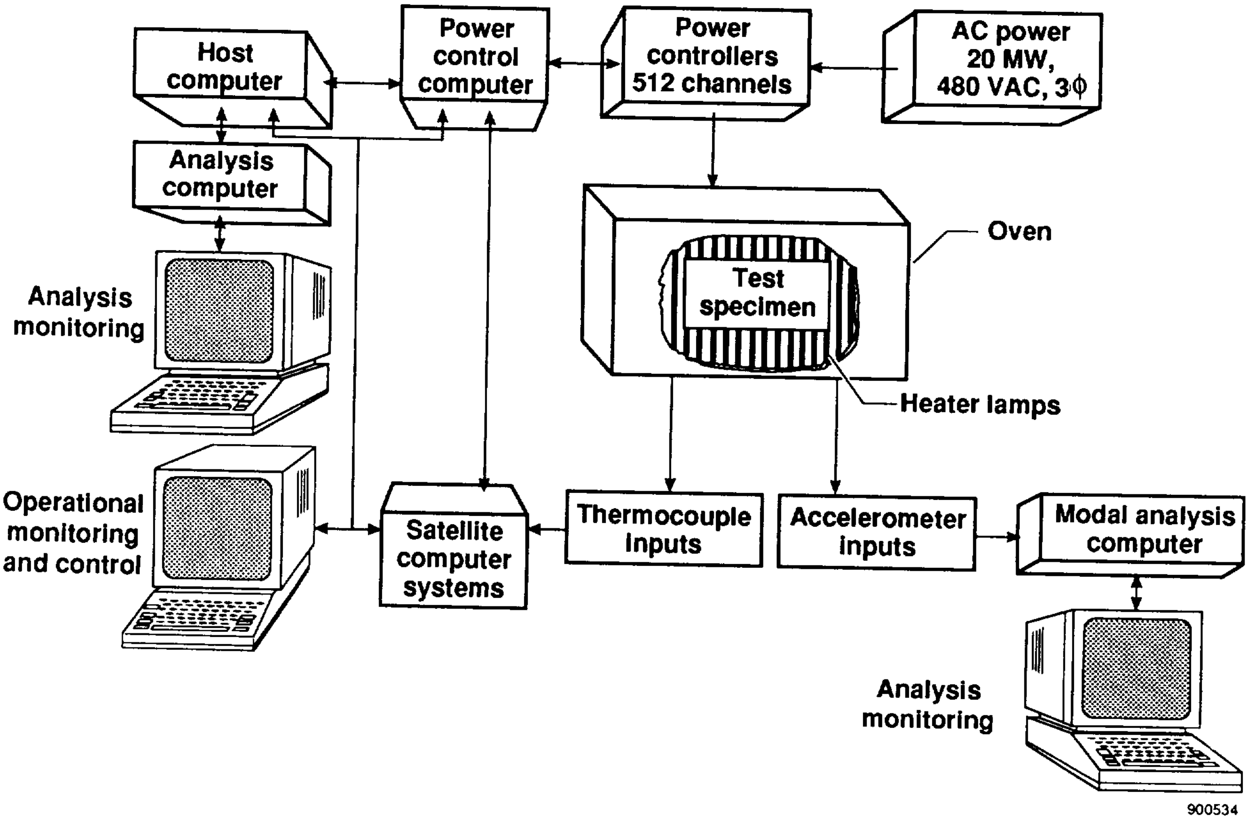

Figure 3. Oven control and data acquisition.

