Linear Heat Analysis by MSC/NASTRAN and ADINA-T

by

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ABSTRACT

In this paper, a comparison is made between two thermal finite element codes: MSC/NASTRAN and ADINA-T. The capabilities of the two codes are compared in terms of the element library, material models, types of analysis available and solution algorithm. The performances of the two codes are examined by solving a linear transient thermal problem involving conduction and convection heat transfer. It is found that the temperature solutions of MSC/NASTRAN and ADINA-T agree extremely well if both use isoparametric elements. Use of the constant gradient elements (HEXA1, HEXA2) of MSC/NASTRAN results in different, and perhaps less accurate, solution than that of isoparametric element.

The performance of MSC/NASTRAN is further assessed by solving another linear transient thermal problem involving conduction and convection heat transfer and the results are compared with an analytical solution. The temperature solution of MSC/NASTRAN agree very well with the analytical solution at interior nodes but not so well at surface nodes where heat flux takes place.

INTRODUCTION

In my earlier study of the thermal analysis using finite element method, COSMIC/NASTRAN was found to be less than satisfactory. Especially those special techniques described in [1] for imposing time-dependent ambient temperature and heat flux failed to work with COSMIC/NASTRAN. At that time another thermal code ADINA-T (Automatic Dynamic Incremental Nonlinear Analysis of Temperature) was installed and was used for the thermal analysis applications. Later on, MSC/NASTRAN was brought in and was found to be able to run those examples in [1] without difficulty. Subsequently the same problem solved by ADINA-T was also solved by MSC/NASTRAN. Thus, for the benefit of those who are interested in the performance of ADINA-T and the heat portion of MSC/NASTRAN, this paper presents a comparison of the two codes. However, this paper is not intended to be a comprehensive study of the two thermal analysis codes. For example, radiation and other nonlinearity are not included here. Furthermore, the examples shown here only simulate the laboratory dynamometer tests and thus represent only very small portion of the total brake system and its associated problem which is far more complex than the examples.

ADINA-T versus MSC/NASTRAN

Both the ADINA-T and the MSC/NASTRAN thermal analyzer solve the partial differential equation with appropriate boundary conditions as shown in Figure 1. After variational formulation and finite element discretization, this differential equation reduces to the familiar form shown at the bottom of Figure 1. As can be seen from Figure 2, the thermal code can be considered as s subset of the mechanical code. Shown also in Figure 2 is the list of "equivalent" quantities in the thermal and mechanical systems.

Element Library

Table 1 shows the conduction element types and their thermal properties available in ADINA-T and MSC/NASTRAN. Letters A and N denotes availability in ADINA-T and MSC/NASTRAN respectively. This table indicates that:

1.) Specific heat can not be made temperature dependent (i.e., nonlinear) for all conduction element types in MSC/NASTRAN.

2.) Both conductivity and specific heat can be made temperature dependent for all conduction element types in ADINA-T except for the 3/D orthotropic element, which can have constant conductivity only.

3.) ADINA-T has ten thermal property combinations compared to six for MSC/NASTRAN.

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* Number in brackets designates Reference at the end of the paper.

Table II shows the convection/radiation element types and their properties available in ADINA-T and MSC/NASTRAN. It says that both convection coefficient and emissivity can be made constant or temperature dependent in both ADINA-T and MSC/NASTRAN for all three types of convection/radiation elements (i.e., point, line and surface).

Problem Solution Capability

ADINA-T can hadle both steady state and transient thermal analysis of both linear and nonlinear types according to [2] . MSC/NASTRAN can handle both linear and nonlinear steady state problems but can only handle linear (but not nonlinear) transient thermal problems. ADINA-T handles nonlinear problems by incremental and iterative methods through stiffness update and equilibrium iteration [2] . MSC/NASTRAN also handles nonlinear steady state problems by some iterative technique [3] . This paper only discusses the linear transient problems.

Transient Analysis Algorithm

Both ADINA-T and MSC/NASTRAN use the same algorithm for numerical time integration. The scheme is shown in Figure 3. It should be noted here that from the viewpoint of stability, β (called α in ADINA-T) should be equal to or greater than 0.5 [3]. β of 1 and 0.55 are used as default values in ADINA-T and MSC/NASTRAN respectively as indicated in Figure 3.

EXAMPLE 1: Comparative Study of Aircraft Brake Disk

The problem on which I have data for comparative study is the temperature prediction of simulated aircraft carbon brake disk tests for three different stops. The disk is an axisymmetric circular ring of rectangular cross section whose dimensions are shown in Figure 4. The disk has the following orthotropic conductivity*:

$K_{radial} = 0.0017$ BTU/in/sec/°F

$K_{axial} = 0.0005$ BTU/in/sec/°F

$K_{hoop} = 0$

The conductivity in the hoop (circumferential) direction is taken to be zero because of the axisymmetric situation. The density (ρ) and specific heat (c) of the carbon composite are 0.0665 lb./in^3 and 0.45 BTU/lb./°F respectively*. The loadings are the time-dependent heat flux Q_1 and Q_2 at the top and bottom surfaces and the boundary conditions are the time-dependent temperatures T_1, T_2 specified at the inner and outer radius. In this study we assumed $Q_1 = Q_2$, which can be derived from the thermal loadings shown in Figure 5. Also assumed is that T_1 and T_2 are to be the same as the inside and outside ambient temperatures which are shown in Figures 6 and 7. The initial temperatures are set to be 150°F.

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* The thermal properites of carbon composite are in general temperature dependent but are assumed to be constant here. This could be a source of discrepancy between the test and the prediction.

For ADINA-T, a 2/D axisymmetric ring element of rectangular cross-section is used in modeling. Figure 4 shows the ADINA-T model with 16 such ring elements. For MSC/NASTRAN, a 3/D solid brick element is used to model a 10° sector of the disk. Figure 8 shows the MSC/NASTRAN model consisting of 16 such brick elements. The use of two different types of elements is not intentional but rather accidental. The axisymmetric ring-type element was initially used for COSMIC/NASTRAN but then was discarded because of its failure to work and it was switched to solid brick element. When MSC/NASTRAN became available, I simply picked up where COSMIC/NASTRAN left off. Therefore, it should be mentioned here that it has never been established whether the axisymmetric ring elements in MSC/NASTRAN is operational or not.

Table III shows the comparison of ADINA-T and MSC/NASTRAN results for the temperature at the center of the disk when t = 30 seconds. Three solid element types are used for MSC/NASTRAN. Both HEXA1 and HEXA2 are constant gradient elements. HEXA is an isoparametric element and so is the ADINA-T 2/D axisymmetric element. Figures 9 to 11 compare the predicted temperature at the disk center using isoparametric elements. It is concluded for this example that:

1.) ADINA-T and MSC/NASTRAN result in practically the same answer if isoparametric elements are used.

2.) The use of different element types for ADINA-T and MSC/NASTRAN makes the agreement of the solution even more significant.

3.) The use of the constant gradient element results in excessively higher temperature and their solutions are probably less accurate (also see Figure 12).

4.) A change in β from 0.5 to 1.0 does not affect the solution.

Additional ADINA-T results are tabulated in Table IV which shows the effect of the number of elements, grid pattern and time step. Again it is concluded that:

1.) The solution converges and levels off at 16 elements.

2.) Changes in time step from 1 second to 0.5 second affect the solution only slightly.

3.) Two grid patterns yield practically the same answer.

Regarding the accuracy of the solutions, Figure 13 compares the ADINA-T solution and experimental data. The agreements are fairly good in spite of the many assumptions made in heat flux load distribution and specified boundary temperatures.

EXAMPLES 2: Additional MSC/NASTRAN Results

Another aircraft brake problem which had difficulty running on COSMIC/NASTRAN previously was also run successfully on MSC/NASTRAN. This problem involves convection between the brake disk and the ambient air which has time-dependent temperature. The dimensions of the disk and its thermal properties are shown in Figure 14. The heat flux at the top and bottom surfaces of the brake disk is again derived from the thermal loading shown in Figure 15. The ambient temperatures at the inner and outer radius of the disk are shown in Figure 16. A 16-element model as shown in Figure 8 is again used here. Both HEXA and HEXA1 type elements are run using $\beta = 1$ and $\beta = 0.5$. For this problem there is an analytical solution avaialble. Table V shows the temperature at various points of the disk when t = 19 seconds from different solutions. Table VI shows the maximum temperature at various points and the corresponding time from different solutions. The analytical solution and the present solution using HEXA element and $\beta = 1$ at various points are compared in graphical form in Figures 17 to 24. From their results it is concluded that:

1.) In comparison with the analytical solution, HEXA performs better than HEXA1. The latter results in an excessively high temperature.

