HOT STRUCTURES THERMAL CORRELATION

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FOREWORD

This report was prepared by The Boeing Company, Seattle, Washington under Contract AF 33(657)-7132, Project 1467, "Structural Analysis Methods", and is identified as Reinstated Documentation Sub-Item No 8-45, ASD Message ASKIT-2-9-2-E, dated 2 September 1964 and ASD Message ASKB-00006, dated 17 October 1964. The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Research and Technology Division, by Mr. Robert M. Bader, Project Engineer. The work was performed by the Aerospace Division, The Boeing Company, in the period of October 1964 to May 1965.

This technical report has been reviewed and is approved.

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FREDERICK C. KRUG
Colonel USAF
Chief, Structures Division

ABSTRACT

Test data generated during the early X-20 (Dyna-Soar) phases is compared with thermal analysis methods evolved throughout the X-20 Program.

Data is taken from the "Hot Structures" concept model test program. This model was similar in shape and concept to the X-20 design.

The thermal analysis approach and methods used follow closely those which created the X-20 design temperatures.

Generally good correlation is shown for two-dimensional cross-sectional cuts, a simple three-dimensional nose region analysis, simple structural joint analyses, and certain other detail areas. Some additional light is shed on joint interface effects. The only major problem evolved was convection currents in and around the test specimen.

This program in combination with an earlier insulated panel correlation program provides general confidence in the X-20 thermal analysis approach and methods.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

REFERENCES

1. ASDTR 62-7-795, Section II, "Manufacturing Methods for 'Hot Structures', Final Technical Engineering Report", by J. Claus and W. Seip of The Boeing Company, March 1962

2. "Heat and Mass Transfer", 2nd Edition, by E. R. G. Eckert and R. M. Drake, Jr., Chaper 11

3. Boeing Document D2-81243, "X-20 Glider Structures Thermal Analysis Methods" (C), by H. C. Cheng, April 1964

4. Boeing Document D2-81280, "Thermal Correlation of Heat Protection System", by J. F. Clawson, July 1964

5. ASD-TN-61-101, "A General Computer Program for the Determination of Radiant-Interchange Configuration Factors", by North American Aviation, Inc. personnel, March 1963

SECTION I

INTRODUCTION

Design of manned reentry vehicles involves the accurate prediction of temperatures and temperature gradients throughout the structure. This prediction task is highly complex, particularly for a "hot structure" vehicle where high temperatures and thermal radiation are dominant.

Many analytic prediction methods were evolved during the X-20A design effort, but experimental verification of these methods is virtually non-existent. One X-20A continuation program, the Heat Protection System test panel, provided some verification of insulated panel regions.

During the early phases of the X-20A design, a separate program entitled "Hot Structures Development" was initiated to prove X-20 structural concepts and provide manufacturing experience. A major element of this program was the design, manufacture and testing of a concept model representative of the X-20A. This model was about ten feet in length and included simulated wings. It was instrumented with about 500 thermocouples distributed on panels, primary structure, and structural joints. During the testing, a wealth of thermal data was gathered.

The intent of this correlation program is to extend the verification of X-20A temperature prediction methods to include uninsulated panels (such as upper wing surfaces) and large open cavities containing structural trusswork. The analysis approach to the concept model is quite similar to the X-20 approach. Two-dimensional cross-sections, and some three-dimensional analyses are included.

SECTION II

TEST SPECIMEN DESCRIPTION

NOTE: This section is abstracted from Reference 1.

2.1 CONCEPT MODEL DESCRIPTION

The test model was a full-size structural representation of the forward 10.5 feet of a typical hypersonic boost-glide vehicle, exclusive of nose cone and leading edges. See Figure 1.

Frames are lettered A through F from front to rear. As viewed from aft, all joints are numbered in order from left to right and from bottom to top. The first joint in each frame begins with the number 1, and all joints in any given frame have that frame letter as a prefix (Joint A1, B3, etc.). Structural members are described by the joints to which they are connected (Member A1-B3, etc.).

Rene' 41, a nickel-base superalloy material was used throughout the structure with the exception of the lower-surface skin panels and panel attachments, which were HS-25, a cobalt base superalloy. The body was composed of two main longitudinal trusses joined together with four cross frames. Diagonal bracing was included in the lateral direction between longerons to provide the capability of reacting asymmetrical loading conditions. The longerons in the main body trusses were built-up sheet-metal members. The remainder of the body truss members were tubes. Joints in the forward two bays of the body were made from sheet-metal parts and the larger fittings in the aft two bays were machined from forged block. Pinned joints were used in the majority of body member connections. However, where complicated multiple connections were made, members that were relatively unaffected by thermal gradients were rigidly connected. Tubular members generally had swaged ends to reduce joint size and to accommodate clearances.

The primary wing structure was made up of wing-spar trusses and leading-edge beams. The wing-spar trusses were perpendicular to the leading edge of the vehicle and were attached to the body truss at the lower longerons and vertical body members.

Drag links in the main body longitudinal trusses reacted wing-spar forces parallel to the centerline of the vehicle. Diagonals were included between wing spars to provide the capability of reacting control surface loads. The wing-spar members were tubes with the exception of the built-up sheet-metal sections used in the vertical direction at the leading edge. Sheet-metal joints and superalloy bolts were used for the wing truss connections. Welded joints were used where the secondary stresses from thermal gradients were not great.

The leading-edge beams were composed of upper and lower chords with corrugated webs. All parts were formed from sheet metal. These beams were discontinuous at the spars with flexible attachments to allow differential thermal expansion between the beams and internal trusswork. These components acted as simply supported beams between spar attachments. Wing intercostals and keel beams were also simply supported in this manner.

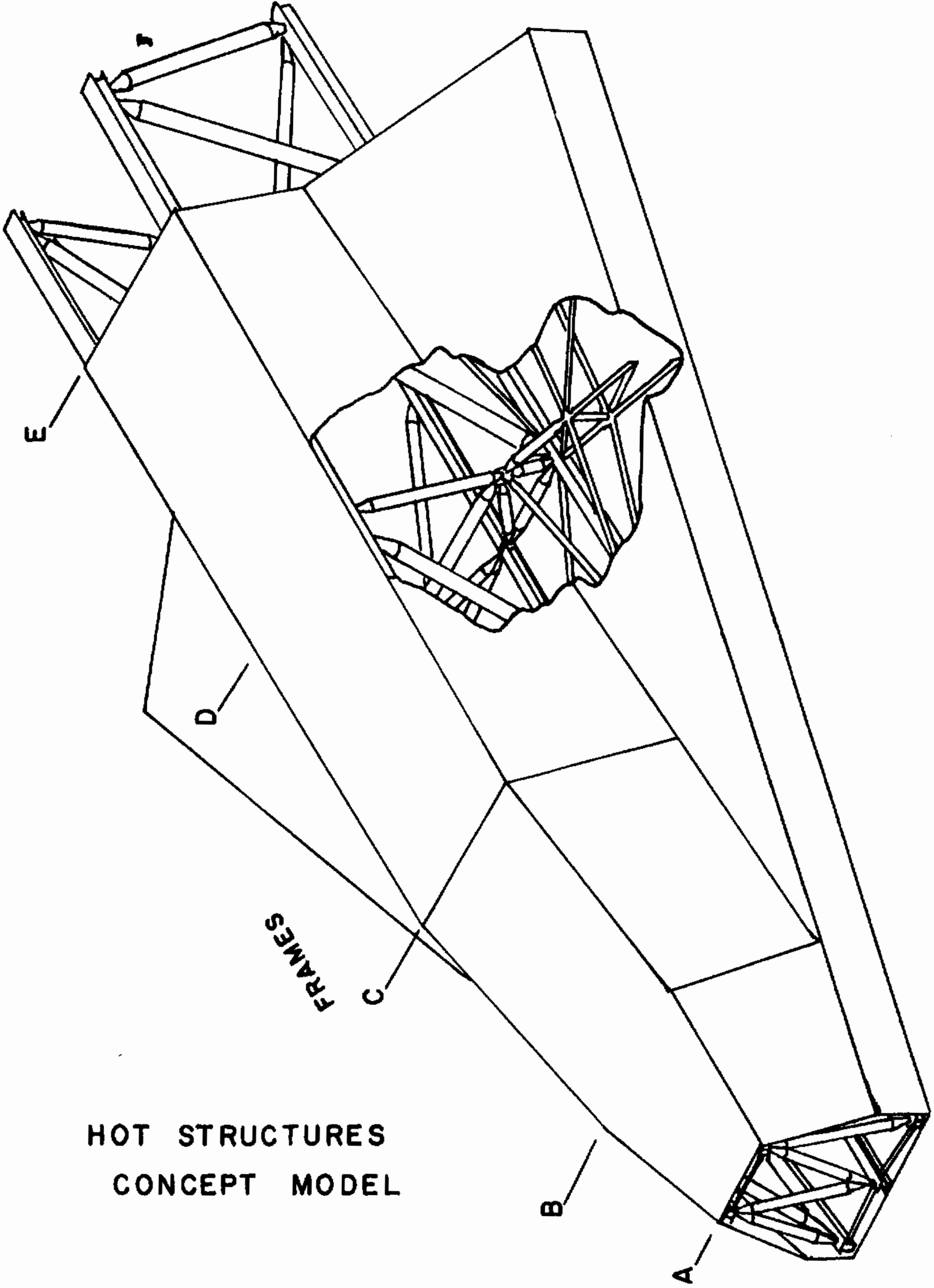
Although test loads were not applied to the skin panels, the panels were representative of those required to withstand the conditions of heat and load specified for this program. They consisted of skin-covered corrugated panels except for those on the sides and crown of the body; here, uncovered corrugated panels were used. These panels had the capability to transfer applied air loads to the leading edge beams, intercostals, longerons, and keel beams by simple beam action. Expansion joints and flexible attachments were included in the lower surface panels to accommodate the differential expansions of structure due to high thermal gradients in this area.

2.2 TEST SETUP

Testing of the "Hot Structures" model component was performed in the Wright Air Development Division Structural Test Facility located at Wright-Patterson Air Force Base, Ohio.

General Electric 1000-, 1500-, and 2000-watt T-3 12-inch radiant heating lamps were mounted on Research Incorporated, ceregold reflectors with an average lamp density of 17 lamps per square foot. The maximum allowable reflector temperature was 1350°F. Since the model was to be heated on the lower surface only, the elevated temperature reflectors were mounted on an aluminum holding frame that was hinged at the rear and beneath the model. The reflector frame was free to rotate in the vertical direction only and was attached to the model by a system of cables and pulleys so that a constant distance would be maintained between the model and the heating lamps.

Since the reflectors were limited to 1350°F, a reflector cooling system was designed and installed under the reflector frame. The cooling system consisted of an array of 1-inch aluminum tubes having .070-inch holes regularly spaced along the tube length. Liquid CO_2 was used as a coolant and was manually controlled by two valves. The tubes were arranged along the programmed isotherms of the model and each valve controlled the flow of CO_2 to a particular isotherm region. The CO_2 was liquid while in the tubes, but by the time it reached the reflectors it was in the gaseous state. The cooling system was sufficient to keep the reflector temperature to less than 900°F. The amount of CO_2 cooling that was needed was determined by 15 reflector thermocouples spaced in critical temperature areas.



HOT STRUCTURES
CONCEPT MODEL

FIGURE 1

2.3 THERMOCOUPLE INSTRUMENTATION

Extensive instrumentation was utilized in gathering data that could be used in evaluating the performance of the model.

Originally a total of 476 chromel-alumel thermocouples were attached to the model. Temperatures sensed by the control thermocouples were recorded on Brown recorders in the form of continuous time-temperature plots. The remainder of the thermocouples were used as data thermocouples. They were attached to the model at numerous points on the structure, including the outer surface of the bottom skin panels. Data thermocouples were installed on the left-hand half of the model only. Since the model is essentially symmetrical about the centerline, instrumentation of both sides would produce nearly duplicate data for each half. By concentrating thermocouples on the left half, a greater number of typical locations could be covered with the thermocouples available.

The detail locations of the data thermocouples are given in the Appendix of Reference 1.

SECTION III

GENERAL ANALYSIS AND CORRELATION PHILOSOPHY

3.1 ANALYSIS

The analysis of the Hot Structures concept model follows closely the overall approach to the X-20A analysis effort; primary emphasis is placed on two-dimensional cross-section cuts. (See also Reference 3.) Additional three-dimensional work includes the forward fuselage section and two representative joints. All three-dimensional work was done with extreme simplicity in mind in an attempt to prove that simple approaches are feasible in certain cases.

Figure 2 shows the general location and type of each of the seven analyses. Of primary concern are Analyses A and B which are typical cross-section cuts used to provide a large amount of overall thermal information. Analysis C provides more detail in the wing and leading edge area. D is a fairly simple 3-D analysis of the nose region intended to demonstrate end loss effects as compared with Analysis A. Analyses E and F are very simple 3-D joint analyses. These were generated with large nodes, simple boundary conditions, and radiation view factors based on simple handbook curves and estimates. Analysis G is a two-dimensional corrugation detail analysis. It was not originally scheduled but was produced to help understand the gross panel assumptions of Analyses A, B, C, and D.

3.2 CORRELATION

Correlation is based on two tests of the entire heat series. The first set of correlation curves for each analysis is for one or more of the 5 series tests (5.1, 5.4, 5.6, or 5.8). Note that Tests 5.1 through 5.9 were programmed identically; different thermocouple sets were recorded. Certain deviations occurred among these tests due to heat lamp system problems and control thermocouple failures. See also Reference 1 for a discussion of these tests.

The second set of correlation curves (where applicable) are for Test B1 of the second test series. This series included simulated compartments in the aft two fuselage bays. This later test series more closely approximates the X-20 configuration, except that upper surface heating was quite significant in the X-20 but not programmed in the Hot Structures tests. These tests were not documented.

The early series of tests (5.1 through 5.9) included maneuver spikes in the skin temperature profiles. This resulted from test procedures based on early X-20 designs without insulation on the lower surface. The final X-20 designs had lower surface insulation, hence the effect of a maneuver on the external skin was not noticeable on the internal corrugations. The methods used for both the X-20 thermal analysis and this program are not necessarily oriented to accurate maneuver temperature predictions, hence correlation of these spikes is not considered particularly significant.

Due to the length of time that has passed since the test data was collected, and the lack of close test control such as that available for the Reference 4 program, certain deviations from that program's overall philosophy were necessary. For instance, it was not possible to consistently use either analytic data or test data for other analytic boundary conditions; frequently mixtures were necessary. A relatively small percentage of the test data was actually useful for correlation.

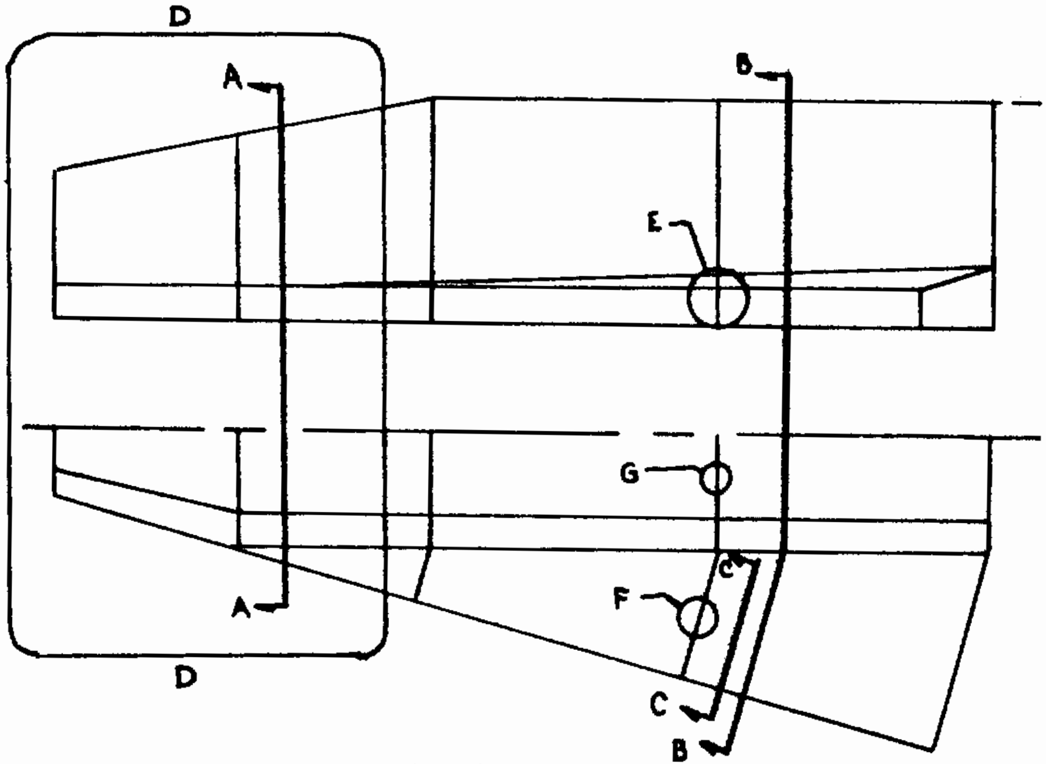


FIGURE 2 LOCATION OF THERMAL ANALYSES

ANALYSIS	DESCRIPTION
A	FORWARD BODY TWO-DIMENSIONAL ANALYSIS
B	CENTRAL BODY AND WING TWO-DIMENSIONAL ANALYSIS
C	CENTRAL WING TWO-DIMENSIONAL ANALYSIS
D	FORWARD BODY THREE-DIMENSIONAL ANALYSIS
E	LONGERON JOINT THREE-DIMENSIONAL ANALYSIS
F	WING JOINT THREE-DIMENSIONAL ANALYSIS
G	CORRUGATION DETAIL TWO-DIMENSIONAL ANALYSIS

SECTION IV

ANALYSIS AND CORRELATION

4.1 GENERAL ASSUMPTIONS AND THERMAL ANALYZER DETAILS

Some of the general assumptions used in most of the analyses follow:

1) Lower skin - driven to test data temperatures.

2) No conduction through spotwelds between skin and corrugations on all lower panels and upper wing panels. (Radiation heat transfer only)

3) No conduction between panels (across edges).

4) Trusswork (except longerons and major diagonals) is neglected.

5) All corrugations are replaced by an equivalent flat plate with compensated mass (except Analysis G).

6) External convection is included on all vertical or near vertical surfaces. Early analytic runs were sometimes 200°F high when this effect was neglected.

   It is based on laminar flow using the equation

$$\frac{h x}{k_w} = .378 \left(\frac{g \beta x^3 (T_w - T_{FLUID})}{\nu^2} \right)^{\frac{1}{4}}$$

(see Reference 2)

Where h = local heat transfer coefficient

x = distance from plate lower edge

$\beta = \frac{1}{T_\infty}$ (R^{-1})

ν = MEAN kinematic viscosity

$$\left(\frac{\nu_w + \nu_\infty}{2} \right)$$

k_w = thermal conductivity of air (at the plate surface temperature)

g = acceleration of gravity

Subscript w = properties at the surface temperature of the plate

Subscript ∞ = properties outside the boundary layer (in this case, room temperature conditions)

Note: In usage, 'x' was removed from the curve value, and reintroduced in a later constant.

7) Radiation from the heat lamps to the leading edge beam is assumed to be totally blocked.

8) All upper external surfaces radiate to an 80°F black body sink (representing the room).

9) Only one-half of the vehicle is considered due to symmetrical heating. Note that internal radiation view factors must include consideration of the other half.

10) Radiation view factors were calculated on an Autonetics Recomp III small computer using cross-string techniques (Analyses A, B, C, and G).

11) Grey body radiation is assumed. Generally the emittance interchange factor is assumed to be the emittance product

i.e. $\dot{q}_{NET} = \epsilon_1 \epsilon_2 A_1 F_{1-2} \sigma \left(T_1^4 - T_2^4\right)$

(Except skin-to-corrugation cases where

$$\dot{q}_{NET} = \frac{1}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)} A_1 F_{1-2} \sigma \left(T_1^4 - T_2^4\right)\Big)$$

(See page 11 for definition of terms)

12) Nominal material properties are assumed.

The analysis descriptions and results of the seven analyses which follow are each organized as follows:

Analysis Description

Correlation

Boundary Conditions

Nodal System Drawings

Numerical Inputs to the BETA Program (see below)

Correlation Curve Set (including test data)

Analysis Discussion

The Boeing Engineering Thermal Analyzer Computer Program (BETA) was used exclusively for this effort. Inputs shown herein include only node and conductor identification, node capacitance values, boundary conditions, and conductor multiplying factors.

Node capacitance is defined as $\rho C_p V$,

where ρ = density

C_p = specific heat

V = node volume

The program requires all conductors to be of the form

$$q_{a-b} = K_{a-b} (T_a - T_b)$$

where K_{a-b} is the conductance of the conductor between Nodes a and b.

For the conduction mode of heat transfer,

$$K_{a-b} = k \frac{A}{L}$$

which is derived from

$$q_{a-b} = - k A \frac{dT}{dx}$$

$$= + \left(k \frac{A}{L}\right) \left(T_a - T_b\right)$$

where k = material thermal conductivity in $\frac{\text{BTU - IN}}{\text{IN}^2 \text{ - MIN - °F}}$

Note that most of the materials used in the test specimen have temperature or temperature-pressure dependent thermal conductivities.

A = Conductor cross-sectional area in square inches

L = Effective conductor length

Due to the temperature dependence of k, the term $(\frac{A}{L})$ is required as a separate input constant (for each conductor). These constants are then multiplied by the appropriate k (through the use of program subroutines) to form the conductance of that particular conductor at any particular time.

For the radiation mode of heat transfer

$$K_{a-b} = \epsilon_a \epsilon_b \sigma A_a F_{a-b} \left(T_a^2 + T_b^2\right)\left(T_a + T_b\right)$$

This is derived as follows

$$q_{a-b} = F_{e_{a-b}} A_a F_{a-b} \sigma\left(T_a^4 - T_b^4\right)$$

$F_{e_{a-b}}$ = Grey body emittance factors - for this program it usually is assumed to equal $\epsilon_a \epsilon_b$

$A_a F_{a-b}$ = Geometric view factor between the node pair

σ = Stephan-Boltzman constant, = $1.98264 \times 10^{-13} \dfrac{\text{BTU}}{\text{IN}^2 - \text{MIN} - {}^\circ\text{R}^4}$

T = Temperature in °R

ϵ = Thermal emittance of a node (usually a function of node temperature)

Therefore:

$$q_{a-b} = \epsilon_a \epsilon_b A_a F_{a-b} \sigma\left(T_a^4 - T_b^4\right)$$

$$\text{but } \left(T_a^4 - T_b^4\right) = \left(T_a - T_b\right)\left(T_a^2 + T_b^2\right)\left(T_a + T_b\right)$$

Therefore:

$$K_{a-b} = \frac{q_{a-b}}{\left(T_a - T_b\right)}$$

$$\approx \epsilon_a \epsilon_b A_a F_{a-b} \sigma\left(T_a^2 + T_b^2\right)\left(T_a + T_b\right)$$

4.2 FORWARD BODY TWO-DIMENSIONAL ANALYSIS (ANALYSIS A) (See Page 7)

4.2.1 Analysis Description

This is a two-dimensional cross-section in the forward body between Frames B and C. See page 4 for frame locations. It is in a region where some three-dimensional end losses (through the front baffle) might be expected to influence the temperature levels. It is analogous to the X-20 thermal analyses at Body Stations 140 and 170 (see Reference 3). The upper and lower longerons, center keel beam, and main side diagonal are included; all other trusswork is neglected.

The assumptions shown in Section 4.1, page 8, apply to this analysis.

Boundary conditions are outlined on page 13 for Test 5 and page 36 for Test Bl.

The nodal system is shown in Figure 3, page 16, for Test 5 and Figure 4, page 39, for Test Bl. Constants, capacitors, etc., are shown on pages 17 through 24 for Test 5, and pages 40 through 46 for Test Bl.

Correlation of this analysis for the Test 5 series is shown on pages 25 through 35. Correlation for Test Bl is shown on pages 47 through 57. Note again that end losses might be expected to invalidate the two-dimensional assumptions of this analysis, particularly for Test Bl.

4.2.2.1 ANALYSIS A CORRELATION

FORWARD BODY TWO-DIMENSIONAL ANALYSIS

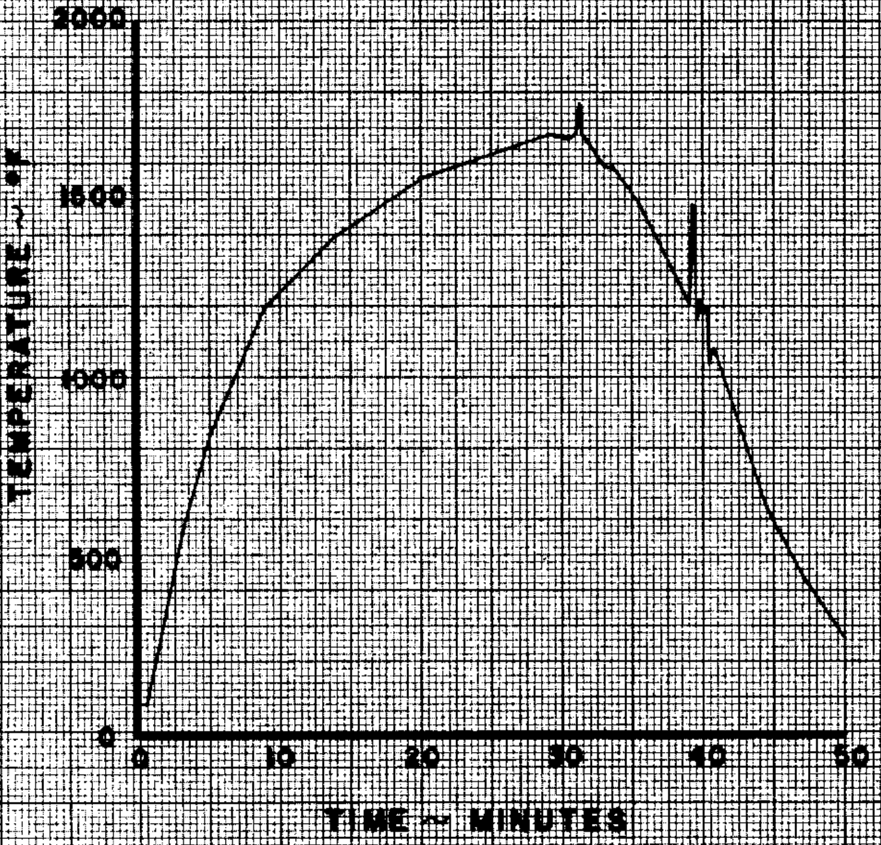
TEST SERIES: 5 CONDITION: 5.1
5.6

BOUNDARY NODES	SOURCE	PAGE
1	THERMOCOUPLE 300 TEST 5.1	14
2	THERMOCOUPLE 300 TEST 5.1	14
3	THERMOCOUPLE 299 TEST 5.1	15
35	ROOM TEMPERATURE	

THERMOCOUPLE #300 TEST 5.1

DRIVE BOUNDARY NODES:

1 ANALYSIS A TEST 5.1
2 ANALYSIS A TEST 5.1
2 ANALYSIS D TEST 5.1
4 ANALYSIS D TEST 5.1



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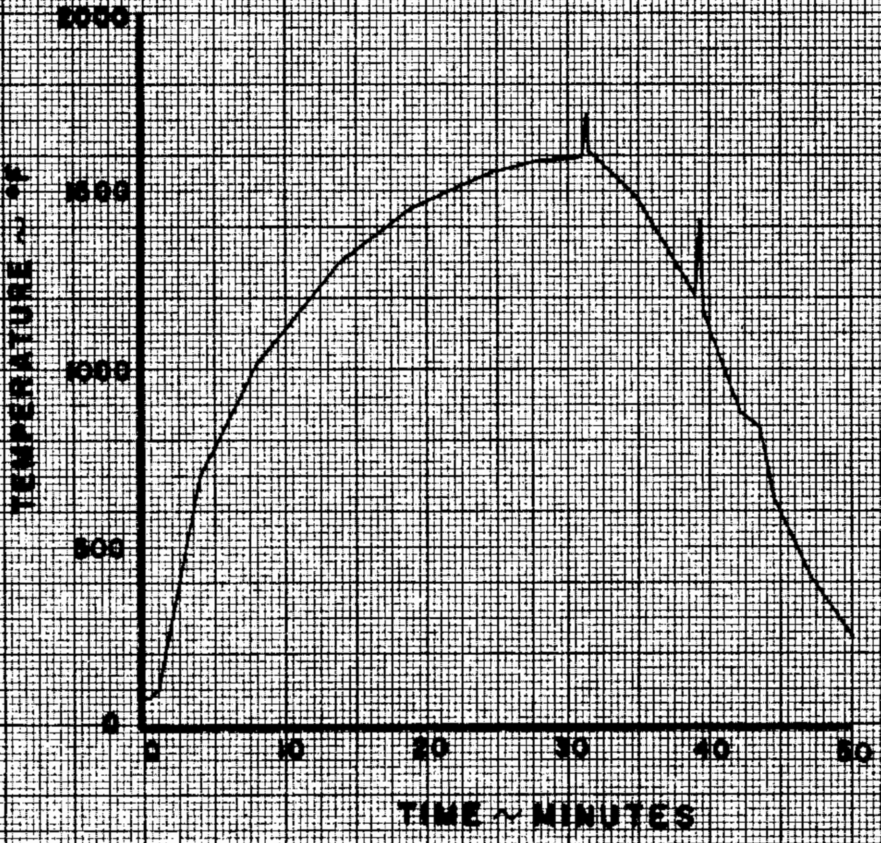
THERMOCOUPLE #299 TEST 5.1

DRIVE BOUNDARY NODES:

3 ANALYSIS A TEST 5.1
5 ANALYSIS D TEST 5.1



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ANALYSIS A

2-DIMENSIONAL FWD. BODY

NODAL DIAGRAM

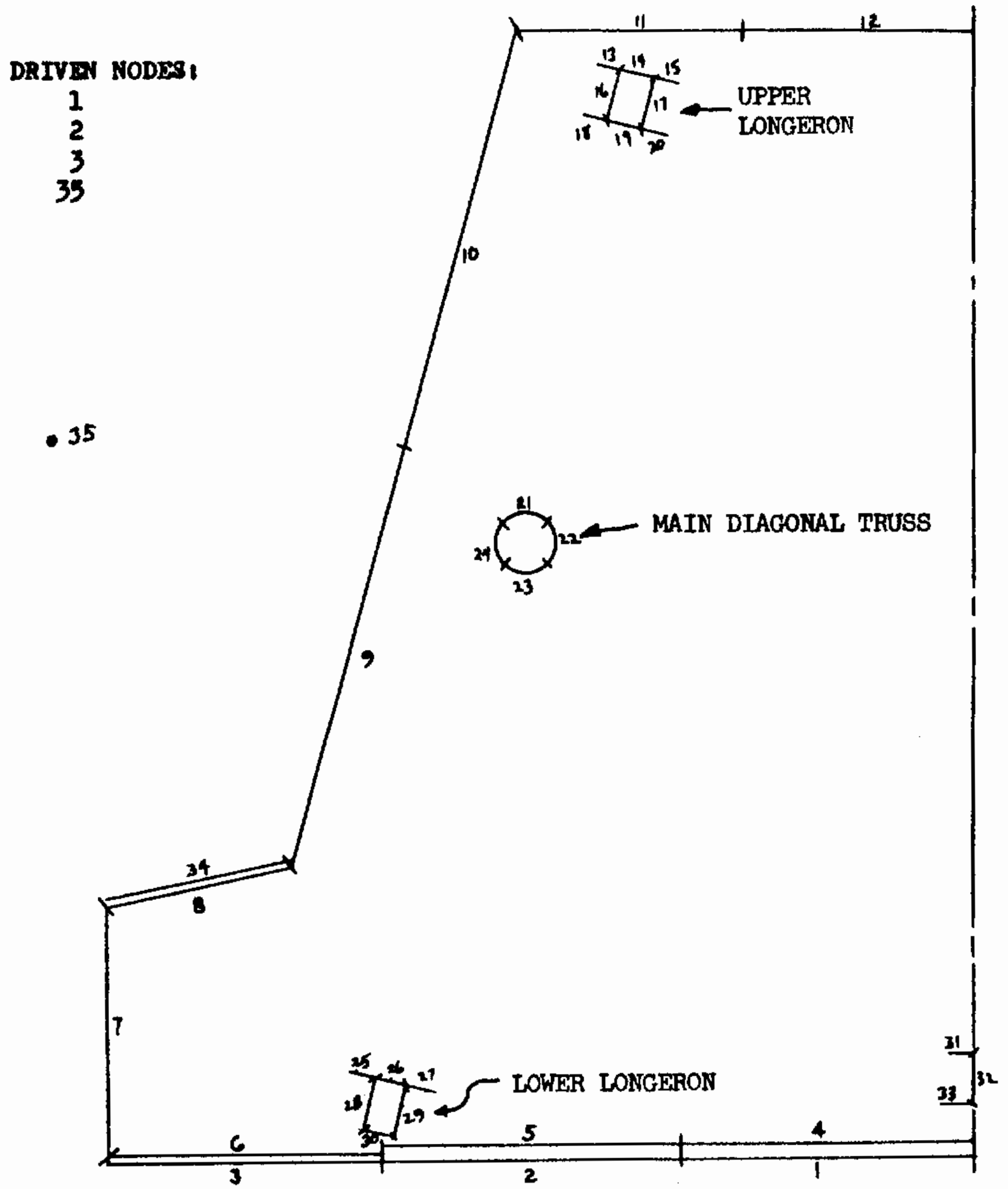


FIGURE 3

ANALYSIS A NODAL DIAGRAM - TEST 5

CAPACITORS - ANALYSIS A TEST 5.1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	HS-25	DRIVEN	--
2		DRIVEN	--
3		DRIVEN	--
4		0.109	3.52×10^{-3}
5		0.109	3.52×10^{-3}
6	HS-25	0.0781	2.42×10^{-3}
7	RENE' 41	0.0711	2.45×10^{-3}
8		0.0537	1.849×10^{-3}
9		0.123	4.24×10^{-3}
10		0.123	4.24×10^{-3}
11		0.065	2.24×10^{-3}
12		0.065	2.24×10^{-3}
13		0.018	6.19×10^{-4}
14		0.008	2.75×10^{-4}
15		0.018	6.19×10^{-4}
16		0.025	8.60×10^{-4}
17		0.025	8.60×10^{-4}
18		0.018	6.19×10^{-4}
19		0.008	2.75×10^{-4}
20		0.018	6.19×10^{-4}
21		0.0232	6.12×10^{-4}
22		0.0232	6.12×10^{-4}
23		0.0232	6.32×10^{-4}
24		0.0232	6.47×10^{-4}
25		0.0264	9.08×10^{-4}
26		0.016	5.50×10^{-4}
27		0.0264	9.08×10^{-4}
28		0.025	8.60×10^{-4}
29		0.025	8.60×10^{-4}
30		0.016	5.50×10^{-4}
31		0.006	2.06×10^{-4}
32	RENE' 41	0.0312	1.075×10^{-3}

CAPACITORS (CONTINUED) - ANALYSIS A TEST 5.1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
33	RENE' 41	0.012	4.13×10^{-4}
34	RENE' 41	0.0344	1.182×10^{-3}
35	BLACK BODY	DRIVEN	--

CONDUCTION CONDUCTORS - ANALYSIS A TEST 5.1

CONDUCTOR	CONNECTING NODES	A/L	k CURVE ▷
1	4 - 5	2.45×10^{-3}	HS-25
2	9 - 10	1.695×10^{-3}	RENE' 41
3	11 - 12	3.21×10^{-3}	↓
4	13 - 14	1.428×10^{-2}	
5	13 - 16	2.14×10^{-2}	
6	14 - 15	1.428×10^{-2}	
9	15 - 17	2.14×10^{-2}	
10	16 - 18	2.14×10^{-2}	
13	17 - 20	2.14×10^{-2}	
14	18 - 19	1.428×10^{-2}	
15	19 - 20	1.428×10^{-2}	
16	21 - 24	1.721×10^{-2}	
17	21 - 22	1.721×10^{-2}	
18	22 - 23	1.721×10^{-2}	
19	23 - 24	1.721×10^{-2}	
20	25 - 26	2.600×10^{-2}	
21	25 - 28	2.070×10^{-2}	
22	26 - 27	2.600×10^{-2}	
25	27 - 29	2.070×10^{-2}	
26	28 - 30	1.932×10^{-2}	
27	29 - 30	1.932×10^{-2}	
28	31 - 32	1.075×10^{-2}	
29	32 - 33	1.942×10^{-2}	RENE' 41

▷ See Appendix for material property curves.

CONVECTION CONDUCTORS - ANALYSIS A TEST 5.1

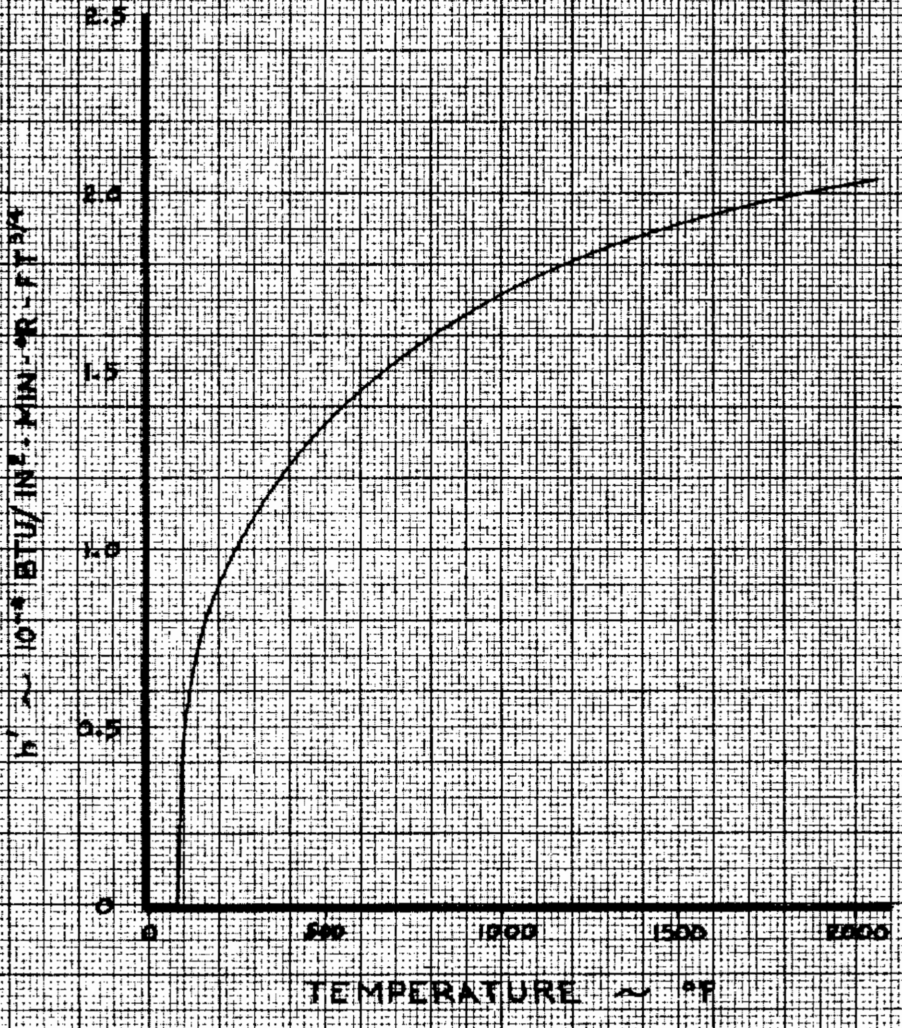
CONDUCTOR	CONNECTING NODES	A'	h'
30	9 - 35	15.60	
31	10 - 35	11.948	SEE
32	11 - 35	1.121	BELOW
33	12 - 35	1.100	

$$\dot{q} = hA(T_w-T_\infty) = h'A'(T_w-T_\infty)$$

$$h' = k_w\,(.378)\left[\frac{\cos 15^\circ\ g\ (T_w-T_\infty)}{T_\infty \nu_m^{2}}\right]^{1/4}$$

SEE PAGE 21
FOR CURVE

$$A' = \left(A/X^{1/4}\right)_{side} = (1/5)\left(A/2^{1/4}\right)_{top}$$



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RADIATION CONDUCTOR MATRIX

NODE (j)	NODE (i) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	-			48													-											-							
2		-			49											-																			
3			-			50																													
4	48			-			51	52	53	54	55	56			81		69	70	71	72		82	83	84	85	86	87	88	89	90	91	92	93		
5		49			-		57	58	59	60	61	62					73	74	75	76		94	95	96	97	98	99	100	101	102	103	104	105		
6			50			-	63	64	65	66	67	68					77	78	79	80		106	107	108	109			110		111					
7				51	57	63	-	112	113	114	115	116			117	118	119	120	121	122	123	184	125		126	127	128	129	130	131	132	133	134	135	326
8				52	58	64	112	-	146																136	137	138	139	140	141	142	143	144	145	
9				53	59	65	113	146	-	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	327
10				54	60	66	114		147	-	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	328
11				55	61	67	115		148	172	-		196	197	198	199	200	201	202	203	204	205			206	207	208				212		213		329
12				56	62	68	116		149	173		-	216	217	218	219	220			221	222	223			209	210	211				214		215		330
13									150	174	196	216	-	224	225	226	227	228	229	230															
14									151	175	197	217	224	-	231	232	233	234	235	236															
15				81			117		152	176	198	218	225	231	-		237	238	239	240	241	242	243	244	245	246	247				248		249		
16							118		153	177	199	219	226	232		-	250	251	252																
17				69	73	77	119		154	178	200	220	227	233	237	250	-		253	254	255	256			258	259	260				257				
18				70	74	78	120		155	179	201		228	234	238	251		-			270	271			261	262	263				276		277		
19				71	75	79	121		156	180	202		229	235	239	252	253		-		272	273			264	265	266				278		279		
20				72	76	80	122		157	181	203	221	230	236	240		254			-	274	275			267	268	269				280		281		
21							123		158	182	204	222			241		255	270	272	274	-	282	283	284											
22				82	94	106	124		159	183	205	223			242		256	271	273	275	282	-	285	286							287	288	289		
23				83	95	107	125		160	184					243						283	285	-	293	294	295	296	297	298		290	291	292		
24				84	96	108			161	185					244						284	286	293	-	299	300	301								
25				85	97	109	126	136	162	186	206	209			245		258	261	264	267			294	299	-			302			303	304	305		
26				86	98		127	137	163	187	207	210			246		259	262	265	268			295	300		-		306	307	308	309	310	311		
27				87	99		128	138	164	188	208	211			247		260	263	266	269			296	301			-		312	313	314	315	316		
28				88	100	110	129	139	165	189													297		302	306		-	317	318					
29				89	101		130	140	166	190													298			307	312	317	-	319	320	321	322		
30				90	102	111	131	141	167	191																308	313	318	319	-					
31				91	103		132	142	168	192	212	214			248		257	276	278	280		287	290		303	309	314		320		-	323	324		
32				92	104		133	143	169	193												288	291		304	310	315		321		323	-	325		
33				93	105		134	144	170	194	213	215			249			277	279	281		289	292		305	311	316		322		324	325	-		
34							135	145	171	195																								-	331
35							326		327	328	329	330																						331	-