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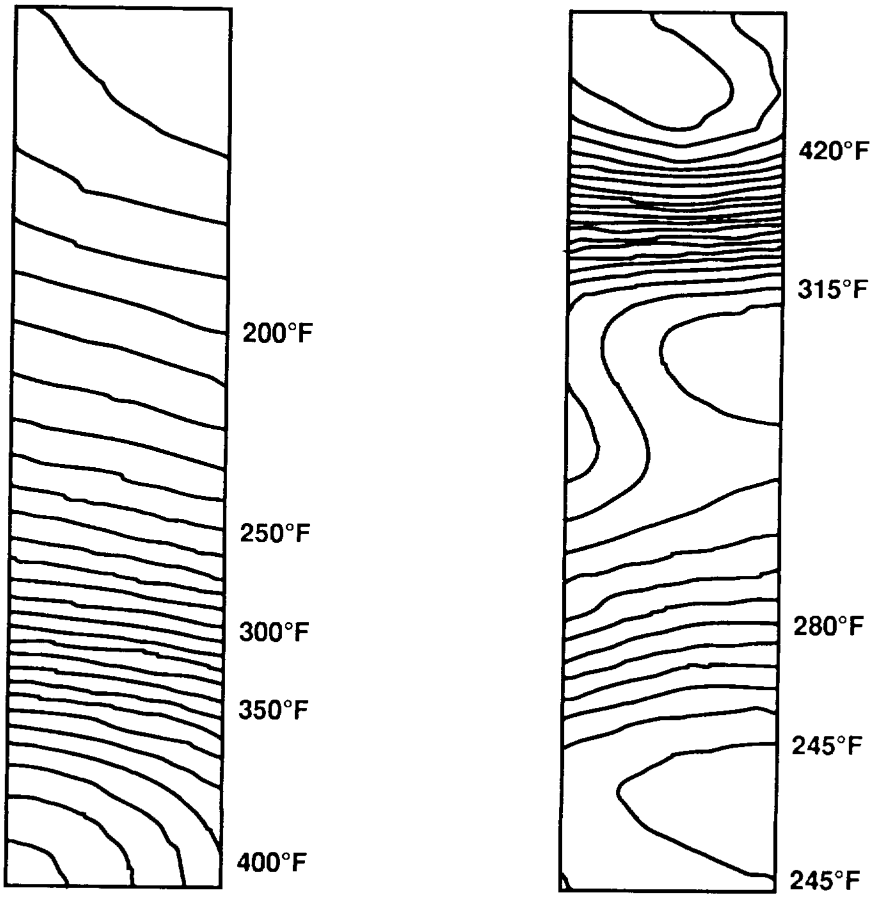
Figure 4. Enclosed oven used to heat an aluminum plate.



Zones 1, 2, and 3 = 100, 200, and 400°F Zones 1, 2, and 3 = 400, 300, and 200°F

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Figure 5. Temperature contours for nonuniform heating tests.