2.) For those points on the mid-plane (points F, G, H, I, J), the HEXA solution and the analytical solution show excellent agreements from t = 0 sec. up to t = 19 sec. (Figures 20-24).

3.) For those points on the friction surfaces (points B, C, D), the HEXA solution agrees with the analytical solution at t = 19 seconds, but the agreements are not so good at other values of t (Figures 17-19).

CONCLUSIONS

Based on the data presented, it may be said that for linear heat problem:

1.) MSC/NASTRAN and ADINA-T seem to have equall performance if isoparametric elements are used. Their answers agree fairly well with experiments in the given examples.

2.) Constant gradient elements(HEXA1, HEXA2) of MSC/NASTRAN seem to be less accurate and probably should be avoided for thermal analysis.

3.) For the first problem treated in this paper the solution is not affected by time step change (1 sec. to 0.5 sec.), change in β (0.5, 0.55, 1.0) and the grid patterns. The solution converges and levels off at 16 elements.

It should be mentioned here also that it is much easier to impose time-dependent variables in ADINA-T than in MSC/NASTRAN.

ACKNOWLEDGEMENT

The author wishes to thank The BFGoodrich Company for the permission to publish this paper.

REFERENCES

1. H. P. Lee, Fifth NASTRAN User's Colloquium, October 5, 1976, pp. 3-19.

2. K.-J. Bathe, "A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis of Temperature", MIT Report 82445-5, May 1977.

3. R. H. McNeal, Ed., The NASTRAN Theoretical Manual, MSR-40, December 1972.

1/D ELEMENT, 2/D AND 3/D ISOTROPIC ELEMENTS

		CONDUCTIVITY	
		CONST.	TEMP. DEPEND.
SP. HEAT	CONST.	A,N	A,N
	TEMP. DEPEND.	A	A

2/D AND 3/D ORTHOTROPIC ELEMENTS

		CONDUCTIVITY	
		CONST.	TEMP. DEPEND.
SP. HEAT	CONST.	A,N	N
	TEMP. DEPEND.	A	

CONDUCTION ELEMENTS

TABLE I

CONVECTION/RADIATION ELEMENTS

- POINT
- LINE (INCLUDES LINE OF REVOLUTION)
- SURFACE

		CONVECTION COEFFICIENT	
		CONST.	TEMP. DEPEND.
EMISSIVITY	CONST.	A,N	A,N
	TEMP. DEPEND.	A,N	A,N

TABLE II

TEMP AT CENTER WHEN τ = 30 SEC. $\Delta\tau$ = 1 SEC.

STOP	NO. OF ELEM	ADINAT	MSC/NASTRAN						
		$\beta=1$	$\beta=1$			$\beta=0.5$			$\beta=0.55$*
		2/D AXISY.	HEXA1	HEXA2	HEXA	HEXA1	HEXA2	HEXA	HEXA1*
637	16	539	779		533	779		536	779
643		730	1111		722	1111		729	1112
648		1156	1803	1803	1155	1799	1799	1169	1801

* 160 ELEMENTS

TABLE III

ADINAT RESULTS

TEMP AT CENTER WHEN t = 30 SEC.

ELEMENT NO. / STOP	4	16		64	
		EQUAL SIZE	UNEQUAL(*) SIZE	$\Delta t=1$	$\Delta t=0.5$
637		539		537	540
643		730	729	728	734
648	1182	1156		1155	1164

(*)

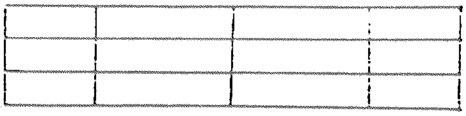


TABLE IV

TABLE V

Temperatures at t = 19 sec.

Pt.	MSC/NASTRAN				ANALY.
	β = 1		β = 0.5		
	HEXA	HEXA1	HEXA	HEXA1	
A	450.5	388.4	463.4	393.1	--
B	463.8	1220.0	477.3	1220.8	460.3
C	417.4	1264.3	428.1	1261.8	410.1
D	324.5	1196.6	330.9	1197.9	319.2
E	198.5	193.5	197.9	1930.8	--
F	431.3	346.1	444.1	351.0	469.5
G	443.1	1208.7	456.5	1209.4	455.3
H	396.7	1240.6	407.4	1238.0	403.5
I	305.8	1182.7	312.1	1184.1	314.5
J	196.5	190.9	196.0	190.5	207.1

TABLE VI

Max Temperature(T_{max}) and Corresponding Time (t)

	MSC/NASTRAN								ANALYTICAL	
	$\beta = 1$				$\beta = 0.5$					
	HEXA		HEXA1		HEXA		HEXA1			
Pt.	T_{max}	t	T_{max}	t	T_{max}	t	T_{max}	t	T_{max}	t
A	679.2	9	578.5	9	694.7	10	587.9	9	--	--
B	714.3	9	1227.1	17	729.4	10	1224.4	18	551.1	12
C	652.1	9	1267.6	18	663.5	9	1261.8	18	506.6	11
D	503.0	8	1206.1	17	508.4	8	1202.7	18	367.9	11
E	208.3	22	206.2	22	209.1	22	206.5	22	--	--
F	540.4	12	419.7	11	557.6	12	430.0	11	531.2	13
G	563.1	11	1210.9	20	581.0	12	1214.9	20	531.5	12
H	496.4	11	1247.7	22	510.8	12	1249.2	21	477.7	12
I	351.5	12	1184.2	20	359.3	12	1188.9	20	348.9	12
J	208.3	22	205.0	22	209.0	22	205.2	22	207.1	19

GOVERNING EQUATION

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial T}{\partial z}\right) + q_v = \rho c \frac{\partial T}{\partial t}$$

BOUNDARY CONDITIONS

• Temperature	Prescribed Temperature	$T = T_p$
• Temp. Gradient	Prescribed Heat Flux	$-k \frac{\partial T}{\partial n} = q_b$
	Convective Heat Transfer	$-k \frac{\partial T}{\partial n} = h(T - T_f) = q_h$
	Radiative Exchange	
	Distance Source	$k \frac{\partial T}{\partial n} = q_s$
	Net Radiation Flux	$-k \frac{\partial T}{\partial n} = q_r$

Variational Formulation

and

F. E. Discretization

$$[B]\left\{\frac{\partial T}{\partial t}\right\} + [K]\{T\} = \{P\} + \{N\}$$

FIGURE 1

$$\overbrace{[M]\left\{\frac{\partial^2 T}{\partial t^2}\right\} + \underbrace{[B]\left\{\frac{\partial T}{\partial t}\right\} + [K]\{T\} = \{P\} + \{N\}}_{\text{Thermal Syetem}}}^{\text{Mechanical System}}$$

Mechanical		Thermal
Displacement	T	Temperature
Velocity	$\frac{\partial T}{\partial t}$	Rate of change of temp.
Acceleration	$\frac{\partial^2 T}{\partial t^2}$	--------
Gradient	∇T	Temp. gradient
Stiffness	K	Conductance
Damping	B	Heat capacitance
Mass	M	-------
Applied load	P	Thermal load (t)
Nonlinear force	N	Nonlinear thermal load (T)

FIGURE 2

TRANSIENT ANALYSIS

Difference equation approximation with a free parameter that is adjusted to produce a compromise of the stability, efficiency and accuracy:

$$[K]\{\beta T_{n+1} + (1-\beta)T_n\} + \frac{1}{\Delta t}[B]\{T_{n+1} - T_n\}$$
$$= \beta\{P_{n+1}\} + (1-\beta)\{P_n\} + (1+\beta)\{N_n\} - \beta\{N_{n-1}\},\ 0 < \beta < 1$$

$$\left[\frac{1}{\Delta t}B + \beta K\right]\{T_{n+1}\} = \left[\frac{1}{\Delta t}B - (1-\beta)K\right]\{T_n\}$$
$$+\beta\{P_{n+1}\} + (1-\beta)\{P_n\} + (1+\beta)\{N_n\} - \beta\{N_{n-1}\}$$

$\beta = 1$ EULER BACKWARD (ADINAT default)