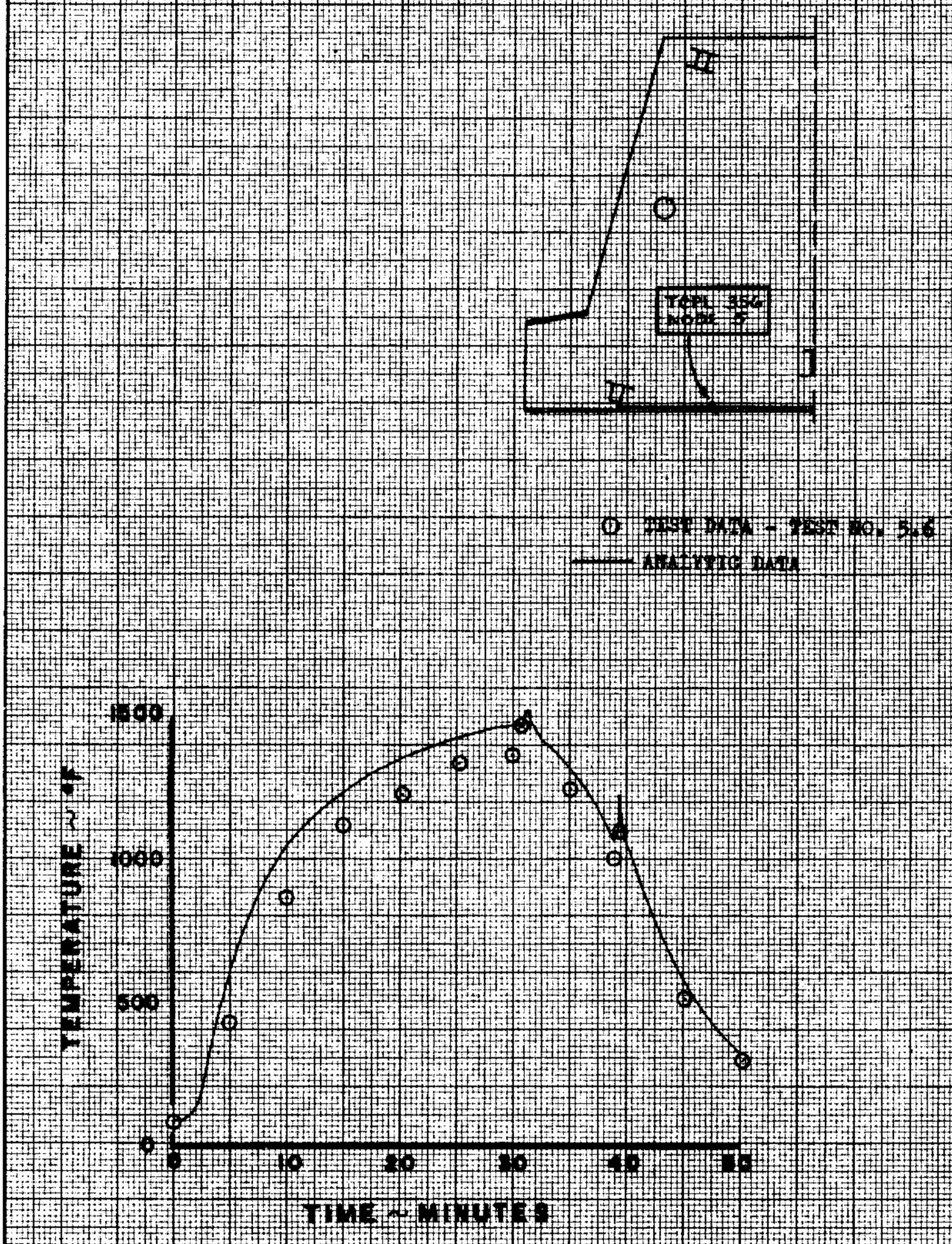
			REVISED	DATE		
CALC	Orend	3/31/65			HOT STRUCTURES THERMAL CORRELATION RADIATION CONDUCTOR MATRIX ANAKYSIS B - TEST 5.1	D2-90709 -1
CHECK						
APPR					THE BOEING COMPANY SEATTLE, WASHINGTON 98124	PAGE 30
APPR						

RADIATION CONDUCTORS - ANALYSIS A TEST 5.1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
48	6.80	98	0	148	.2266	198	.5192
49	6.80	99	.500	149	.563	199	.0914
50	6.25	100	0	150	.100	200	.0179
51	.1301	101	.861	151	0	201	.192
52	.2194	102	.318	152	.0072	202	0
53	1.664	103	.010	153	0	203	.125
54	1.109	104	.056	154	.093	204	.1304
55	.4924	105	.0025	155	.0572	205	.150
56	1.1425	106	.01114	156	.0894	206	.048
57	.0752	107	.1310	157	.0743	207	.0525
58	.433	108	.0391	158	.0162	208	.046
59	1.591	109	.240	159	.141	209	.0985
60	.937	110	.600	160	.290	210	.1164
61	.238	111	.417	161	.780	211	.1065
62	.985	112	1.1906	162	.1845	212	.0563
63	1.7476	113	.600	163	.205	213	.0253
64	1.802	114	.442	164	.2075	214	.1296
65	.240	115	.0589	165	0	215	.0828
66	.2122	116	.090	166	.0858	216	.0266
67	.1846	117	.0152	167	0	217	.0599
68	.305	118	0	168	.1632	218	.0831
69	0	119	.050	169	.122	219	0
70	.1181	120	.010	170	.1195	220	.1471
71	.1575	121	.010	171	.8911	221	.1326
72	.1197	122	.010	172	1.087	222	.1901
73	.0352	123	0	173	.395	223	.1319
74	.0841	124	.080	174	.281	224	.0014
75	.1276	125	.026	175	.025	225	.0010
76	.1077	126	.072	176	.025	226	.1828
77	.0256	127	.0202	177	.728	227	.0051
78	.0513	128	.0202	178	.1414	228	.1319
79	.0609	129	.508	179	.262	229	0
80	.0356	130	.031	180	.242	230	.0010
81	.1156	131	.020	181	.182	231	.0011
82	.1269	132	.020	182	.4468	232	.2896
83	.2274	133	.1082	183	.1655	233	.2552
84	0	134	.0064	184	0	234	0
85	.0027	135	0	185	.220	235	.2331
86	.0046	136	.130	186	.101	236	.0010
87	.0015	137	.1189	187	.112	237	.2413
88	0	138	.0989	188	.1051	238	0
89	.0342	139	.0475	189	0	239	0
90	0	140	.0064	190	.0365	240	.1481
91	.271	141	0	191	0	241	.00176
92	.310	142	.0127	192	.1324	242	.0038
93	.5622	143	.0492	193	0	243	0
94	.0681	144	.0128	194	.060	244	0
95	.240	145	4.300	195	.1376	245	.0034
96	.0076	146	.300	196	.4978	246	.0037
97	0	147	.987	197	.6889	247	.0034

RADIATION CONDUCTORS - ANALYSIS A TEST 5.1 (CONTINUED)

COND. NO.	AF	COND. NO.	AF
248	.013	298	.0027
249	.0058	299	.0050
250	.6751	300	.0038
251	.2478	301	.0023
252	.2854	302	.2539
253	.270	303	.0001
254	.2218	304	.0067
255	.0093	305	.0002
256	.01732	306	.2769
257	.003	307	.2542
258	.0066	308	.1970
259	.0065	309	.0002
260	.0058	310	.0088
261	.0087	311	.0002
262	.0032	312	.2264
263	.0029	313	0
264	.0168	314	.0003
265	.0172	315	.0064
266	.0159	316	.0001
267	.0124	317	.6588
268	.0129	318	.2336
269	.0078	319	.2562
270	.1259	320	.0019
271	.0026	321	.0423
272	.0016	322	.0001
273	.0044	323	.2281
274	.0305	324	.1863
275	.0102	325	.2772
276	.0122	326	5.69
277	.0065	327	8.959
278	.0165	328	9.7124
279	.0082	329	5.2
280	.0125	330	5.2
281	.0053	331	3.271
282	.2798		
283	.4315		
284	.2793		
285	.2798		
286	.3615		
287	.017		
288	.0134		
289	.0110		
290	.0215		
291	.0083		
292	.0154		
293	.2793		
294	.0312		
295	.0426		
296	.03		
297	0		



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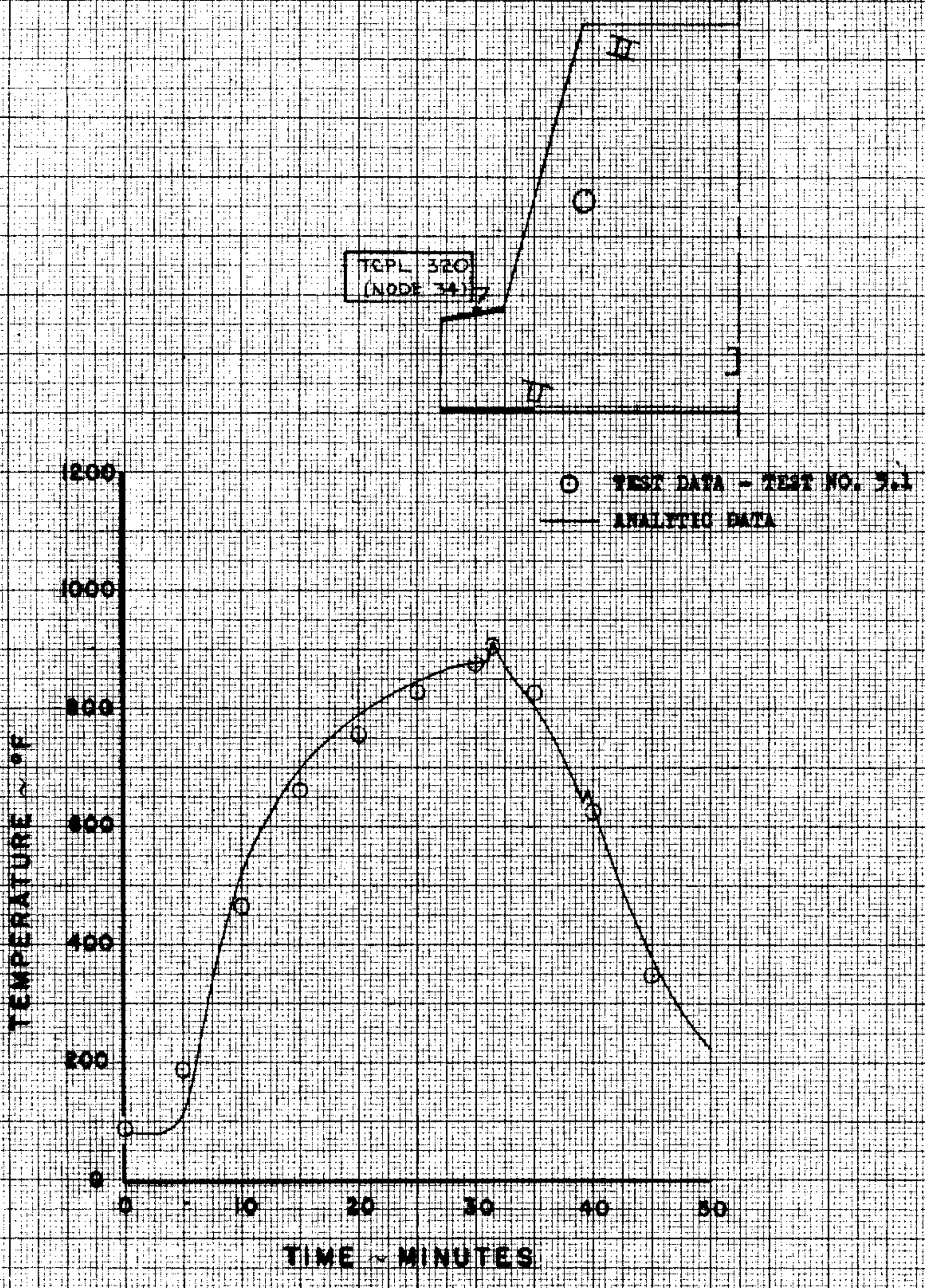
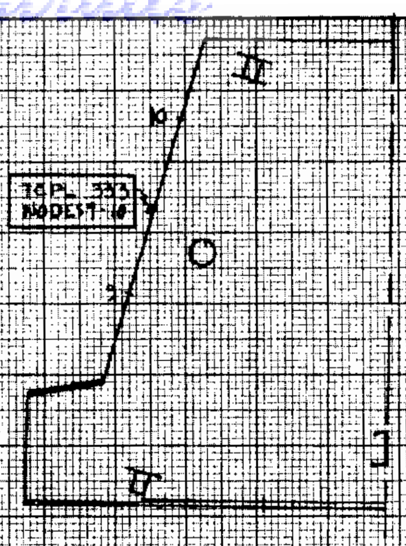
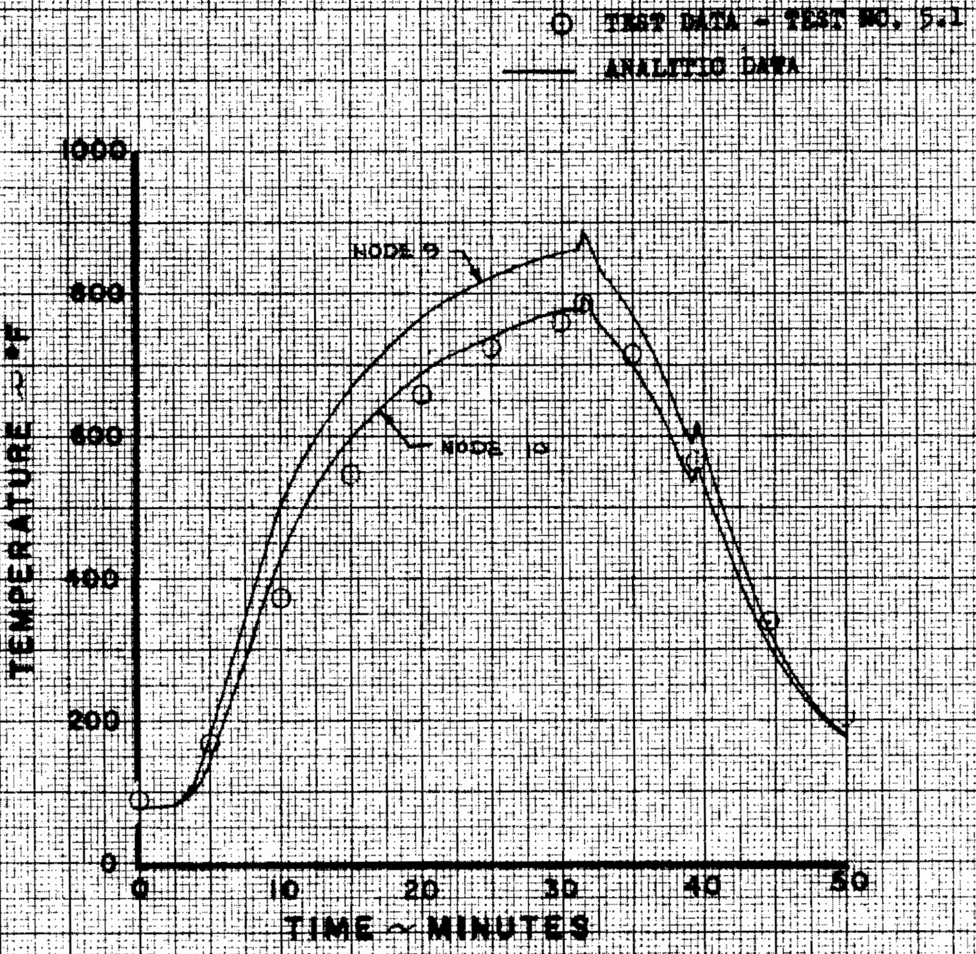
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A
FORWARD BODY

THE BOEING COMPANY



CALC	Arend	3/16/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS A FORWARD BODY	D2-90709 -1
CHECK						
APR					THE BOEING COMPANY	PAGE 36
APR						





			REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS A FORWARD BODY	D2-90709 -1
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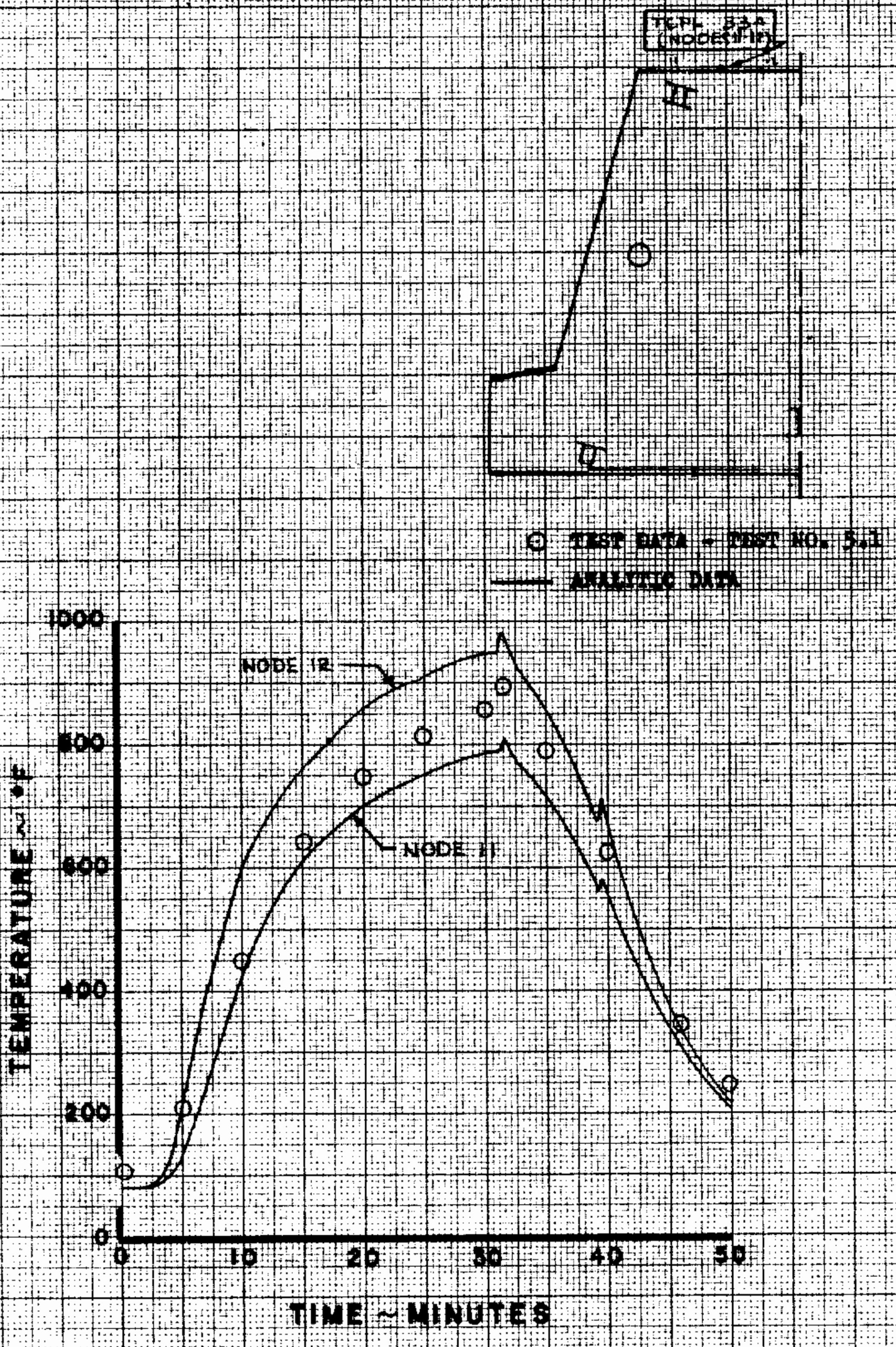
APR						



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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A
FORWARD BODY

THE BOEING COMPANY

D2-90709
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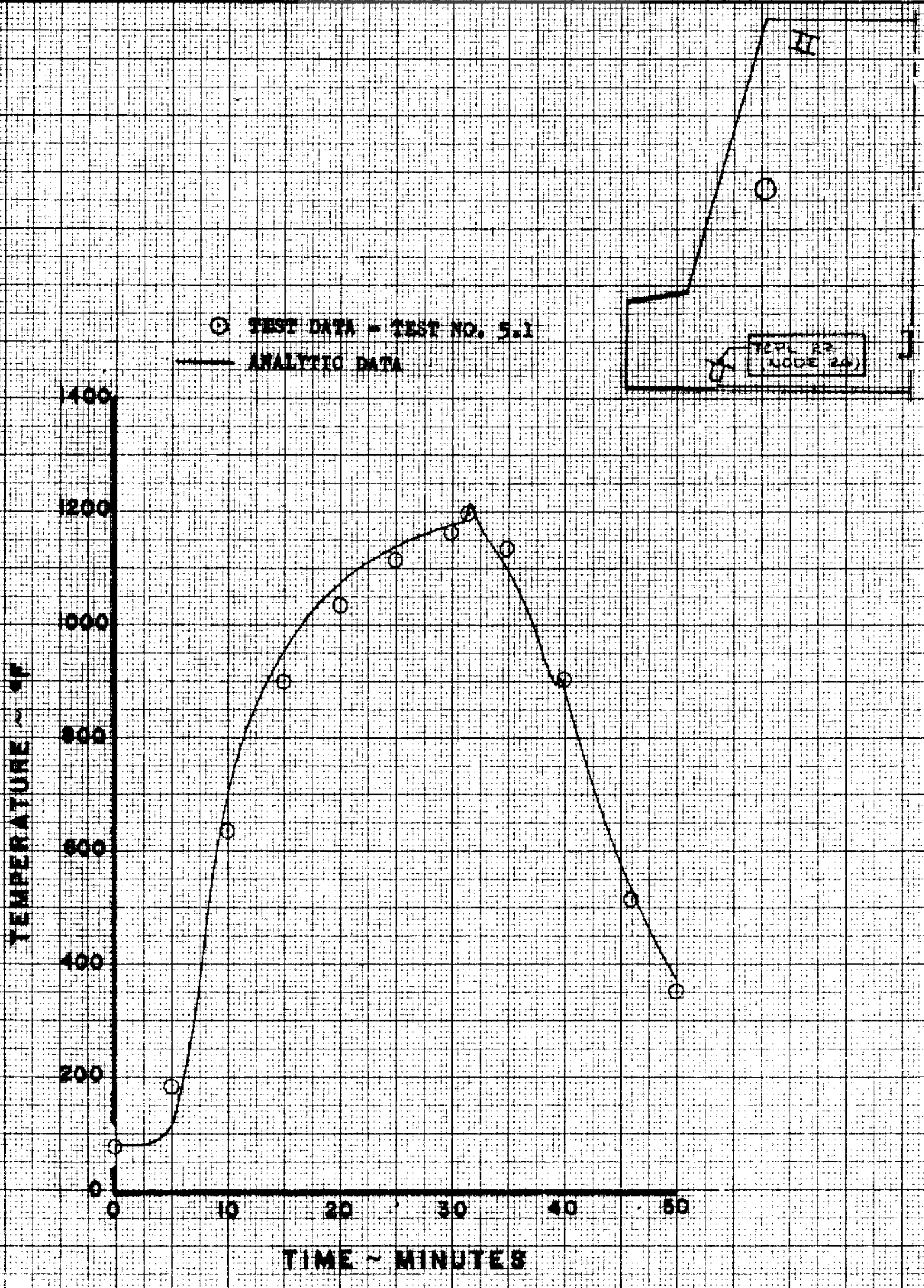
PAGE



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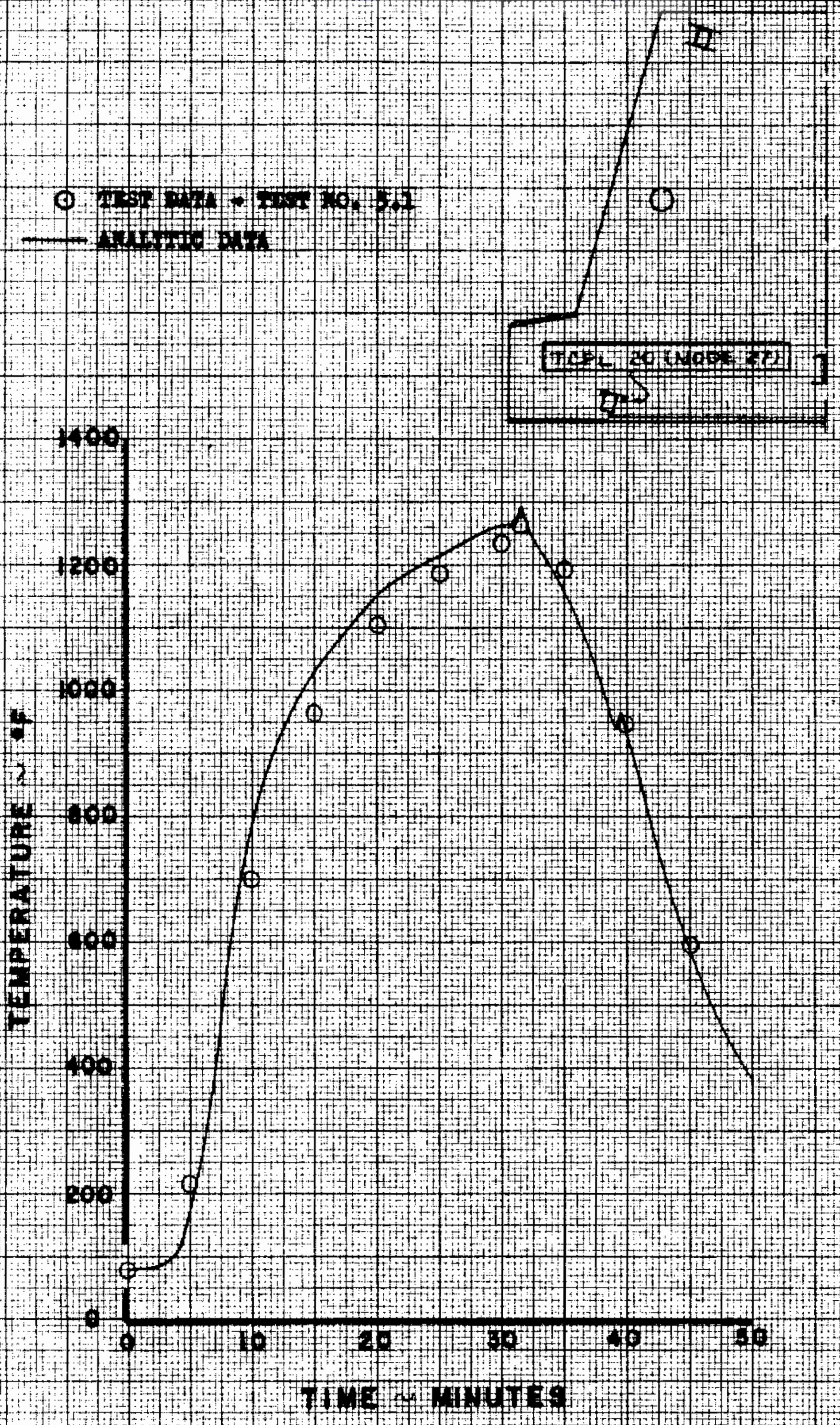
APR					THE BOEING COMPANY



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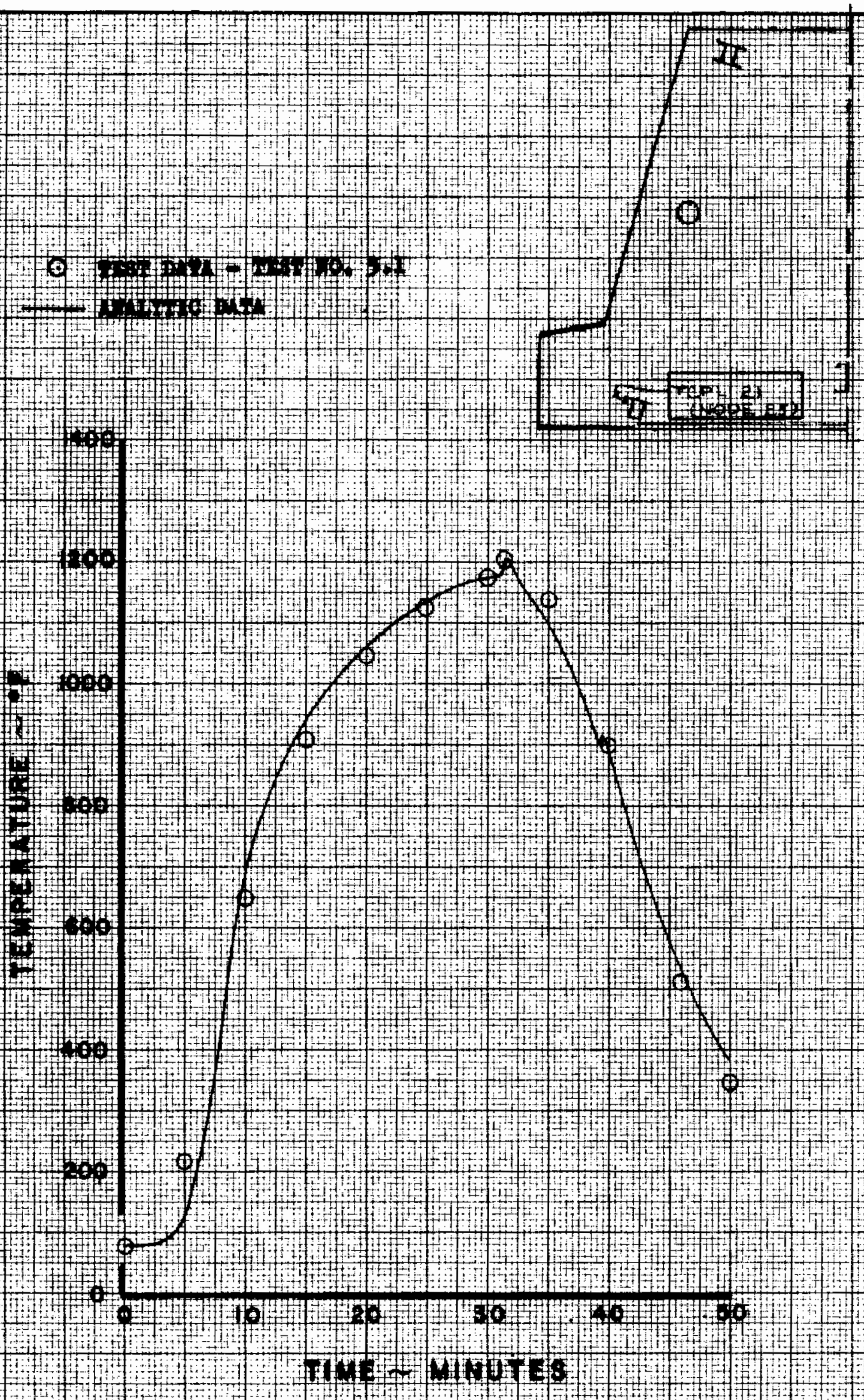
					THE BOEING COMPANY	PAGE 30



CALC	Drench	3/16/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS A FORWARD BODY
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APR					THE BOEING COMPANY

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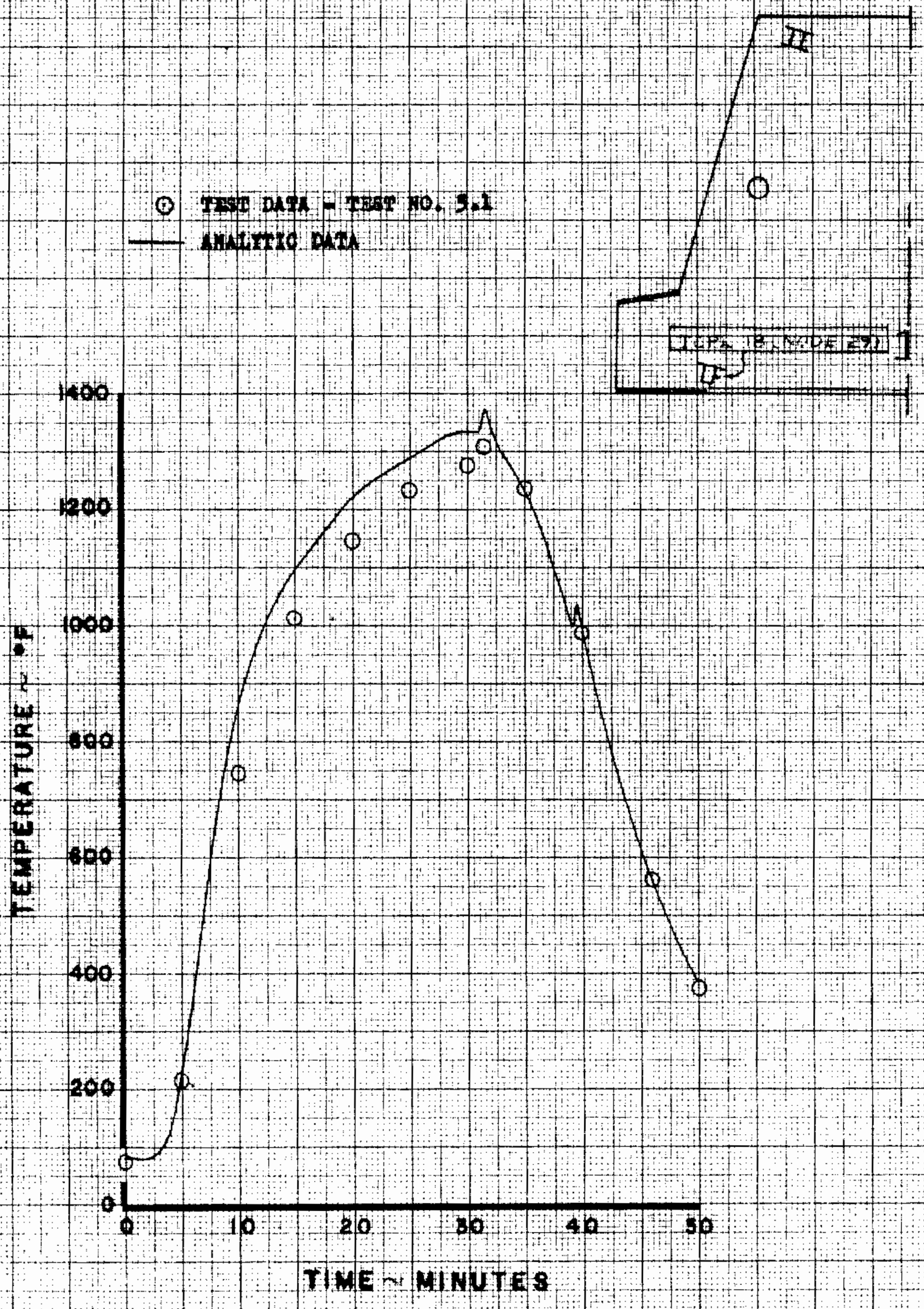

CALC	Drench	3/16/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS A FORWARD BODY	D2-90709 -1
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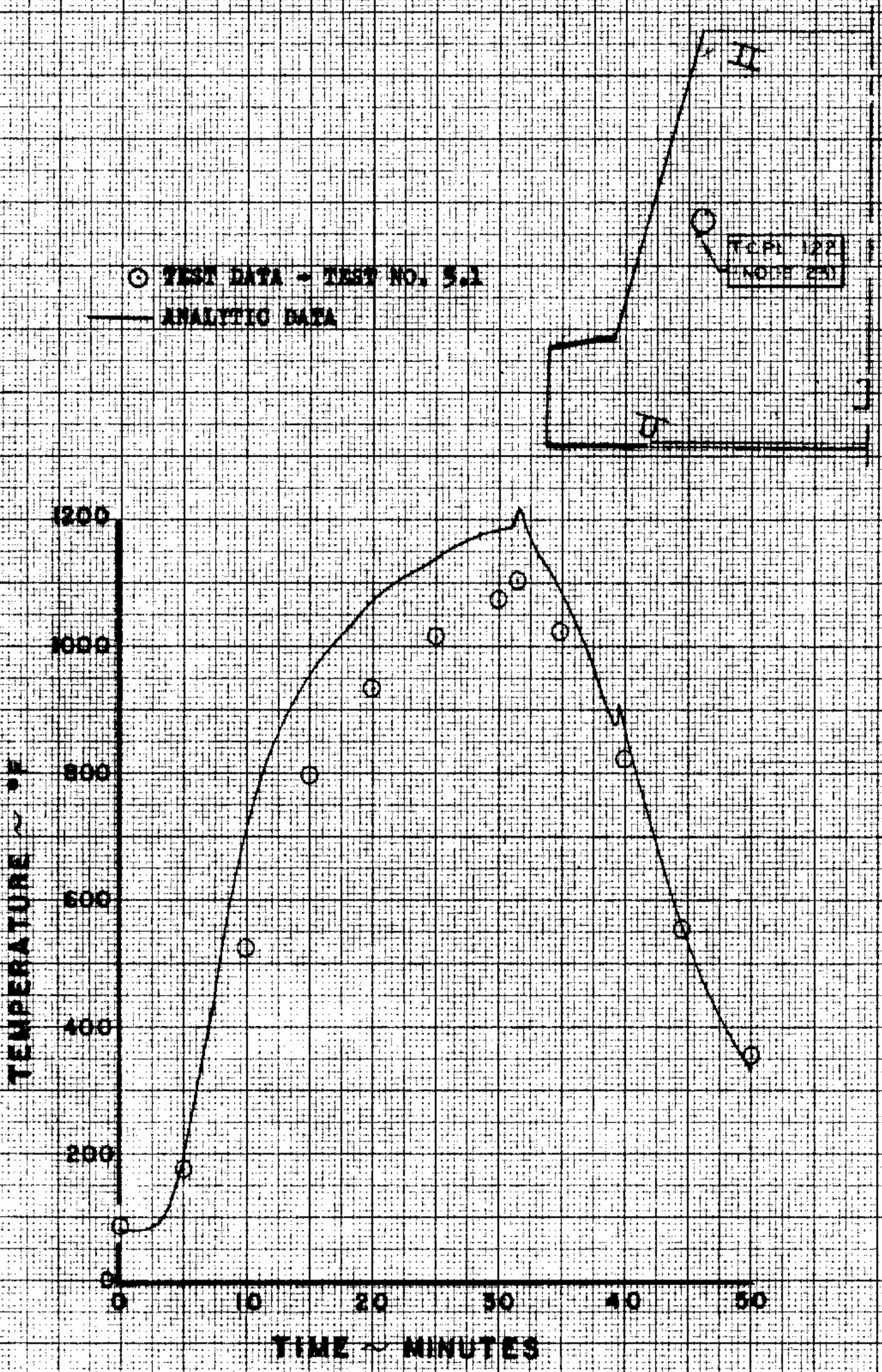
APR					THE BOEING COMPANY	PAGE



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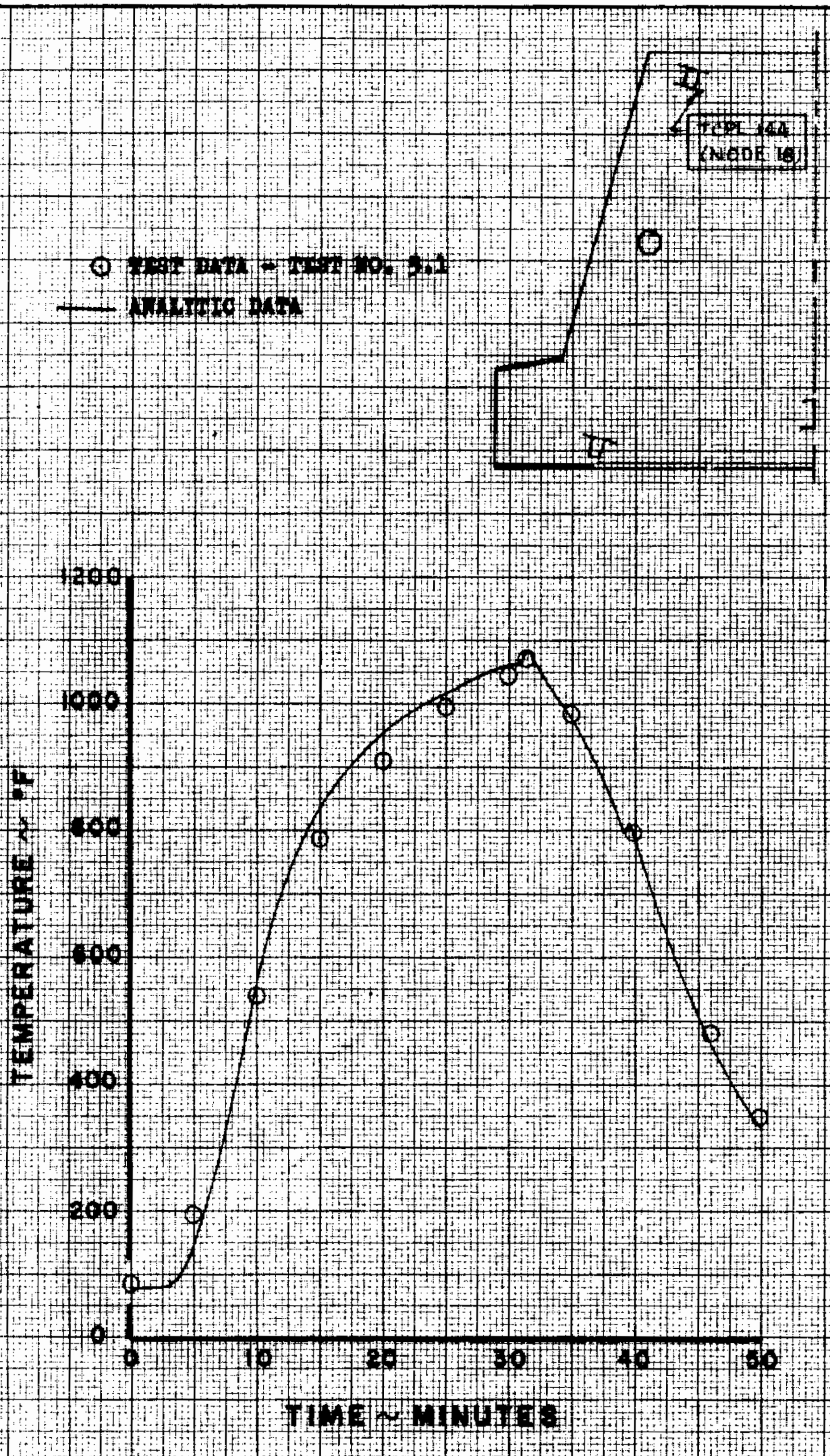

CALC		3/16/65	REVISED	DATE
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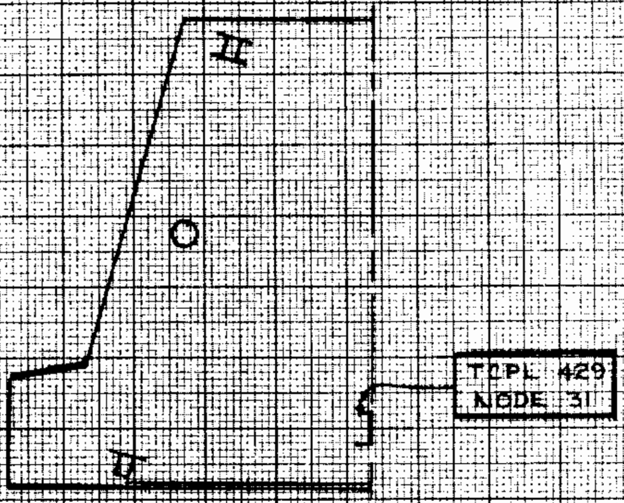
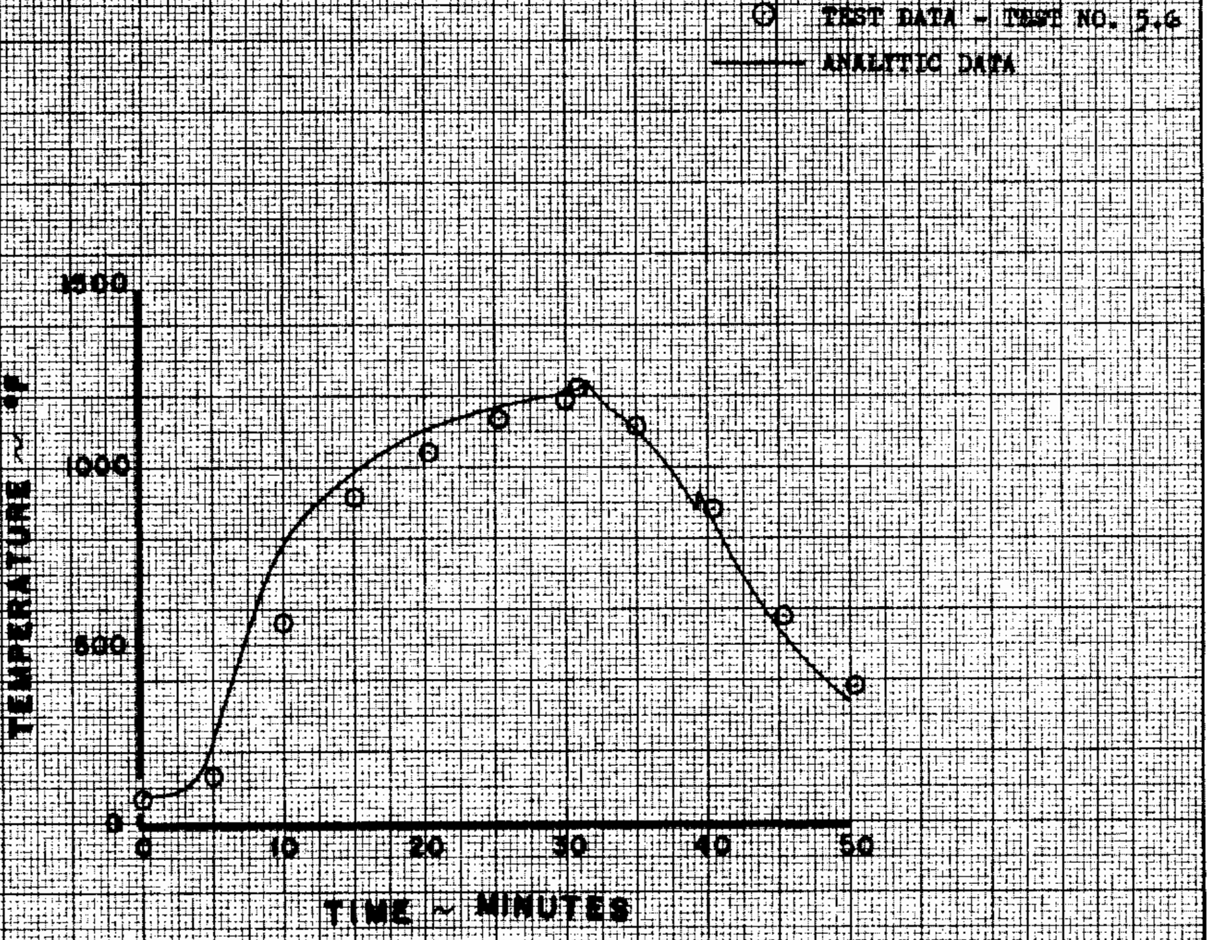
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A
FORWARD BODY