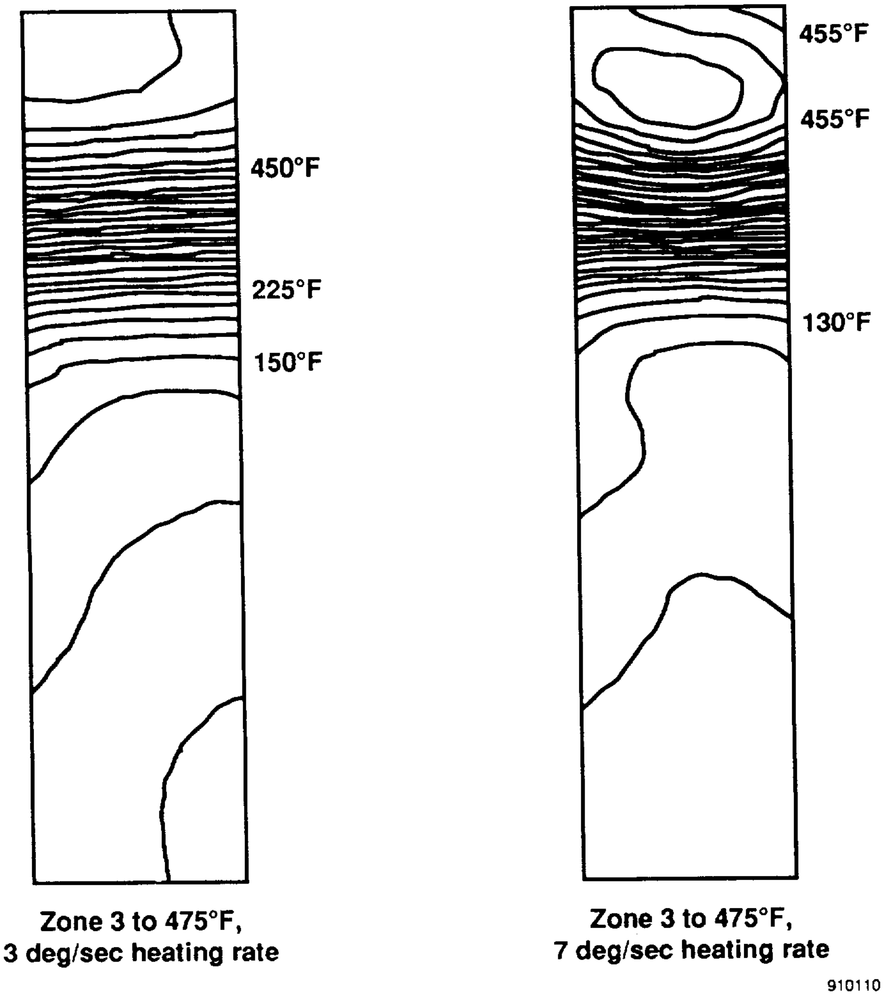

Figure 6. Temperature contours for transient heating tests.

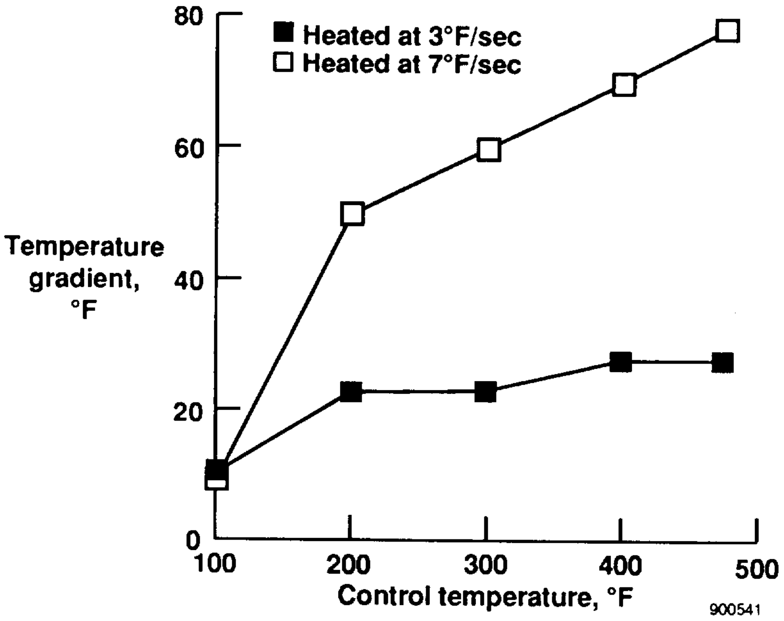

Figure 7. Plate thickness temperature gradient during transient heating of zone 3.