$= 0.5$ CENTRAL/TRAPEZOIDAL

$= 0$ EULER FORWARD

$= 0.55$ (NASTRAN default)

FIGURE 3

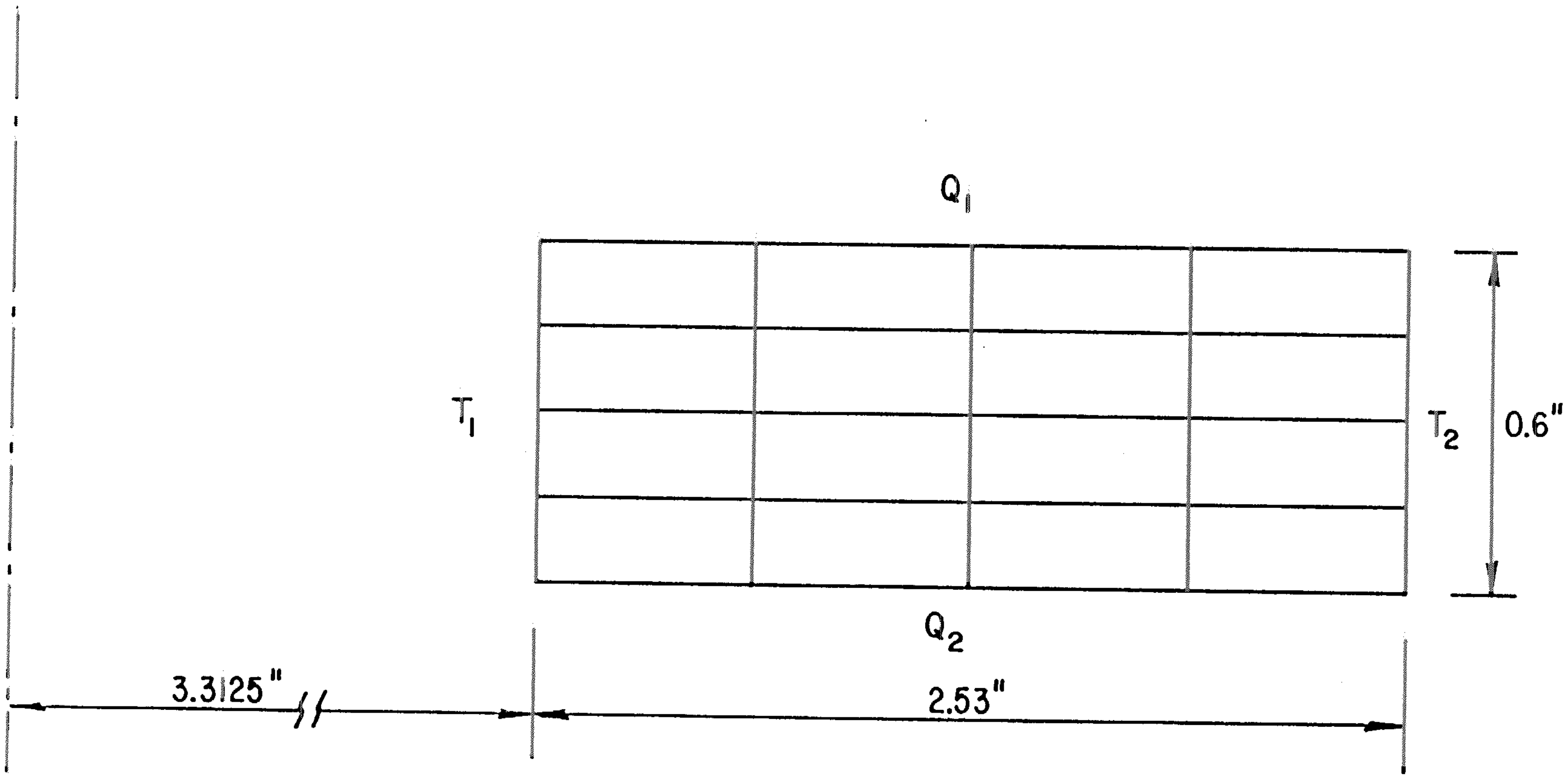


Figure 4

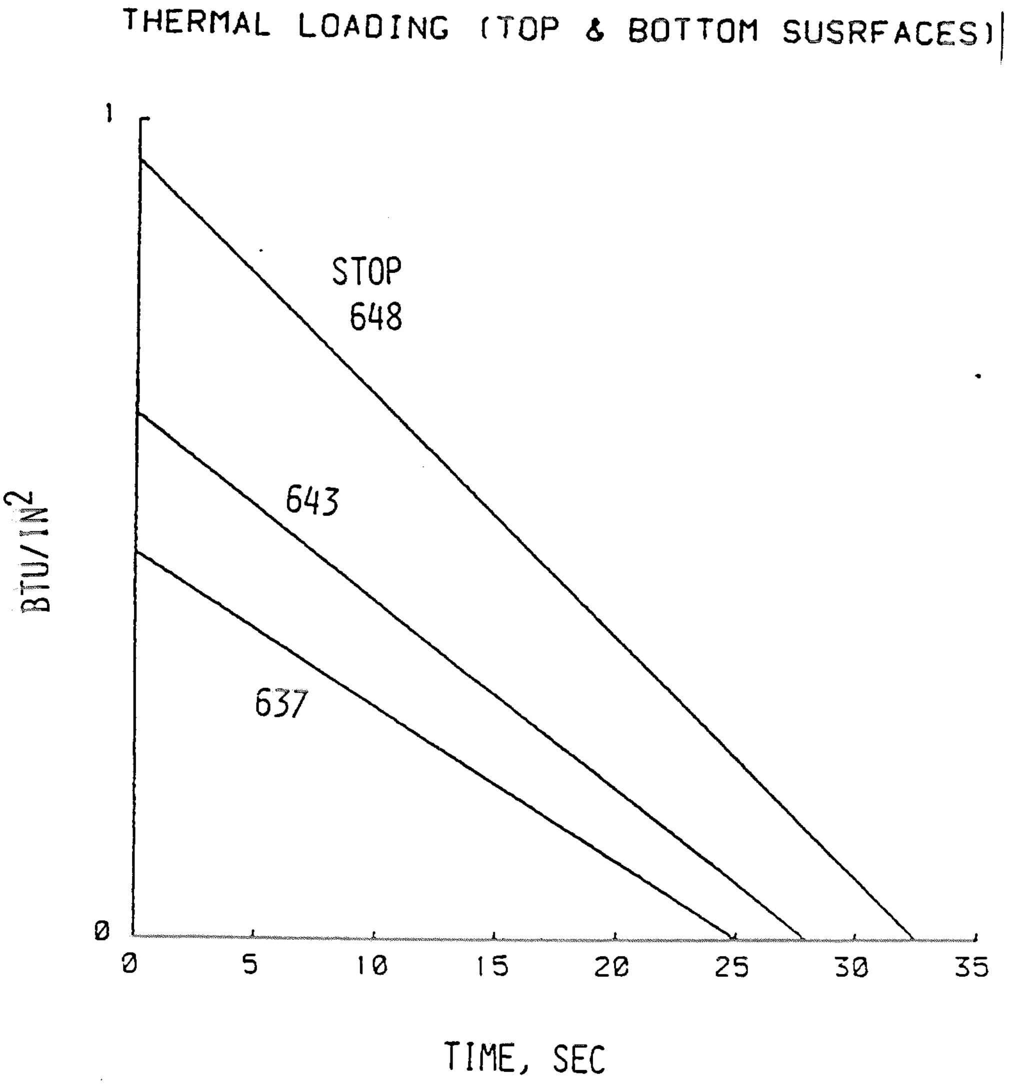

THERMAL LOADING (TOP & BOTTOM SUSRFACES)