THE BOEING COMPANY





CALC		3/16/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS A FORWARD BODY	D2-90709 -1
CHECK						
APR					THE BOEING COMPANY	PAGE 35
APR						

4.2.2.2 ANALYSIS A CORRELATION

FORWARD BODY TWO-DIMENSIONAL ANALYSIS

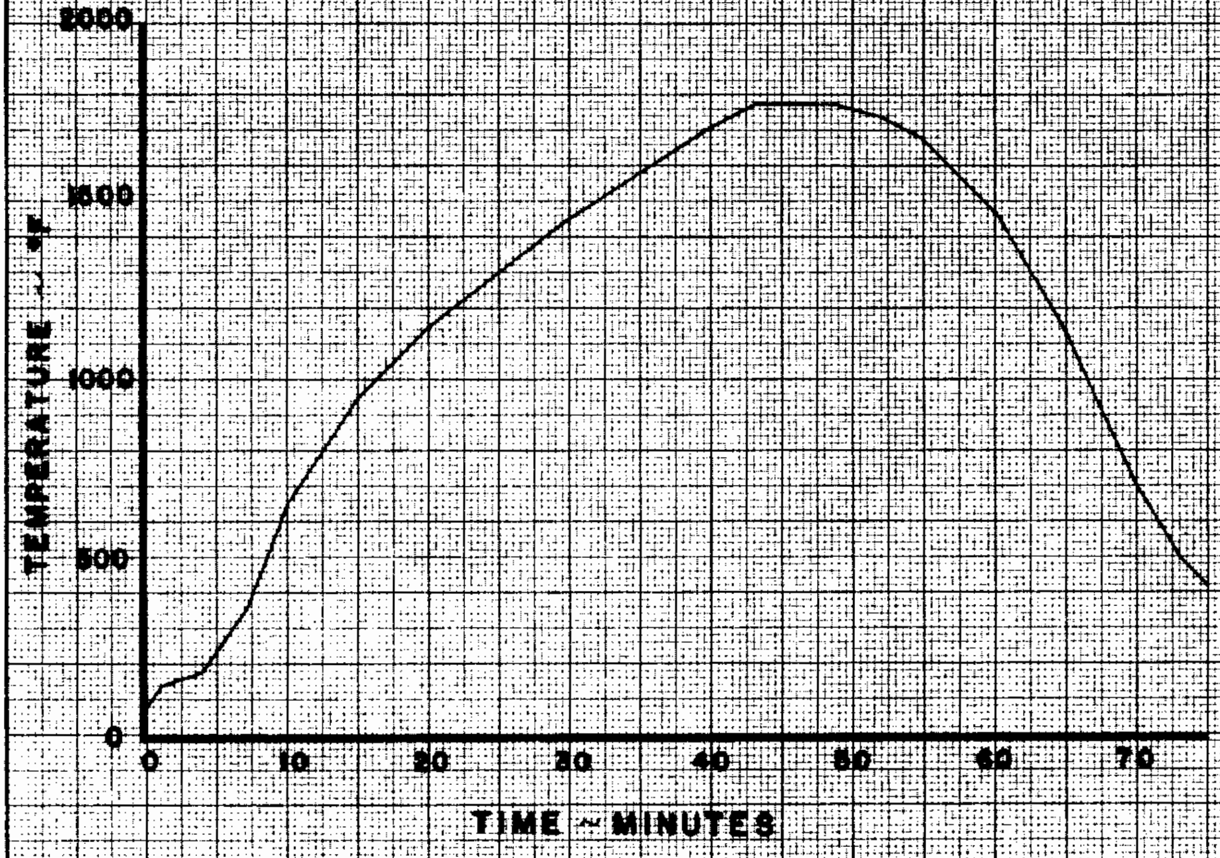
TEST SERIES: B-1

BOUNDARY NODES	SOURCE	PAGE
1	CONTROL AREA 62 TEST B-1	37
2	CONTROL AREA 62 TEST B-1	37
3	CONTROL AREA 64 TEST B-1	38
35	ROOM TEMPERATURE	

CONTROL AREA 62 TEST B-1

DRIVE BOUNDARY NODES:

1 & 2 ANALYSIS A TEST B-1
1, 2, & 3 ANALYSIS B TEST B-1
1, 2, 3, & 4 ANALYSIS D TEST B-1



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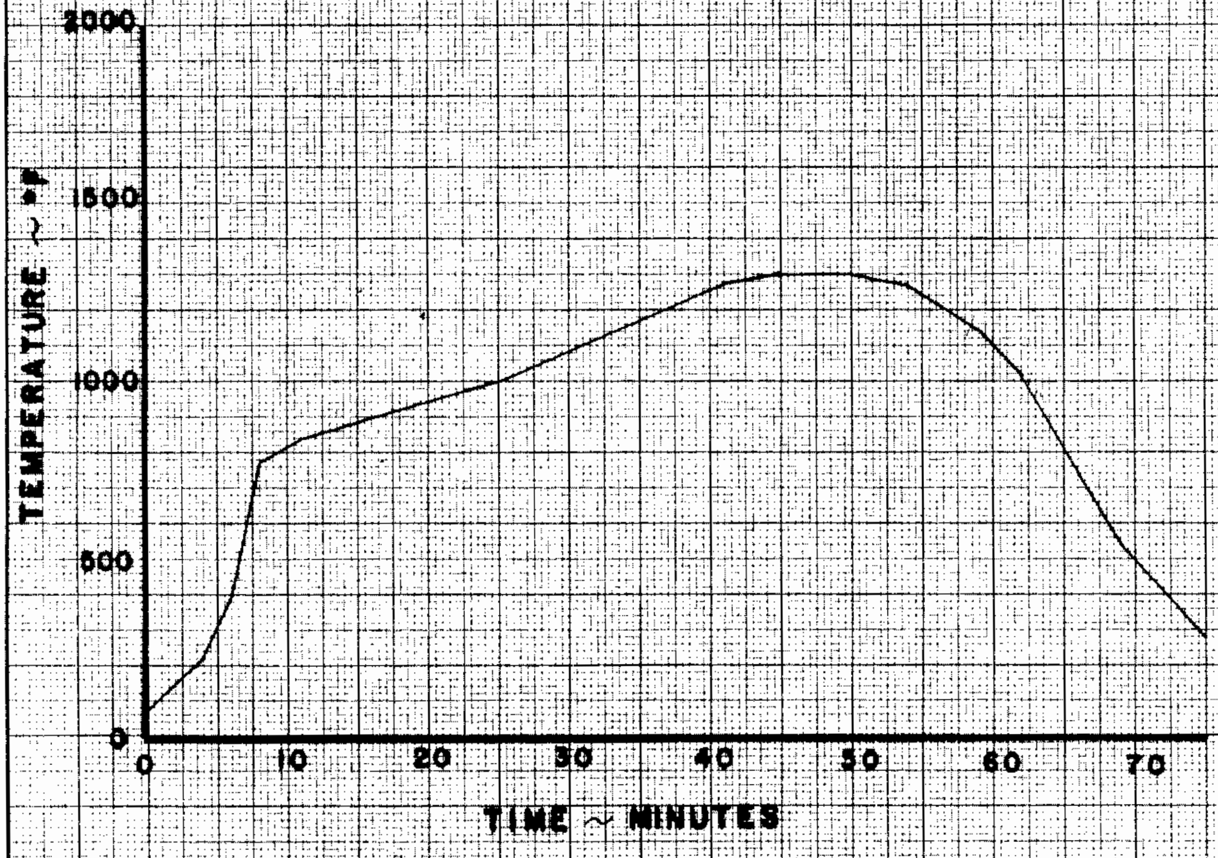
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 37

CONTROL AREA 64 TEST B-1

DRIVE BOUNDARY NODES:

3 ANALYSIS A TEST B-1
4, 5, 6 & 7 ANALYSIS B TEST B-1
5 ANALYSIS D TEST B-1



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ANALYSIS A

2-DIMENSIONAL FWD. BODY

NODAL DIAGRAM

DRIVEN NODES:
1
2
3
35

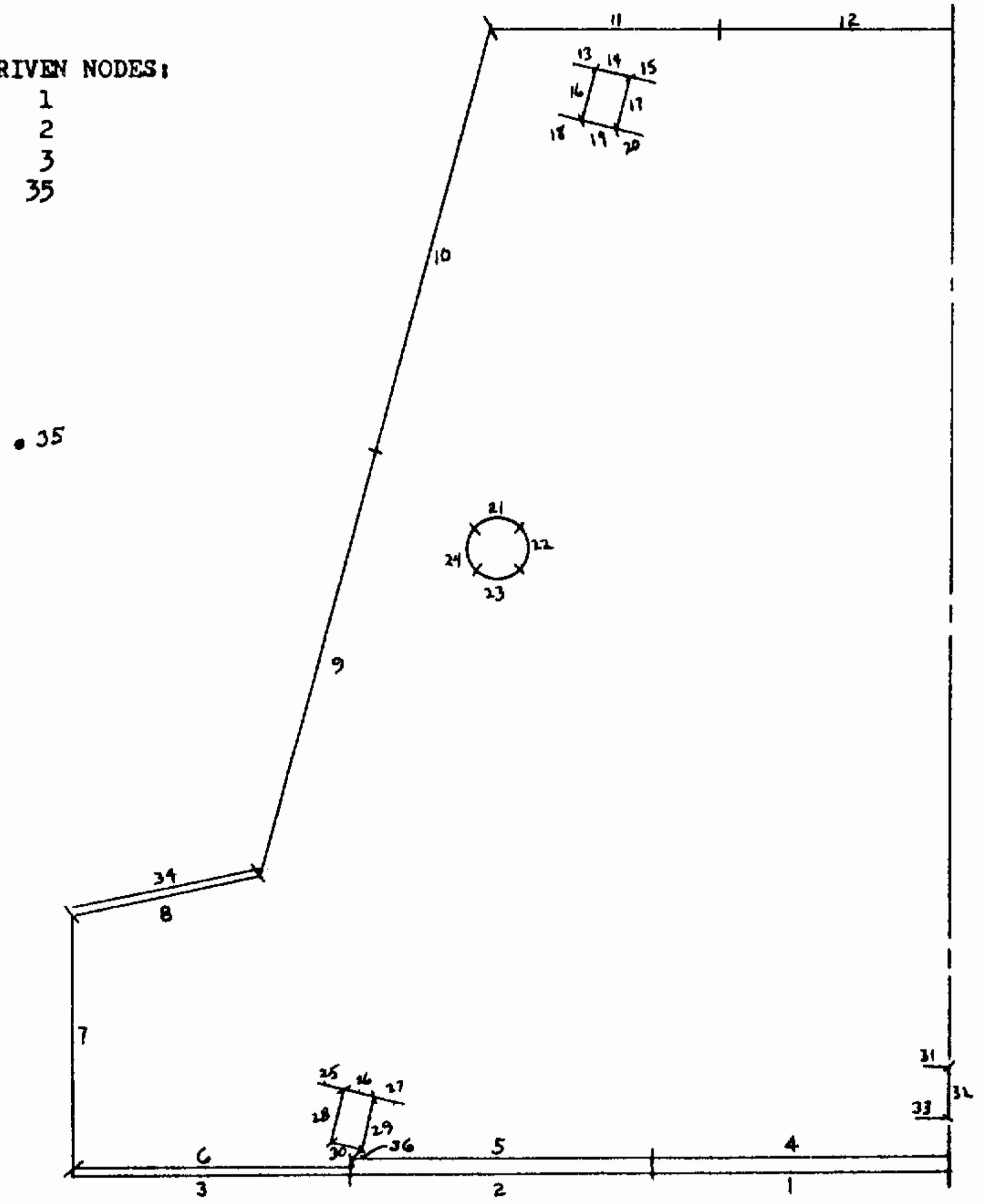

FIGURE 4

CAPACITORS - ANALYSIS A TEST B-1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	HS-25	DRIVEN	--
2		DRIVEN	--
3		DRIVEN	--
4		0.109	3.52×10^{-3}
5		0.109	3.52×10^{-3}
6	HS-25	0.0781	2.42×10^{-3}
7	RENE' 41	0.0711	2.45×10^{-3}
8		0.0537	1.849×10^{-3}
9		0.123	4.24×10^{-3}
10		0.123	4.24×10^{-3}
11		0.065	2.24×10^{-3}
12		0.065	2.24×10^{-3}
13		0.018	6.19×10^{-4}
14		0.008	2.75×10^{-4}
15		0.018	6.19×10^{-4}
16		0.025	8.60×10^{-4}
17		0.025	8.60×10^{-4}
18		0.018	6.19×10^{-4}
19		0.008	2.75×10^{-4}
20		0.018	6.19×10^{-4}
21		0.0232	7.99×10^{-4}
22		0.0232	7.99×10^{-4}
23		0.0232	7.99×10^{-4}
24		0.0232	7.99×10^{-4}
25		0.0264	9.08×10^{-4}
26		0.016	5.50×10^{-4}
27		0.0264	9.08×10^{-4}
28		0.025	8.60×10^{-4}
29		0.025	8.60×10^{-4}
30		0.016	5.50×10^{-4}
31		0.006	2.06×10^{-4}
32	RENE' 41	0.0312	1.075×10^{-3}

CAPACITORS (CONTINUED) - ANALYSIS A TEST B-1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
33	RENE' 41	0.012	4.13×10^{-4}
34	RENE' 41	0.0344	1.182×10^{-3}
35	BLACK BODY	DRIVEN	--
36	RENE' 41	0.225	$.774 \times 10^{-3}$

CONDUCTION CONDUCTORS - ANALYSIS A TEST B-1

CONDUCTOR	CONNECTING NODES	A/L	k CURVE
1	4 - 5	2.45×10^{-3}	HS-25
2	9 - 10	1.695×10^{-3}	RENE' 41
3	11 - 12	3.21×10^{-3}	
4	13 - 14	1.428×10^{-2}	
5	13 - 16	2.14×10^{-2}	
6	14 - 15	1.428×10^{-2}	
9	15 - 17	2.14×10^{-2}	
10	16 - 18	2.14×10^{-2}	
13	17 - 20	2.14×10^{-2}	
14	18 - 19	1.428×10^{-2}	
15	19 - 20	1.428×10^{-2}	
16	21 - 24	1.721×10^{-2}	
17	21.- 22	1.721×10^{-2}	
18	22 - 23	1.721×10^{-2}	
19	23 - 24	1.721×10^{-2}	
20	25 - 26	2.600×10^{-2}	
21	25 - 28	2.070×10^{-2}	
22	26 - 27	2.600×10^{-2}	
25	27 - 29	2.070×10^{-2}	
26	28 - 30	1.932×10^{-2}	
27	29 - 30	1.932×10^{-2}	
28	31 - 32	1.075×10^{-2}	
29	32 - 33	1.942×10^{-2}	RENE' 41

CONVECTION CONDUCTORS - ANALYSIS A TEST B-1

CONDUCTOR	CONNECTING NODES	A'	h'
30	9 - 35	15.60	
31	10 - 35	11.948	SEE BELOW
32	11 - 35	1.121	
33	12 - 35	1.100	

$$\dot{q}_x = hA(T_w - T_\infty) = h'A'(T_w - T_\infty)$$

$$h' = k_w\,(.378)\left[\frac{\cos 15^\circ\ g\ (T_w - T_\infty)}{T_\infty \nu_m^{\,2}}\right]^{1/4}$$

SEE PAGE 21
FOR CURVE

$$A' = (A/X^{1/4})_{side} = (1/50)(A/2^{1/4})_{top}$$

RADIATION CONDUCTOR MATRIX

NODE (j)	NODE (i)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	-			48												-	-											-	-							
2		-			49											-	-											-	-							
3			-			50																														
4	48			-			51	52	53	54	55	56			81		69	70	71	72		82	83	84	85	86	87	88	89	90	91	92	93			
5		49			-		57	58	59	60	61	62					73	74	75	76		94	95	96	97	98	99	100	101	102	103	104	105			332
6			50			-	63	64	65	66	67	68					77	78	79	80		106	107	108	109			110		111						333
7				51	57	63	-	112	113	114	115	116			117	118	119	120	121	122	123	124	125		126	127	128	129	130	131	132	133	134	135	326	334
8				52	58	64	112	-	146																136	137	138	139	140	141	142	143	144	145		
9				53	59	65	113	146	-	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	327	
10				54	60	66	114		147	-	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	328	
11				55	61	67	115		148	172	-		196	197	198	199	200	201	202	203	204	205			206	207	208				212		213		329	
12				56	62	68	116		149	173		-	216	217	218	219	220			221	222	223			209	210	211				214		215		330	
13									150	174	196	216	-	224	225	226	227	228	229	230																
14									151	175	197	217	224	-	231	232	233	234	235	236																
15				81			117		152	176	198	218	225	231	-		237	238	239	240	241	242	243	244	245	246	247				248		249			
16							118		153	177	199	219	226	232		-	250	251	252																	
17				69	73	77	119		154	178	200	220	227	233	237	250	-		253	254	255	256			258	259	260				257					
18				70	74	78	120		155	179	201		228	234	238	251		-			270	271			261	262	263				276		277			
19				71	75	79	121		156	180	202		229	235	239	252	253		-		272	273			264	265	266				278		279			
20				72	76	80	122		157	181	203	221	230	236	240		254			-	274	275			267	268	269				280		281			
21							123		158	182	204	222			241		255	270	272	274	-	282	283	284												
22				82	94	106	124		159	183	205	223			242		256	271	273	275	282	-	285	286							287	288	289			
23				83	95	107	125		160	184					243						283	285	-	293	294	295	296	297	298		290	291	292			
24				84	96	108			161	185					244						284	286	293	-	299	300	301									
25				85	97	109	126	136	162	186	206	209			245		258	261	264	267			294	299	-			302			303	304	305			
26				86	98		127	137	163	187	207	210			246		259	262	265	268			295	300		-		306	307	308	309	310	311			
27				87	99		128	138	164	188	208	211			247		260	263	266	269			296	301			-		312	313	314	315	316			
28				88	100	110	129	139	165	189													297		302	306		-	317	318						
29				89	101		130	140	166	190													298			307	312	317	-	319	320	321	322			
30				90	102	111	131	141	167	191				-												308	313	318	319	-						335
31				91	103		132	142	168	192	212	214			248		257	276	278	280		287	290		303	309	314		320		-	323	324			
32				92	104		133	143	169	193												288	291		304	310	315		321		323	-	325			
33				93	105		134	144	170	194	213	215			249			277	279	281		289	292		305	311	316		322		324	325	-			
34							135	145	171	195																								-	331	
35							326		327	328	329	330																						331	-	
36					332	333	334																							335						-

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HOT STRUCTURES THERMAL CORRELATION
RADIATION CONDUCTOR MATRIX
ANALYSIS A - TEST B-1

D2-90709
-1

THE BOEING COMPANY
SEATTLE, WASHINGTON 98124

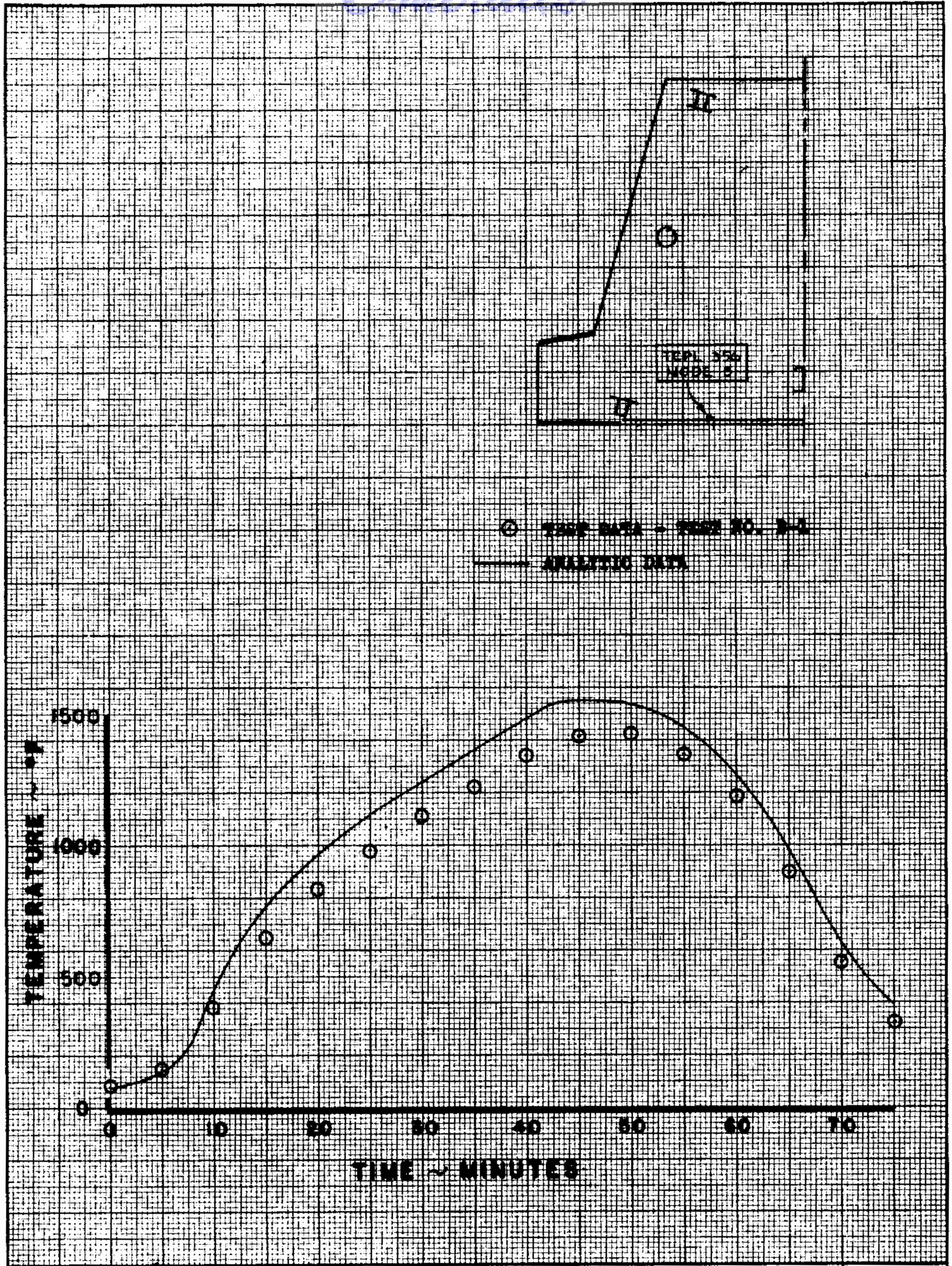
PAGE
44

RADIATION CONDUCTORS - ANALYSIS A TEST B-1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
48	6.80	98	0	148	.2266	198	.5192
49	6.80	99	.500	149	.563	199	.0914
50	6.25	100	0.	150	.100	200	.0179
51	.1301	101	.861	151	0	201	.192
52	.2194	102	0	152	.0072	202	0
53	1.664	103	.010	153	0	203	.125
54	1.109	104	.056	154	.093	204	.1304
55	.4924	105	.0025	155	.0572	205	.150
56	1.1425	106	.01114	156	.0894	206	.048
57	.0752	107	.1310	157	.0743	207	.0525
58	.433	108	.0391	158	.0162	208	.046
59	1.591	109	.240	159	.141	209	.0985
60	.937	110	.600	160	.290	210	.1164
61	.238	111	.417	161	.780	211	.1065
62	.985	112	1.1906	162	.1845	212	.0563
63	1.7476	113	.600	163	.205	213	.0253
64	1.802	114	.442	164	.2075	214	.1296
65	.240	115	.0589	165	0	215	.0828
66	.2122	116	.090	166	.0858	216	.0266
67	.1846	117	.0152	167	0	217	.0599
68	.305	118	0	168	.1632	218	.0831
69	0	119	.050	169	.122	219	0
70	.1181	120	.010	170	.1195	220	.1471
71	.1575	121	.010	171	.8911	221	.1326
72	.1197	122	.010	172	1.087	222	.1901
73	.0352	123	0	173	.395	223	.1319
74	.0841	124	.080	174	.281	224	.0014
75	.1276	125	.026	175	.025	225	.0010
76	.1077	126	.072	176	.025	226	.1828
77	.0256	127	.0202	177	.728	227	.0051
78	.0513	128	.0202	178	.1414	228	.1319
79	.0609	129	.508	179	.262	229	0
80	.0356	130	.031	180	.242	230	.0010
81	.1156	131	.020	181	.182	231	.0011
82	.1269	132	.020	182	.4468	232	.2896
83	.2274	133	.1082	183	.1655	233	.2552
84	0	134	.0064	184	0	234	0
85	.0027	135	0	185	.220	235	.2331
86	.0046	136	.130	186	.101	236	.0010
87	.0015	137	.1189	187	.112	237	.2413
88	0	138	.0989	188	.1051	238	0
89	.0342	139	.0475	189	0	239	0
90	0	140	.0064	190	.0365	240	.1481
91	.271	141	0	191	0	241	.00176
92	.310	142	.0127	192	.1324	242	.0038
93	.5622	143	.0492	193	0	243	0
94	.0681	144	.0128	194	.060	244	0
95	.240	145	4.300	195	.1376	245	.0034
96	.0076	146	.300	196	.4978	246	.0037
97	0	147	.987	197	.6889	247	.0034

RADIATION CONDUCTORS - ANALYSIS A TEST B-1 (CONTINUED)

COND. NO.	AF	COND. NO.	AF
248	.013	298	.0027
249	.0058	299	.0050
250	.6751	300	.0038
251	.2478	301	.0023
252	.2854	302	.247
253	.270	303	.0001
254	.2218	304	.0067
255	.0093	305	.0002
256	.01732	306	.2769
257	.003	307	.2769
258	.0066	308	.2268
259	.0065	309	.0002
260	.0058	310	.0088
261	.0087	311	.0002
262	.0032	312	.247
263	.0029	313	0
264	.0168	314	.0003
265	.0172	315	.0064
266	.0159	316	.0001
267	.0124	317	.6859
268	.0129	318	.2768
269	.0078	319	.2768
270	.1259	320	.0019
271	.0026	321	.0423
272	.0016	322	.0001
273	.0044	323	.2281
274	.0305	324	.1863
275	.0102	325	.2772
276	.0122	326	5.69
277	.0065	327	8.959
278	.0165	328	9.7124
279	.0082	329	5.2
280	.0125	330	5.2
281	.0053	331	3.271
282	.3022	332	.300
283	.4278	333	.1488
284	.3022	334	.135
285	.3022	335	.3238
286	.4278		
287	.017		
288	.0134		
289	.0110		
290	.0215		
291	.0083		
292	.0154		
293	.3022		
294	.0312		
295	.0426		
296	.03		
297	0		



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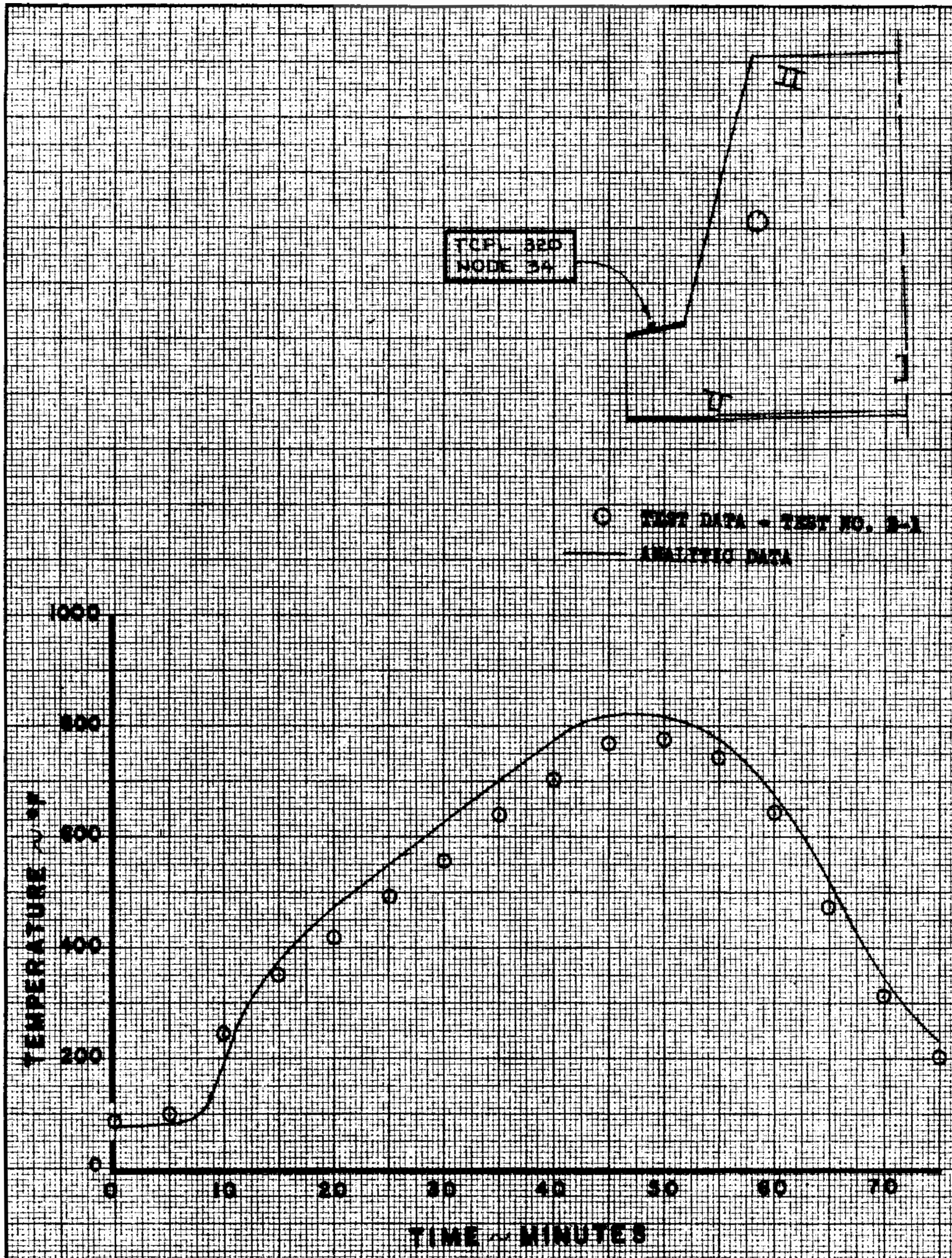
APR					PAGE 47



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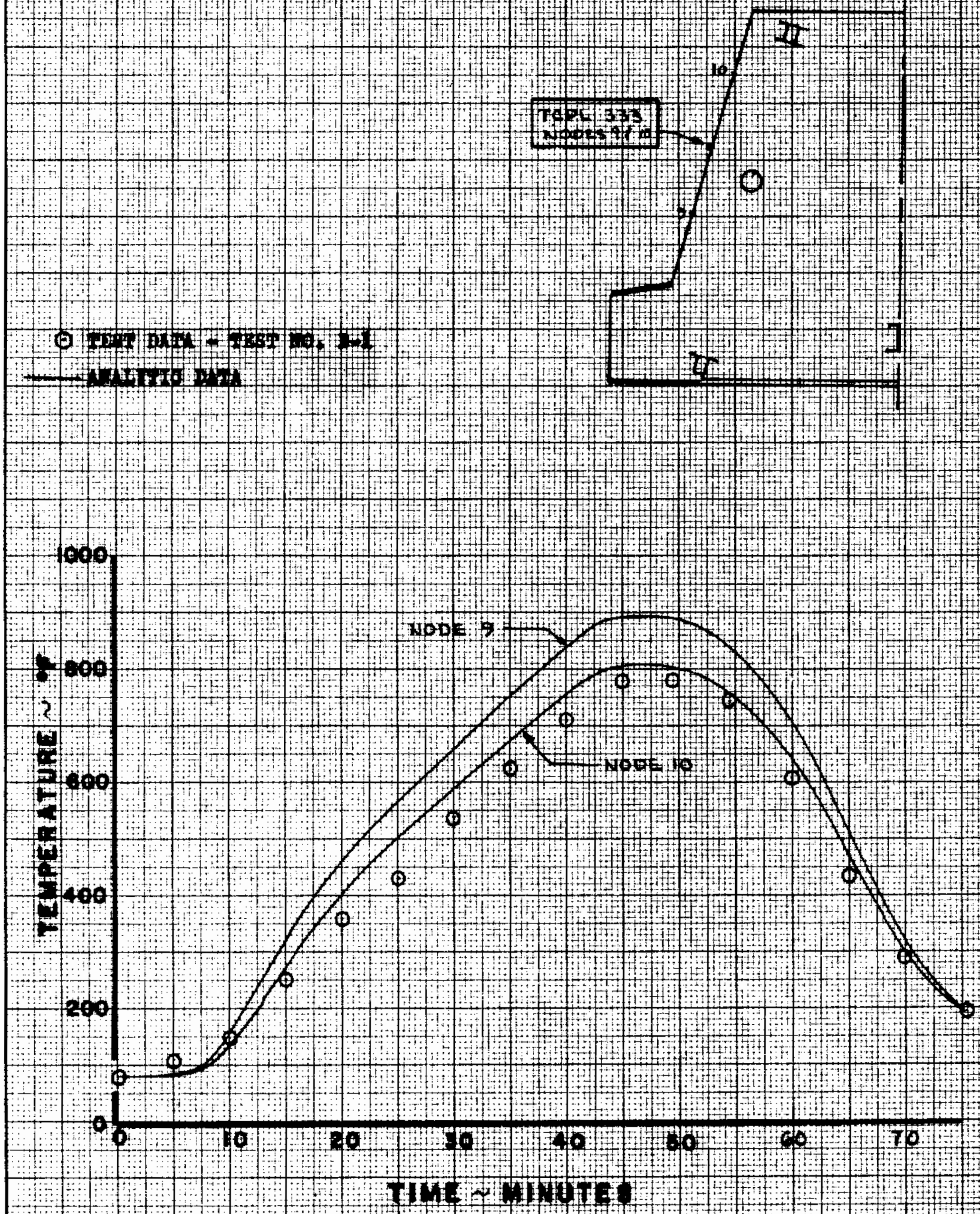

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A - B1
FORWARD BODY

THE BOEING COMPANY

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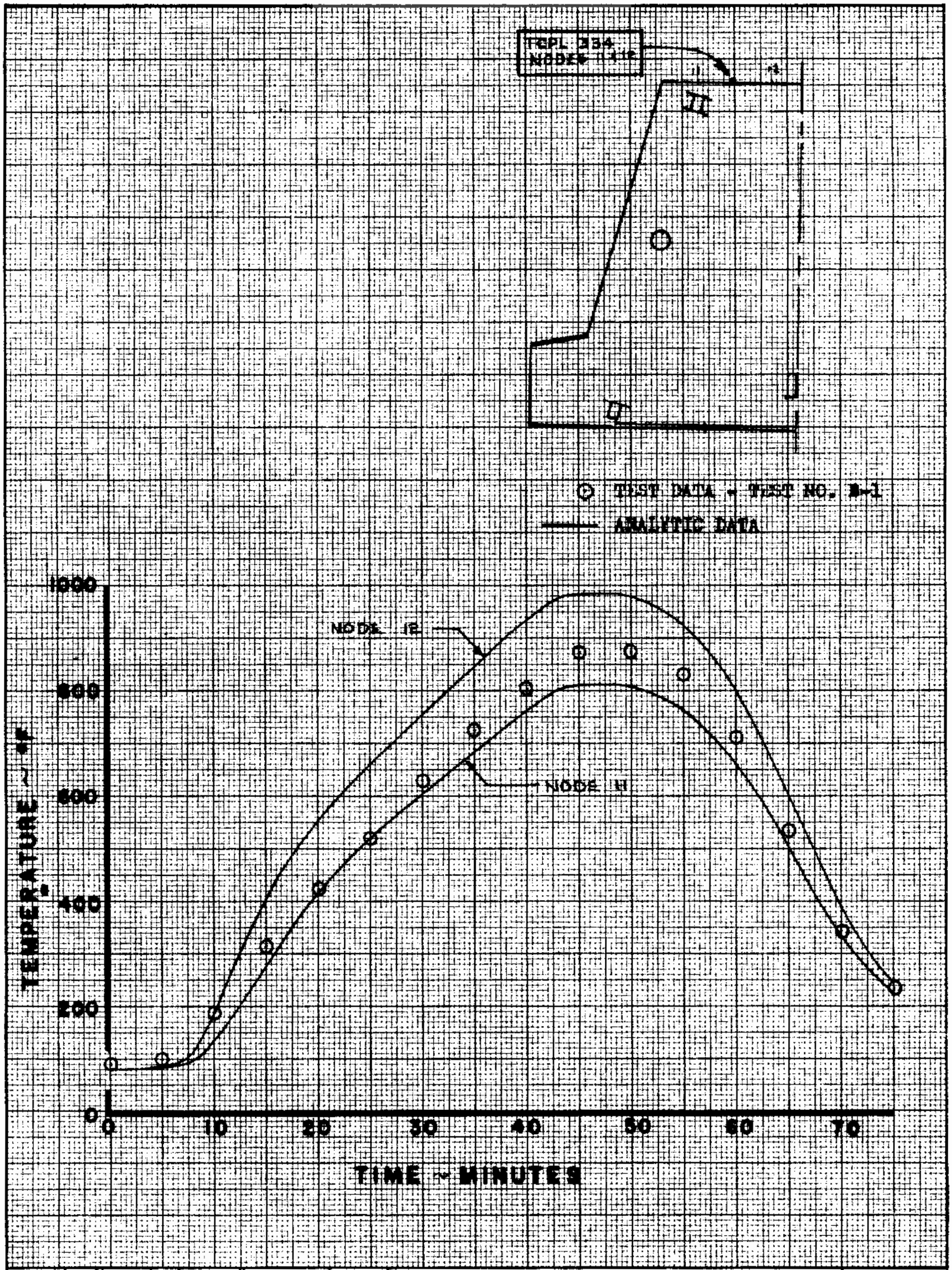

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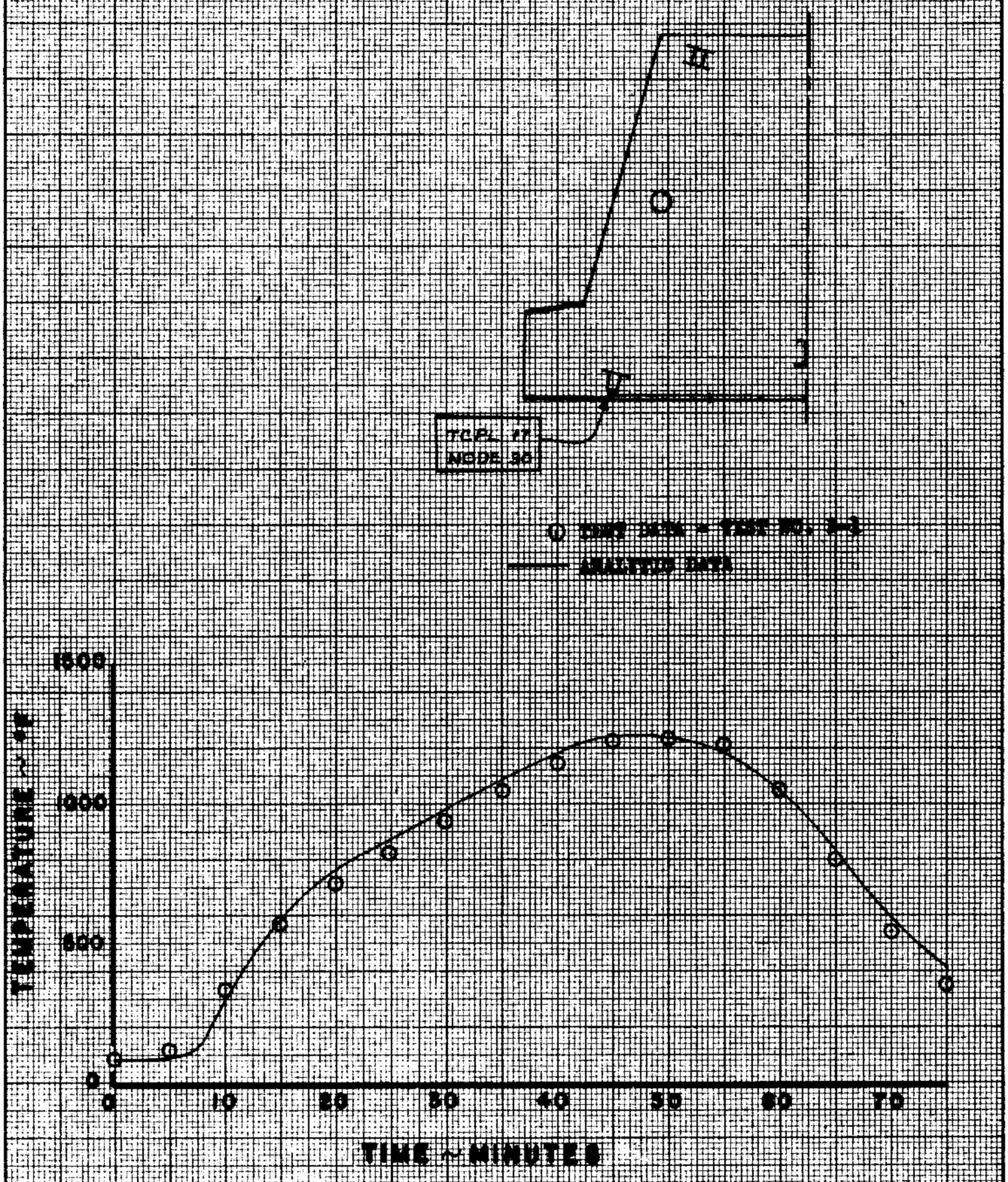

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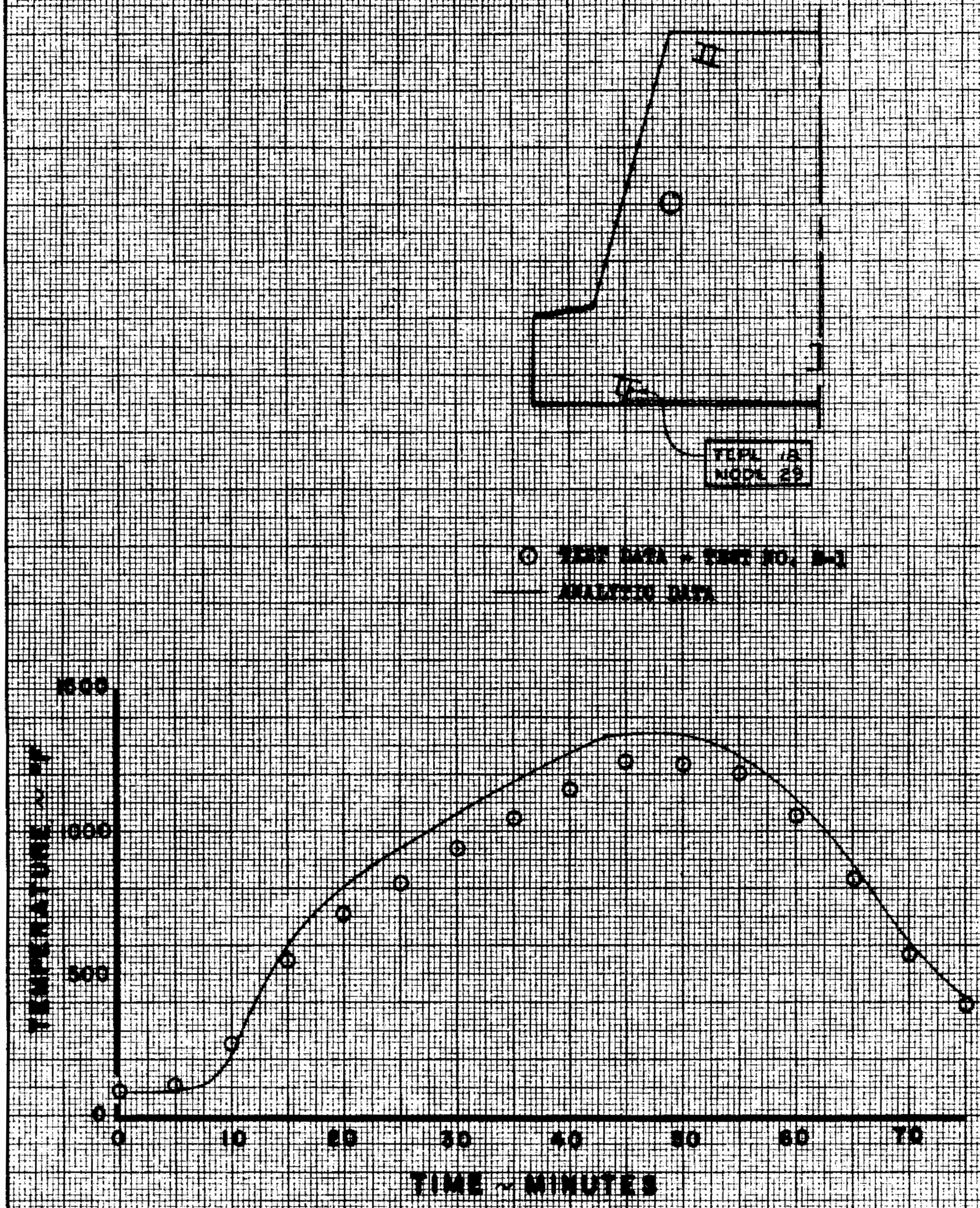