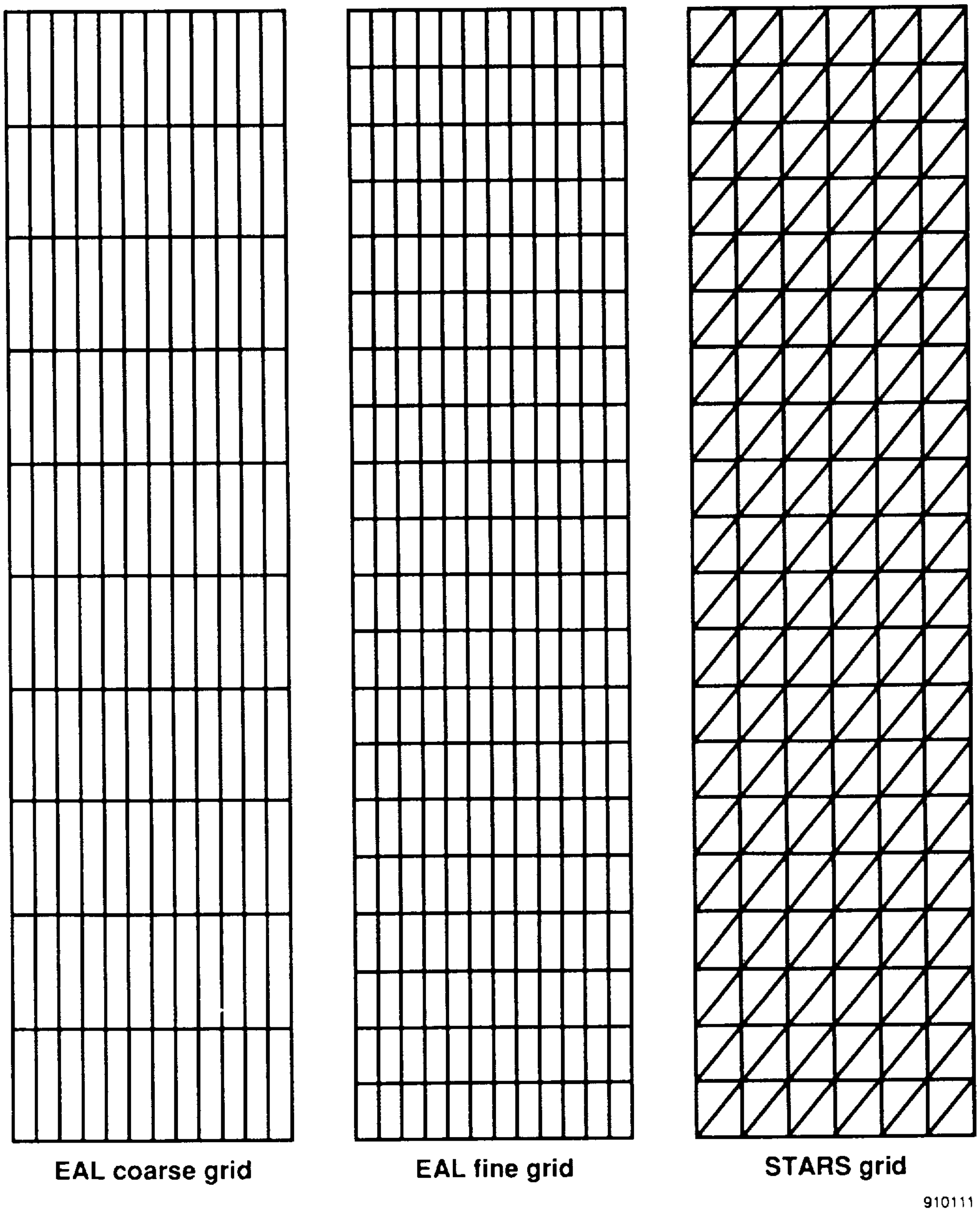

Figure 8. Finite-element grids used in analysis.