FIGURE 5

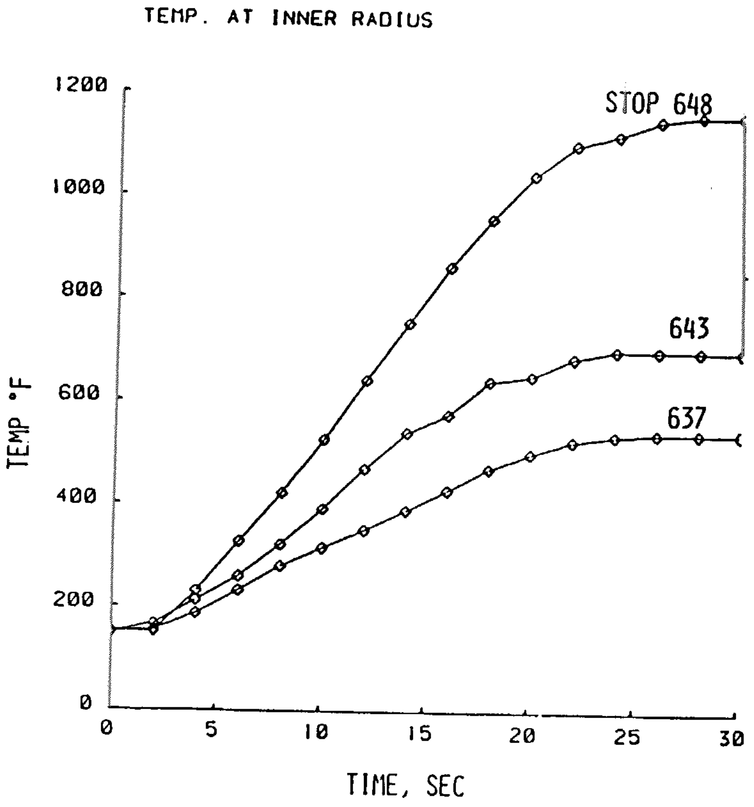


FIGURE 6

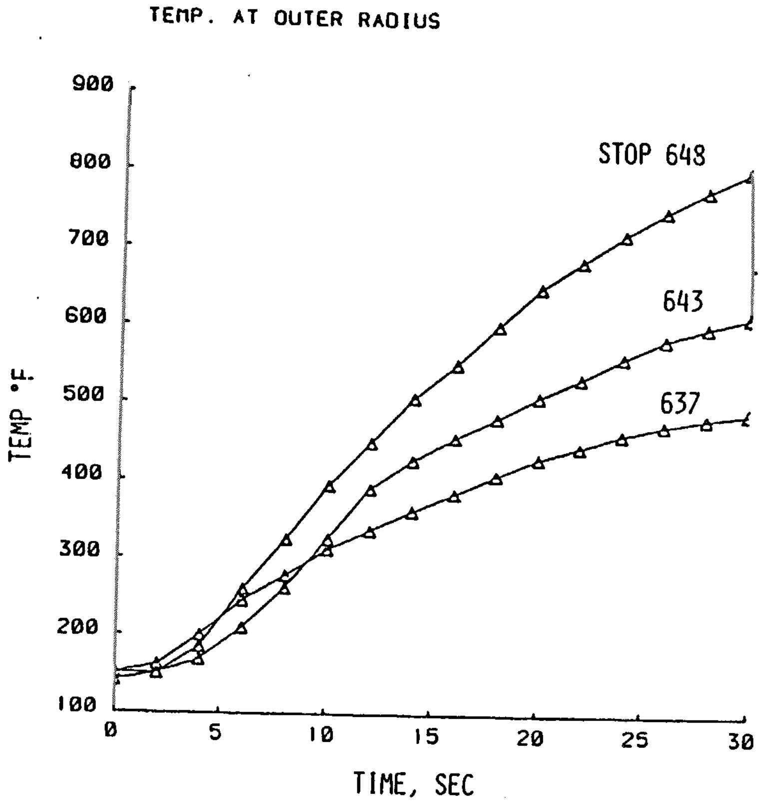


FIGURE 7

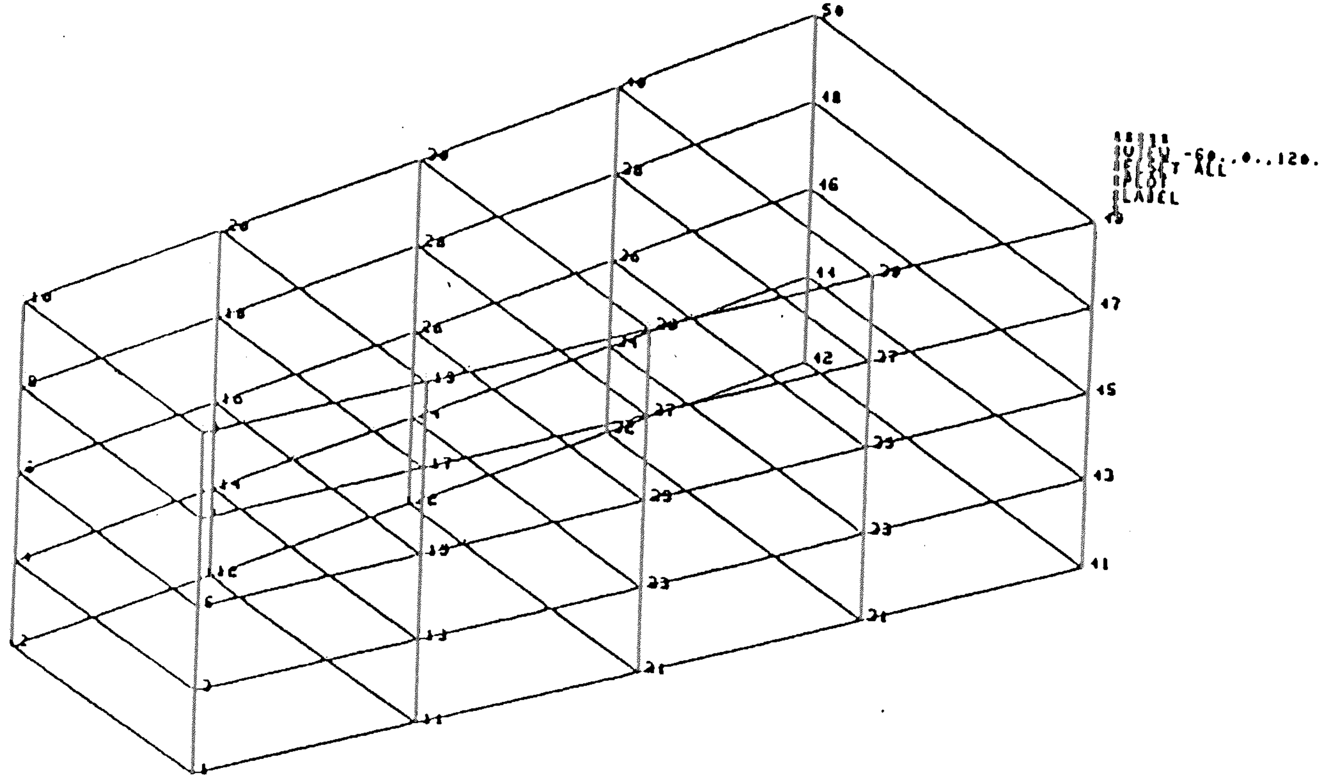


FIGURE 8 - EXAMPLE MESH USING "HEXA " ELEMENTS

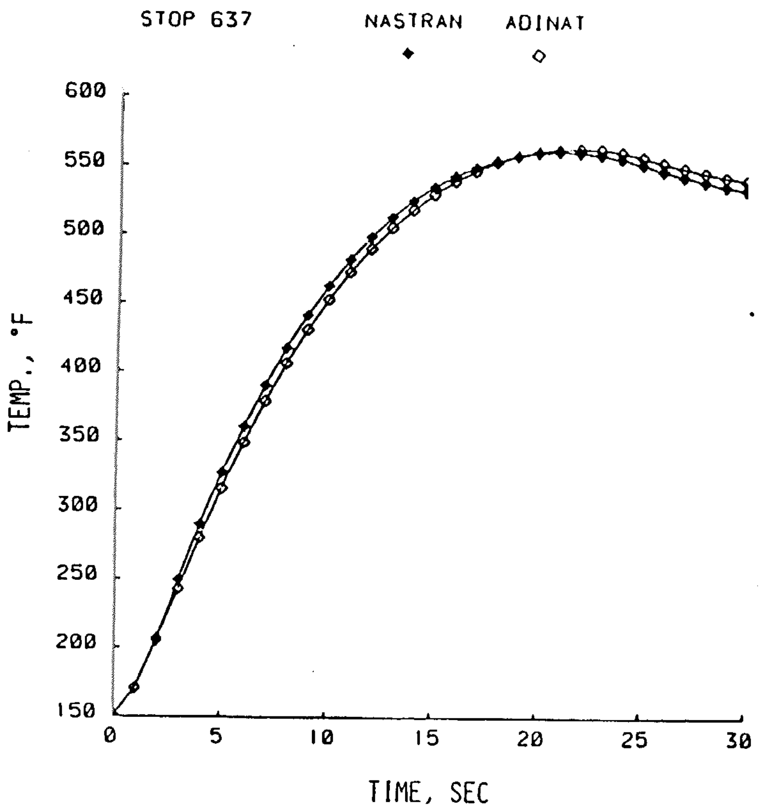


FIGURE 9