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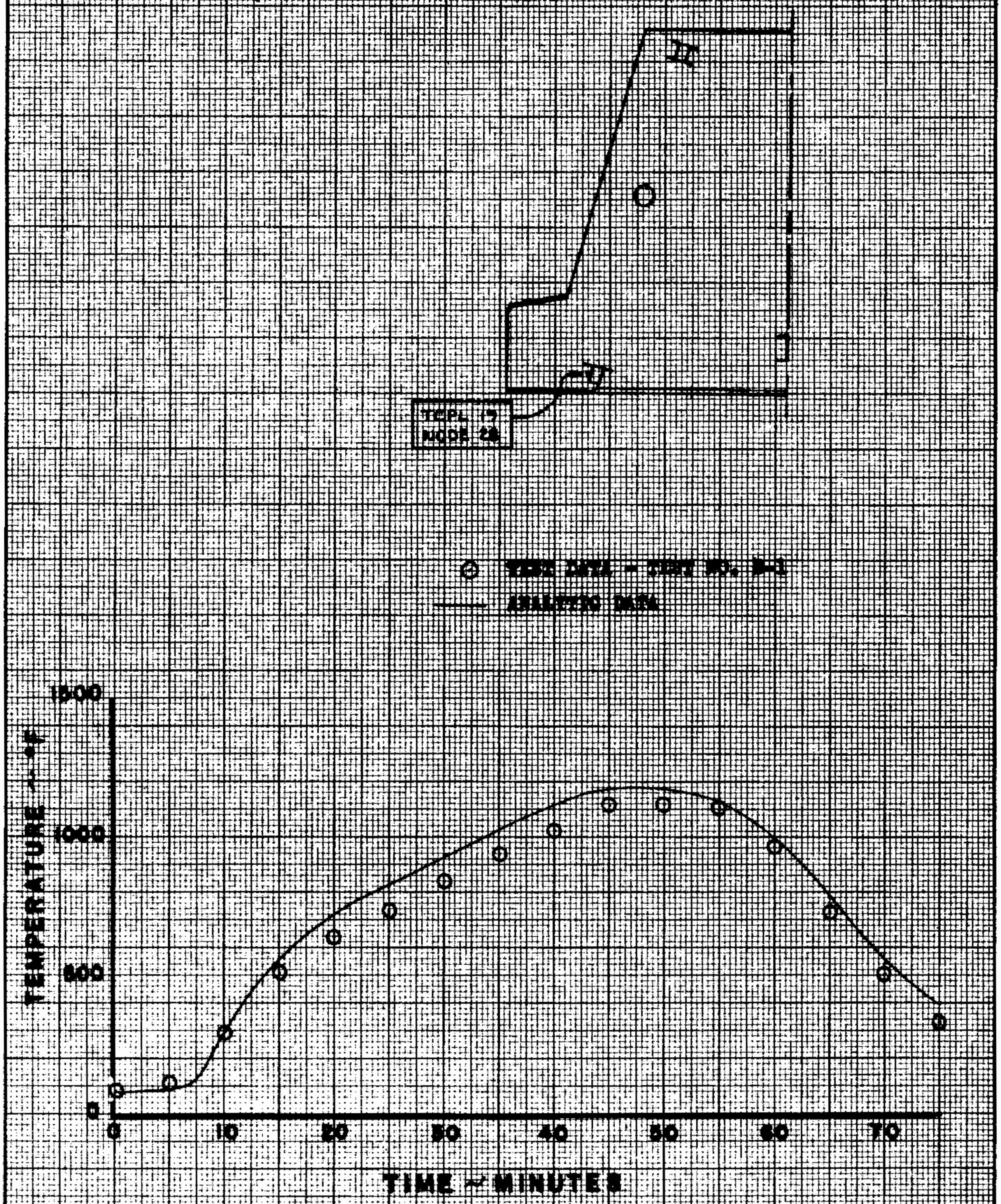

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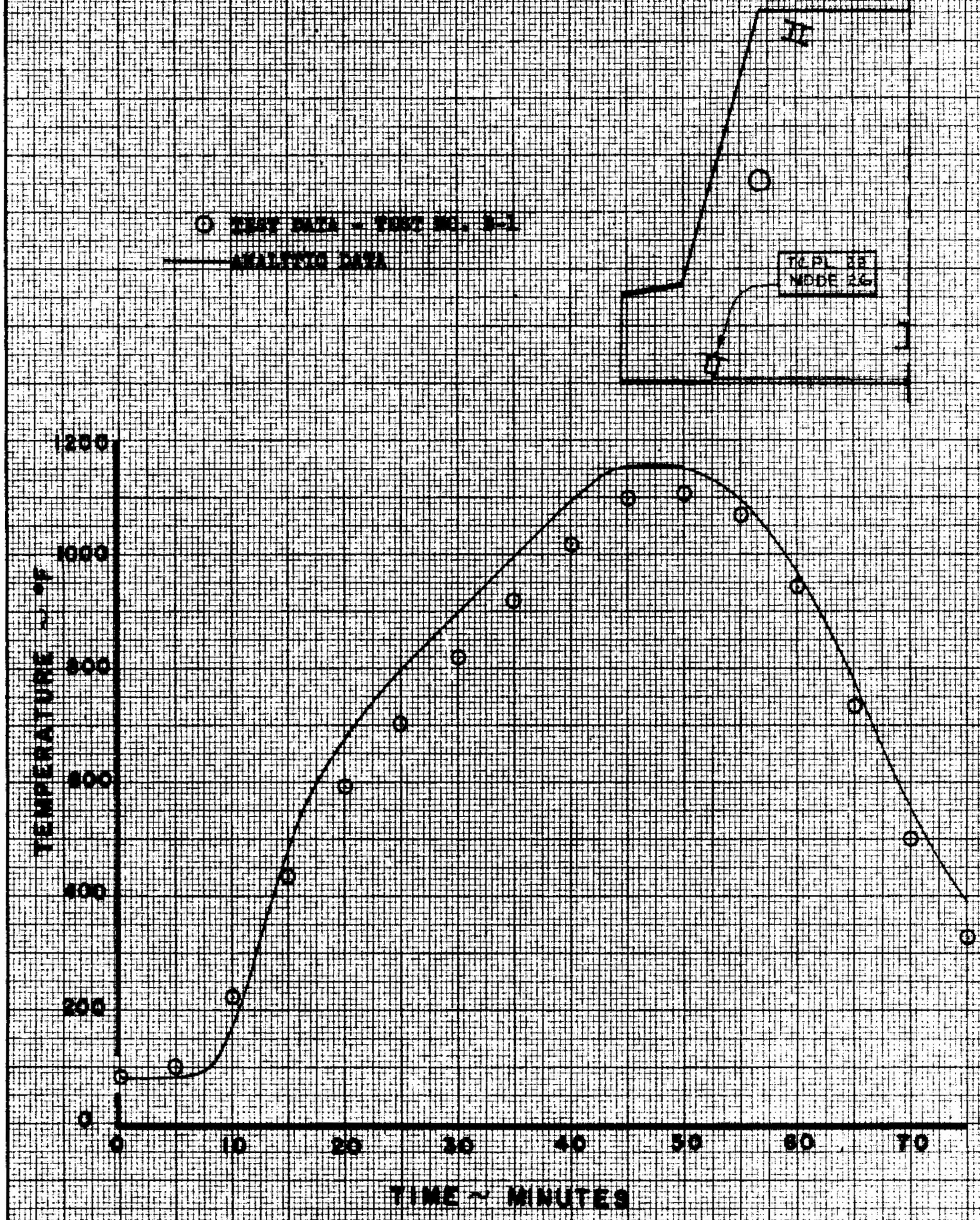

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A - B1
FORWARD BODY

THE BOEING COMPANY

D2-90709
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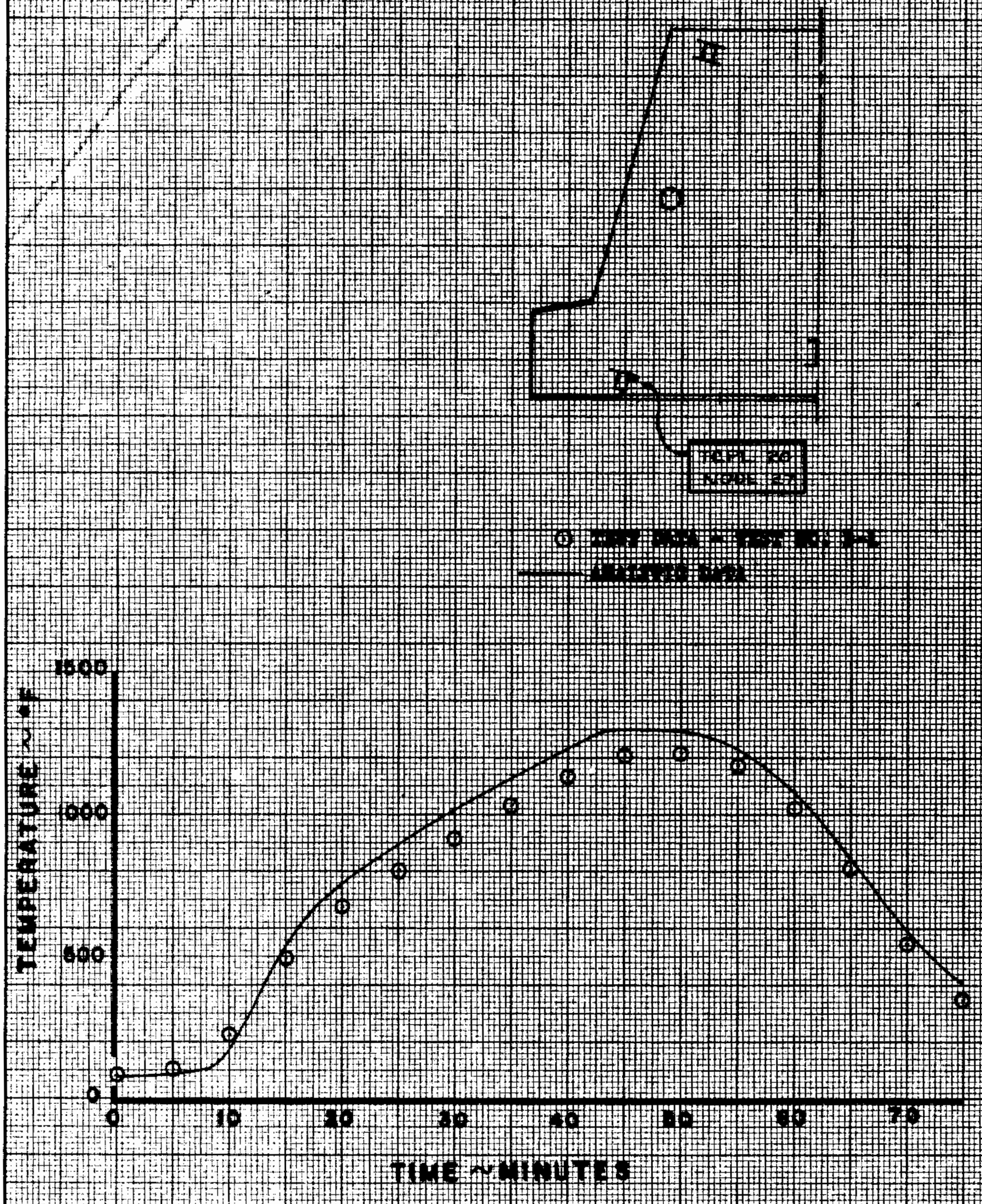

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS A - B1
FORWARD BODY

THE BOEING COMPANY

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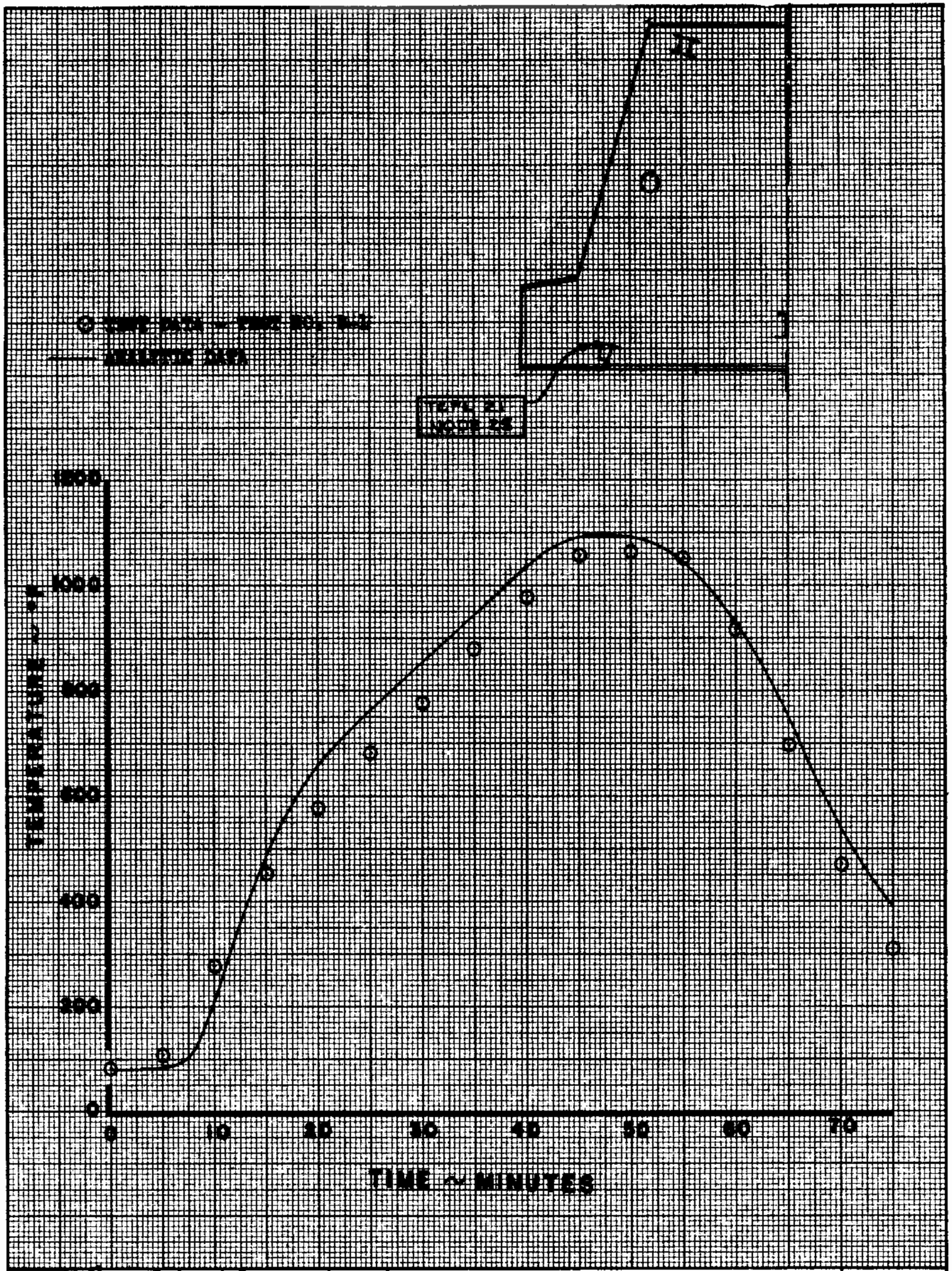

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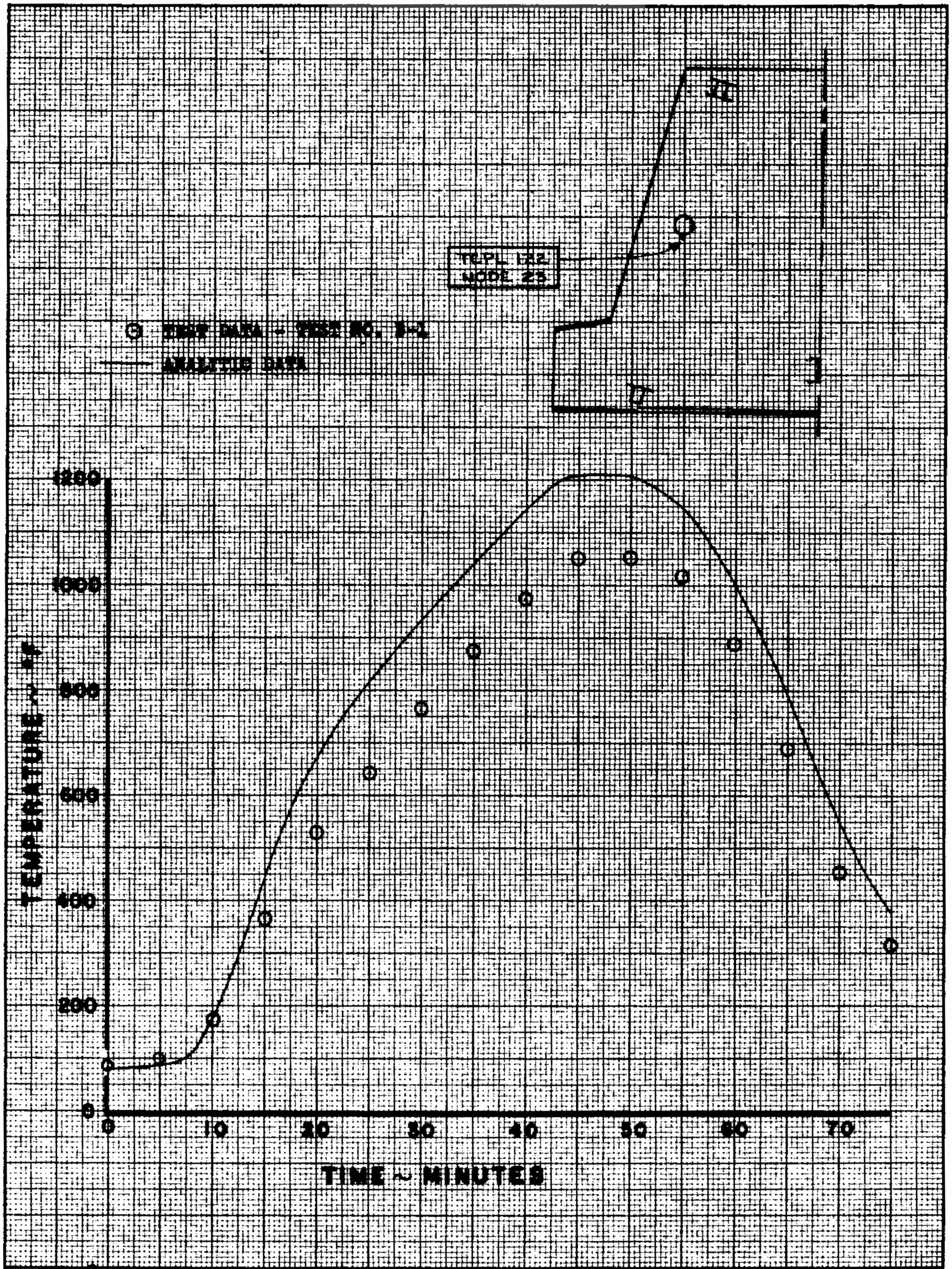

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4.2.3 Discussion (Analysis A)

Generally, this analysis provides excellent overall correlation, particularly for the Test 5 series (Test 5.1 in this case).

For both test cases, the worst discrepancy occurs on the diagonal truss tube. This error is probably due to internal convective currents which are not included. They would not be significant in a reentry environment due to the much lower density air inside such a vehicle structure.

The overall deviations are slightly greater for Test B1 due to the greater three-dimensional end effects in the forward region for this test. However, the differences are still rather small. This does not prove two-dimensional validity in such a region since a real vehicle probably has a large massive nose cap (such as the X-20) where thermal lag effects are much stronger than for this concept model.

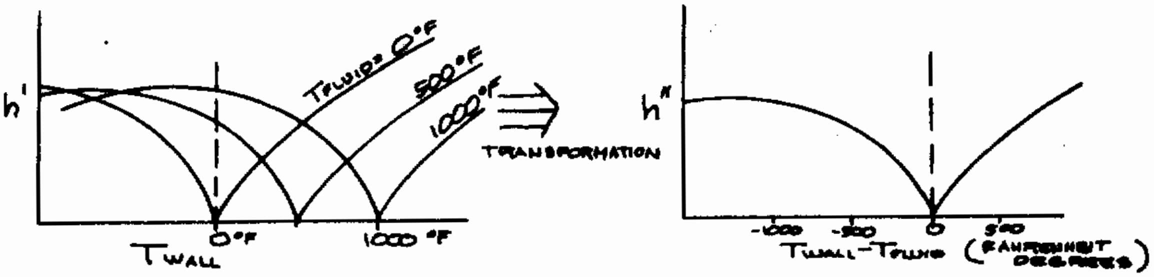
See also Section 4.8.3 of Analysis G for a discussion of the corrugation-skin assumptions used in this analysis.

4.3 CENTRAL BODY AND WING TWO-DIMENSIONAL ANALYSIS (ANALYSIS B)

4.3.1 Analysis Description

Perhaps the most significant of the seven analyses in the program, Analysis B is a two-dimensional cross-section in the aft body between Frames D and E. This section was chosen basically 10 inches aft of Frame D due to availability of thermocouple data in the region, and wing width at this point. It is analogous to the X-20 thermal analyses at Body Stations 240, 299, 320, and 430 (see Reference 3). As in Analysis A, the longerons, keel beam, and main diagonal are the only trusswork included.

Internal convection was included in one case for Test B1 in the upper fuselage region (see also Section 4.3.3 for discussion of this). The inclusion of this convection was very simple. A hot reservoir at the mean wing cavity temperature is assumed as the source. Hand calculations indicated that such a source is not appreciably cooled as it moves up the inside surfaces next to the compartment, hence such cooling is neglected. The heat transfer coefficient is based on the same basic equation as external cooling (see Section 4.1). However since the source (fluid) temperature is a variable, a bivariant relation exists (i.e. h is a function of T_{wall} and T_{fluid}). This curve also is discontinuous when T_{wall} equals T_{fluid}. Due to this complexity and the desire for a simple approach, the coefficient was reduced to a single variable by a transformation approximation which is shown pictorially below.



(See page 91 for calculated curve)

This simpler coefficient is not exact but is a reasonable approximation for the purposes of this analysis.

The assumptions shown in Section 4.1, page 8, apply to this analysis.

Boundary conditions are referenced on page 60 for Test 5 and page 84 for Test B1.

The nodal system is shown in Figure 5, page 65 for Test 5, and Figure 6, page 85, for Test B1. The various constants, conductors, capacitors, etc., are shown on pages 66 through 72 for Test 5, and pages 86 through 96 for Test B1.

Correlation of this analysis for the Test 5 series is shown on pages 73 through 83. Test B1 comparisons are shown on pages 97 through 104 with and without internal convection.

4.3.2.1 ANALYSIS B CORRELATION

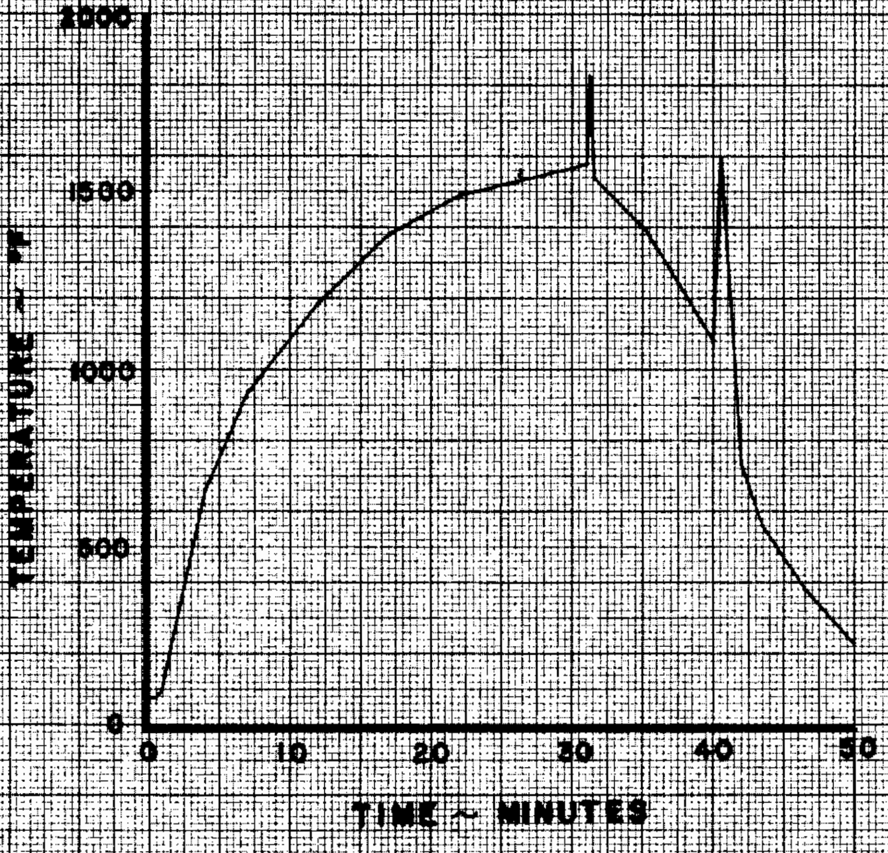
CENTRAL BODY AND WING TWO-DIMENSIONAL ANALYSIS

TEST SERIES: 5 CONDITIONS: 5.1
5.6

BOUNDARY NODES	SOURCE		PAGE
1	THERMOCOUPLE 308	TEST 5.1	61
2	THERMOCOUPLE 308	TEST 5.1	61
3	THERMOCOUPLE 308	TEST 5.1	61
4	THERMOCOUPLE 311	TEST 5.1	62
5	THERMOCOUPLE 311	TEST 5.1	62
6	THERMOCOUPLE C-30	TEST 5.1	63
7	THERMOCOUPLE 309	TEST 5.1	64
30	ROOM TEMPERATURE		

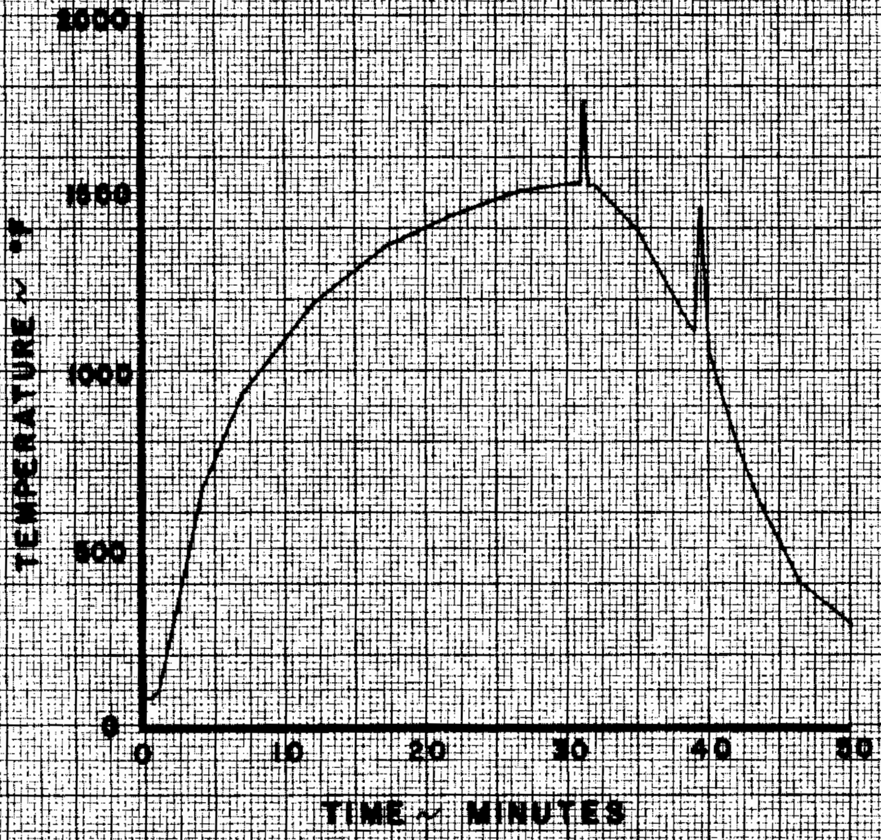
THERMOCOUPLE #308 TEST 5.1

DRIVE BOUNDARY NODES:
1, 2 & 3 ANALYSIS B TEST 5.1



THERMOCOUPLE #311 TEST 5.1

DRIVE BOUNDARY NODES:
4 & 5 ANALYSIS B TEST 5.1
1 & 2 ANALYSES C TEST 5.1



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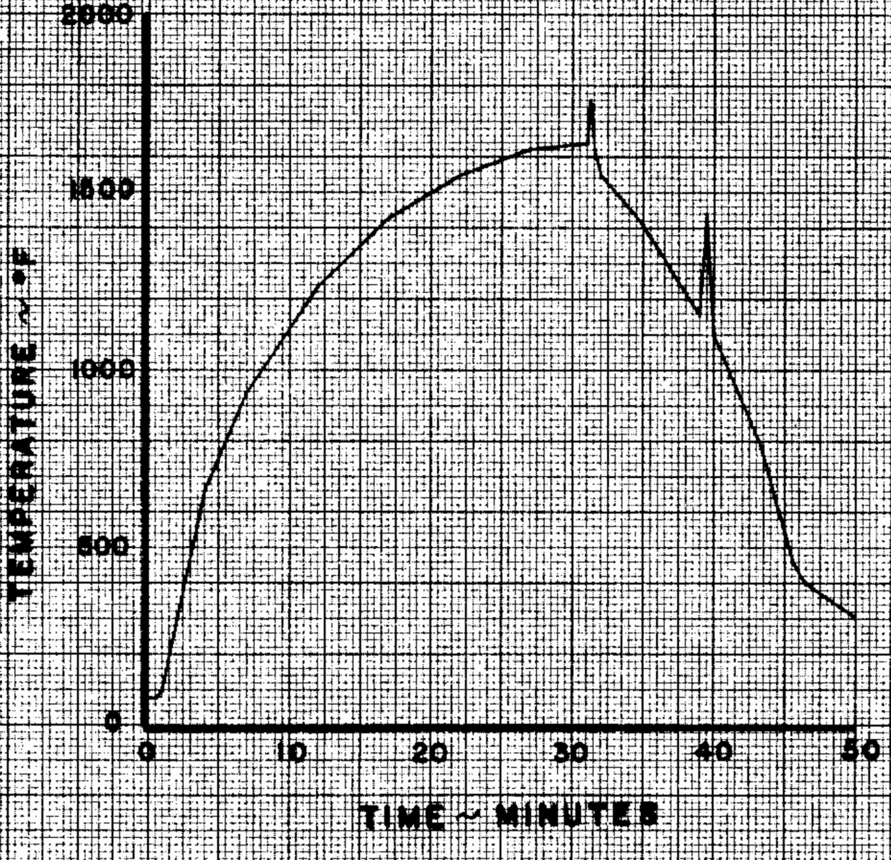
THERMOCOUPLE #C-30 TEST 5.1

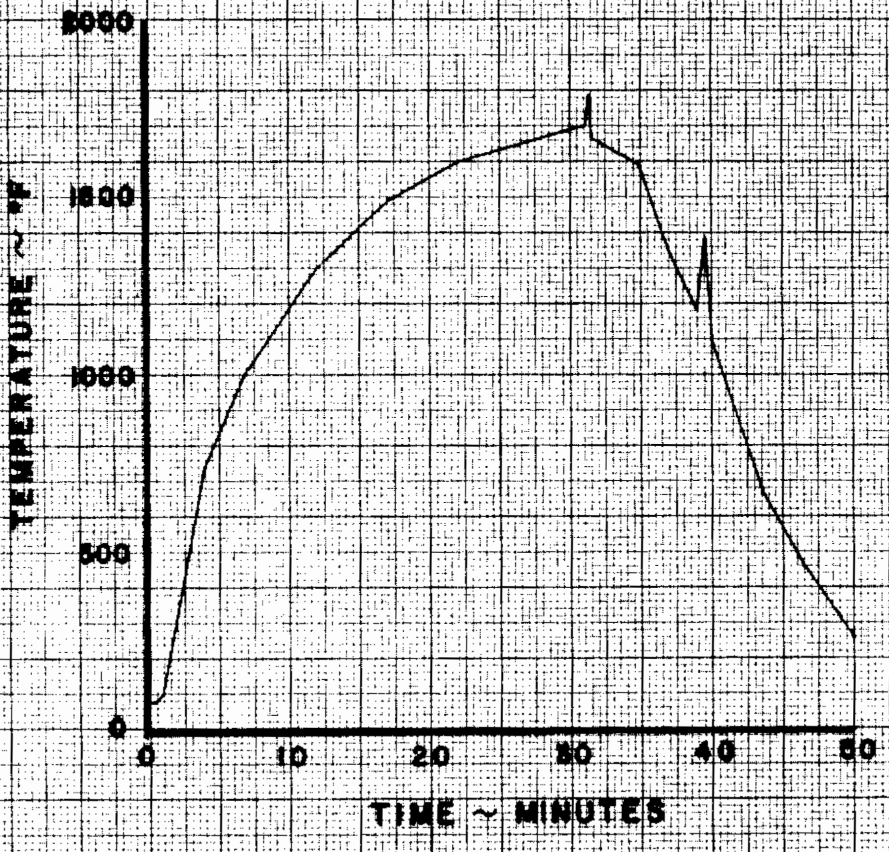
DRIVE BOUNDARY NODES:
6 ANALYSIS B TEST 5.1
3 & 4 ANALYSIS C TEST 5.1



THERMOCOUPLE #309 TEST 5.1

DRIVE BOUNDARY NODES:

7 ANALYSIS B TEST 5.1
5, 6 & 7 ANALYSIS C TEST 5.1



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HOT STRUCTURES THERMAL ANALYSIS

ANALYSIS B
2-DIMENSIONAL AFT BODY
NODAL DIAGRAM

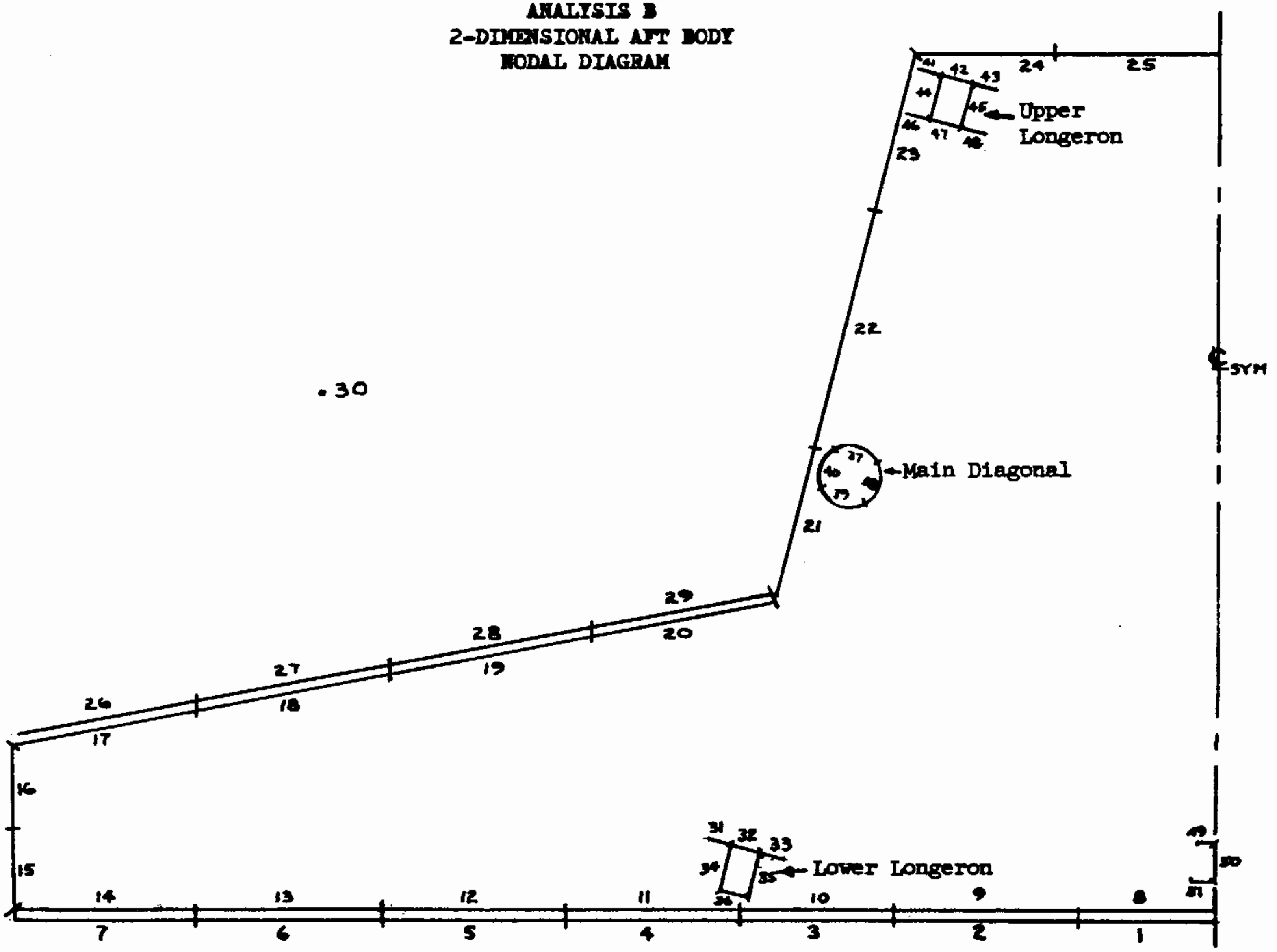

FIGURE 5 - ANALYSIS B NODAL DIAGRAM - TEST 5.1

CAPACITANCE - ANALYSIS B TEST 5.1

NODE	MATERIAL	VOLUME	CAPACITANCE
1	HS-25	DRIVEN	--
2	↓	↓	↓
3			
4			
5			
6			
7	HS-25	DRIVEN	--
8	HS-25	.044	1.364 x 10^{-3}
9	↓	.06	1.860 ↓
10		.05	1.550
11		.057	1.767
12		.06	1.860
13		.06	1.860
14	HS-25	.06	1.860
15	RENE' 41	.03	1.200
16	↓	.027	1.080
17		.06	2.064
18		.064	2.202
19		.066	2.270
20		.06	2.064
21		.05	1.720
22		.08	2.752
23		.053	1.823
24		.045	1.548
25		.053	1.823
26		.06	2.064
27		.064	2.202
28		.066	2.270
29	RENE' 41	.06	2.064 x 10^{-3}
30	BLACK BODY	DRIVEN	--
31	RENE' 41	.068	2.720 x 10^{-3}
32	↓	.037	1.480 ↓
33	RENE' 41	.068	2.720 x 10^{-3}

CAPACITANCE - ANALYSIS B TEST 5.1 (CONTINUED)

NODE	MATERIAL	VOLUME	CAPACITANCE
34	RENE' 41	.058	2.320×10^{-3}
35	↓	.058	2.320 ↓
36		.038	1.520
37		.099	3.762
38		.099	3.762
39		.099	3.762
40		.099	3.762
41		.068	2.380
42		.037	1.295
43		.068	2.380
44		.097	3.395
45		.057	1.995
46		.068	2.380
47		.037	1.295
48		.068	2.380
49		.016	0.640
50		.05	2.000
51	RENE' 41	.04	1.600×10^{-3}

CONDUCTION CONDUCTORS - ANALYSIS B TEST 5.1

COND. NO.	NODE/NODE	A/L
12	8 - 9	.00336
13	9 - 10	.00318
14	11 - 12	.00299
15	13 - 14	.00292
16	15 - 16	.00421
17	17 - 18	.00194
18	19 - 20	.00191
19	21 - 22	.00185
20	22 - 23	.00180
21	24 - 25	.00245
22	26 - 27	.0016
23	28 - 29	.0016
30	32 - 31	.0455
31	32 - 33	.0455
32	31 - 34	.0348
33	33 - 35	.0348
34	36 - 34	.0331
35	36 - 35	.0331
40	37 - 38	.0402
41	38 - 39	.0402
42	39 - 40	.0402
43	37 - 40	.0402
50	41 - 42	.0455
51	42 - 43	.0455
52	41 - 44	.0354
53	43 - 45	.0354
54	44 - 46	.0354
55	45 - 48	.0354
56	46 - 47	.0455
57	47 - 48	.0455
60	49 - 50	.028
61	50 - 51	.0356

CONVECTION CONDUCTORS - ANALYSIS B TEST 5.1

COND. NO.	NODE/NODE	A'	h'
71	21 - 30	8.960	SEE PAGE 2
72	22 - 30	10.715	
73	23 - 30	6.288	
74	24 - 30	.9589	
75	25 - 30	1.1293	

RADIATION CONDUCTOR MATRIX

NODE	NODE (i)																																																		
(j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
1	-							101																																											
2		-							102																																										
3			-							103																																									
4				-							104																																								
5					-							105																																							
6						-							106																																						
7							-							107																																					
8	101							-								108	109	110	111	112	113	114	115	116	117													274	281								334	340	350		361
9		102							-								118	119	120	121	122	123	124	125	126										256			275	282							331	335	341	351	359	
10			103							-								127	128	129	130	131	132	133	134								239		257	258		276	283							332	336	342			
11				104							-				135	136	137	138	139	140		141	142	143	144						221			247		259			284												
12					105							-			145	146	147	148	149	150	151	152	215								222			248					285												
13						106							-		153	154	155	156	157	158	159	160	161											249																	
14							107							-	162	163	164	165	166	167	168	214												250																	
15											135	145	153	162	-	165	170	171	172	173										178				264																	
16								108			136	146	154	163	169	-	174	175	176	177										179				265																	
17								109	118		137	147	155	164	170	174	-									180								251																	
18								110	119	127	138	148	156	165	171	175		-									181							252																	
19								111	120	128	139	149	157	166	172	176			-									182			223	230	240	253																	
20								112	121	129	140	150	158	167	173	177				-									183		224	231	241																		
21								113	122	130		151	159	168							-	184	185	186	187	188	189	190	191	192	225	232	242				272	277	308	303									352		362
22								114	123	131	141	152	160	214							184	-	193	194	195	196	197	198	199	200	226	233	243				273	278		304			319		328		337	343	353		363
23								115	124	132	142	215	161								185	193	-	201	202	203	204	205	206	207	227	234	244				261	279			310			324		333	338	344	354		
24								116	125	133	143										186	194	201	-						208							262				311	314	320					345	355		
25								117	126	134	144										187	195	202		-					209	228	235	245				263	280				315	321		329			346	356		
26																	180				188	196	203			-				210																					
27																		181			189	197	204				-			211																					
28																			182		190	198	205					-		212																					
29																				183	191	199	206						-	213																					
30															178	179					192	200	207	208	209	210	211	212	213	-																					
31											221	222							223	224	225	226	227		228						-			229					286												
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33										239									240	241	242	243	244		245								-		246				288												
34											247	248	249	250	264	265	251	252	253												229	236		-	254	255															
35									256	257																						237	246	254	-	260															
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38								274	275	276											277	278	279		280												294	-	297	298											
39								281	282	283	284	285									308										286	287	288				295	297	-	302											
40																					303	304															296	298	302	-											
41																							310	311																	-			312		318					
42																								314	315																	-					318				
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44																							324																		312			-	325	326	327				
45																						328			329																		322	325	-		339	330			
46									331	332													333														305				313			326		--					
47								334	335	336												337	338														306					328		327	339		-				
48								340	341	342												343	344	345	346												307						323		330			-			
49								350	351												352	353	354	355	356																								-		
50									359																																									-	360
51								361													362	363																												360	-