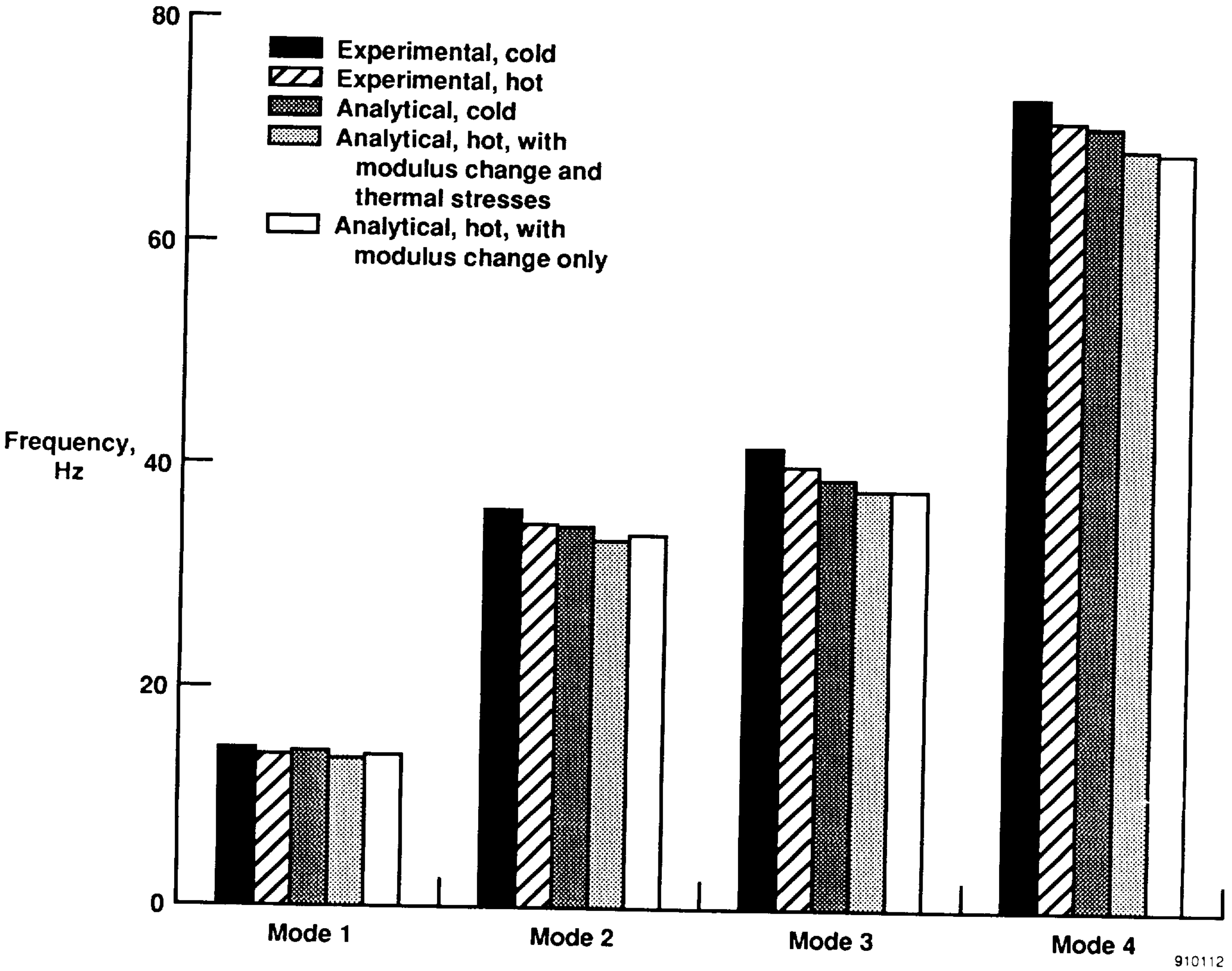

Figure 9. Experimental and analytical data for nonuniform heating, zones 1, 2, and 3 at 100, 200, and 400°F, respectively.