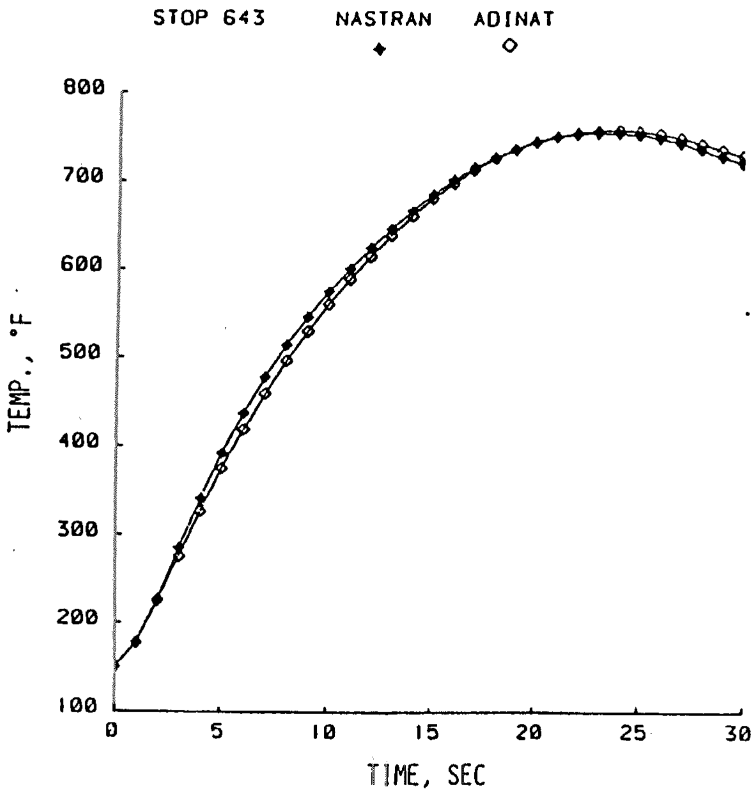


FIGURE 10

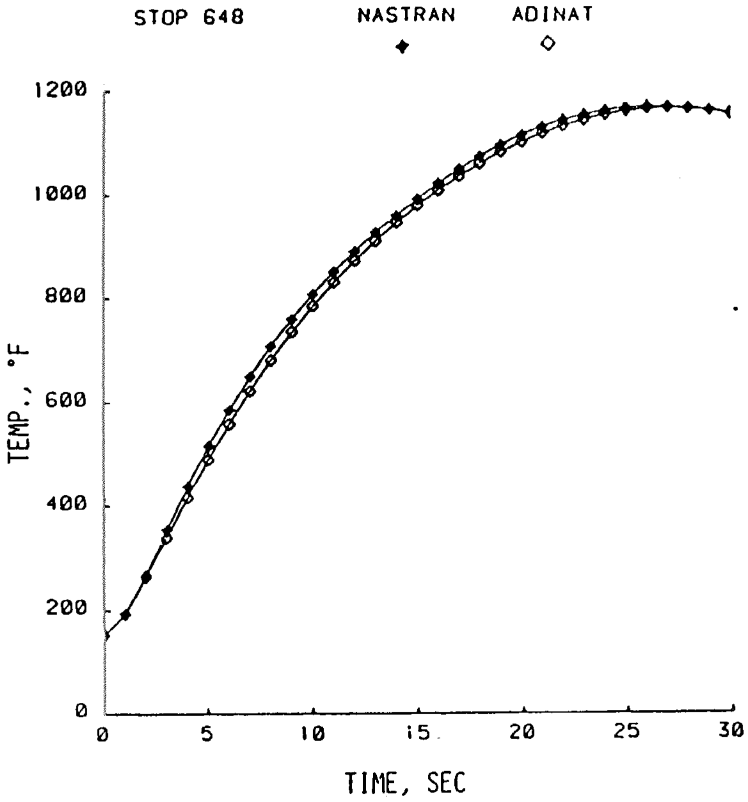


FIGURE 11

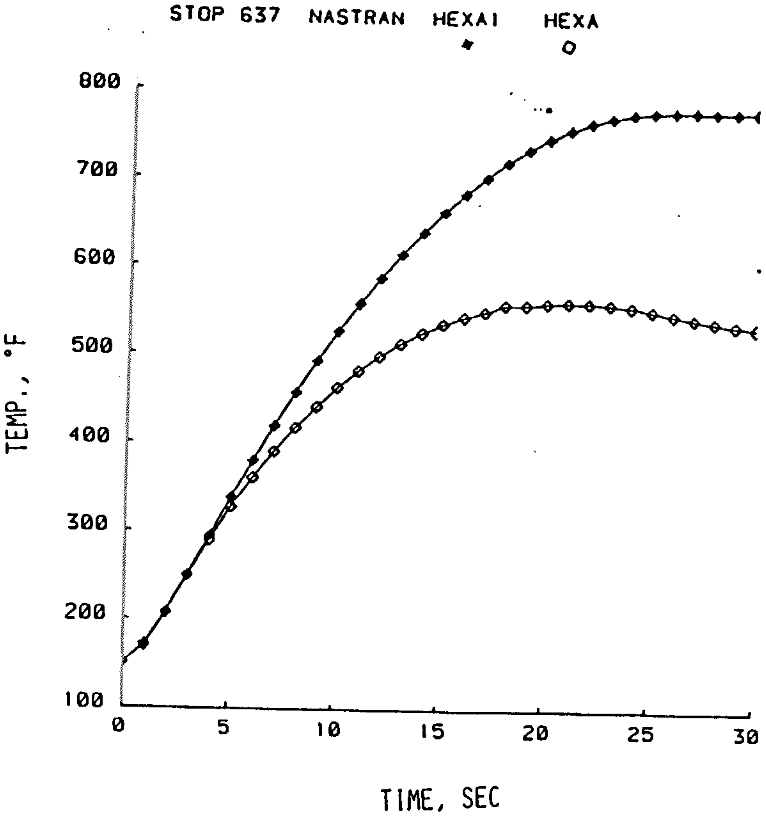


FIGURE 12

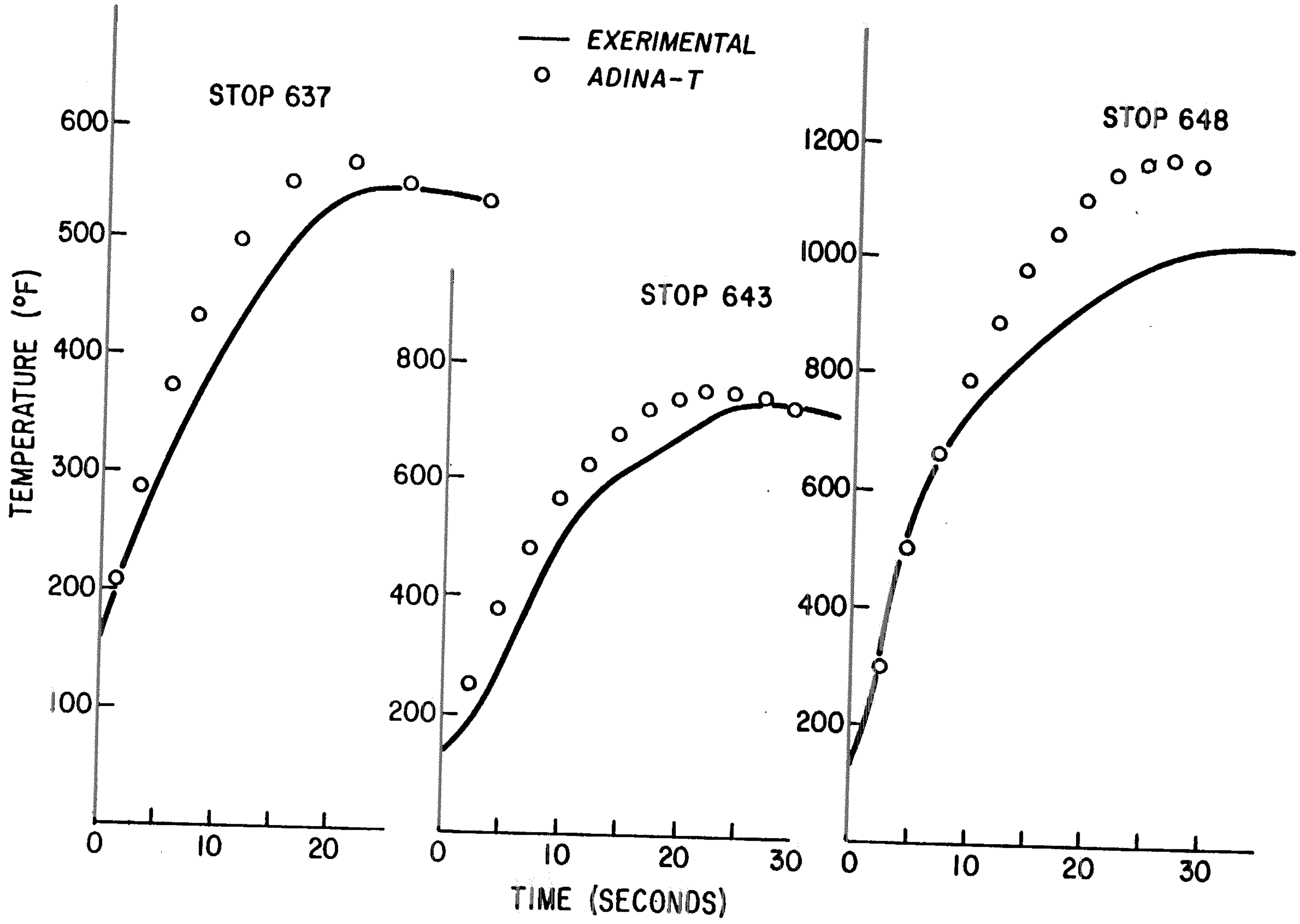
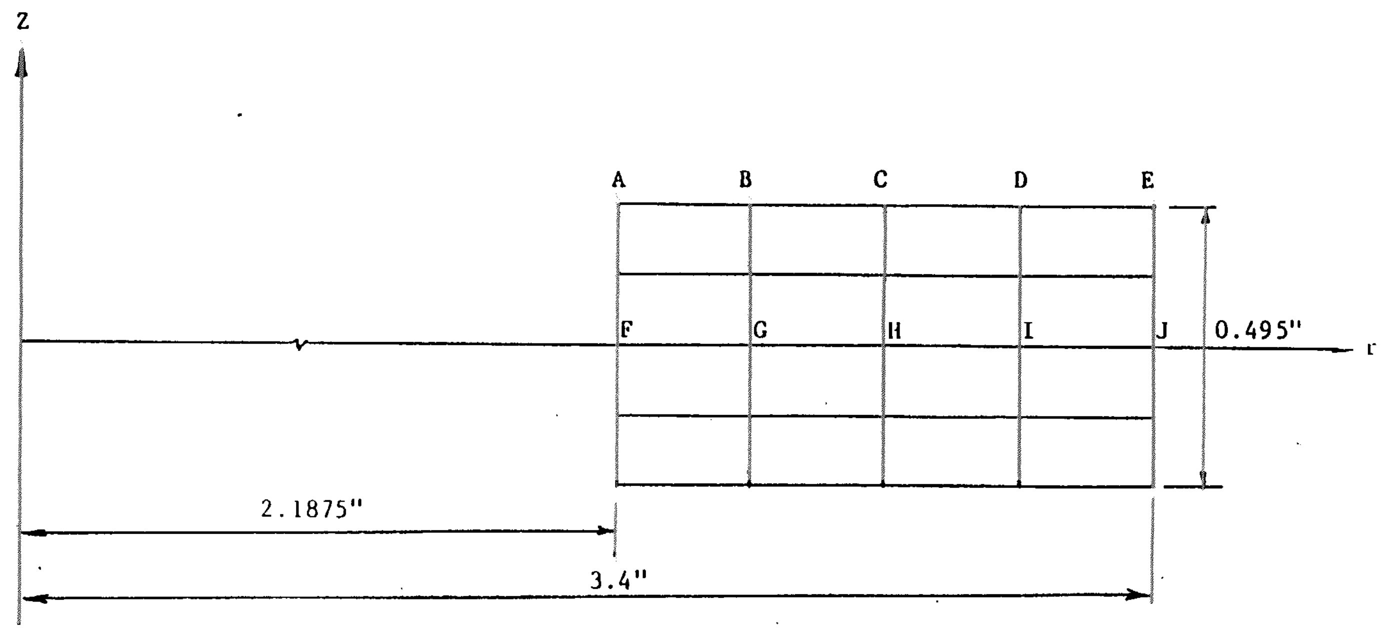


Figure 13. COMPARISON of PREDICTED and MEASURED TEMPERATURES.



Conductivity	K_r = 0.00167 BTU/in/sec/°F
	K_z = 0.0004 "
Convection	Inner radius h_i = 0.001
	Outer radius h_o = 0.1
Density	ρ = 0.06648 lb/in^3
Sp. Heat	c = 0.45 BTU/lb/°F
Initial Temp.	T_o = 0°F