CALC	Dizenel	4-7-65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION RADIATION CONDUCTOR MATRIX ANALYSIS B - TEST 5.1	D2-90709 -1
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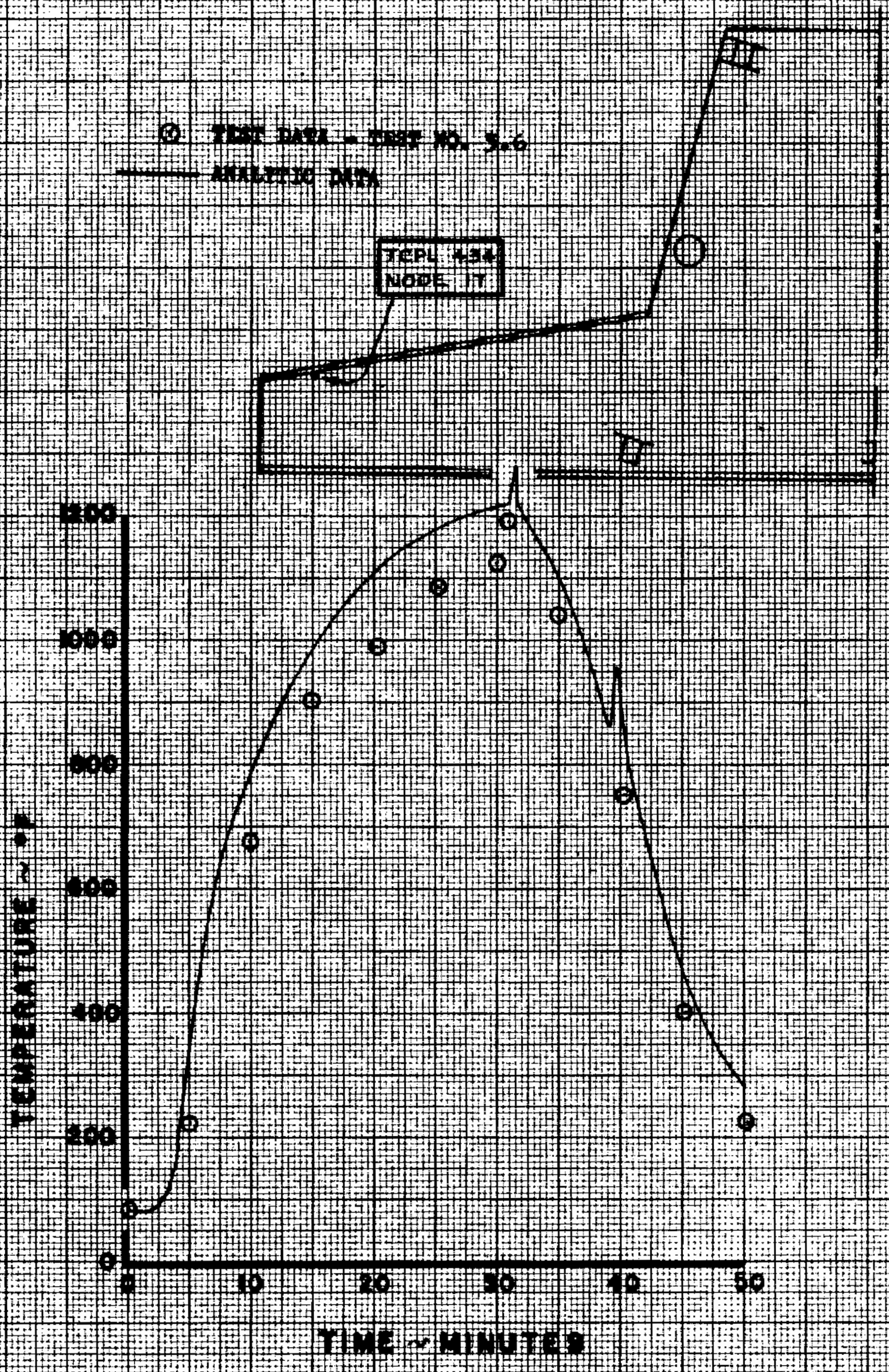
APPR					THE BOEING COMPANY SEATTLE, WASHINGTON 98124	PAGE 79
APPR						

RADIATION CONDUCTORS - ANALYSIS B TEST 5.1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
101	4.40	150	.9328	199	.4384	253	.234
102	6.00	151	.04	200	6.5794	254	.8335
103	5.00	152	.22	201	.310	255	.3371
104	5.70	153	.1327	202	.160	256	.1012
105	6.00	154	.3207	203	.1335	257	.7678
106	6.00	155	1.3698	204	.187	258	.2350
107	6.00	156	2.2529	205	.219	259	.745
108	.0022	157	1.0987	206	.1194	260	.3538
109	.0336	158	.3469	207	4.6411	261	.08
110	.0827	159	.05	208	4.50	262	.12
111	.1625	160	.22	209	5.30	263	.29
112	.2778	161	.07	210	5.6427	264	.086
113	.35	162	1.038	211	5.8096	265	.086
114	.61	163	.6218	212	5.6382	272	.035
115	.2342	164	2.4142	213	4.6227	273	.75
116	.2490	165	1.1005	214	.130	274	.15
117	.6888	166	.3612	215	.130	275	.30
118	.0133	167	.1363	221	.425	276	.12
119	.1099	168	.04	222	.049	277	.10
120	.4396	169	.0118	223	.095	278	.20
121	.80	170	.4674	224	.2922	279	.08
122	.78	171	.2712	225	.04	280	.14
123	.66	172	.0924	226	.07	281	.14
124	.3464	173	.0663	227	.029	282	.25
125	.3847	174	.8141	228	.1107	283	.22
126	1.0133	175	.1648	229	.2947	284	.12
127	.0060	176	.0887	230	.1131	285	.01
128	.2145	177	.0624	231	.3295	286	.04
129	.73	178	3.00	232	.045	287	.06
130	.39	179	2.70	233	.073	288	.04
131	.44	180	6.00	234	.0363	294	.413
132	.10	181	6.40	235	.1446	295	.5919
133	.2337	182	6.60	236	.36	296	.4196
134	.6362	183	6.00	237	.3336	297	.4108
135	.0227	184	.340	238	.2872	298	.5884
136	.069	185	.080	239	.4945	302	.4261
137	.1571	186	.080	240	.0749	303	1.03
138	.5152	187	.100	241	.2489	304	.38
139	1.4688	188	.0426	242	.04	305	.04
140	1.4162	189	.0971	243	.06	306	.10
141	.0344	190	.2481	244	.0299	307	.04
142	.0508	191	.8195	245	.1212	308	1.371
143	.05	192	3.7927	246	.3082	310	.4036
144	.23	193	.4988	247	.1995	311	.70
145	.0467	194	.1432	248	.0923	312	.2995
146	.135	195	1.0075	249	.0303	313	.1969
147	.4247	196	.1812	250	.0149	314	.9124
148	1.4496	197	.3063	251	.0905	315	.088
149	2.0597	198	.4947	252	.1584	316	.3533

RADIATION CONDUCTORS - ANALYSIS B TEST 5.1 (CONTINUED)

COND. NO.	AF
317	.3473
318	.3037
319	.0137
320	.6967
321	.1
322	.2991
323	.1969
324	.901
325	.8081
326	.2995
327	.3473
328	.2122
329	.16
330	.2995
331	.0776
332	.1286
333	.605
334	.1025
335	.1675
336	.08
337	.1415
338	.31
339	.3533
340	.0849
341	.1378
342	.05
343	.1548
344	.175
345	.13
346	.1476
350	.157
351	.0282
352	.08
353	.12
354	.0457
355	.0439
356	.1209
357	.2322
358	.1762
359	.0855
360	.2837
361	.7831
362	.04
363	.07



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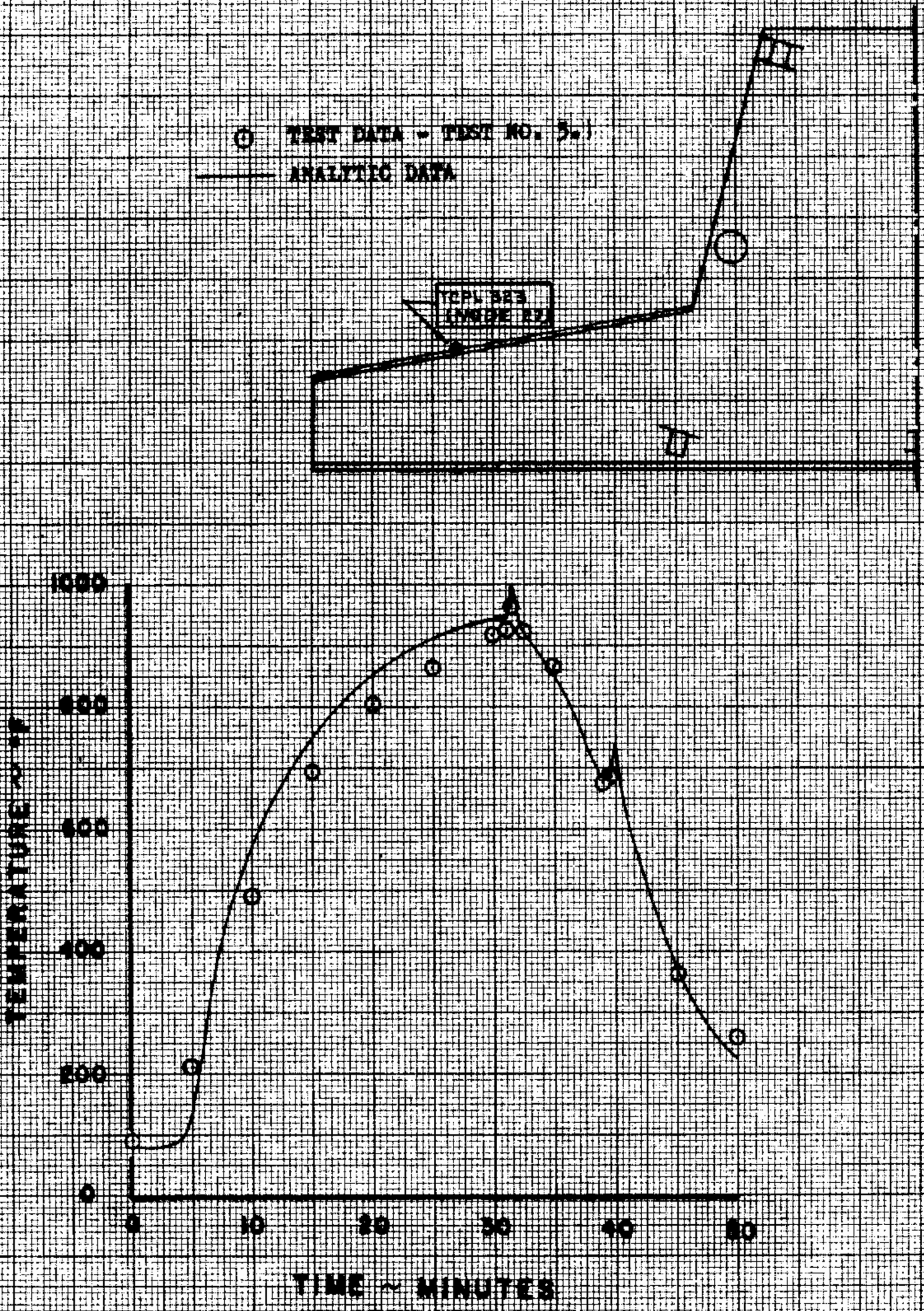
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS B
AFT BODY

THE BOEING COMPANY



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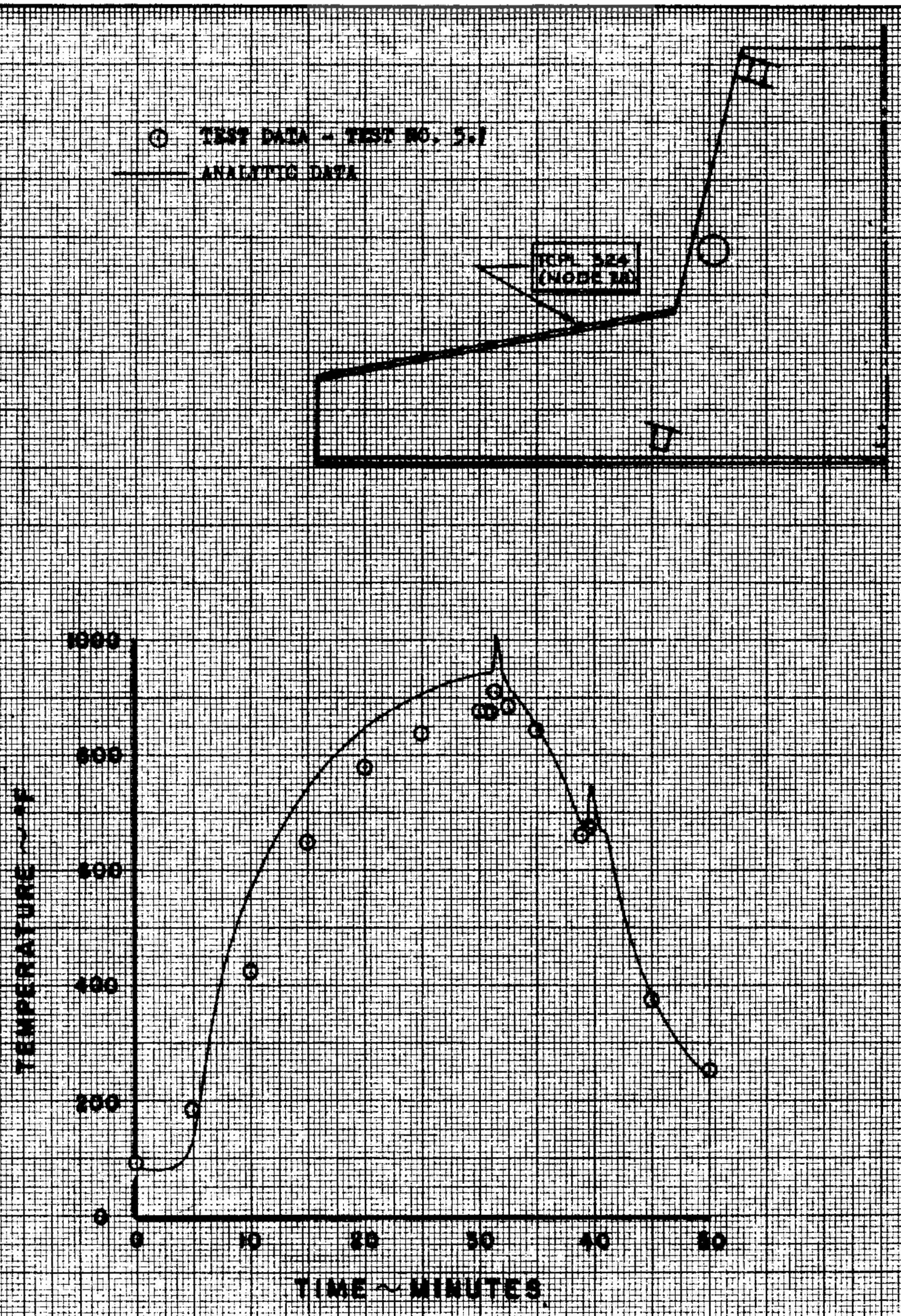

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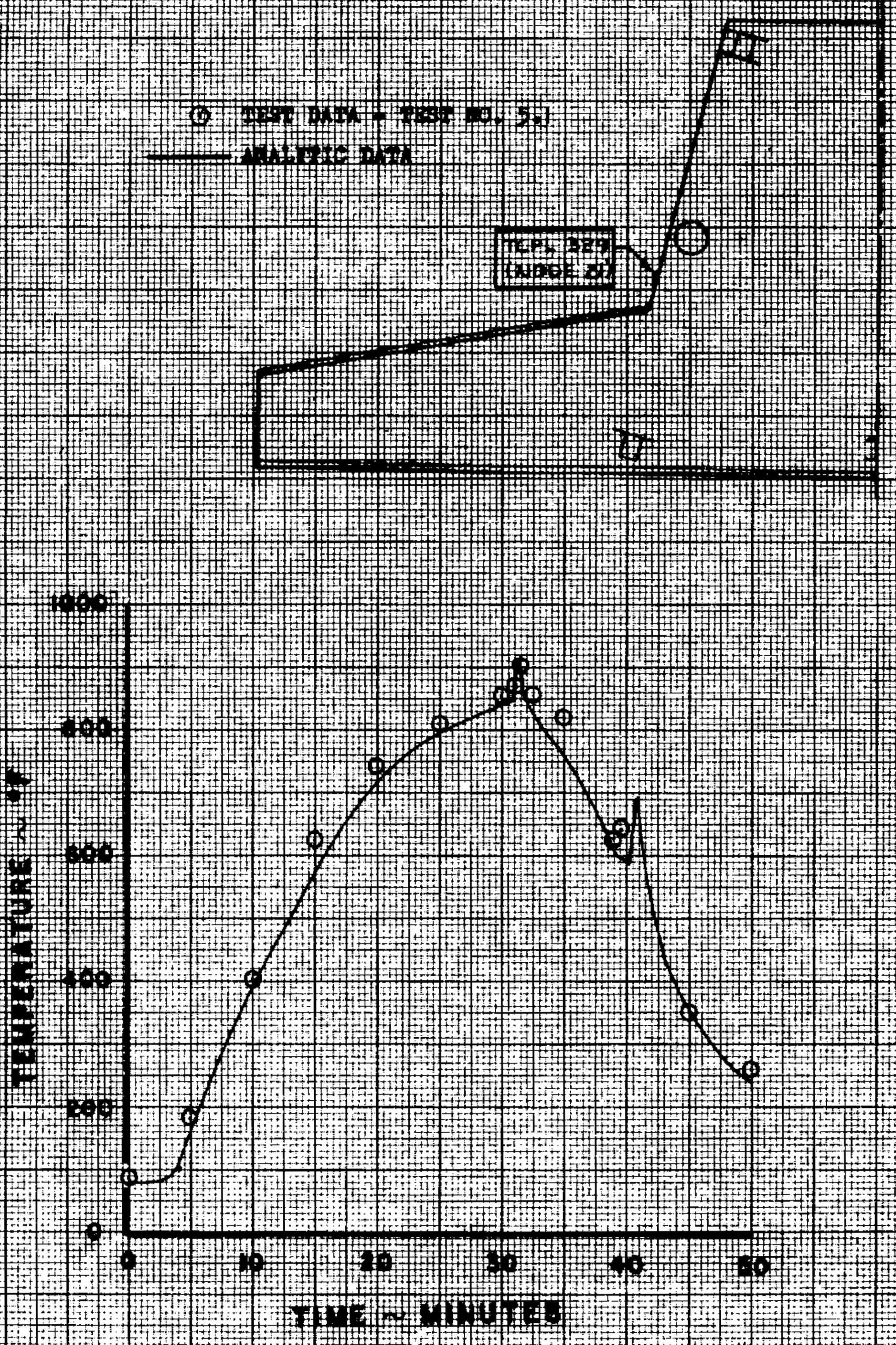

CALC		3/23/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS B AFT BODY	D2-90709 -1
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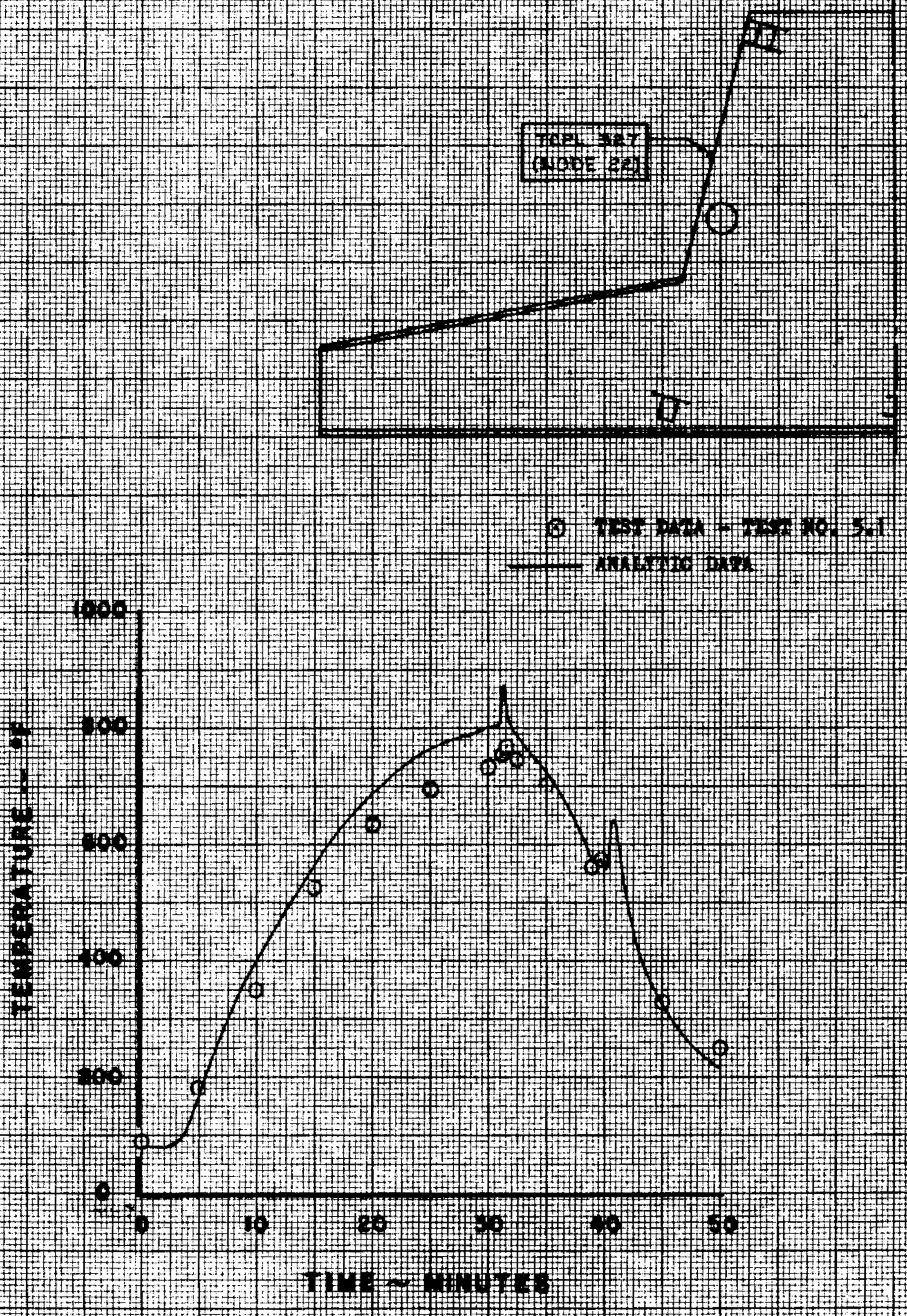

CALC	Olenoh	3/23/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS B AFT BODY	D2-90709 -1
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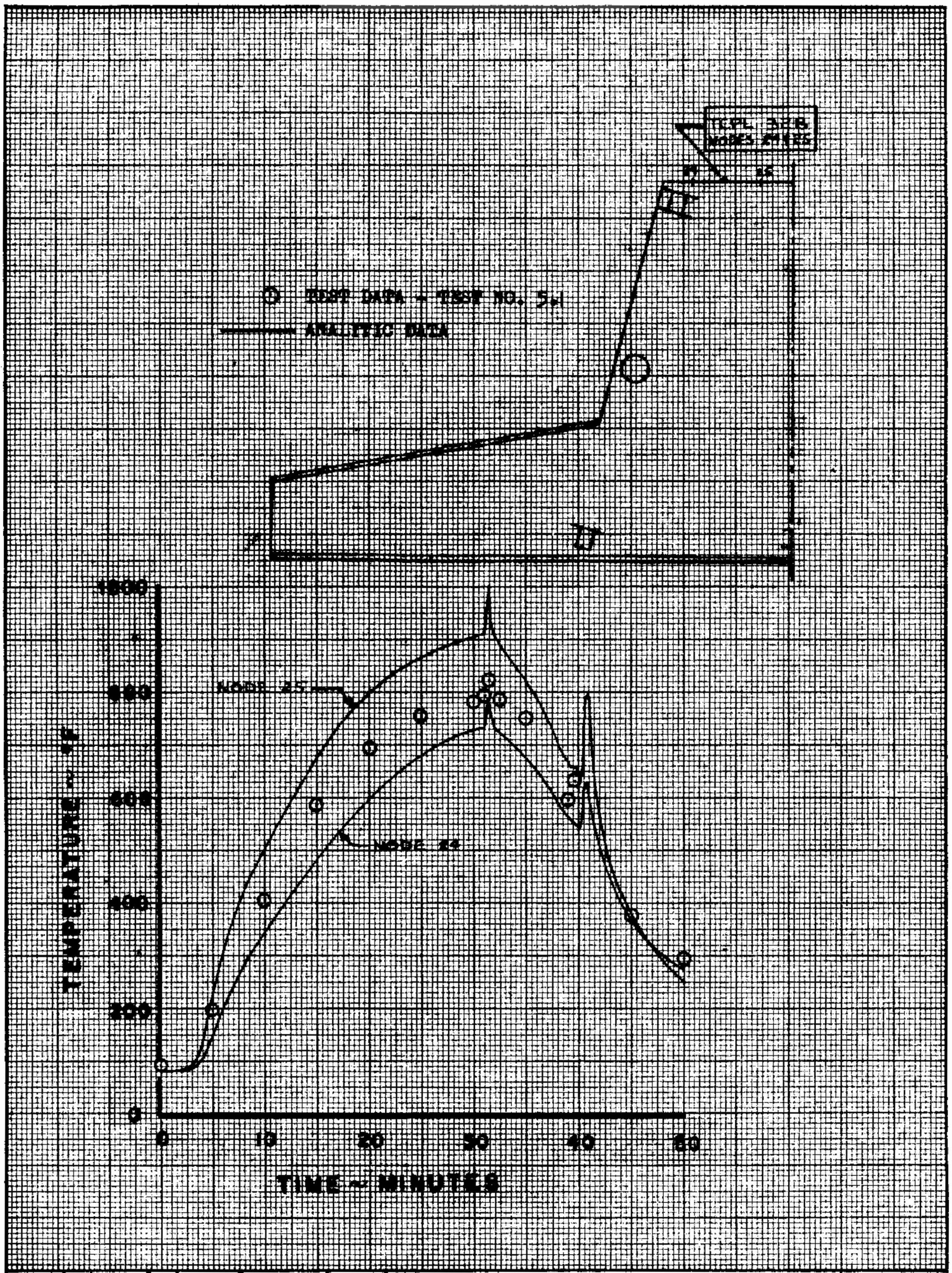

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS B
AFT BODY

THE BOEING COMPANY

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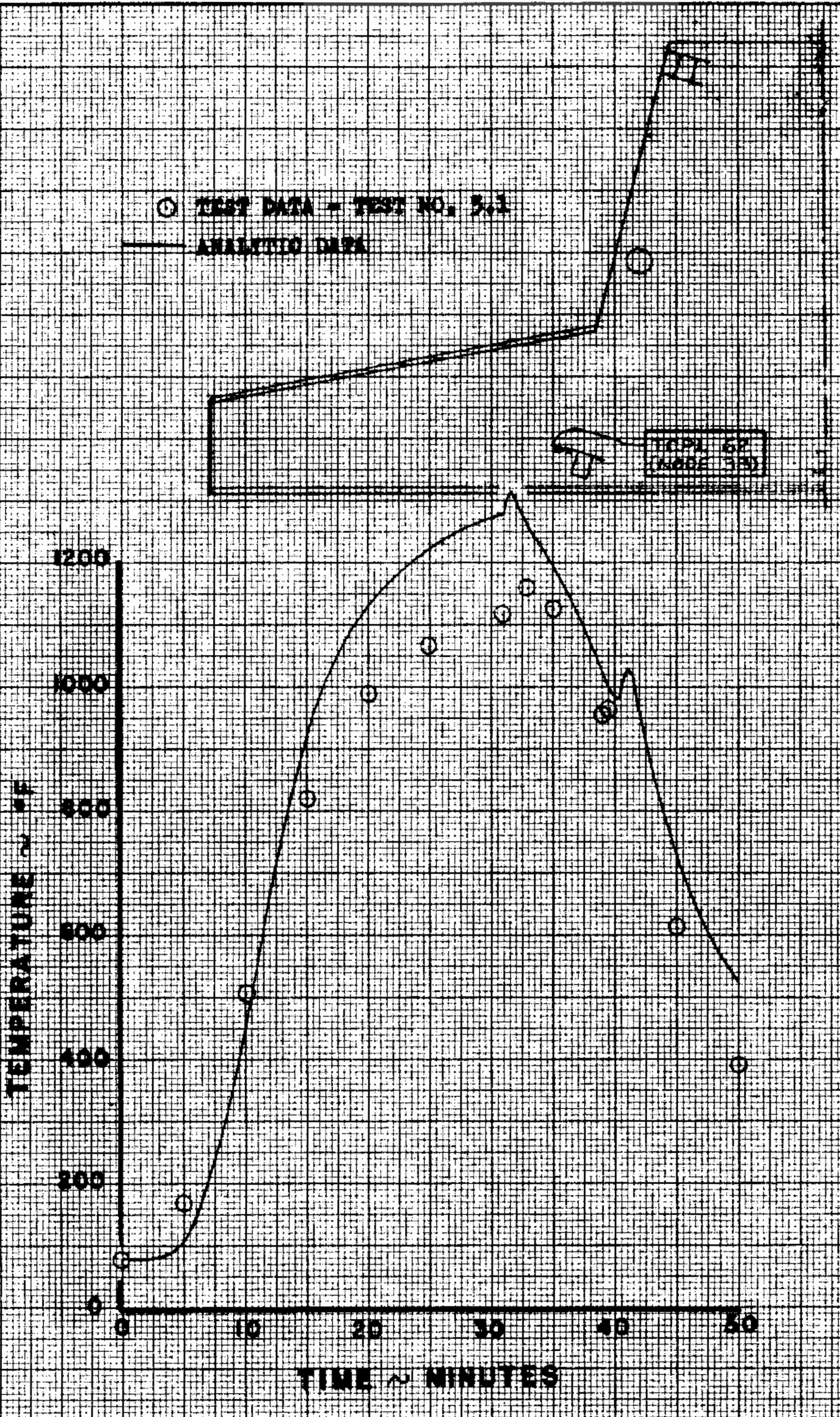

CALC		3/23/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS B AFT BODY	D2-90709 -1
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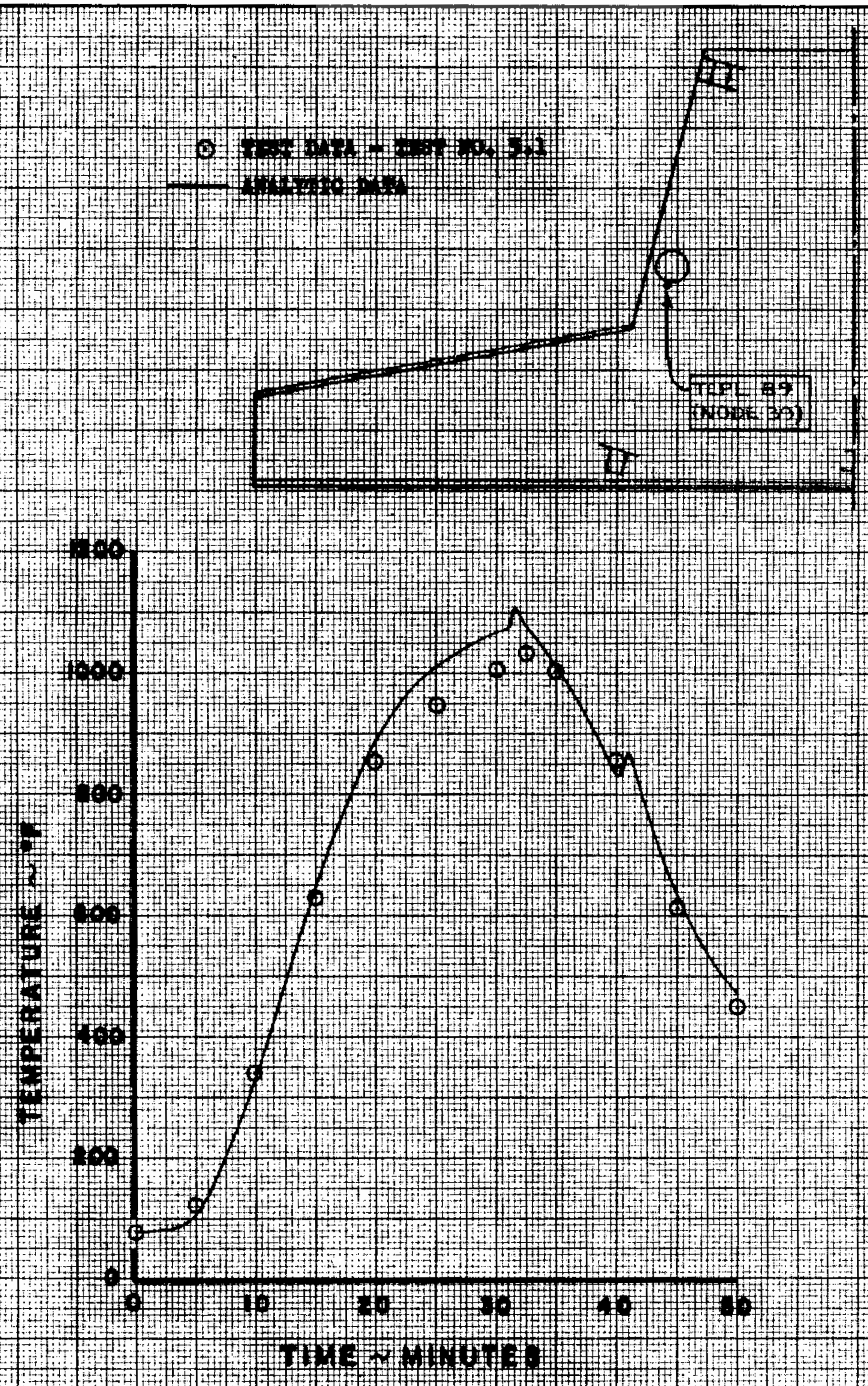

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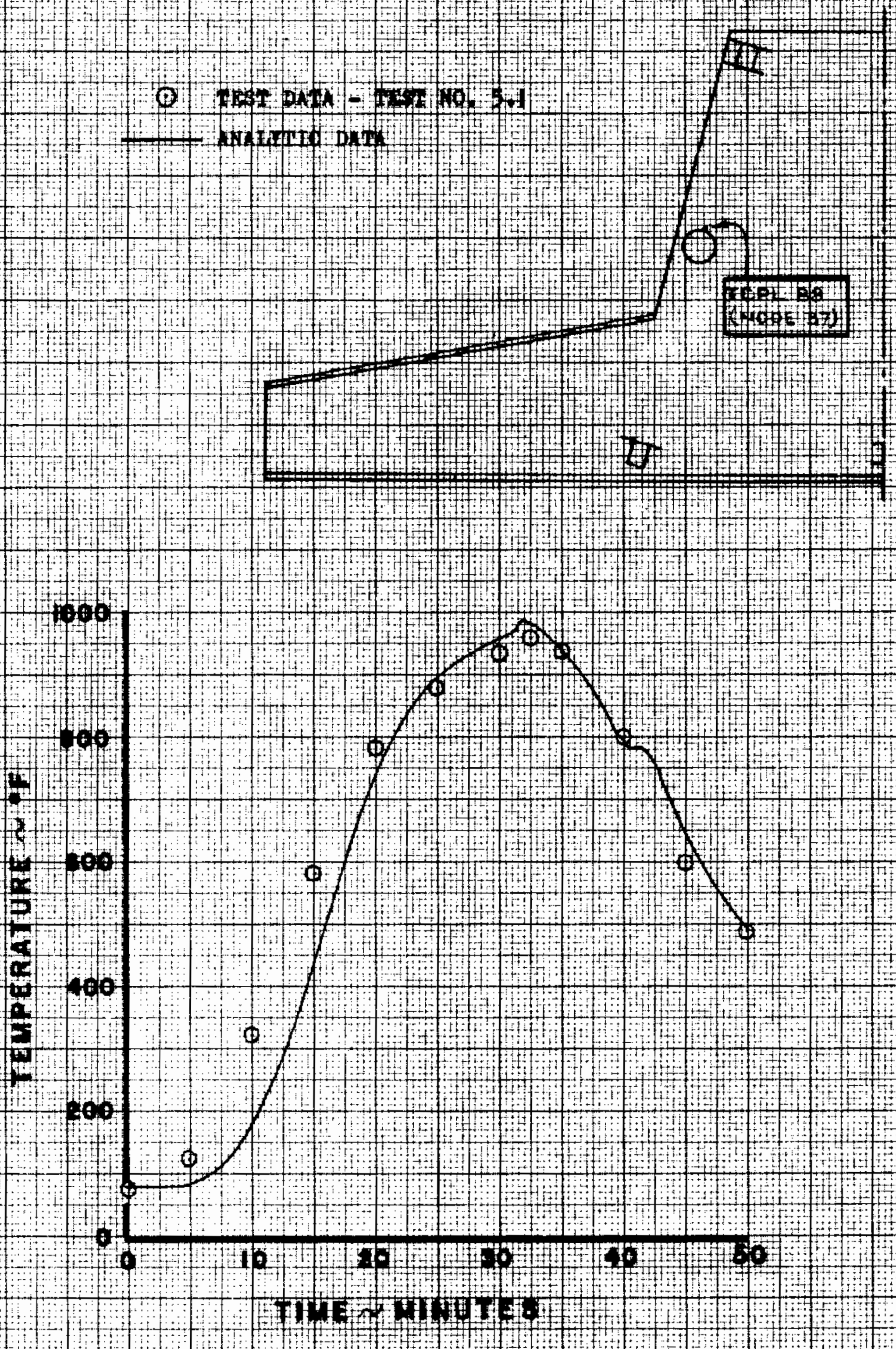
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS B
AFT BODY

D2-90709
-1

THE BOEING COMPANY



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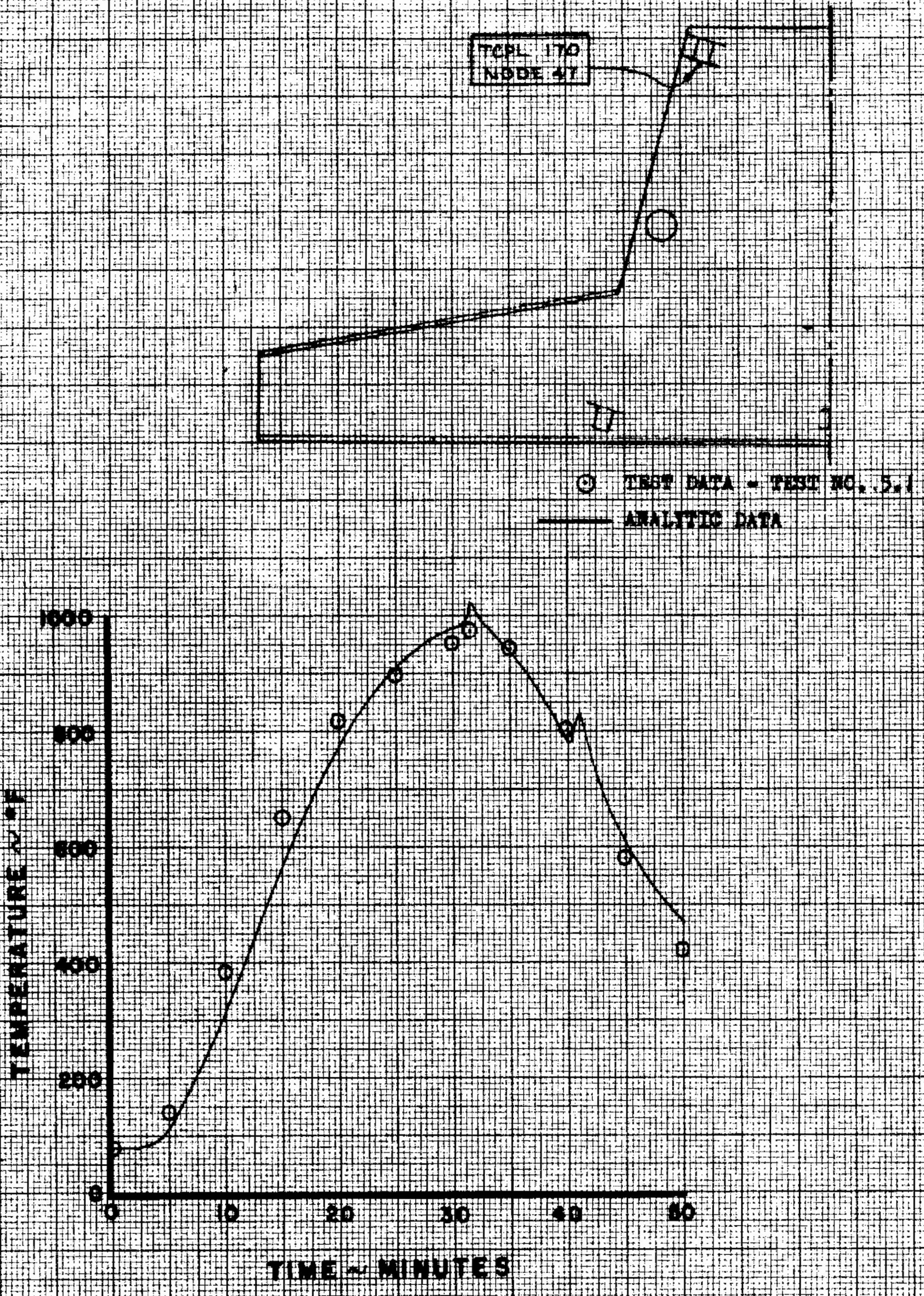

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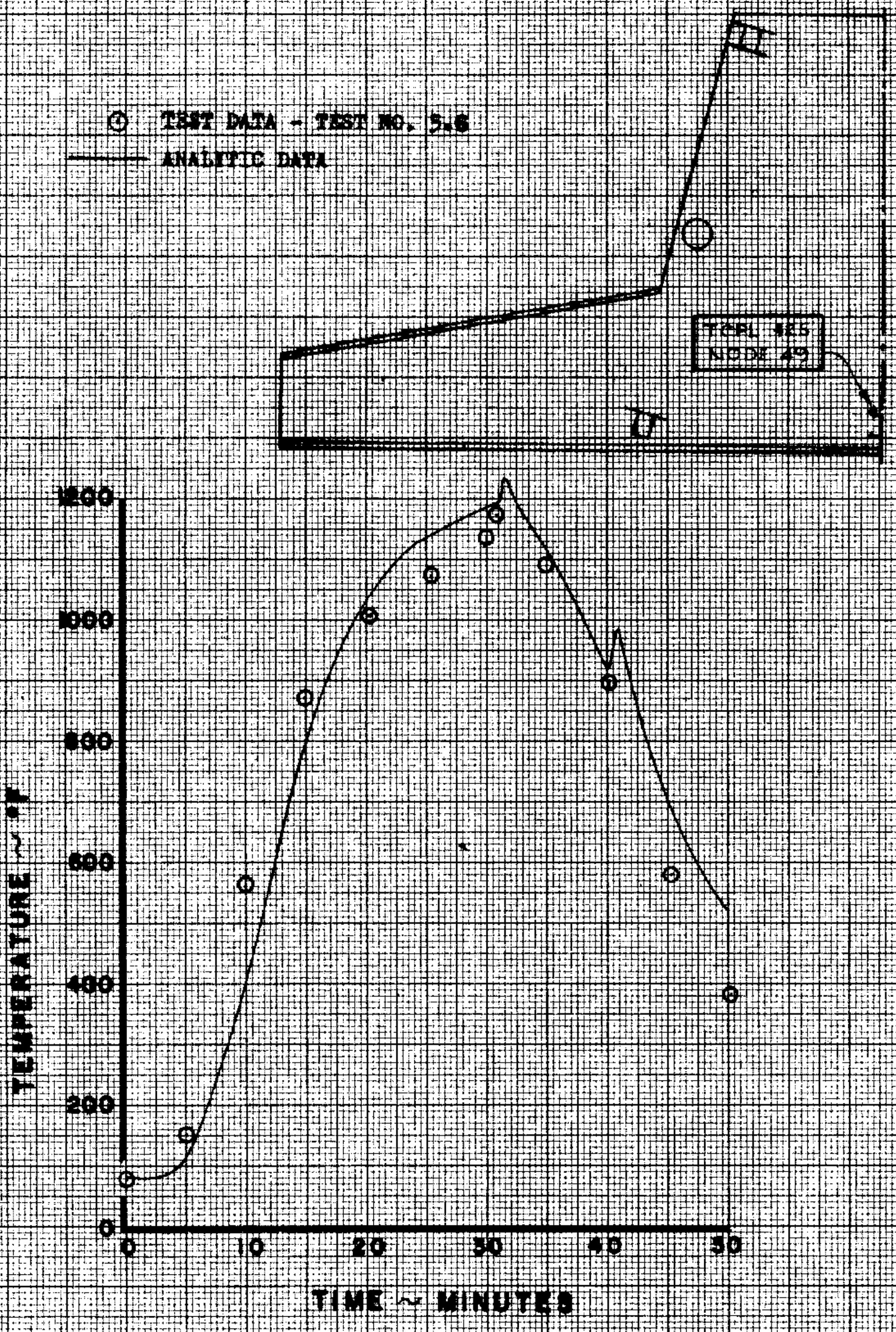

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PAGE

4.3.2.2 ANALYSIS B CORRELATION

CENTRAL BODY AND WING TWO-DIMENSIONAL ANALYSIS

TEST SERIES: B-1

BOUNDARY NODES	SOURCE	PAGE	
1	CONTROL AREA 24 TEST B-1	37	A
2	CONTROL AREA 24 TEST B-1	37	
3	CONTROL AREA 24 TEST B-1	37	
4	CONTROL AREA 26 TEST B-1	38	
5	CONTROL AREA 26 TEST B-1	38	
6	CONTROL AREA 26 TEST B-1	38	
7	CONTROL AREA 26 TEST B-1	38	
30	ROOM TEMPERATURE		