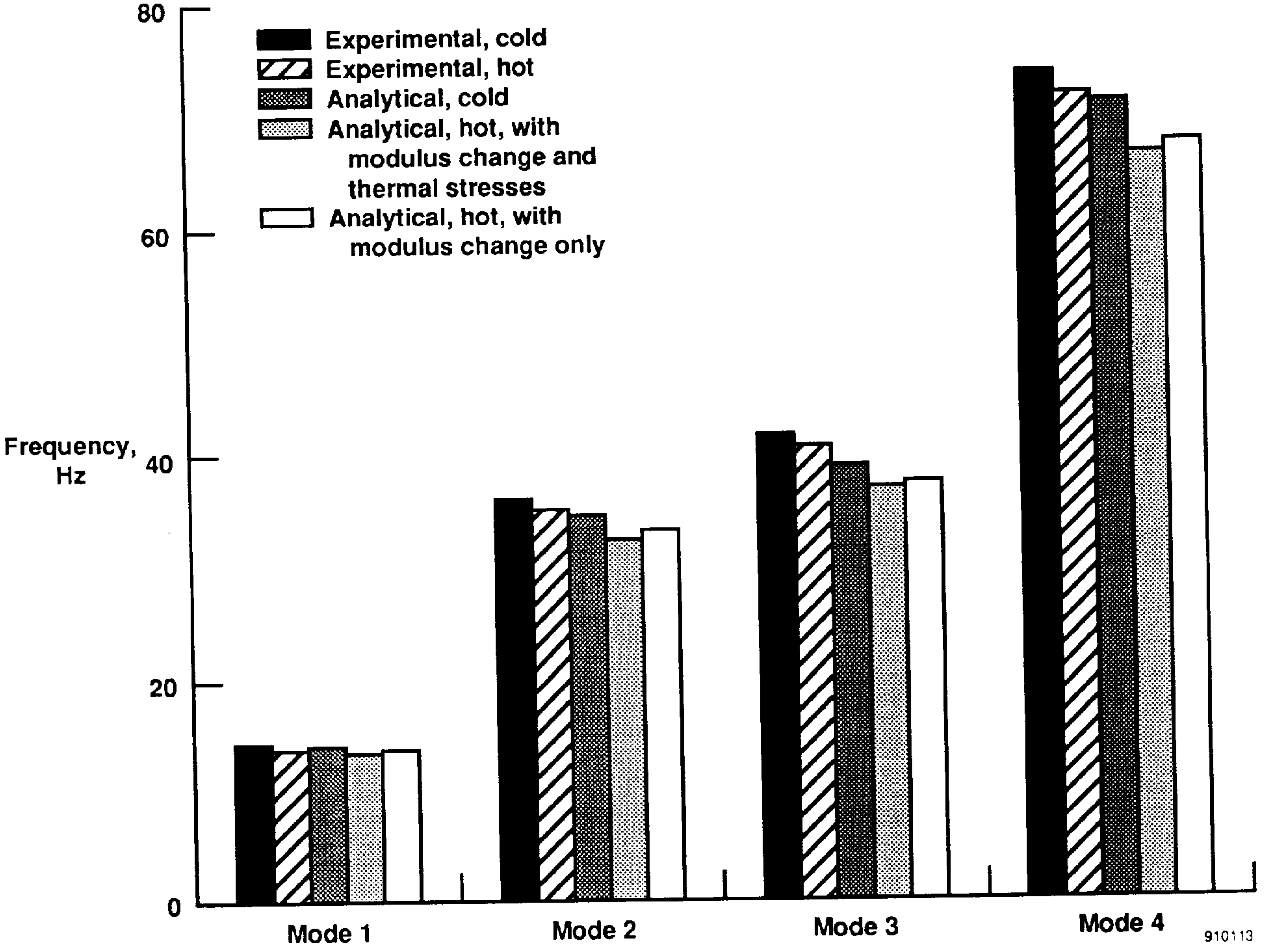

Figure 10. Experimental and analytical data for nonuniform heating, zones 1, 2, and 3 at 400, 300, and 200°F, respectively.