FIGURE 14

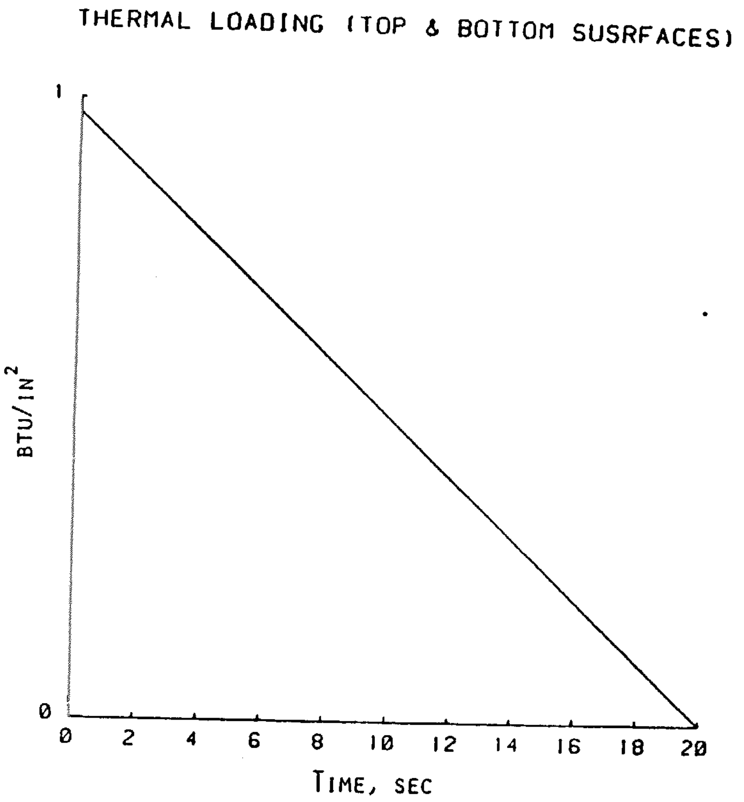


FIGURE 15

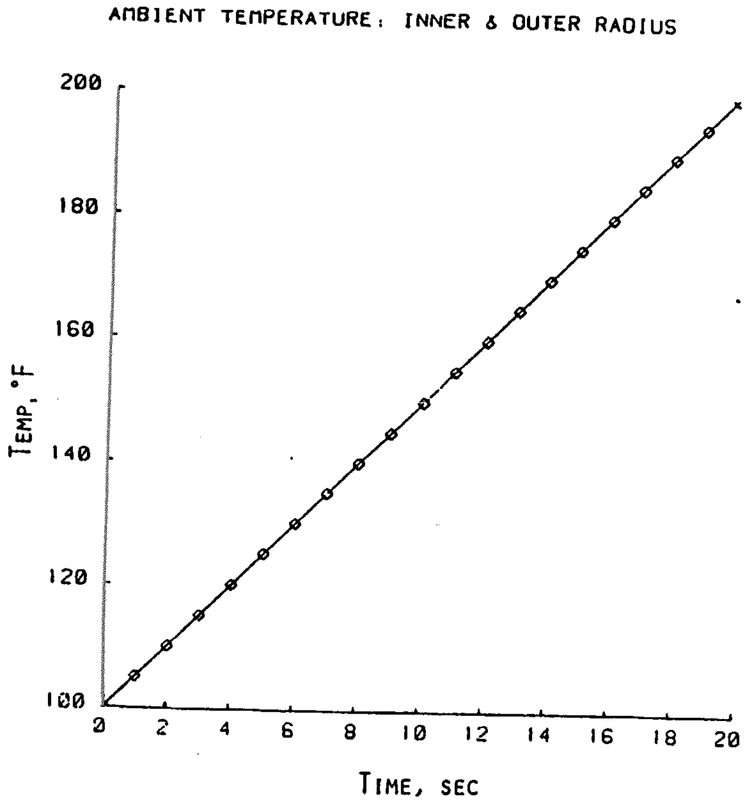


FIGURE 16

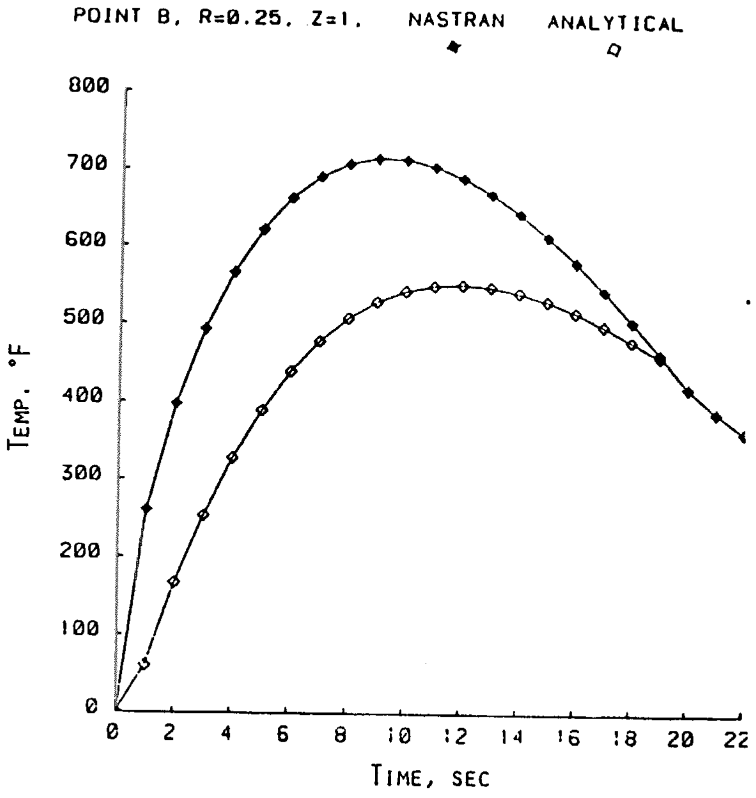


FIGURE 17

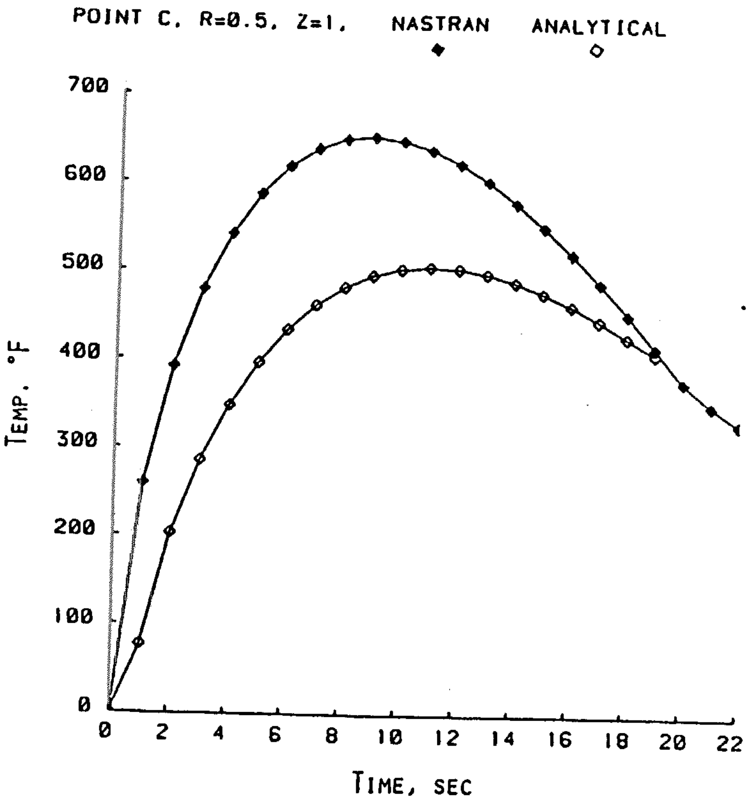


FIGURE 18

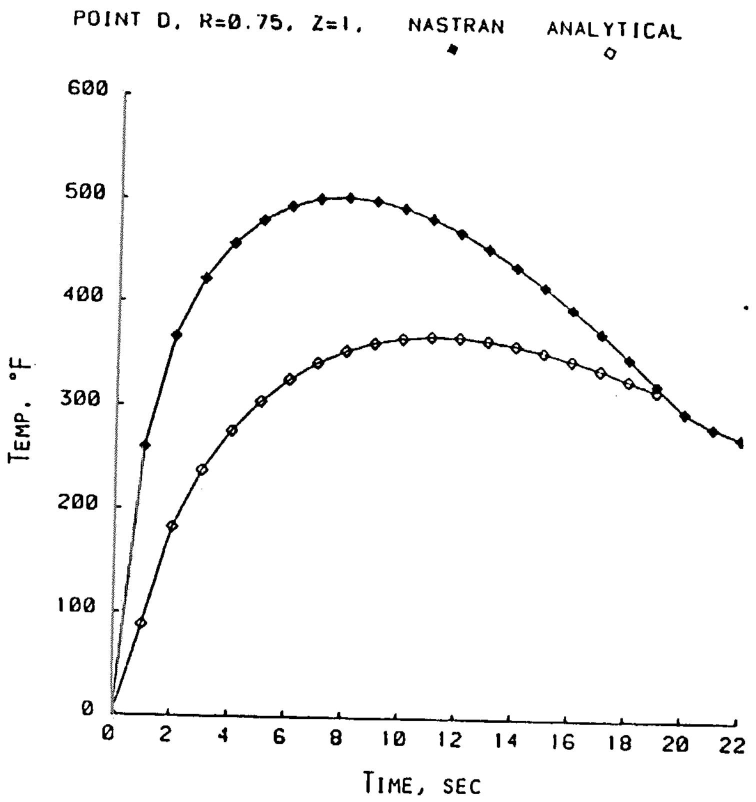