A Shown is the boundary conditions of Analysis A

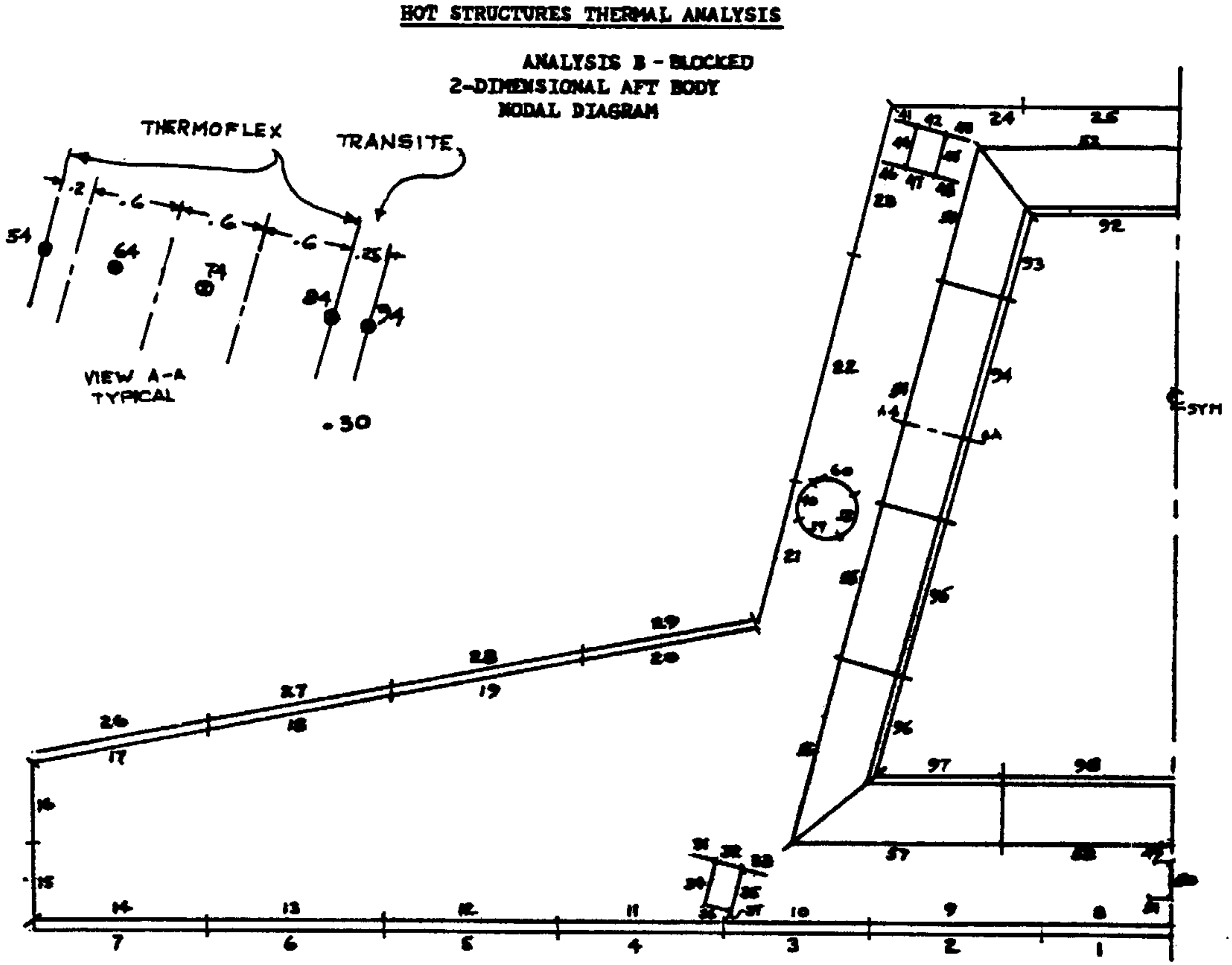


FIGURE 6 - ANALYSIS B NODAL DIAGRAM - TEST B1

CAPACITANCE - ANALYSIS B TEST B-1

NODE	MATERIAL	VOLUME	CAPACITANCE
1	HS-25	DRIVEN	--
2	↓	↓	↓
3			
4			
5			
6			
7		DRIVEN	--
8		.044	1.364×10^{-3}
9		.06	1.860 ↓
10		.05	1.550
11		.057	1.767
12		.06	1.860
13		.06	1.860
14	HS-25	.06	1.860
15	RENE' 41	.03	1.200
16	↓	.027	1.080
17		.06	2.064
18		.064	2.202
19		.066	2.270
20		.06	2.064
21		.05	1.720
22		.08	2.752
23		.053	1.823
24		.045	1.548
25		.053	1.823
26		.06	2.064
27		.064	2.202
28		.066	2.270
29	RENE' 41	.06	2.064×10^{-3}
30	BLACK BODY	DRIVEN	--
31	RENE' 41	.068	2.720×10^{-3}
32	↓	.037	1.480 ↓
33		.068	2.720
34	RENE' 41	.058	2.320×10^{-3}

CAPACITANCE - ANALYSIS B TEST B-1 (CONTINUED)

NODE	MATERIAL	VOLUME	CAPACITANCE
35	RENE' 41	.058	2.320×10^{-3}
36	↓	.038	1.520 ↓
37		.0104	0.416
38		.099	3.762
39		.099	3.762
40		.099	3.762
41		.068	2.380
42		.037	1.295
43		.068	2.380
44		.097	3.395
45		.057	1.995
46		.068	2.380
47		.037	1.295
48		.068	2.380
49		.016	0.640
50		.05	2.000
51	RENE' 41	.04	1.600×10^{-3}
52	CERAFELT	1.334	1.111×10^{-3}
53	↓	.957	.797 ↓
54		1.58	1.316
55		1.09	.908
56		1.262	1.051
57		1.405	1.170
58	CERAFELT	1.170	.975
60	RENE' 41	.099	3.762
62	CERAFELT	3.803	3.168
63	↓	2.696	2.246
64		4.740	3.948
65		3.270	2.724
66		3.473	2.893
67		3.910	3.257
68		3.510	2.924
72		3.508	2.922
73	CERAFELT	2.432	2.026×10^{-3}

CAPACITANCE - ANALYSIS B TEST B-1 (CONTINUED)

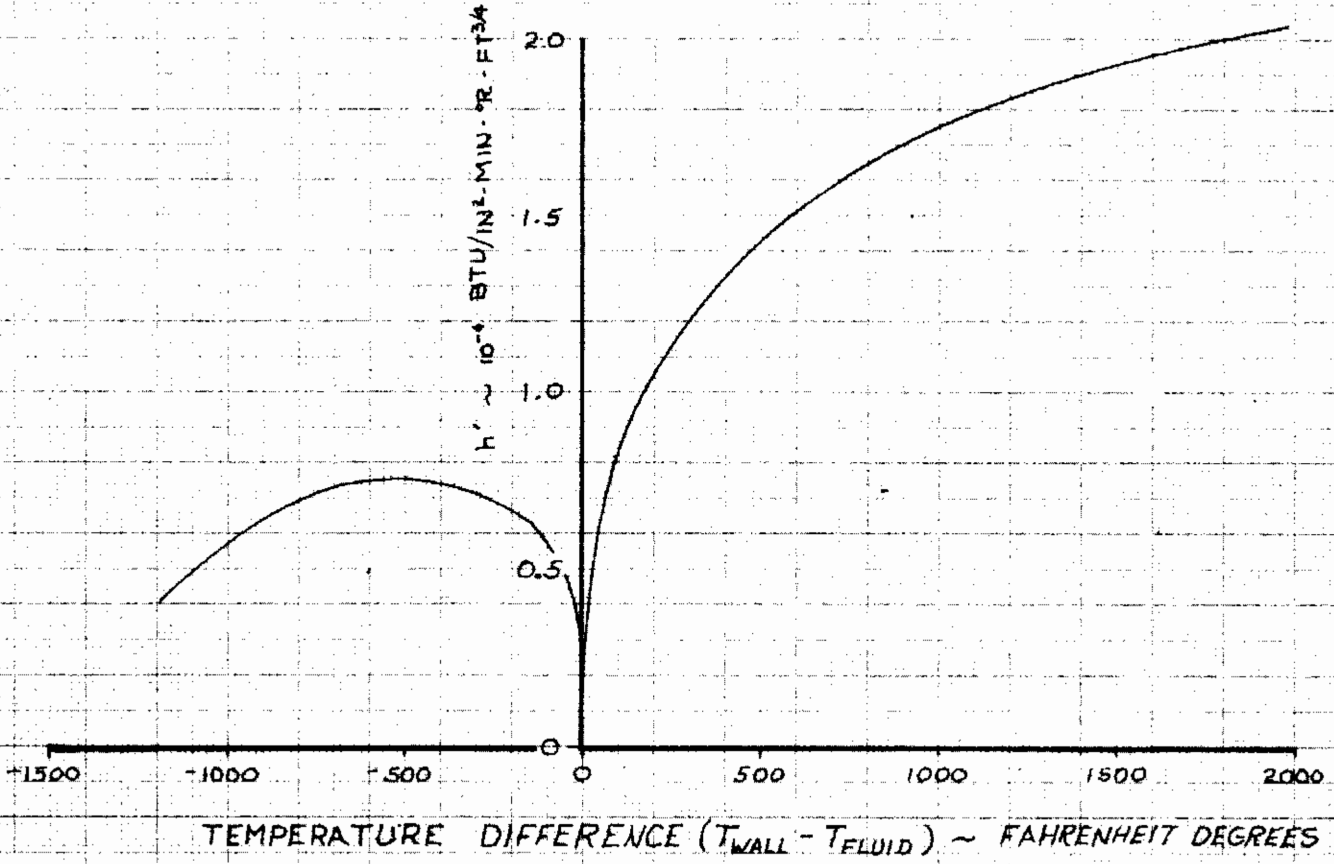
NODE	MATERIAL	VOLUME	CAPACITANCE
74	CERAFELT	4.740	3.948×10^{-3}
75	↓	3.270	2.724 ↓
76	↓	3.004	2.502 ↓
77	↓	3.454	2.877 ↓
78	↓	3.510	2.924 ↓
82	↓	3.211	2.675 ↓
83	↓	2.168	1.806 ↓
84	↓	4.740	3.948 ↓
85	↓	3.270	2.724 ↓
86	↓	2.535	2.112 ↓
87	↓	2.998	2,497 ↓
88	CERAFELT	3.510	2.924×10^{-3}
92	TRANSITE	1.251	.0145
93	↓	.826	.0096
94	↓	1.975	.0229
95	↓	1.362	.0158
96	↓	.918	.0106
97	↓	1.114	.0129
98	TRANSITE	1.462	.0170

CONDUCTION CONDUCTORS - ANALYSIS B TEST B-1

COND. NO.	NODE/NODE	A/L
12	8 - 9	.00336
13	9 - 10	.00318
14	11 - 12	.00299
15	13 - 14	.00292
16	15 - 16	.00421
17	17 - 18	.00194
18	19 - 20	.00191
19	21 - 22	.00185
20	22 - 23	.00180
21	24 - 25	.00245
22	26 - 27	.0016
23	28 - 29	.0016
30	32 - 31	.0455
31	32 - 33	.0455
32	31 - 34	.0348
33	33 - 35	.0348
34	36 - 34	.0331
35	36 - 35	.0331
36	38 - 39	.0402
37	39 - 40	.0402
38	40 - 60	.0402
39	38 - 60	.0402
50	41 - 42	.0455
51	42 - 43	.0455
52	41 - 44	.0354
53	43 - 45	.0354
54	44 - 46	.0354
55	45 - 48	.0354
56	46 - 47	.0455
57	47 - 48	.0455
60	49 - 50	.028
61	50 - 51	.0356
501	52 - 62	12.678
502	53 - 63	8.986
503	54 - 64	15.8
504	55 - 65	10.9
505	56 - 66	11.576
506	57 - 67	13.034
507	58 - 68	11.7
511	62 - 72	9.743
512	63 - 73	6.755
513	64 - 74	13.167
514	65 - 75	9.083
515	66 - 76	8.345
516	67 - 77	9.595
517	68 - 78	9.75
521	72 - 82	5.72
522	73 - 83	3.813
523	74 - 84	8.778
524	75 - 85	6.056
525	76 - 86	4.336
526	77 - 87	5.203
527	78 - 88	6.50
531	82 - 92	19.6
532	83 - 93	12.84
533	84 - 94	31.6
534	85 - 95	21.8
535	86 - 96	14.032
536	87 - 97	17.2
537	88 - 98	23.4
541	62 - 63	.1108
542	63 - 64	.0968
543	64 - 65	.0899
544	65 - 66	.1068
545	66 - 67	.0975
551	72 - 73	.1212
552	73 - 74	.1004
553	74 - 75	.0899
554	75 - 76	.1148
555	76 - 77	.1115
556	77 - 78	.1034
561	82 - 83	.1399
562	83 - 84	.1059
563	84 - 85	.0899
564	85 - 86	.1283
565	86 - 87	.1398
566	87 - 88	.1139
571	92 - 93	.0602
572	93 - 94	.0446
573	94 - 95	.0375
574	95 - 96	.0548
575	96 - 97	.0615
576	97 - 98	.0485

CONVECTION CONDUCTORS - ANALYSIS B TEST B-1

COND. NO.	NODE/NODE	A'	h'
71	21 - 30	8.960	SEE PAGE 21
72	22 - 30	10.715	
73	23 - 30	6.288	
74	24 - 30	.9589	
75	25 - 30	1.1293	
650	21 - 61	8.960	INTERNAL CONVECTION ONLY SEE PAGE 91
651	22 - 61	10.715	
652	23 - 61	6.288	
653	24 - 61	.9589	
654	25 - 61	1.1293	
655	52 - 61	1.127	
656	53 - 61	4.120	
657	54 - 61	7.370	
658	55 - 61	5.770	
659	56 - 61	9.100	



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-1

RADIATION CONDUCTOR MATRIX

NODE	NODE (i)																																							
(j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	-							101																																
2		-							102																															
3			-							103																														
4				-							104																													
5					-							105																												
6						-							106																											
7							-							107																										
8	101							-									109	110													221	231	233		267		277			
9		102							-								118	119	120	121											222	232	234		268		278			
10			103							-									128	129	130	131	132								223		235		269		279		616	
11				104							-				135	136	137	138	139	140											224			257		270	280		617	
12					105							-			145	146	147	148	149	150											225			258		271	281		618	
13						106							-		153	154	155	156	157	158											226			259		272	282			
14							107							-	162	163	164	165	166	167											227			260		273	283			
15											135	145	153	162	-		170	171	172	173										178	228			261		274	284			
16											136	146	154	163		-	174	175	176	177										179	229			262		275	285			
17								109	118		137	147	155	164	170	174	-									180					230			263		276	286			
18								110	119		138	148	156	165	171	175		-									181				236	243	250	264			287			
19									120	128	139	149	157	166	172	176			-									182			237	244	251	265			288			
20									121	129	140	150	158	167	173	177				-									183		238	245	252	266						
21										130											-					188	189	190	191	192	239	246	253						633	628
22										131												-				196	197	198	199	200	240	247	254							629
23										132													-	201	202	203	204	205	206	207	241	248	255							
24																							201	-						208	242	249	256							
25																							202		-					209										
26																	180				188	196	203			-				210										
27																		181			189	197	204				-			211										
28																			182		190	198	205					-		212										
29																				183	191	199	206						-	213										
30															178	179					192	200	207	208	209	210	211	212	213	-										
31								221	222	223	224	225	226	227	228	229	230	236	237	238	239	240	241	242							-			289					619	
32								231	232									243	244	245	246	247	248	249								-		290	291	294			620	
33								233	234	235								250	251	252	253	254	255	256									-		292	295	298		621	
34											257	258	259	260	261	262	263	264	265	266											289	290		-	293	296	299			
35								267	268	269																						291	292	293	-	297	300			
36											270	271	272	273	274	275	276															294	295	296	297	-	301			
37								277	278	279	280	281	282	283	284	285	286	287	288														298	299	300	301	-			
38																																						-	625	626
39										616	617	618									633										619	620	621					625	-	627
40																					628	629																626	627	-
41																							510	511																
42																							545	514	515															
43																							546	520	521															
44																							524																	
45																								547	548															
46										525	529										612	549	553								362	365	368							
47										531	532										613	537	538								363	366	369							
48										540	541										614	543	544	554	555						364	367	370							
49								550	551	552																					463	464	465							
50								553	554	555																					466	467	468		595		596			
51								559	560																						469	470	471							
52																							450	571	572															
53											454										452	576	577	451							577	583	589							
54											455	456									453	384	385								578	584	590					637		
55										422	423	424	425	426	427	428	429	430	431	432	433	434	435								579	585	591					638	640	
56										436	437	438	439	440	441	442	443	444	445	446	447	448	449								580	586	592					639	641	
57								457	458	459																					581	587	593		597		598			
58								460	461	462																					582	588	594		599		600			
60																						615																622	623	624

CALC	3/31/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION RADIATION CONDUCTOR MATRIX - ANALYSIS B TEST B-1	D2-90709 -1
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APPR				THE BOEING COMPANY SEATTLE, WASHINGTON 98124	PAGE
APPR					

RADIATION CONDUCTOR MATRIX (CONTINUED)

NODE (j)	NODE (l) 41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	60
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8									350	353	359						457	460	
9									351	354	360						458	461	
10						328	331	340	352	355					422	436	459	462	
11						329	332	341					454	455	423	437			
12														456	424	438			
13															425	439			
14															426	440			
15															427	441			
16															428	442			
17															429	443			
18															430	444			
19															431	445			
20															432	446			
21						612	613	614					452	453	433	447			
22						349	337	343					376	384	434	448			615
23	310	345	346	324		333	338	344				450	377	385	435	449			
24	311	314	320		347			334				371	451						
25		315	321		348			335				372							
26																			
27																			
28																			
29																			
30																			
31						362	363	364	463	466	469		577	578	579	580	581	582	
32						365	366	367	464	467	470		583	584	585	586	587	588	
33						368	369	370	465	468	471		589	590	591	592	593	594	
34																			
35										595							597	599	
36																			
37										596							598	600	
38														637	638	639			622
39															640	641			623
40																			624
41	-			312		313						373							
42		-		316	317		318					374							
43			-		322			323				375	379						
44	312	316		-	325	326	327												
45		317	322	325	-		339	330					380						
46	313			326		-							381	388	601	604			630
47		318		327	339		-						382	389	602	605			631
48			323		330			-					383	390	603	606			632
49									-	357	358							609	
50									357	-	356						607	610	
51									358	356	-						608	611	
52	373	374	375									-							
53			379		380	381	382	383					-						634
54						388	389	390						-					635
55						601	602	603							-				636
56						604	605	606								-			
57										607	608						-		
58									609	610	611							-	
60						630	631	632					634	635	636				-

CALC		3/31/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION RADIATION CONDUCTOR MATRIX ANALYSIS B - TEST B-1	D2-90709 -1
CHECK						
APPR					THE BOEING COMPANY SEATTLE, WASHINGTON 98124	PAGE 93
APPR						

RADIATION CONDUCTOR MATRIX (CONTINUED)

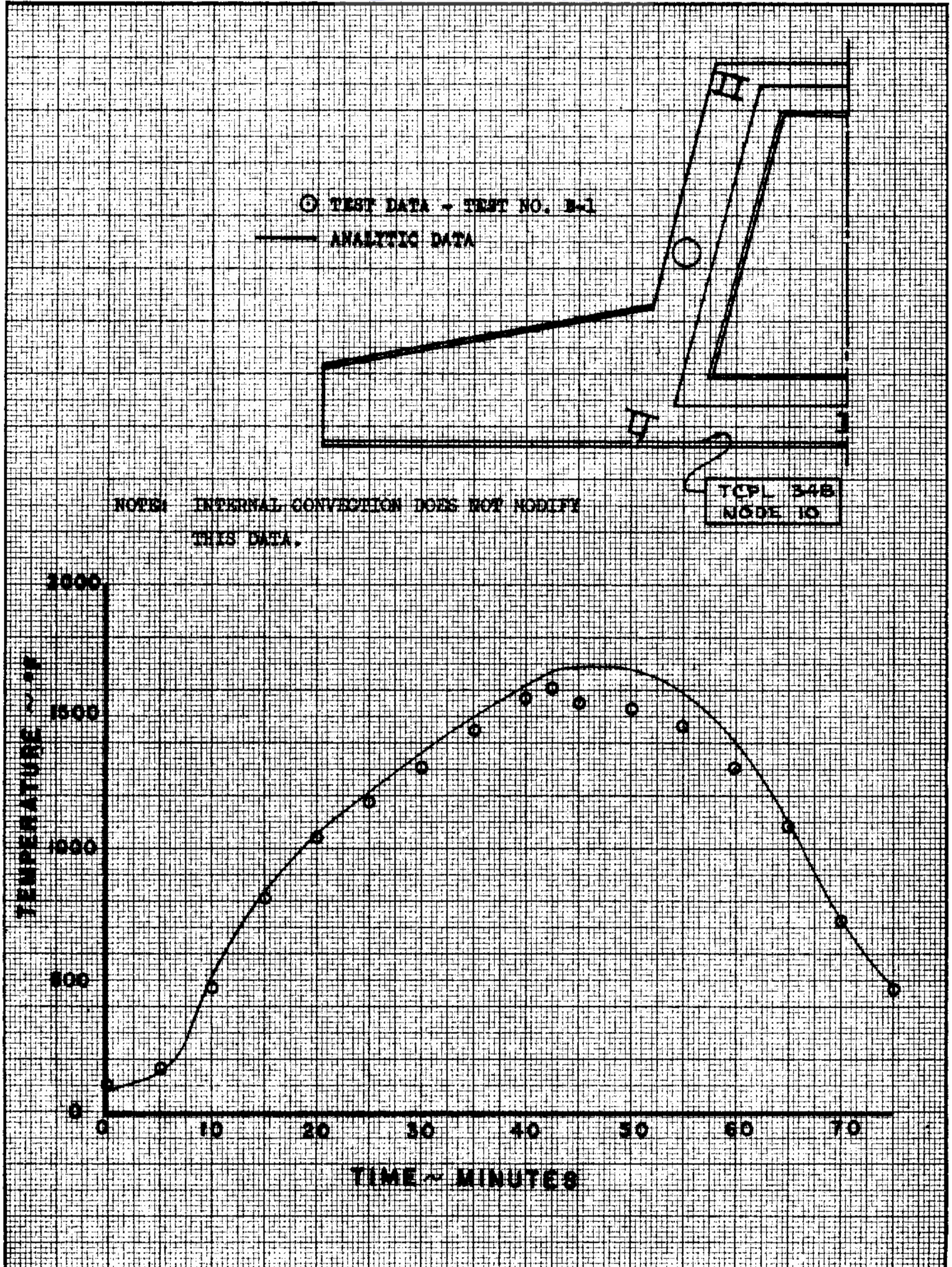
NODE (j)	NODE (i)						
	92	93	94	95	96	97	98
92	-	480	481	482	483	484	485
93	480	-	486	487	488	489	490
94	481	486	-	491	492	493	494
95	482	487	491	-	495	496	497
96	483	488	492	495	-	498	499
97	484	489	493	496	498	-	
98	485	490	494	497	499		-

RADIATION CONDUCTORS - ANALYSIS B - TEST B-1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
101	4.40	179	2.70	244	.0849	295	0
102	6.00	180	6.00	245	.30	296	.324
103	5.00	181	6.40	246	.0274	297	.324
104	5.70	182	6.60	247	.01	298	.005
105	6.00	183	6.00	248	0	299	0
106	6.00	188	.0426	249	0	300	0
107	6.00	189	.0971	250	.01	301	.305
109	.018	190	.2481	251	.0601	310	.4036
110	.022	191	.8195	252	.2203	311	.70
118	.005	192	3.7927	253	.0375	312	.2995
119	.075	196	.1812	254	.0045	313	.1969
120	.150	197	.3063	255	0	314	.9124
121	.010	198	.4947	256	.0072	315	.088
128	.090	199	.4384	257	.25	316	.3533
129	.380	200	6.5794	258	.1056	317	.3473
130	.050	201	.27	259	.0357	318	.3037
131	0	202	.010	260	.0178	320	.6967
132	0	203	.1335	261	.084	321	.10
135	.0227	204	.187	262	.0893	322	.2991
136	.069	205	.219	263	.0887	323	.1969
137	.1571	206	.1194	264	.185	324	.901
138	.5152	207	4.6411	265	.26	325	.8081
139	1.450	208	4.50	266	.04	326	.2995
140	1.370	209	5.30	267	.035	327	.3473
145	.0467	210	5.6427	268	.1348	328	0
146	.135	211	5.8096	269	.765	329	.0023
147	.4247	212	5.6382	270	.636	330	.2995
148	1.4496	213	4.6227	271	.0134	331	.0023
149	2.0597	221	.0023	272	.0038	332	0
150	.9313	222	.0031	273	.0018	333	.605
153	.1327	223	0	274	.0143	334	.110
154	.3207	224	.400	275	.0085	335	.010
155	1.3698	225	.0536	276	.01	337	.1377
156	2.2529	226	.0136	277	.0025	338	.31
157	1.0789	227	.0059	278	.0117	339	.3533
158	.3269	228	.0146	279	.5123	340	.009
162	1.038	229	.0101	280	.1671	341	0
163	.6218	230	.0042	281	.008	343	.1498
164	2.4142	231	.0033	282	0	344	.175
165	1.0988	232	.0038	283	0	345	.03
166	.3312	233	.0026	284	.0350	346	.01
167	.1163	234	.0108	285	.0377	347	.03
170	.4513	235	.485	286	.0500	348	.08
171	.2512	236	.015	287	.0600	349	.0467
172	.1166	237	.0846	288	.03	350	.157
173	.0556	238	.2701	289	.2976	351	.0282
174	.791	239	.0061	290	.324	352	.005
175	.1362	240	.0025	291	.324	353	.15
176	.0537	241	.0009	292	.2976	354	.0855
177	.0222	242	0	293	.772	355	.04
178	3.00	243	.012	294	.272	356	.2839

RADIATION CONDUCTORS - ANALYSIS B TEST B-1 (CONTINUED)

COND. NO.	AF
357	.2322
358	.1762
359	.96
360	.01
362	.0038
363	0
364	0
365	.0159
366	.0201
367	.0159
368	.013
369	.0166
370	.0131
371	1.6250
372	5.0500
373	.0250
374	.0250
375	.0250
376	.975
377	1.5375
379	.2
380	.9104
381	.15
382	.3
383	.5
384	5.12
385	.875
388	.1549
389	.1541
390	.0687
422	.001
423	.18
424	.33
425	.18
426	.11
427	.08
428	.15
429	0
430	.02
431	.04
432	.18
433	1.688
434	.279
435	.0421
436	.08
437	.16
438	.41
439	.26
440	.17
441	.27
442	.3
443	.16
444	.33
445	.76
446	1.85
447	.762
448	.0144
449	0
450	.07
451	.24
452	.0163
453	.1583
454	0
455	.0313
456	.0009
457	.4562
458	3.7162
459	2.3749
460	2.5250
461	1.6817
462	.1343
463	.0008
464	.0008
465	.0005
466	.006
467	.009
468	.008
469	.001
470	.001
471	.001
480	.9612
481	1.1579
482	.3762
483	.1726
484	.8509
485	1.3811
486	.7328
487	.254
488	.1067
489	.2413
490	.4765
491	.992
492	.4517
493	.7534
494	1.7935
495	.4485
496	.933
497	1.6904
498	1.5213
499	.5085
577	0
578	.0115
579	.0518
580	.24
581	.0084
582	.0011
583	.0018
584	.019
585	.0454
586	.3176
587	.0395
588	.0034
589	.0035
590	.0122
591	.0191
592	.2278
593	.1034
594	.0051
595	.048
596	.103
597	.17
598	.1005
599	.05
600	.0259
601	.0268
602	.0272
603	.0118
604	.0026
605	.0073
606	.0039
607	.0702
608	.0174
609	.5960
610	.3
611	.275
612	.0051
613	.0135
614	.0095
615	.65
616	.04
617	.12
618	.01
619	.04
620	.06
621	.04
622	.413
623	.5919
624	.4196
625	.4108
626	.5884
627	.4261
628	1.03
629	.38
630	.04
631	.10
632	.04
633	1.371
634	.0831
635	.62
636	.01
637	.48
638	.98
639	.02
640	.49
641	.18



NOTE: INTERNAL CONVECTION DOES NOT MODIFY THIS DATA.

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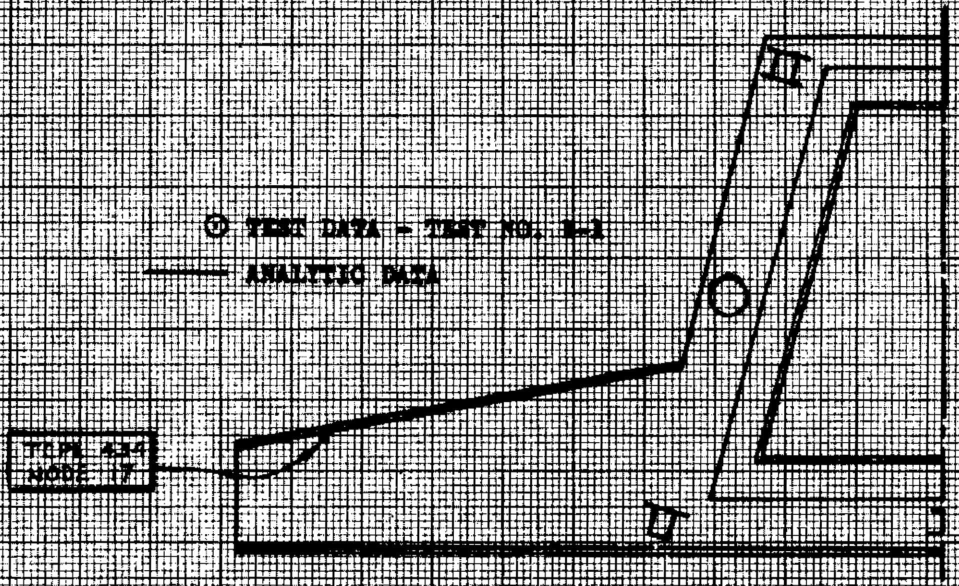
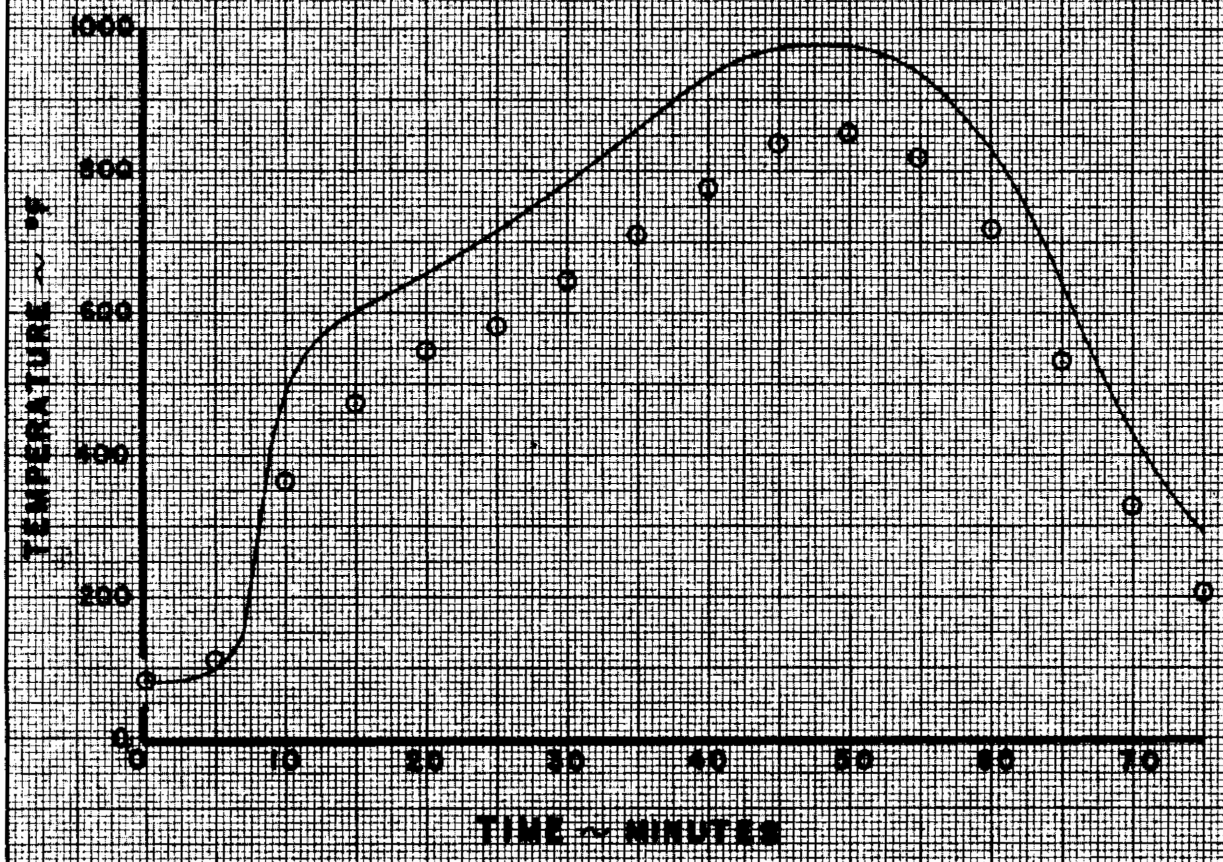
CHECK						
APR					THE BOEING COMPANY	PAGE 97
APR						



NOTE: INTERNAL CONVECTION DOES NOT MODIFY THIS DATA.



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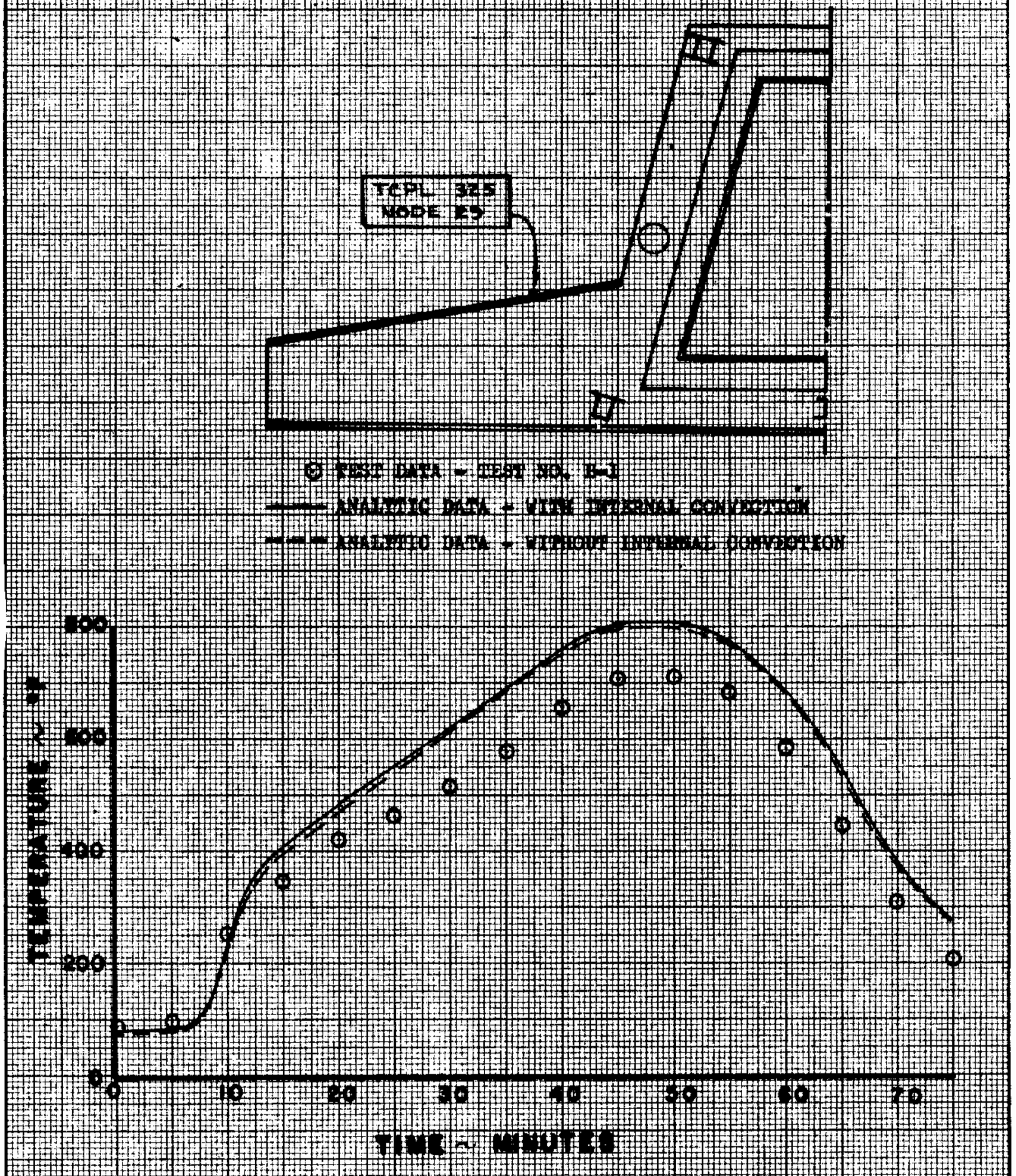
CHECK						
APR					THE BOEING COMPANY	PAGE 98
APR						



CALC	OFrench	3/23/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS B - BLOCKED AFT BODY
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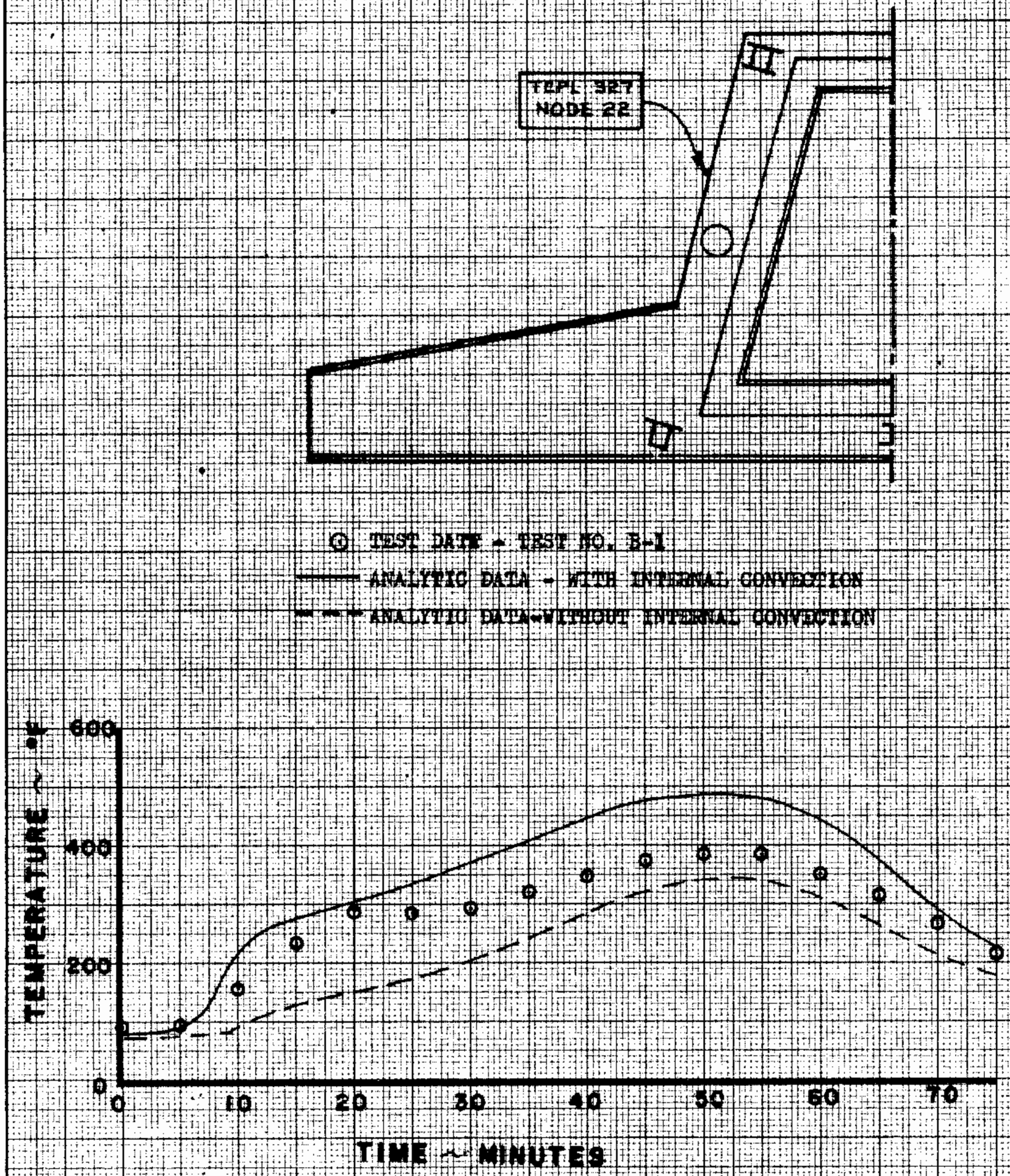

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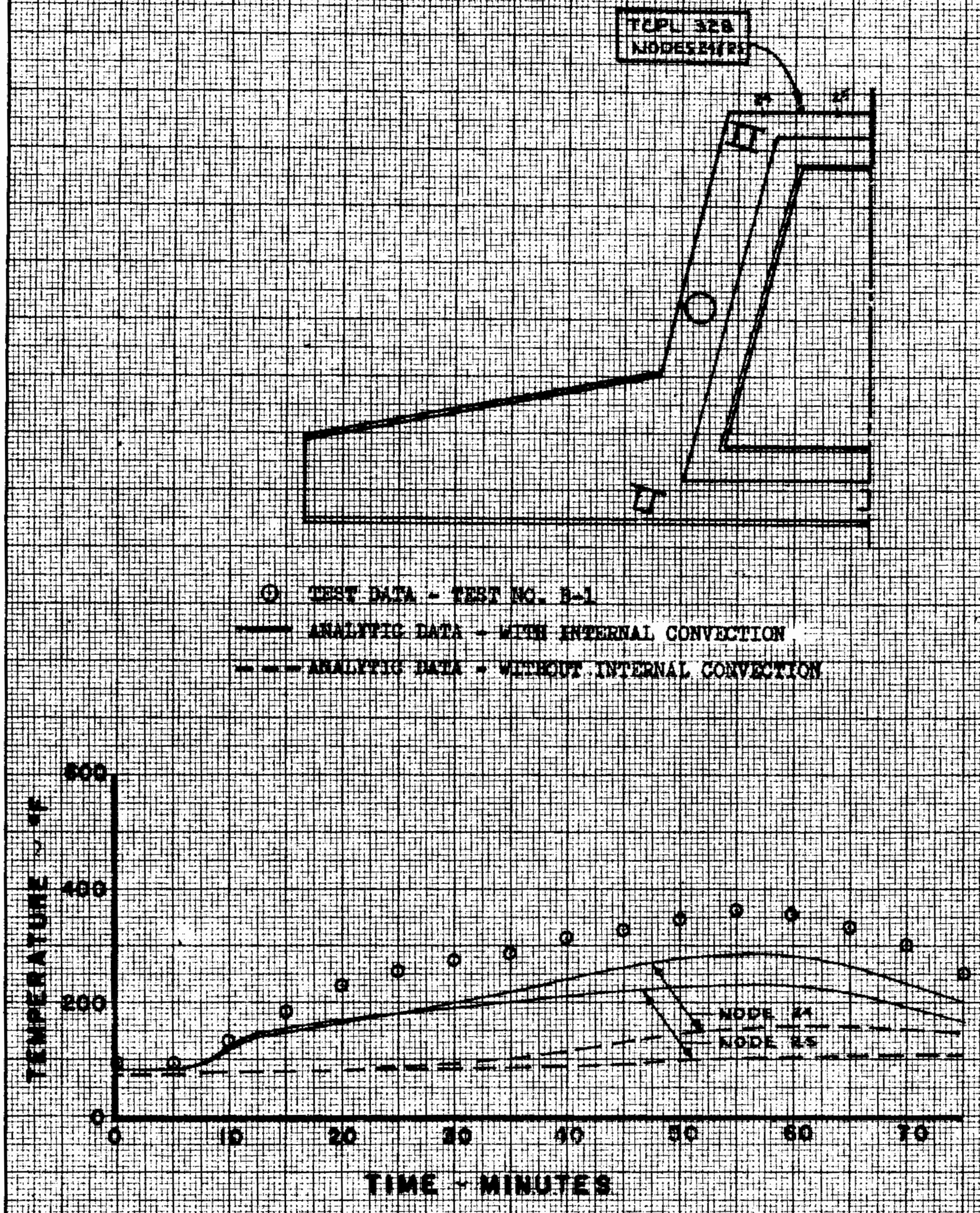

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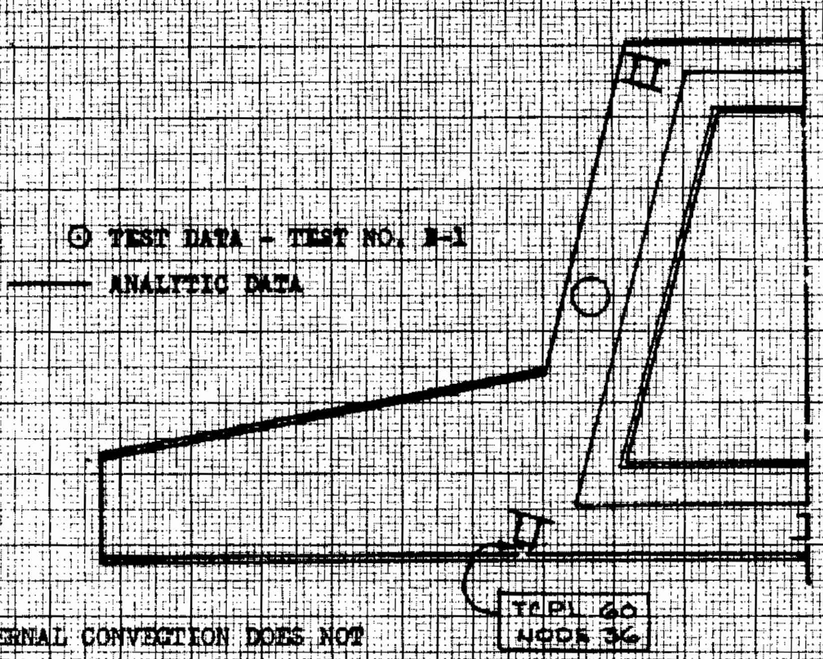
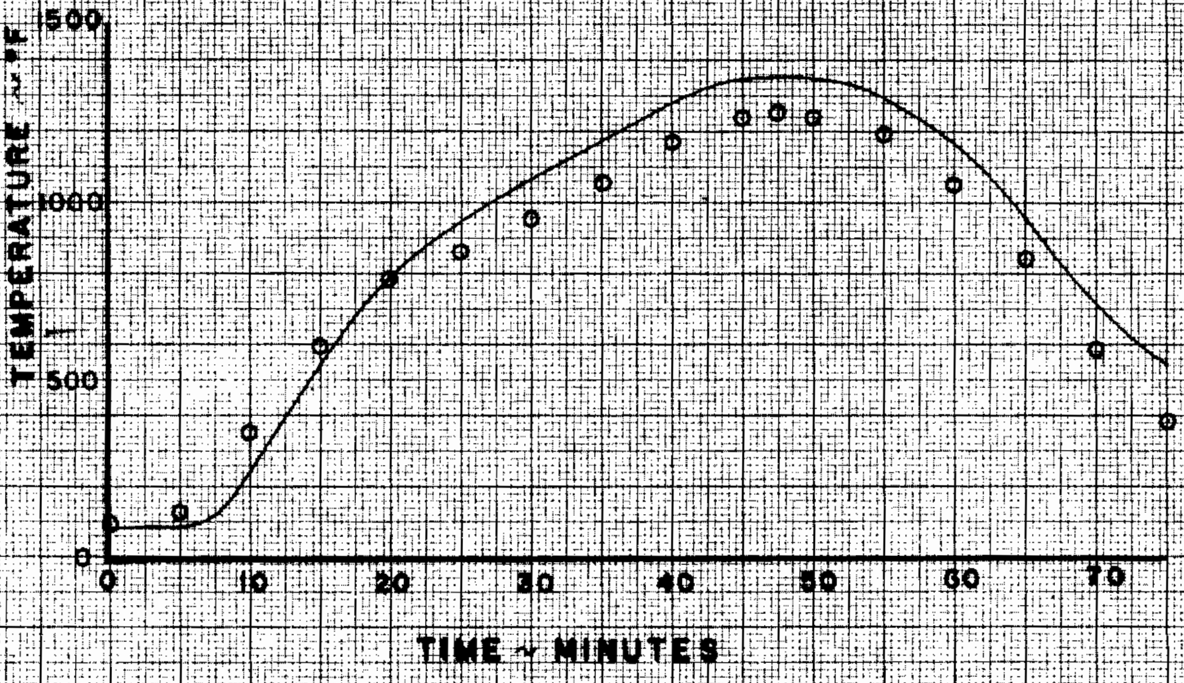
CHECK						
APR					THE BOEING COMPANY	PAGE 101
APR						



⊙ TEST DATA - TEST NO. B-1

——— ANALYTIC DATA

NOTE: INTERNAL CONVECTION DOES NOT MODIFY THIS DATA.