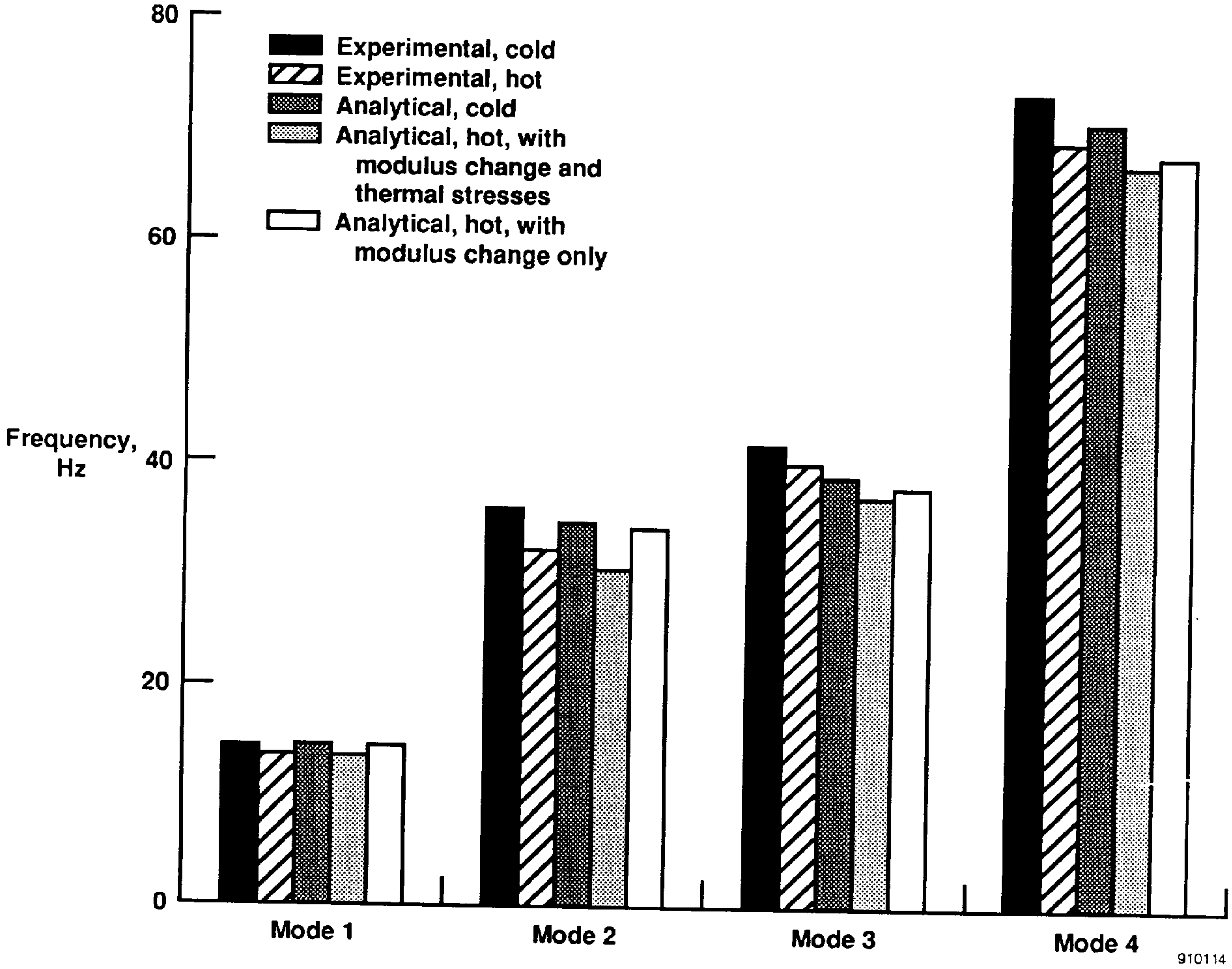

Figure 11. Experimental and analytical data for nonuniform heating, zone 3 to 475°F at 3 deg/sec transient.