FIGURE 19

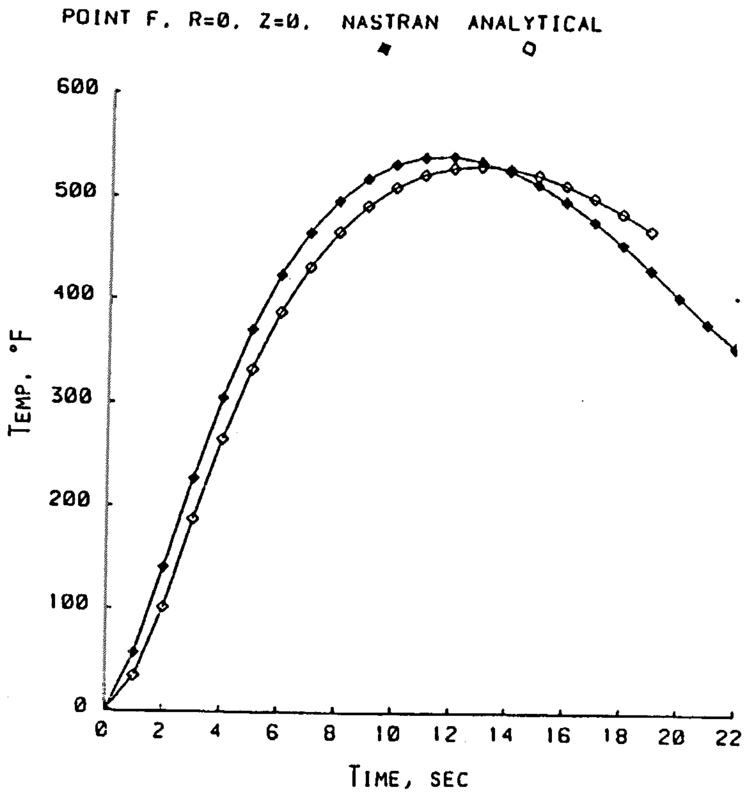


FIGURE 20

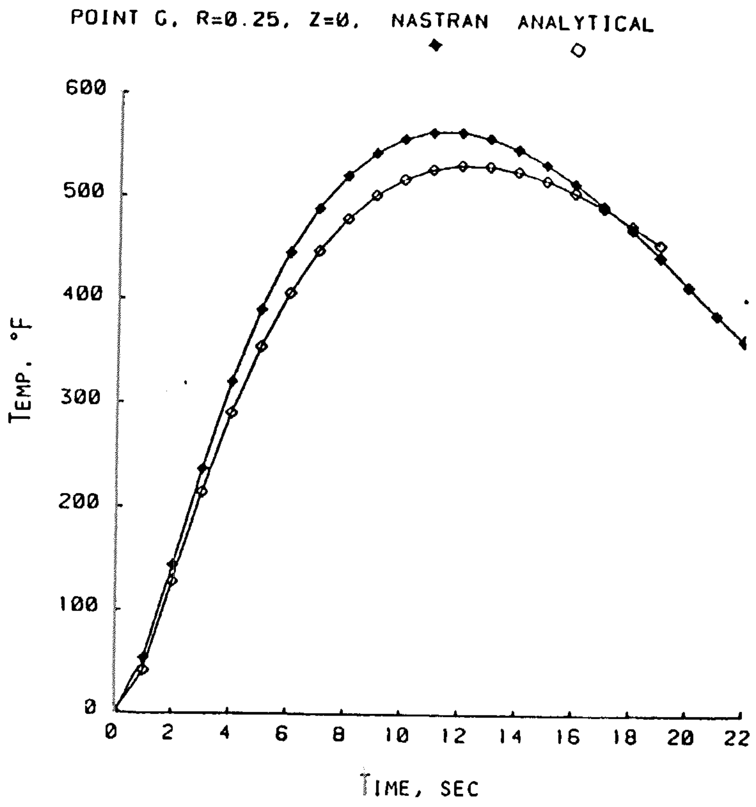


FIGURE 21

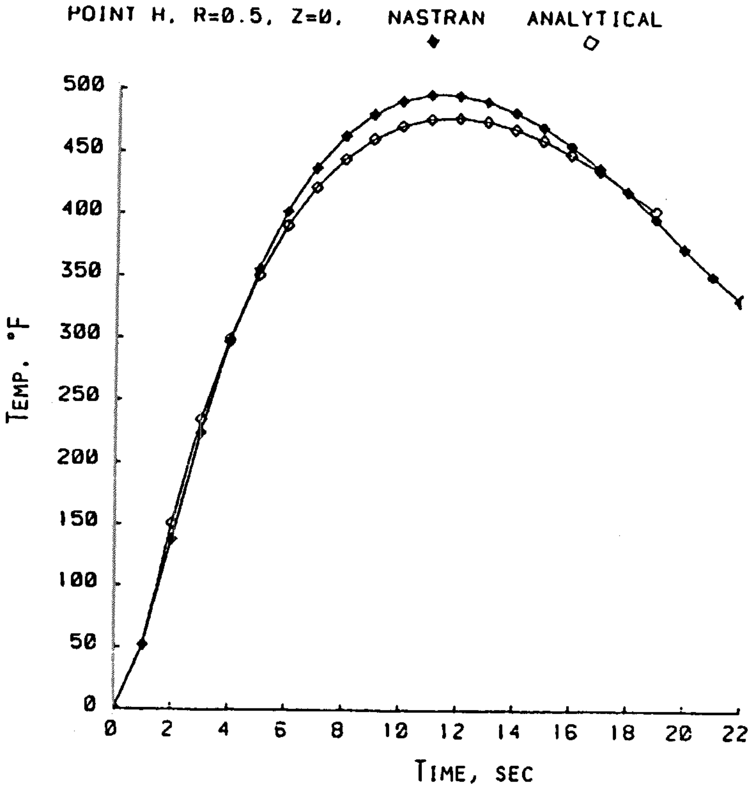


FIGURE 22

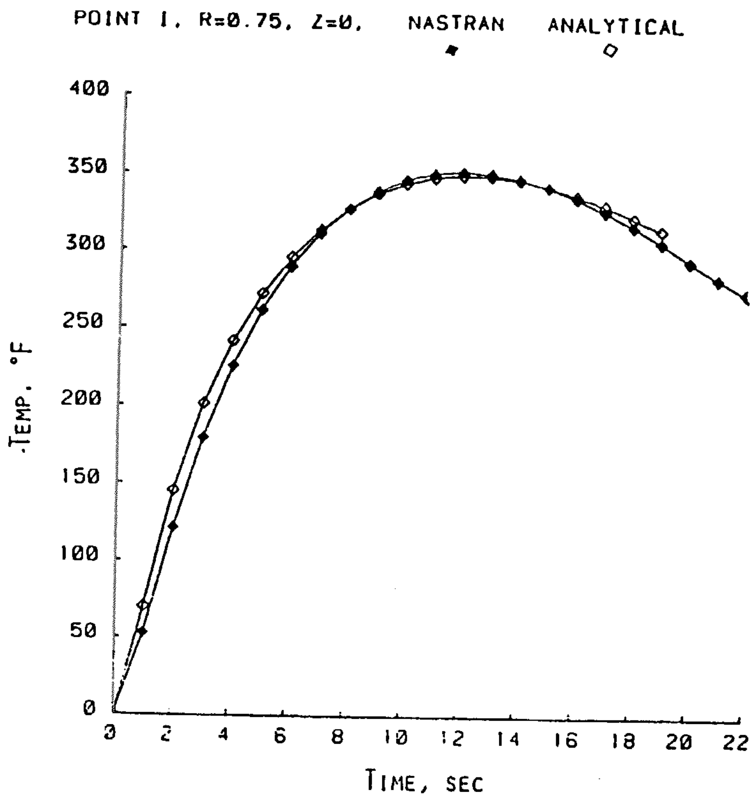


FIGURE 23

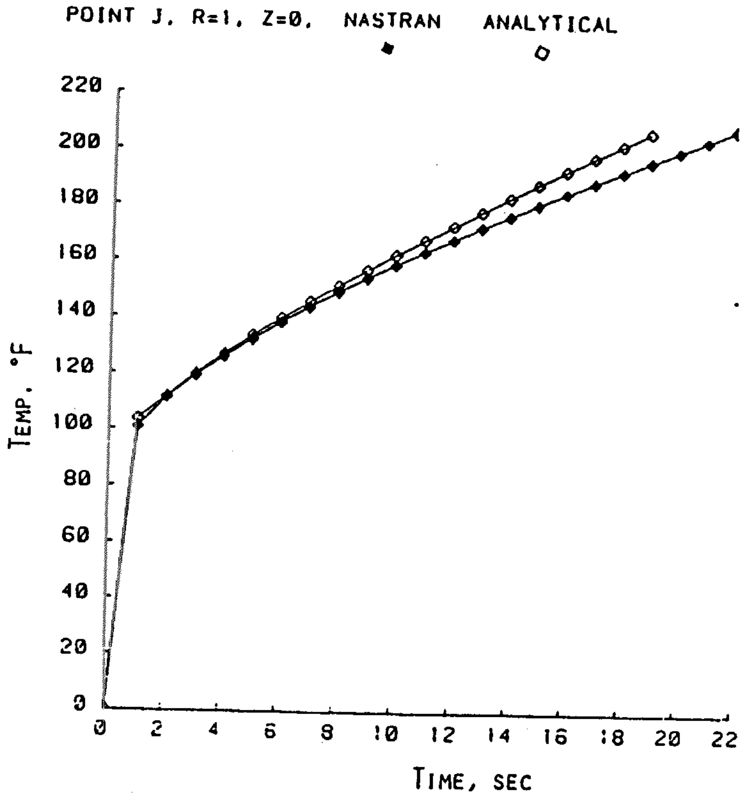


FIGURE 24