CALC		3/23/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS B - BLOCKED AFT BODY
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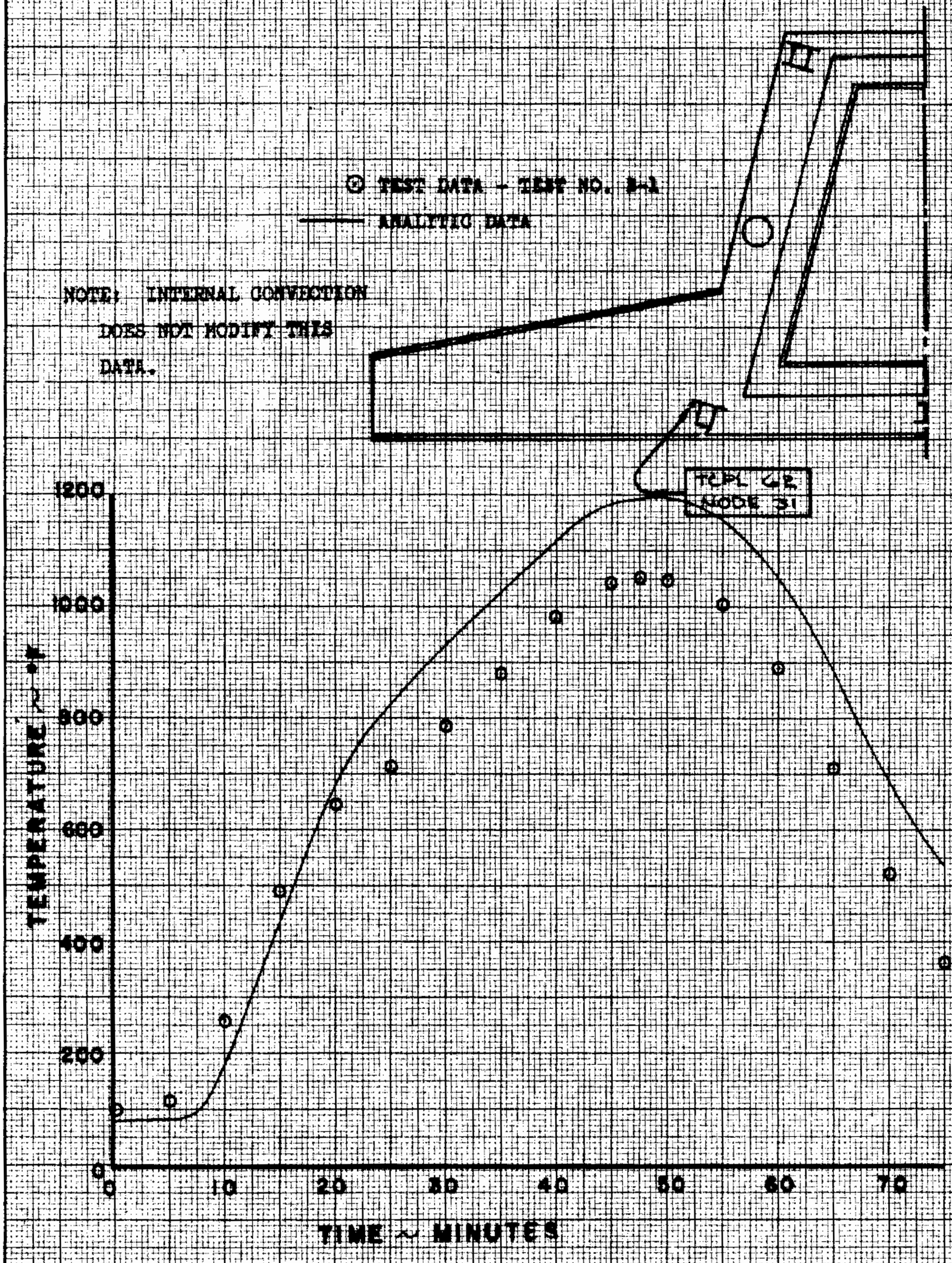
APR					THE BOEING COMPANY

D2-90709
-1



NOTE: INTERNAL CONVECTION DOES NOT MODIFY THIS DATA.

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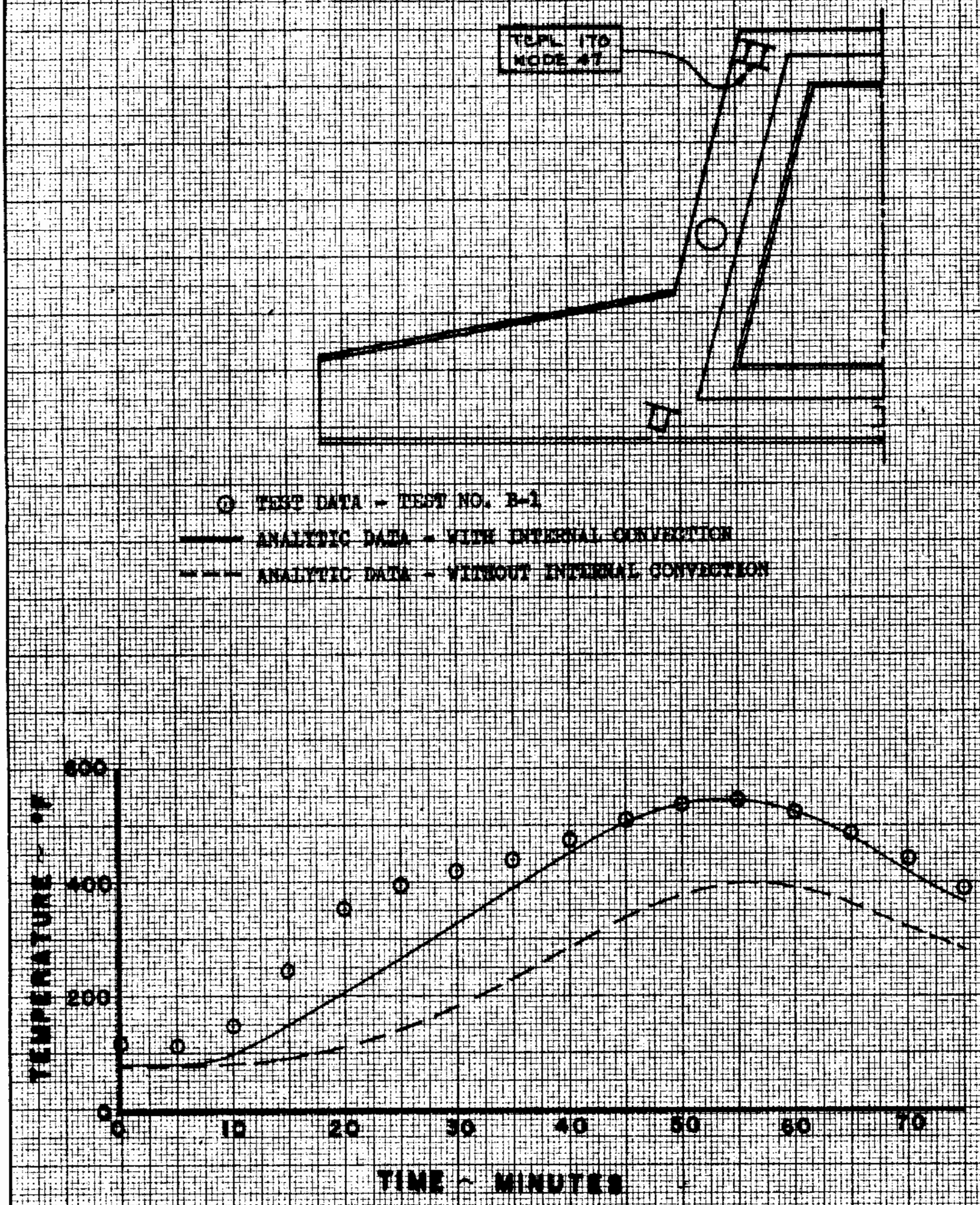
APR					THE BOEING COMPANY	PAGE 103
APR						



CALC Drench 3/23/65
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DATE

HOT STRUCTURES THERMAL CORRELATION
ANALYSIS B - BLOCKED
AFT BODY

THE BOEING COMPANY

D2-90709
-1

4.3.3 Discussion (Analysis B)

Correlation of this analysis with test data is not quite as close as that of Analysis A.

Discrepancies from Test 5.1 data are largest on the trusswork (longerons and diagonal). Much of this is due to instrumentation locations—many of which were somewhat removed from the analysis cross-section. Hot and cold spots due to the test heat lamp system also contribute to these differences.

The blocked case (Test B1) provided severe analytic discrepancies on the upper fuselage panels and the upper longeron. It was concluded that internal convective currents, which are normally insignificant compared to internal radiation, had caused the differences. This does not imply that they actually convect more heat than in an unblocked case, just that the internal radiation effects are so reduced due to the blockage that convection becomes significant. Currents of this type are not of interest in a reentry vehicle, since air density is reduced. Only in a sea level test, where no upper surface heating system is used, would such convection become apparent. Due to these facts and the extreme complexity of analytically predicting such currents, no major attempt was made to include them. A very simple approach was used to indicate order-of-magnitude effects (see Section 4.3.1, page 58). The results of this are shown along with those assuming no convection. Note that the test data is bracketed in some cases. Much of the upper surface data from this test exhibits a peculiar hump or flat spot from about 10 to 30 minutes which is not fully explainable. It is considered possible that transient internal convection is occurring during this time region then stabilizing.

An interesting detail addition was necessary. The lower surface panel attachment dips at the lower longeron are normally neglected. Due, however, to the large gradient between body and wing panels (1775°F to 1300°F respectively) for Test B1, the longeron became highly sensitive to the details of the standoff clip. Therefore, a node representing the clips and their associated radiation baffle effects was added in both Analyses A and B.

4.4 CENTRAL WING TWO-DIMENSIONAL ANALYSIS (ANALYSIS C) (See Page 7)

4.4.1 Analysis Description

This analysis represents a more detailed approach to the wing region than Analysis B. Cross-panel gradients were somewhat higher in this region for the X-20A, thus requiring smaller nodes. A similar wing cross-section analysis was made during the X-20 program at Body Station 299.

The assumptions shown in Section 4.1, page 8, apply to this analysis except that the wing intercostal beams are included and external convection is excluded. Boundary conditions for Test 5 are referenced on page 107. Schematics of the conductor system to the lower and upper intercostal beams are shown for general interest on pages 110 and 111 (Figures 8 and 9), respectively.

The nodal system is shown in Figure 7, page 109. The various constants, conductors, capacitors, etc., are shown on pages 112 through 115.

Correlation of this analysis, for Test Series 5 only, is shown on pages 116 through 126. Note that usage of three tests (5.1, 5.4, 5.6) was necessary for sufficient data.

4.4.2.1 ANALYSIS C CORRELATION

CENTRAL WING TWO-DIMENSIONAL ANALYSIS

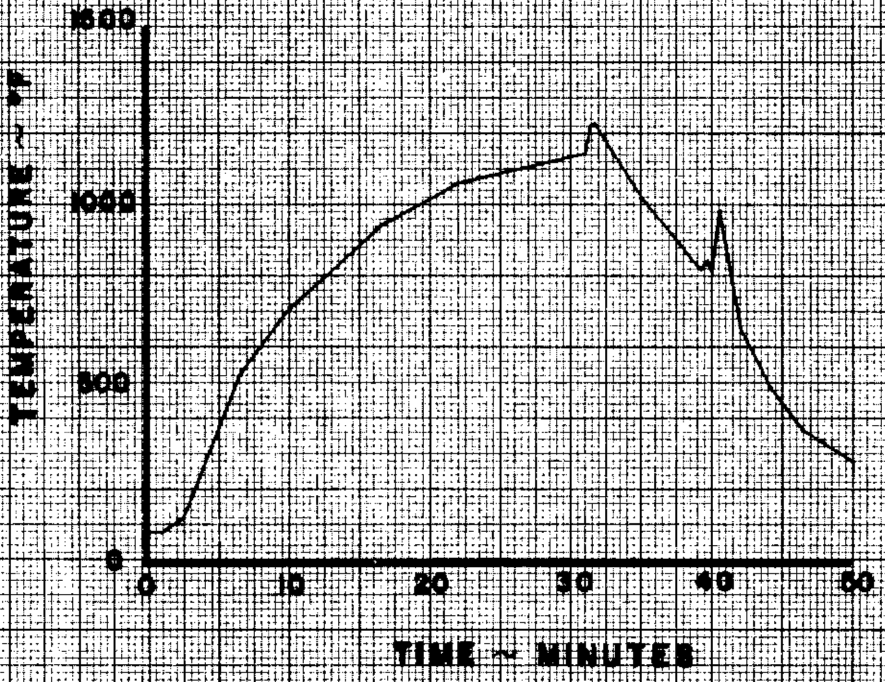
TEST SERIES: 5 CONDITIONS: 5.1
5.4
5.6

BOUNDARY NODES	SOURCE	PAGE
1	THERMOCOUPLE #311 TEST 5.1	62
2	THERMOCOUPLE #311 TEST 5.1	62
3	THERMOCOUPLE #C-30 TEST 5.1	63
4	THERMOCOUPLE #C-30 TEST 5.1	63
5	THERMOCOUPLE #309 TEST 5.1	64
6	THERMOCOUPLE #309 TEST 5.1	64
7	THERMOCOUPLE #309 TEST 5.1	64
25	RESULTS OF ANALYSIS B	108
41	ROOM TEMPERATURE	

RESULTS OF ANALYSIS B TEST 5.1:

46.8% NODE 8
3.5% NODE 13
4.9% NODE 15
8.2% NODE 18
36.6% NODE 22

DRIVE BOUNDARY NODE:
25 ANALYSIS C TEST 5.1



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APR						
APR					THE BOEING COMPANY	PAGE 108

HOT STRUCTURES THERMAL CORRELATION

ANALYSIS C
2-DIMENSIONAL WING
NODAL DIAGRAM

DRIVEN NODES:
1
2
3
4
5
6
7
25
41

NODES 1 THRU 14 ARE HS-25
NODES 15 THRU 24 ARE RENE' 41
NODES 25 THRU 40 ARE RENE' 41
NODE 41 IS A BLACK BODY

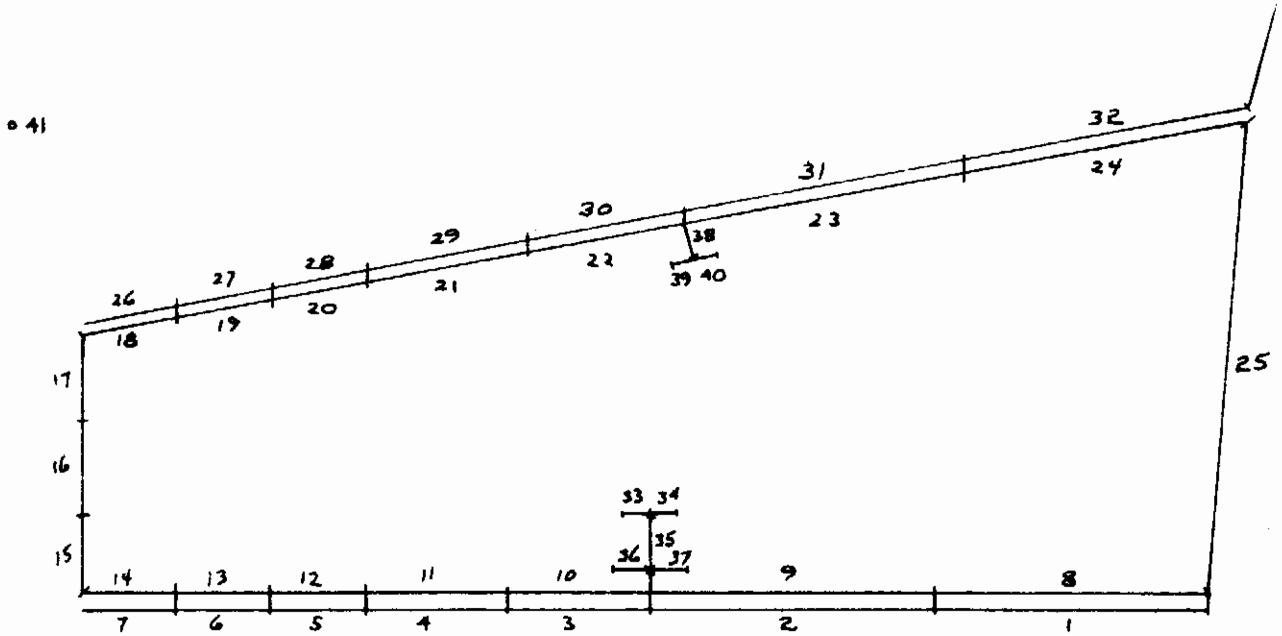

FIGURE 7

LOWER TRUSS RADIATION
NODES 33 TO 37

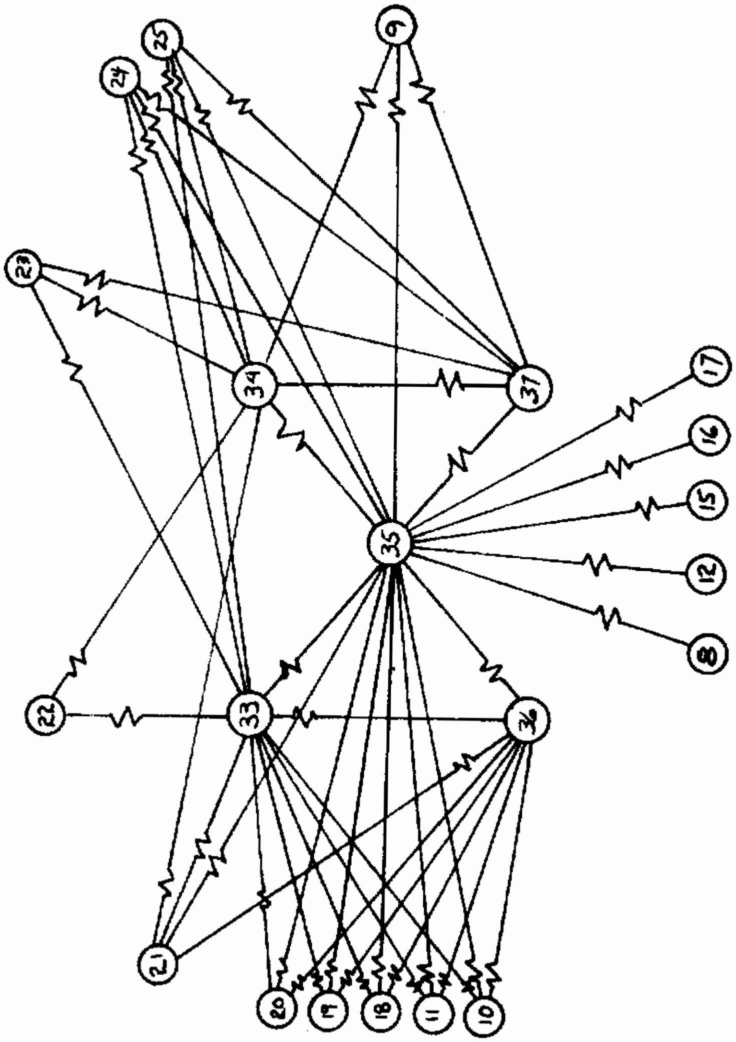

FIGURE 8

UPPER TRUSS RADIATION
NODES 38 - 40

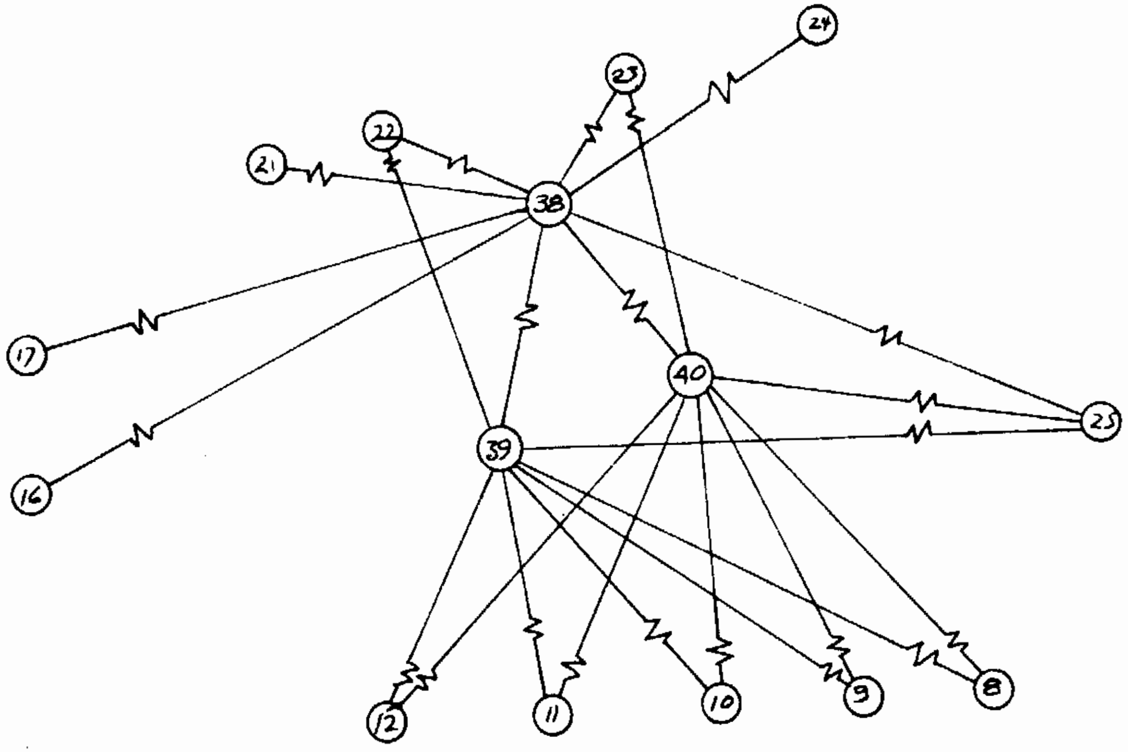

FIGURE 9

CAPACITORS - ANALYSIS C

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	HS-25	DRIVEN	--
2	↓	↓	↓
3			
4			
5			
6			
7		DRIVEN	--
8		0.06	1.86×10^{-3}
9		0.06	1.86
10		0.03	0.93
11		0.03	0.93
12		0.02	0.62
13		0.02	0.62
14	HS-25	0.018	0.558
15	RENE' 41	0.02	0.80
16	↓	0.02	0.80
17		0.02	0.80
18		0.018	0.619
19		0.02	0.688
20		0.02	0.688
21		0.035	1.204
22		0.033	1.135
23		0.059	2.030
24	RENE' 41	0.061	2.098
25	RENE' 41	DRIVEN	--
26	RENE' 41	0.02	0.688
27	↓	0.02	0.638
28		0.02	0.688
29		0.035	1.204
30		0.034	1.170
31		0.06	2.064
32		0.061	2.098
33		0.0125	0.50
34		0.0125	0.50
35		0.100	4.00
36		0.032	1.28
37		0.032	1.28
38		0.04	1.376
39		0.01	0.344
40	RENE' 41	0.01	0.344×10^{-3}
41	BLACK BODY	DRIVEN	--

CONDUCTOR MATRIX

NODE (j)	NODE (i)																																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	-							51																																	
2		-							52																										c18						
3			-							53																									c19						
4				-							54																														
5					-							55																													
6						-							56																												
7							-							57																											
8	51							-	c1								58	59	60	61	62	63	64	65	66										198				225	230	
9		52						c1	-										67	68	69	70	71	72	73									184	199		185		226	231	
10			53							-	c2				74	75	76	77	78	79	80	81	82										170		200	172			227	232	
11				54						c2	-	c3			83	84	85	86	87	88	89	90	91	92	93								171		201	173			228	233	
12					55						c3	-	c4		94	95	96	97	98	99	100	101	102	103	104										202				229	234	
13						56						c4	-	c5	105	106	107	108	109	110	111	112	113	114	115																
14							57						c5	-	116	117	118	119	120	121	122	123	124	125	126																
15										74	83	94	105	116	-	c6		127	128	129	130	131	132	133	134										203						250
16										75	84	95	106	117	c6	-	c7	135	136	137	138	139		145	146										204			221			251
17								558		76	85	96	107	118		c7	-	140	141	142	143	144			147										205			222			252
18								59		77	86	97	108	119	127	135	140	-	c8						148	155							174		206	214					
19								60	67	78	87	98	109	120	128	136	141	c8	-	c9					149		156						175		207	215					
20								61	68	79	88	99	110	121	129	137	142		c9	-	c10				150			157					176		208	216					
21								62	69	80	89	100	111	122	130	138	143			c10	-	c11			151				158				177	186	209	217		191			
22								63	70	81	90	101	112	123	131	139	144				c11	-			152					159			178	187				192	235		
23								64	71	82	91	102	113	124	132								-	c12	153						160		179	188			218	193		237	
24								65	72		92	103	114	125	133	145							c12	-	154							161	180	189	210		219	194			
25								66	73		93	104	115	126	134	146	147	148	149	150	151	152	153	154	-								181	190	211		220	195	236	238	
26																		155								-	c13														253
27																			156							c13	-	c14													254
28																				157							c14	-	c15												255
29																					158							c15	-	c16											256
30																						159							c16	-								c24			257
31																							160								-	c17						c25			258
32																								161							c17	-									259
33										170	171							174	175	176	177	178	179	180	181								-		①	183					
34									184												186	187	188	189	190									-	②		197				
35		c18	c19					198	199	200	201	202			203	204	205	206	207	208	209			210	211								①	②	-	③	④				
36										172	173							214	215	216	217												183		③	-					
37									185														218	219	220									197	④		-				
38																221	222				191	192	193	194	195					c24	c25							-	⑤	⑥	
39								225	226	227	228	229										235			236													⑤	-		
40								230	231	232	233	234											237		238													⑥		-	
41															250	251	252								253	254	255	256	257	258	259										-

NOMENCLATURE:

cXX = CONDUCTION CONDUCTOR NO. XX
XXX = RADIATION CONDUCTOR NO. XXX
Ⓧ = CONTAINS BOTH RADIATION AND CONDUCTION CONDUCTORS
① = 182 & c20
② = 196 & c21
③ = 212 & c22
④ = 213 & c23
⑤ = 223 & c26
⑥ = 224 & c27

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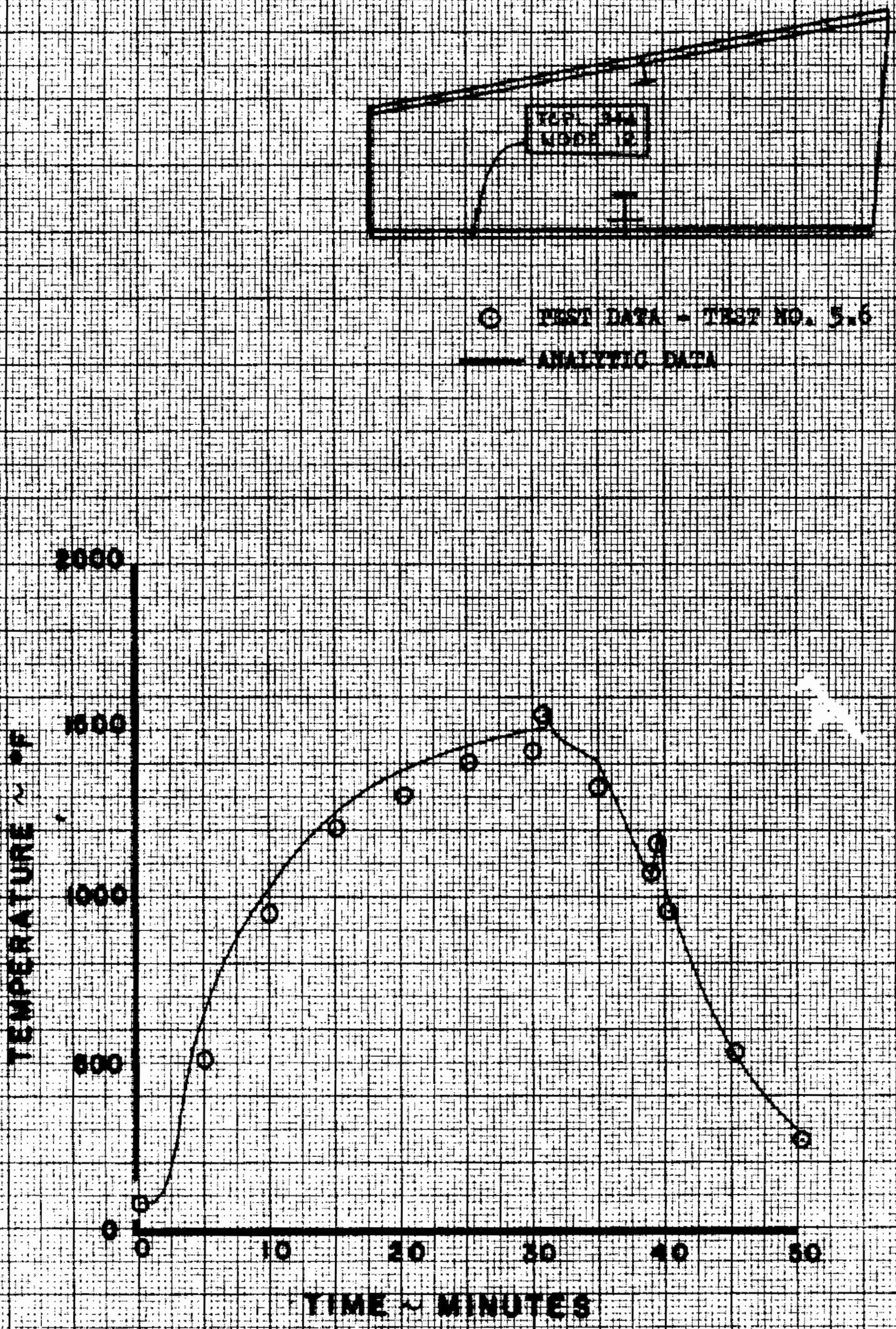
CONDUCTION CONDUCTORS - ANALYSIS C

CONDUCTOR	A/L
c1	2.916 x 10^{-3}
c2	5.833
c3	7.000
c4	8.750
c5	9,210
c6	6.000
c7	6.000
c8	6.315
c9	6.000
c10	4.363
c11	3.529
c12	2.000
c13	5.000
c14	5.000
c15	3.636
c16	2.898
c17	1.667
c18	8.333
c19	8.333
c20	21.276
c21	21.276
c22	19.512
c23	19.512
c24	20.000
c25	20.000
c26	16.000
c27	16.000 x 10^{-3}

RADIATION CONDUCTORS - ANALYSIS C

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
51	5.80	101	.1817	151	.1938	209	.0332
52	6.00	102	.0892	152	.0723	210	.0610
53	3.00	103	.0551	153	1.4030	211	.3700
54	3.00	104	.0609	154	2.9321	212	.2853
55	2.00	105	.1297	155	2.0396	213	.2853
56	2.00	106	.2412	156	2.0396	214	.0187
57	2.00	107	.1499	157	2.0396	215	.0307
58	.0242	108	.3123	158	3.4600	216	.0499
59	.0364	109	.3236	159	3.3850	217	.1414
60	.0518	110	.2526	160	5.9900	218	.1627
61	.0742	111	.2508	161	6.100	219	.0790
62	.2054	112	.1156	170	.1650	220	.0870
63	.2472	113	.0508	171	.0340	221	.0512
64	1.3639	114	.0397	172	.6351	222	.0550
65	1.6487	115	.0542	173	.0042	223	.1753
66	1.9368	116	.5240	174	.0098	224	.1895
67	.0357	117	.2184	175	.0174	225	.0719
68	.0921	118	.0791	176	.0317	226	.1591
69	.03836	119	.3454	177	.1121	227	.0561
70	.5750	120	.2636	178	.1526	228	.0494
71	1.5750	121	.1691	179	.1315	229	.0179
72	.9011	122	.1563	180	.0453	230	.0793
73	.9526	123	.0731	181	.0500	231	.1639
74	.0180	124	.0309	182	.2332	232	.0500
75	.0655	125	.0290	183	.1738	233	.0441
76	.0861	126	.0510	184	.1804	234	.0160
77	.0972	127	.0590	185	.6393	235	.3088
78	.1507	128	.1017	186	.0974	236	.0750
79	.2165	129	.0878	187	.1442	237	.3298
80	.5019	130	.1059	188	.1502	238	.0800
81	.4450	131	.0637	189	.0517	250	1.6250
82	.1400	132	.0220	190	.0700	251	2.0000
83	.0353	133	.0399	191	.0233	252	1.8000
84	.1184	134	.2327	192	.3575	253	2.0396
85	.1364	135	.1607	193	.4012	254	2.0396
86	.1896	136	.1768	194	.0145	255	2.0396
87	.2972	137	.1116	195	.2200	256	3.4600
88	.3992	138	.1115	196	.2332	257	3.385
89	.6973	139	.0582	197	.1738	258	5.990
90	.4473	140	.4332	198	.0513	259	6.100
91	.2527	141	.1210	199	.2073		
92	.1251	142	.0511	200	.1350		
93	.0390	143	.0455	201	.0949		
94	.0507	144	.0198	202	.0263		
95	.1434	145	.0216	203	.0863		
96	.1316	146	.3668	204	.0986		
97	.2207	147	.3359	205	.0735		
98	.2970	148	.0938	206	.0457		
99	.3044	149	.1104	207	.0523		
100	.3688	150	.1307	208	.0537		



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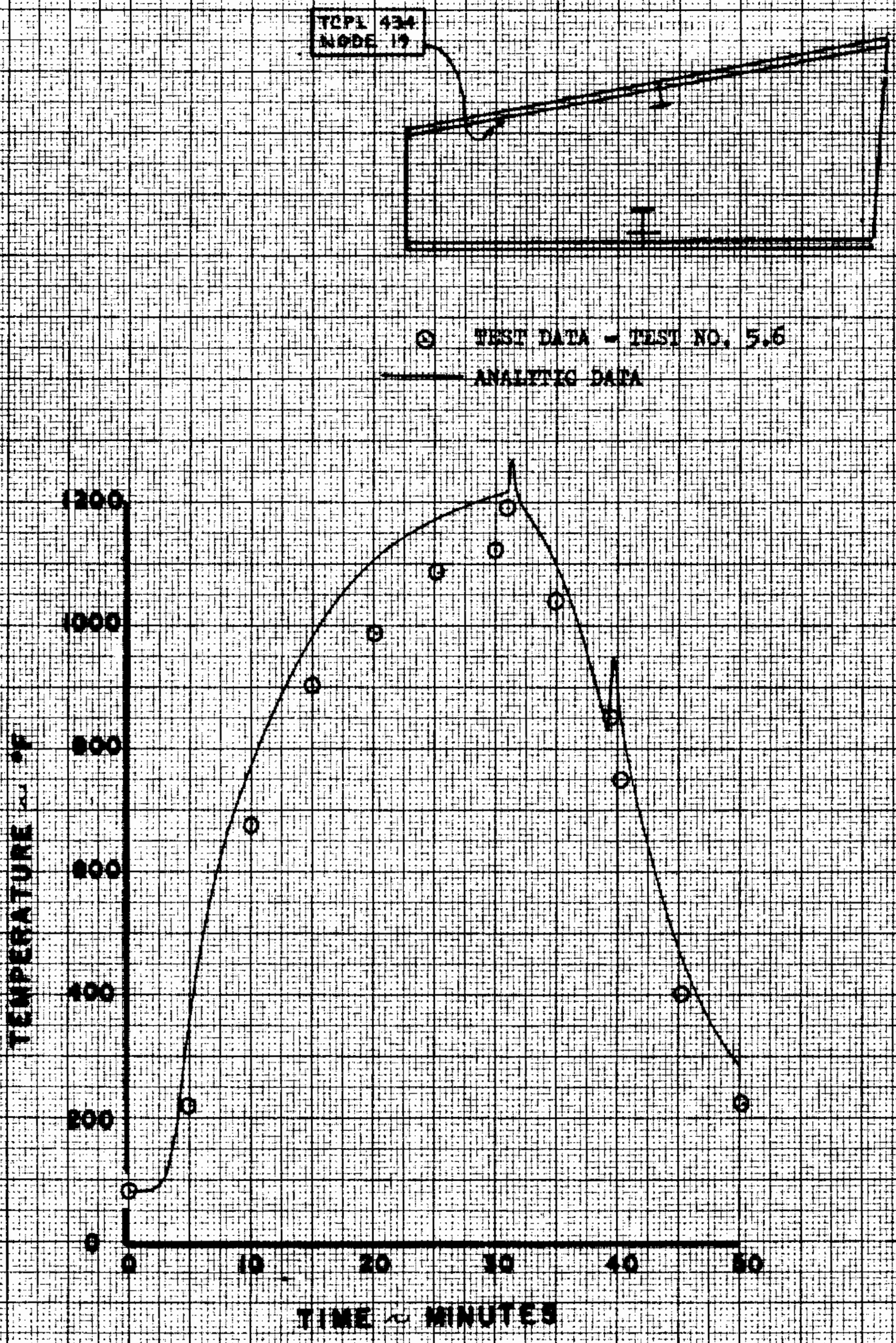

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AFT WING

D2-90709
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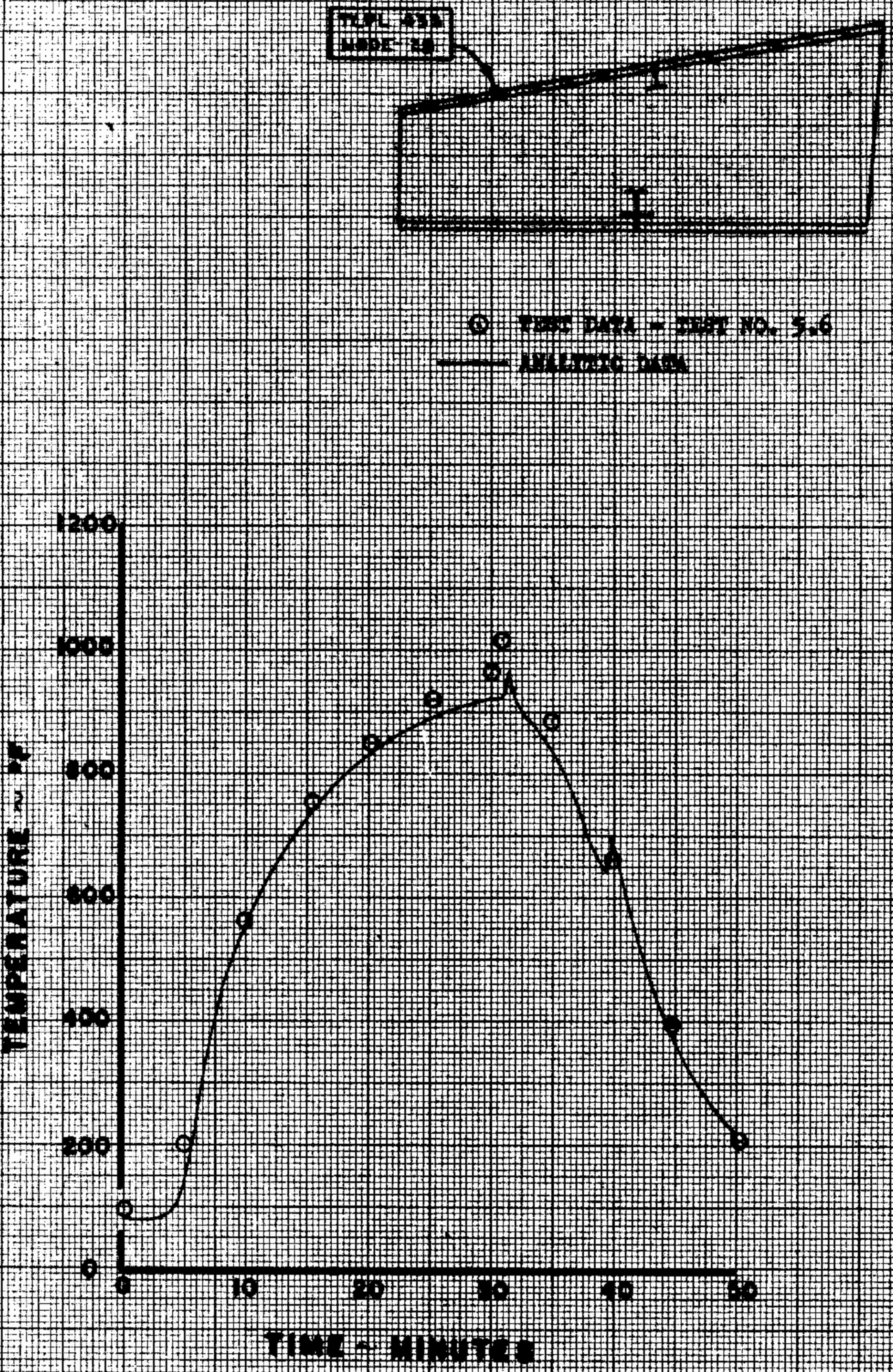