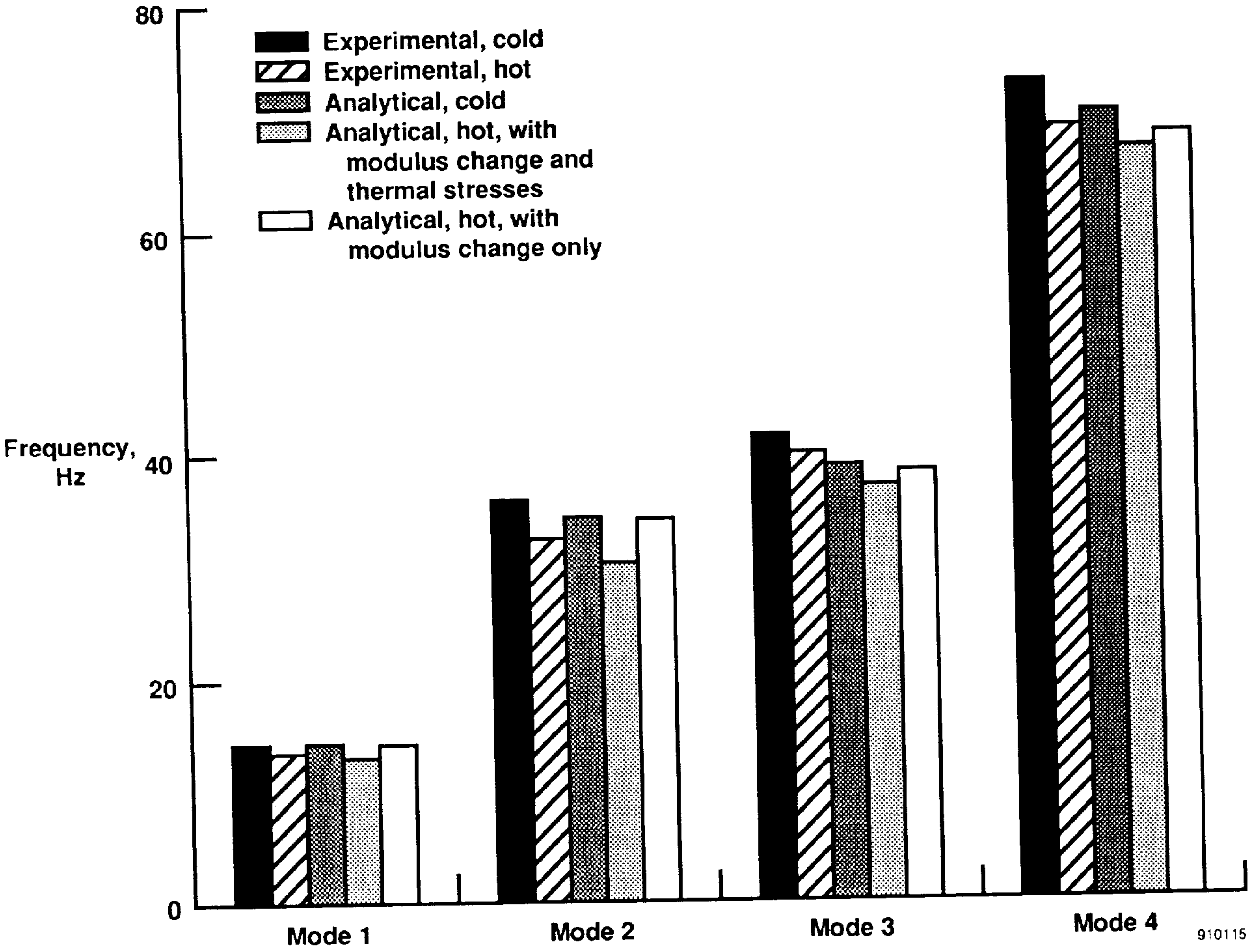

Figure 12. Experimental and analytical data for nonuniform heating, zone 3 to 475°F at 7 deg/sec transient.

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H. Todd Snyder and Michael W. Kehoe

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H. Todd Snyder: Planning Research Corporation, Edwards, California.
Michael W. Kehoe: Ames Research Center, Dryden Flight Research Facility, Edwards, California.

16. Abstract

The structural integrity of proposed high-speed aircraft can be seriously affected by the extremely high surface temperatures and large temperature gradients throughout the vehicle's structure. Variations in the structure's elastic characteristics as a result of thermal effects can be seen by changes in vibration characteristics. Analysis codes that predict these changes must be correlated and verified with experimental data. This report gives analytical and experimental modal test results from uniform, nonuniform, and transient thermoelastic vibration tests of a 12- by 50- by 0.19-in. aluminum plate. The data show the effect of heat on the modal characteristics of the plate. The results showed that frequencies decreased, damping increased, and mode shapes remained unchanged as the temperature of the plate was increased. Analytical predictions provided good correlation with experimental results.

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