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS C
AFT WING

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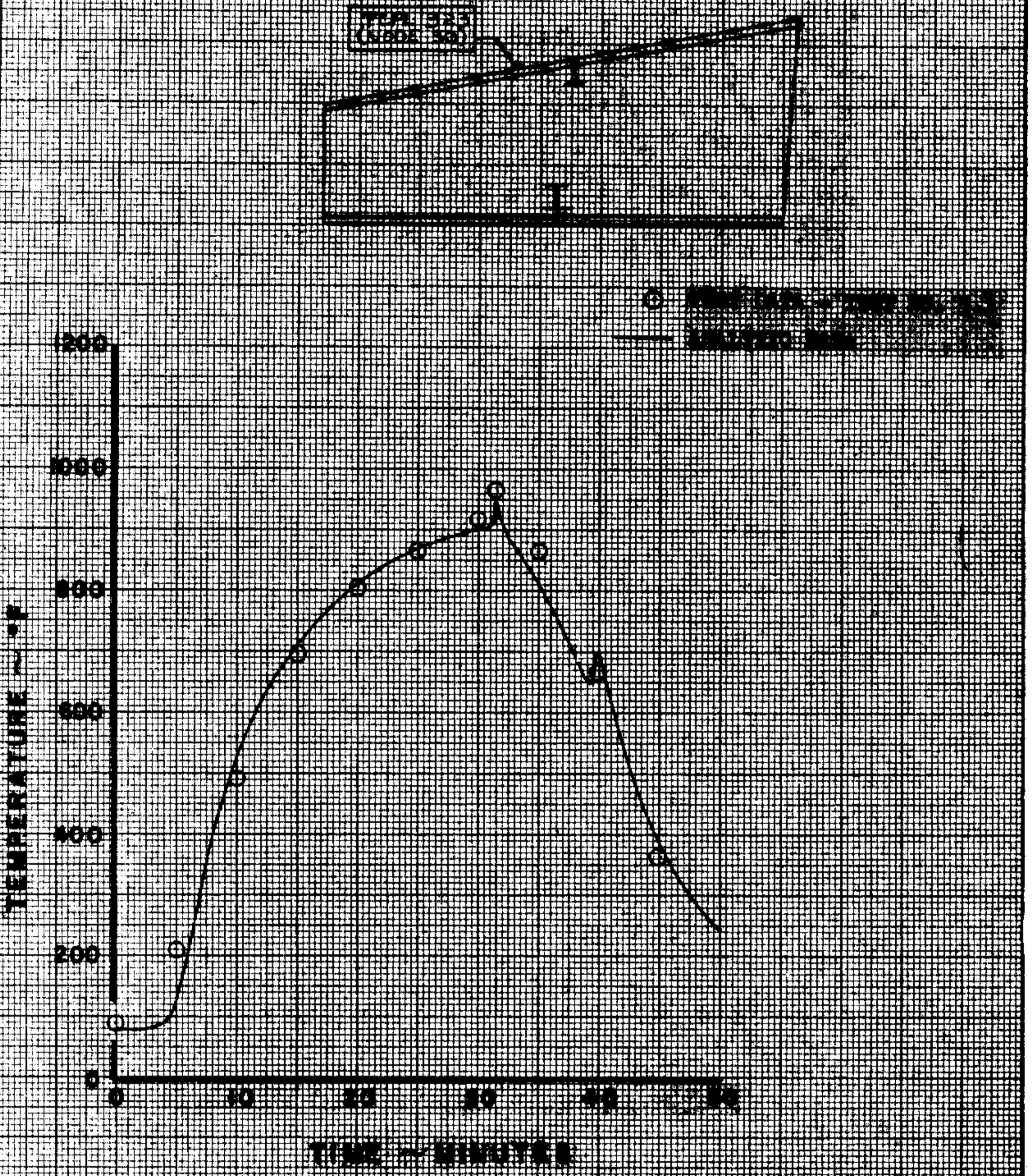

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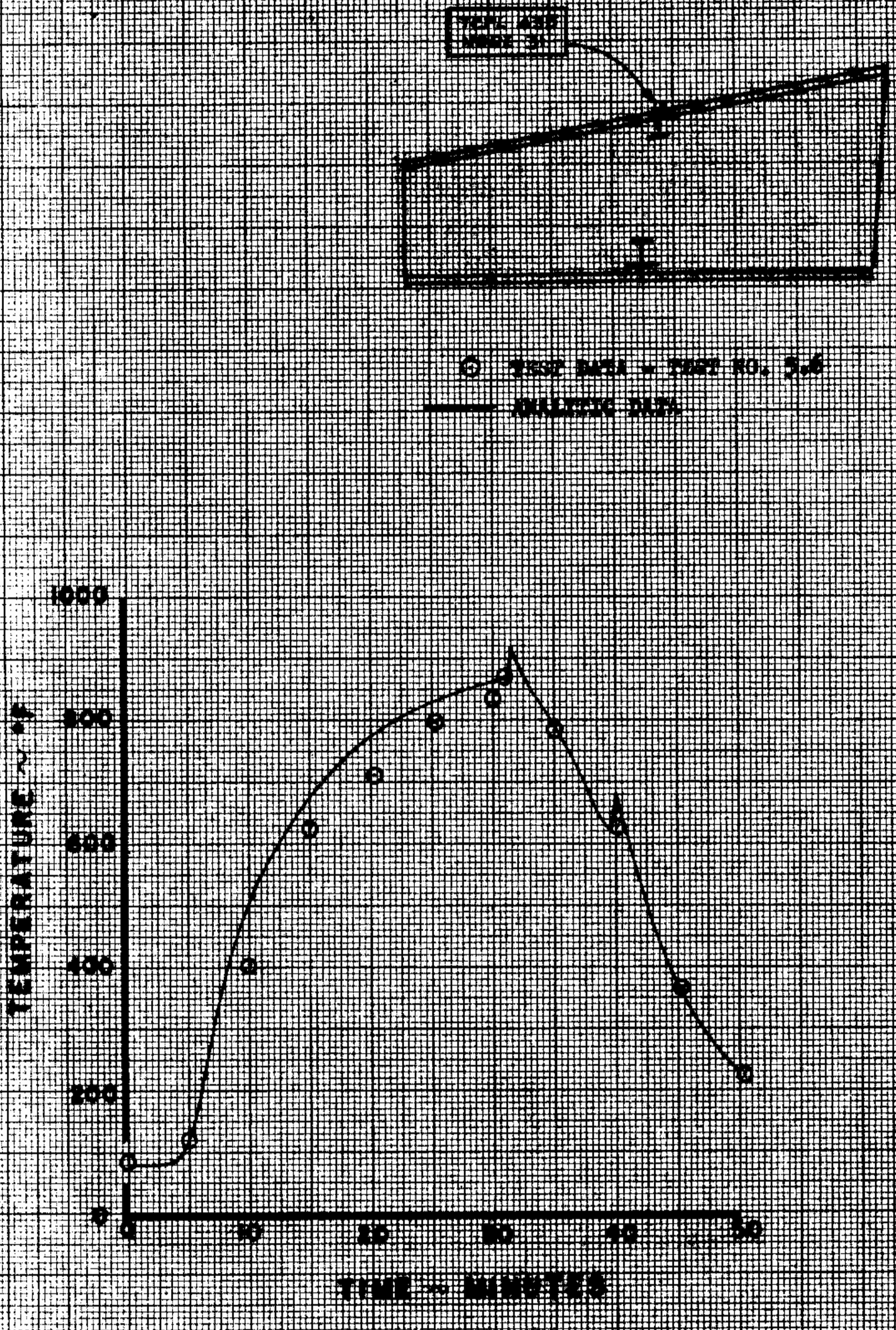
APR						



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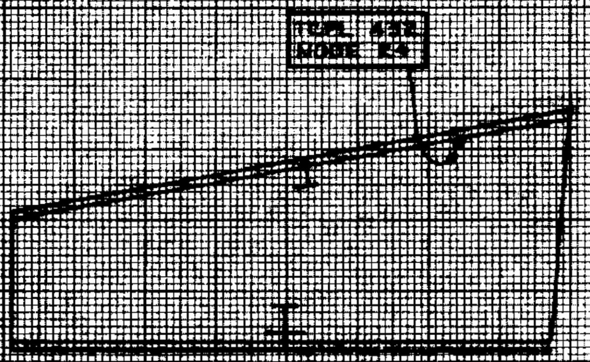

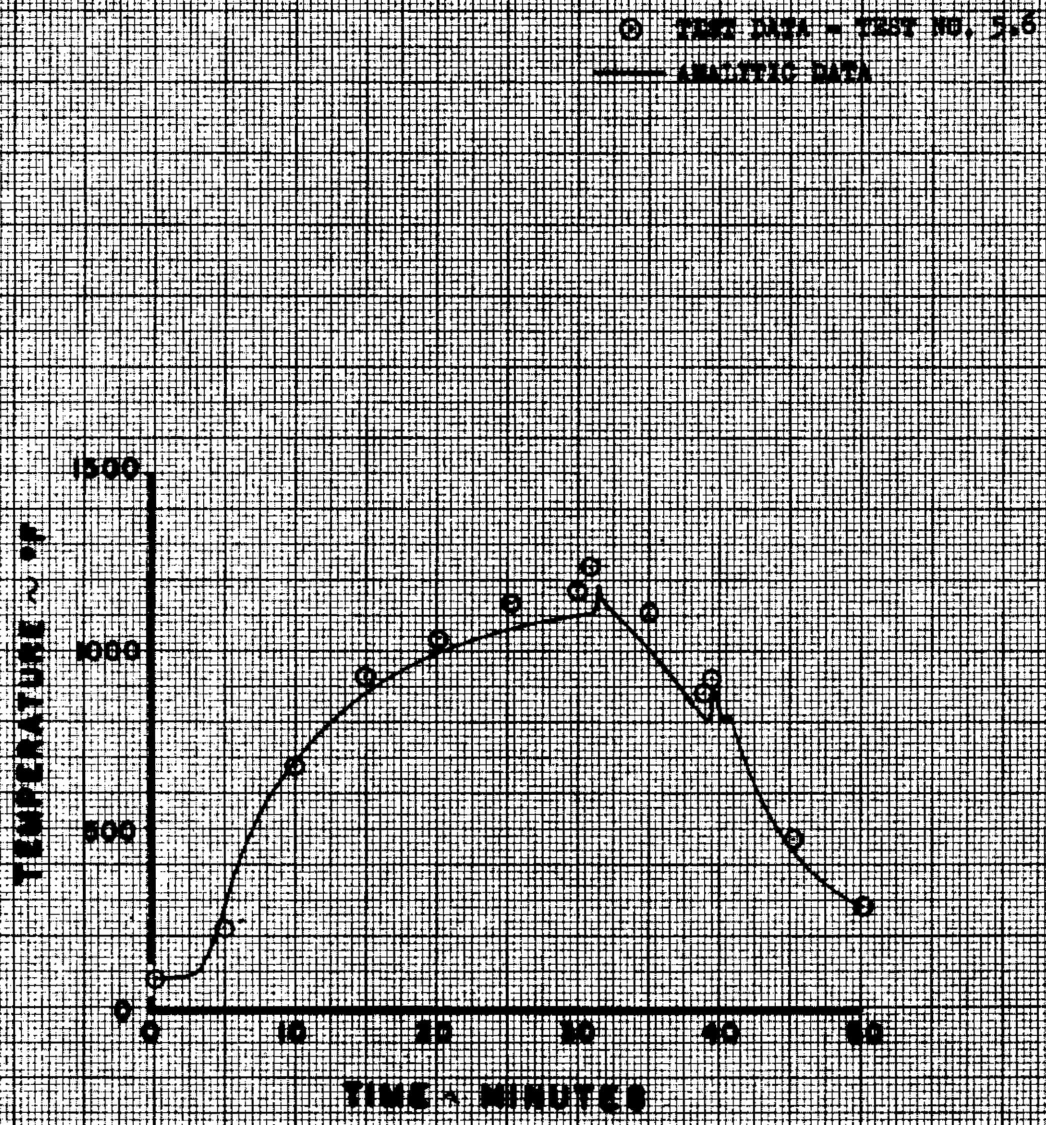

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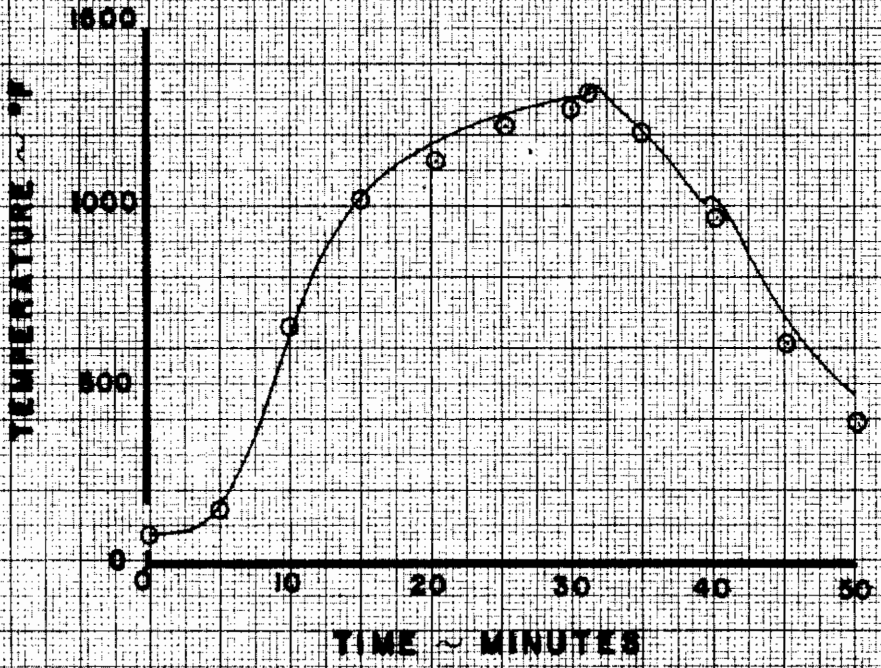
APR					THE BOEING COMPANY	PAGE 121

⊙ TEST DATA - TEST NO. 5.6

—— ANALYTIC DATA



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APR					THE BOEING COMPANY	PAGE 122
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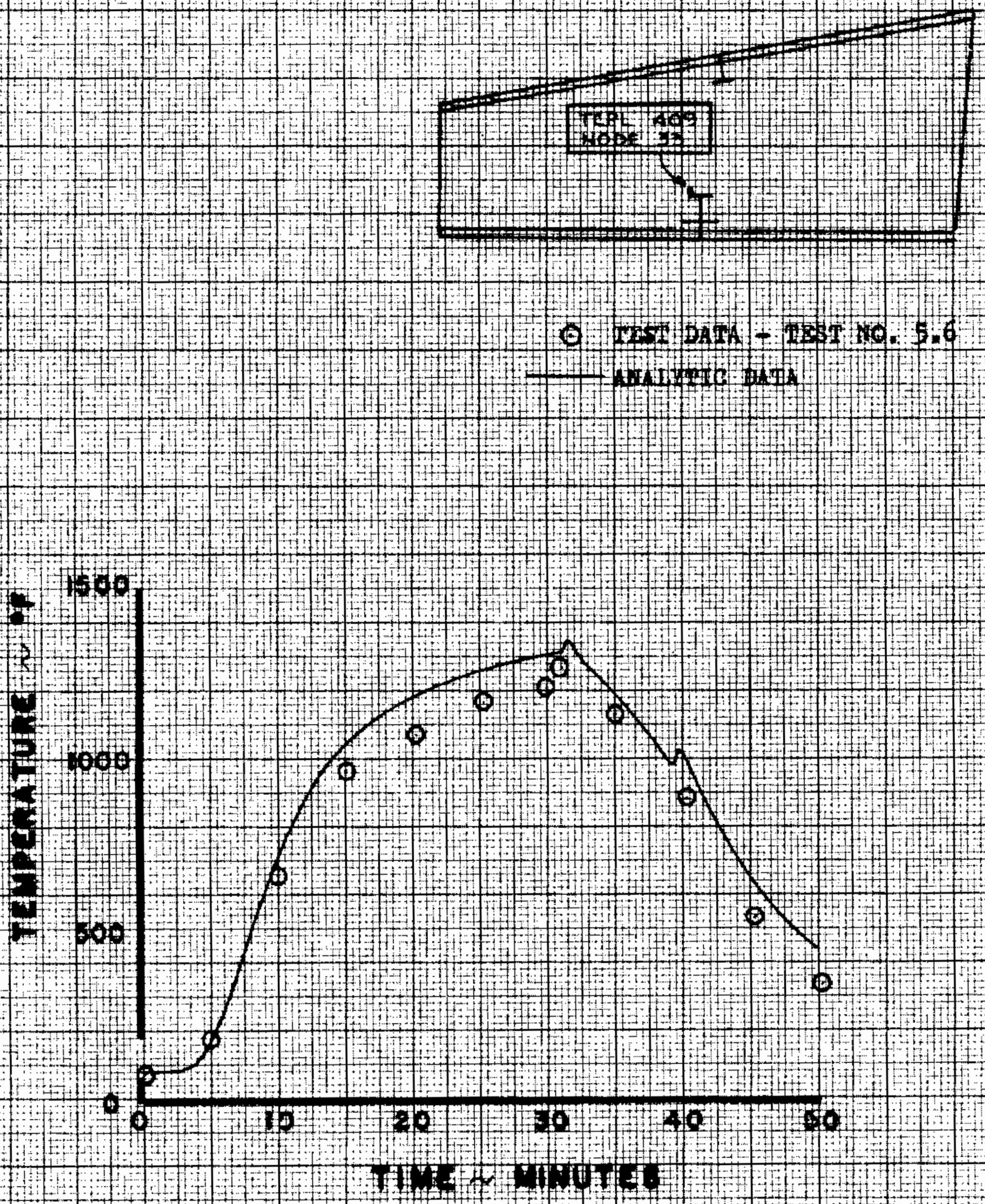

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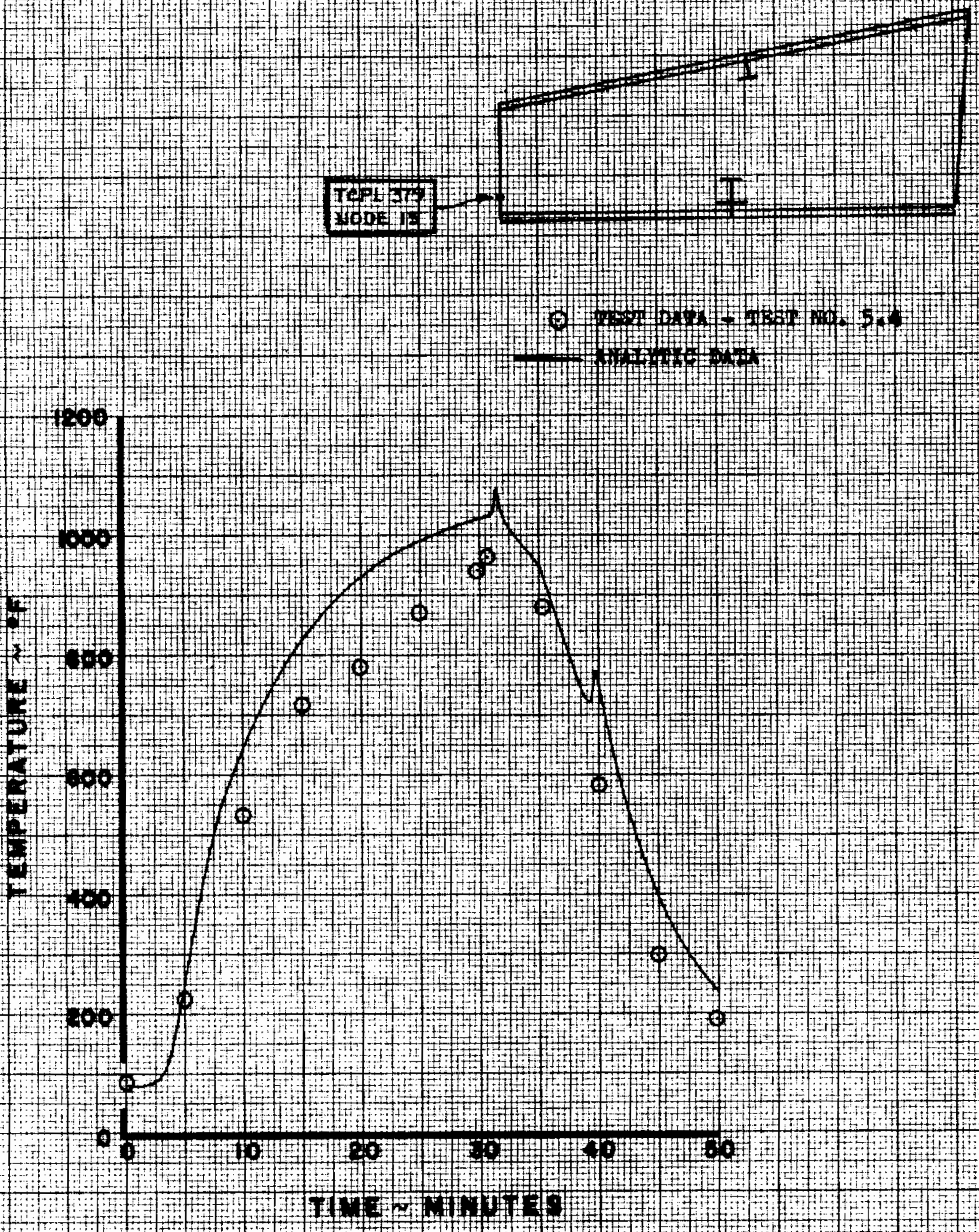

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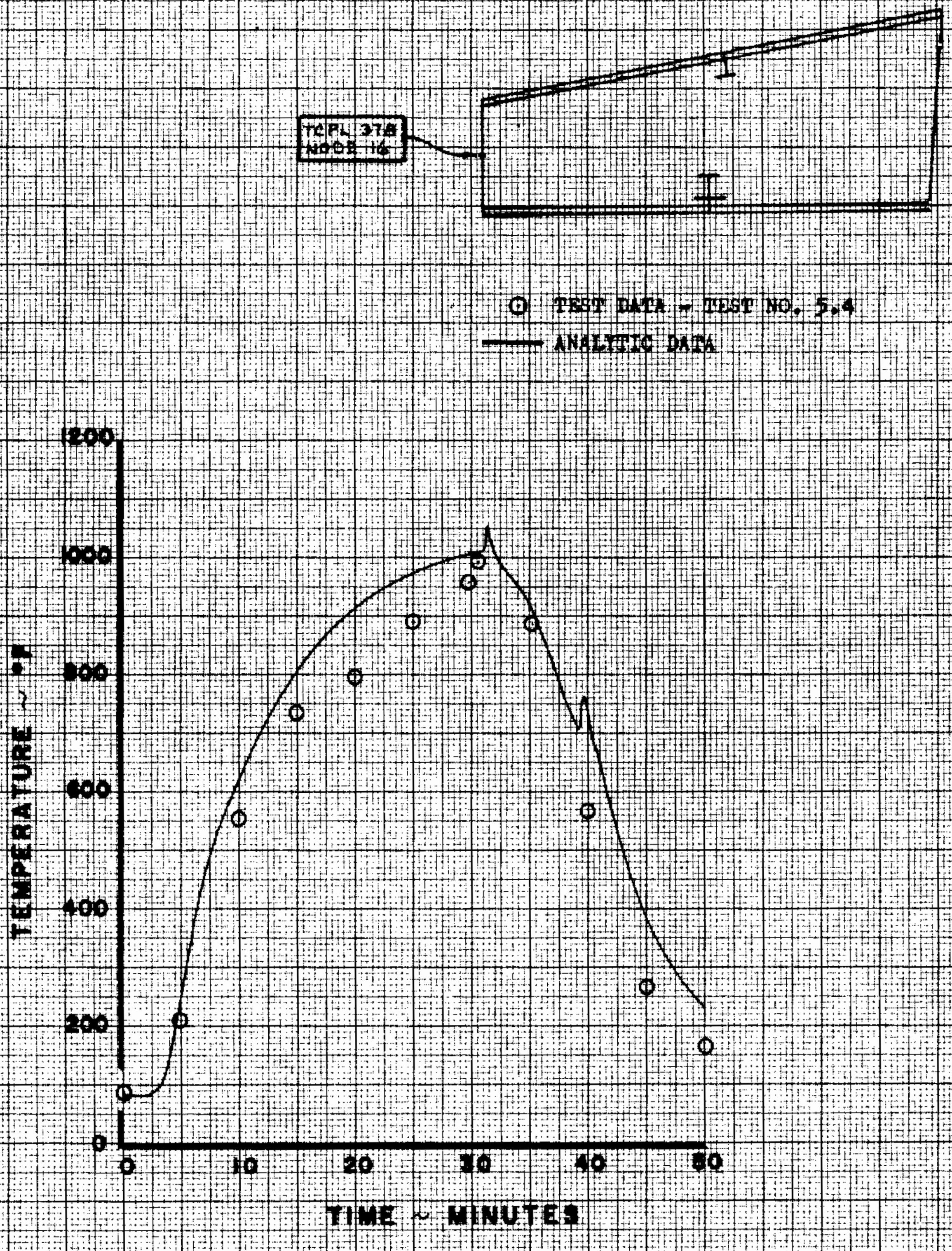

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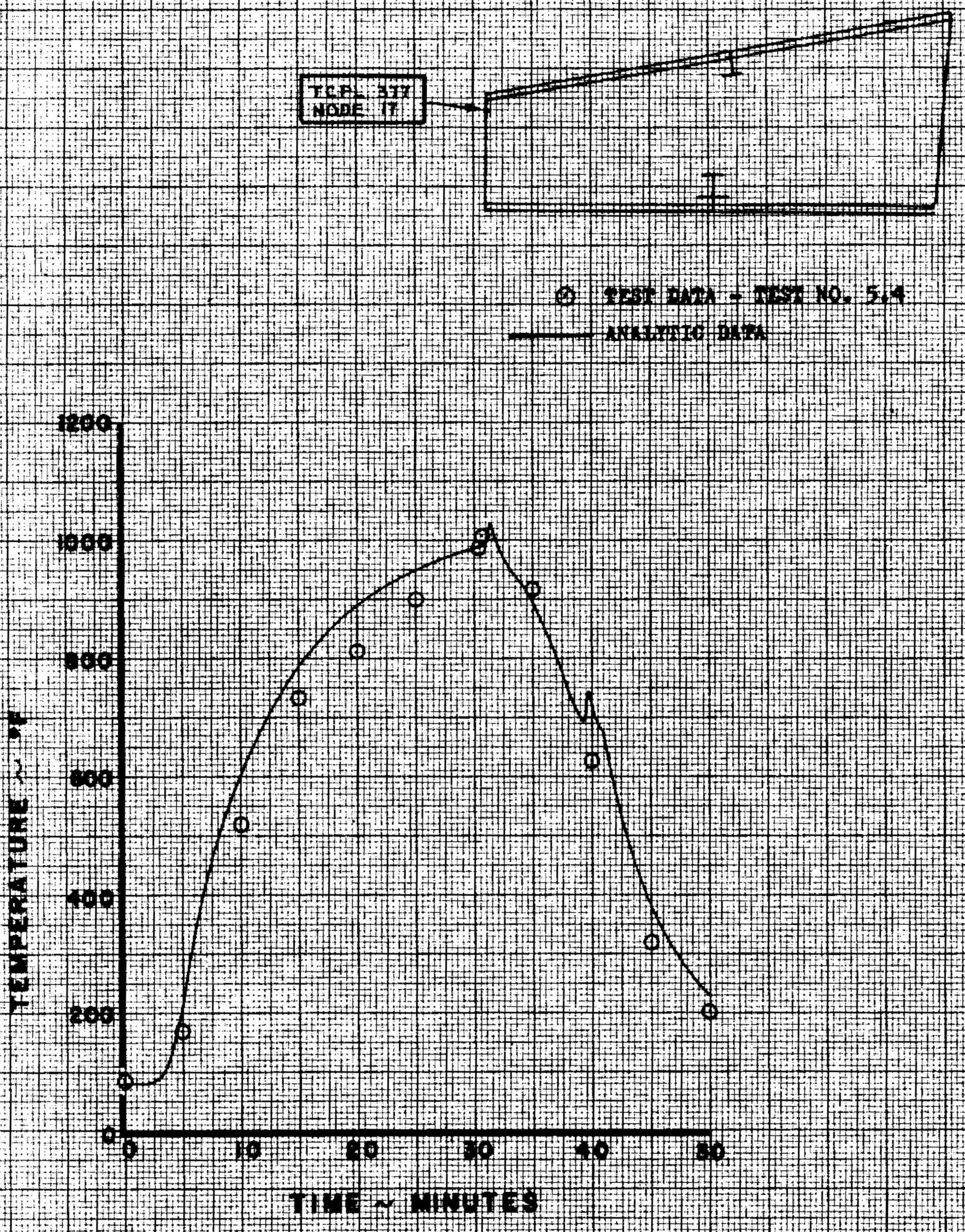

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ANALYSIS C
AFT WING

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4.4.3 Discussion (Analysis C)

In general, correlation of this analysis follows the pattern of the others. The two-dimensional assumption would appear valid for the wing region.

Except for the leading edge beam, discrepancies are somewhat random and relatively small; no significant trends are apparent.

The leading edge beam presents rather poor agreement, particularly in gradient direction. Upon examination of photographs of the test setup, it appeared that hot air from the heated lower surface escaped through thermocouple lead cut-out holes in the heat baffle (see Reference 1). These currents would have occurred in the region where the correlated data was taken (Thermocouples 377, 378, and 379). No attempt to analyze these currents was made, since no analogy to flight vehicles exists, and future ground tests could avoid the problem.

The correlation of the lower intercostal (pages 122 and 123) is quite close.

4.5 FORWARD BODY THREE-DIMENSIONAL ANALYSIS (ANALYSIS D) (See Page 7)

4.5.1 Analysis Description

The forward fuselage of the X-20 presented three-dimensional end effects to any two-dimensional approach. Although not as severe, the Hot Structure concept model, as tested, had some similar effects. This analysis, though simpler than early X-20 efforts, was made in order to demonstrate three-dimensional effects. Its results are intended for comparison not only with test data, but with Analysis A results as well.

Its simplicity is intended to prove that large-node three-dimensional techniques are valid.

All trusswork is neglected. View factors were generated by a three-dimensional computer program (Reference 5).

The forward boundary (Nodes 21 and 25) represents a one-eighth inch asbestos blanket. The thickness is an estimate from the memory of those involved in the test program.

The aft fuselage boundary in the case of Test B1 (blocked case) was driven by test data from the simulated compartment forward face. For the Test 5 series, it was driven by an averaged cavity temperature from Analysis B. (This is not a good theoretical assumption, since the upper forward surface receives radiation primarily from the lower surface thermal level rather than some lower mean value. However, it is an assumption consistent with simplicity and provides interesting results.)

Similarly the wing cavity boundary node (Node 23) was formed as a mean cavity value.

The assumptions shown in Section 4.1, page 8, apply (except 4 and 10).

Boundary conditions are outlined on page 129 for Test 5 and page 145 for Test B1.

The nodal system is shown in Figure 10, page 134. Constants, conductors, capacitors, etc., are shown on pages 135 through 139 for Test 5, and pages 148 through 152 for Test B1.

Correlation for Test 5.1 is shown on pages 140 through 144; Test B1 correlation is on pages 153 through 157.

4.5.2.1 ANALYSIS D CORRELATION

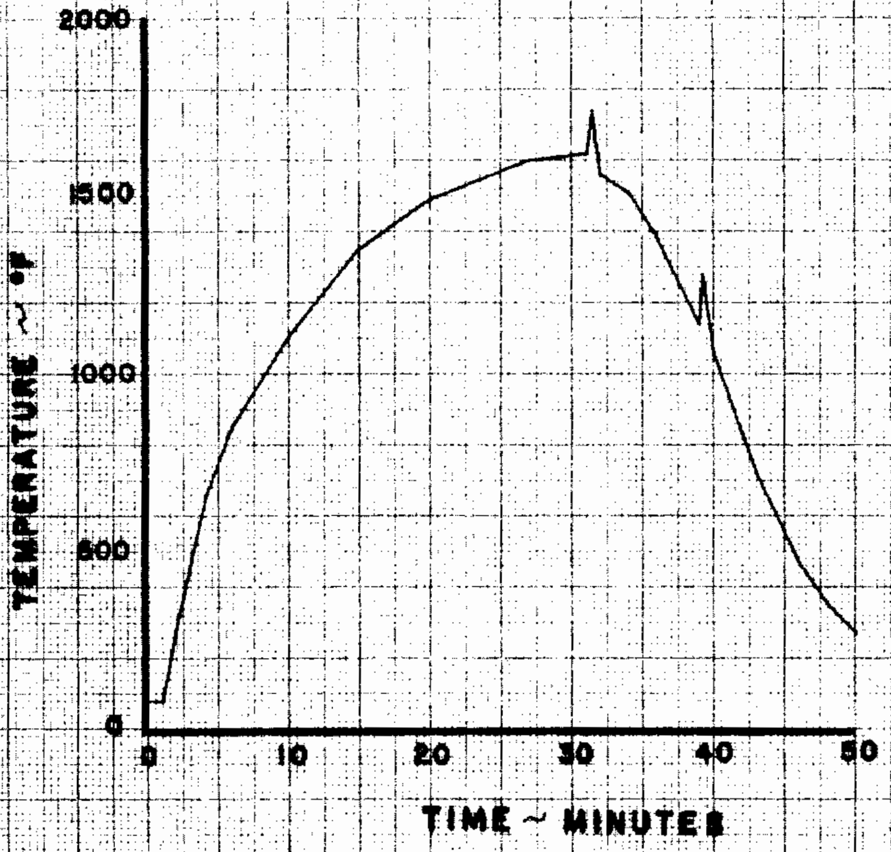
FORWARD BODY THREE-DIMENSIONAL ANALYSIS

TEST SERIES: 5 CONDITION: 5.1

BOUNDARY NODES	SOURCE	PAGE
1	THERMOCOUPLE 296 TEST 5.1	130
2	THERMOCOUPLE 300 TEST 5.1	14
3	THERMOCOUPLE 295 TEST 5.1	131
4	THERMOCOUPLE 300 TEST 5.1	14
5	THERMOCOUPLE 299 TEST 5.1	15
22	TCPL'S 329, 332 & 356 TEST 5.1	132
23	TCPL'S 353 & 434 TEST 5.6	133
24	ROOM TEMPERATURE	

THERMOCOUPLE #296 TEST 5.1

DRIVE BOUNDARY NODE:
1 ANALYSIS D TEST 5.1



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BOUNDARY CONDITIONS

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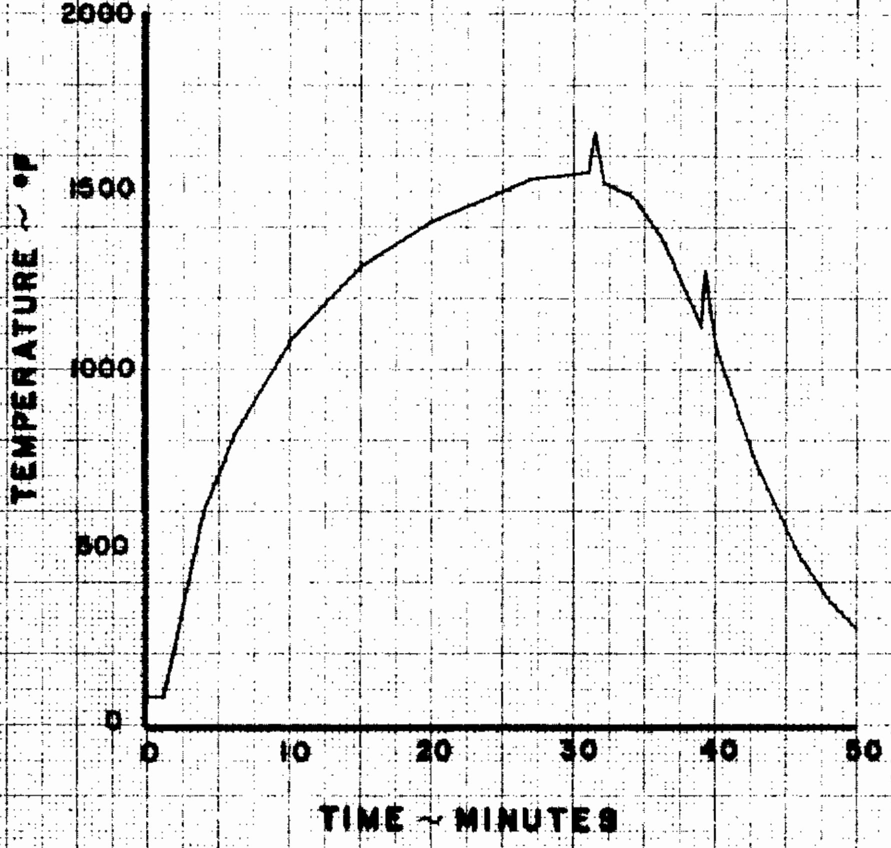
THERMOCOUPLE #295 TEST 5.1

DRIVE BOUNDARY NODE:

3 ANALYSIS D TEST 5.1



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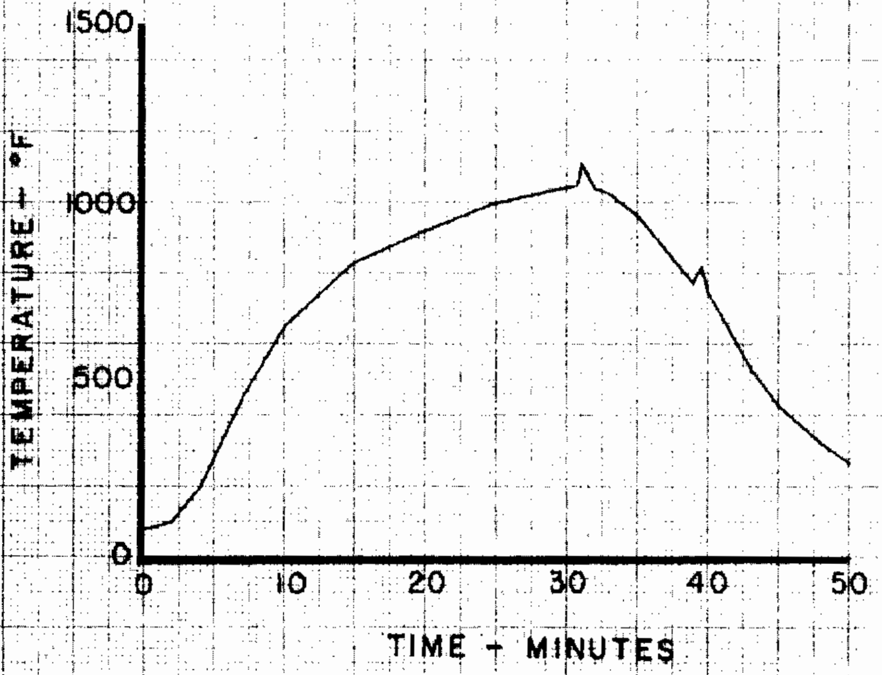
RESULTS FROM TEST 5.1:

15.8% OF THERMOCOUPLE #332
38.7% OF THERMOCOUPLE #356
45.5% OF THERMOCOUPLE #329

DRIVE BOUNDARY NODE:

22 ANALYSIS D TEST 5.1



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BOUNDARY CONDITIONS

D2-90709
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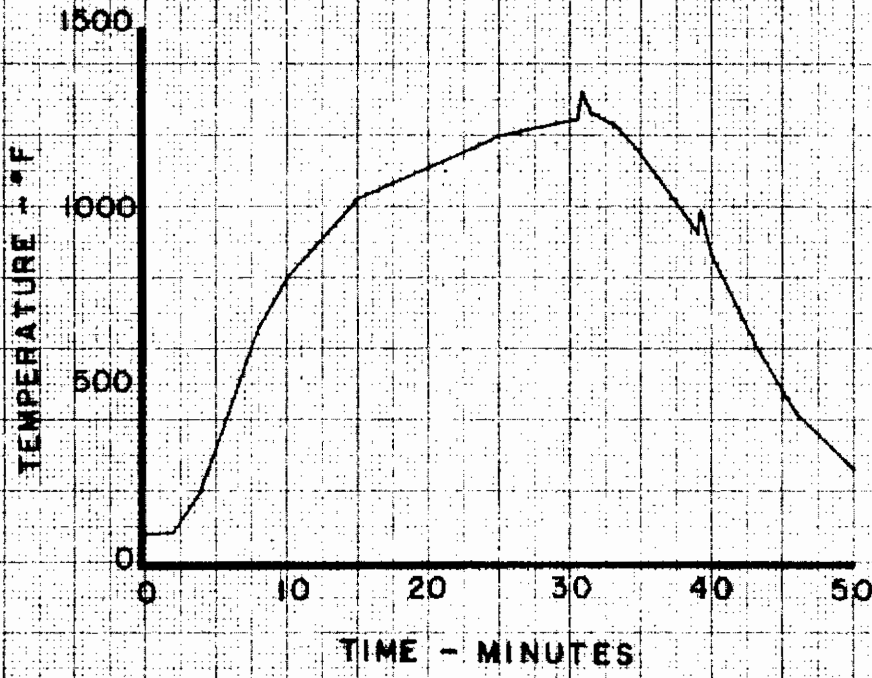
RESULTS FROM TEST 5.6:

48% OF THERMOCOUPLE #353
52% OF THERMOCOUPLE #434

DRIVE BOUNDARY NODE:

23 ANALYSIS D TEST 5.1



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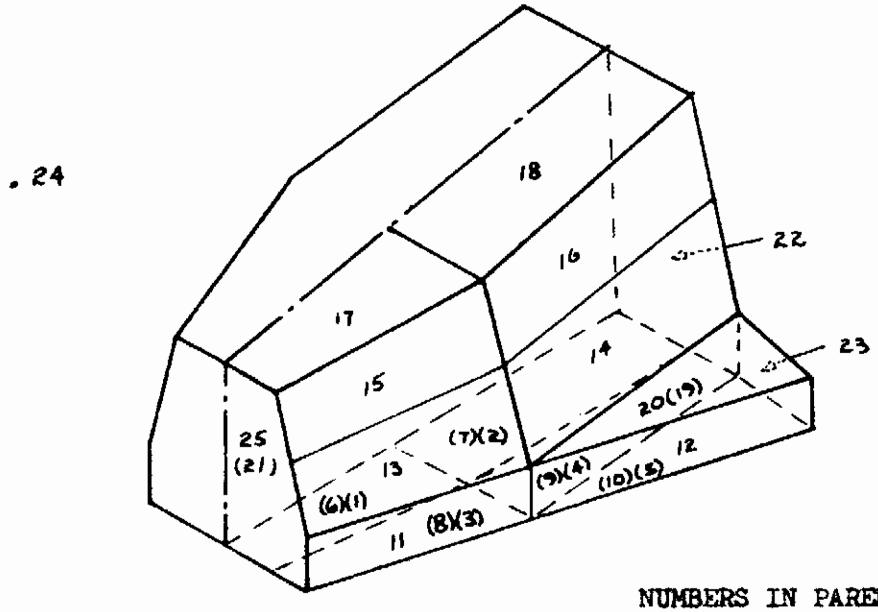
HOT STRUCTURES THERMAL CORRELATION
BOUNDARY CONDITIONS

THE BOEING COMPANY

HOT STRUCTURES THERMAL CORRELATION

ANALYSIS D
3-DIMENSIONAL FORWARD BODY
NODAL DIAGRAM



NUMBERS IN PARENTHESIS ARE HIDDEN

Nodes 1 thru 5 are lower skin
Nodes 6 thru 10 are lower corrugation
Nodes 11 & 12 are leading edge corrugation
Nodes 13 thru 16 are side body corrugation
Nodes 17 & 18 are top body corrugation
Nodes 19 is upper wing corrugation
Node 20 is upper wing skin
Nodes 22 & 23 are boundary conditions
Nodes 21 & 25 are asbestos cover
Node 24 is room temperature

FIGURE 10

CAPACITORS - ANALYSIS D TEST 5.1

NODE	MATERIAL	VOLUME	CAPACITANCE
1	HS-25	DRIVEN	--
2	↓	↓	↓
3	↓	↓	↓
4	↓	↓	↓
5	↓	DRIVEN	--
6	↓	2.27	.0704
7	↓	3.47	.1077
8	↓	2.19	.0679
9	↓	3.39	.1050
10	HS-25	1.36	.0421
11	RENE' 41	1.65	.0567
12	↓	1.83	.0628
13	↓	2.15	.0740
14	↓	3.32	.1121
15	↓	2.14	.0735
16	↓	3.11	.1069
17	↓	2.36	.0811
18	↓	3.58	.1232
19	↓	1.39	.0479
20	RENE' 41	1.11	.0383
21	ASBESTOS	9.85	.02225
22	BL'K BODY	DRIVEN	--
23	BL'K BODY	DRIVEN	--
24	BL'K BODY	DRIVEN	--
25	ASBESTOS	9.85	.02225

CONDUCTION CONDUCTORS - ANALYSIS D TEST 5.1

COND. NO.	NODE/NODE	A/L
1	6 - 7	.002038
2	6 - 8	.045674
3	7 - 9	.055488
4	8 - 9	.002038
5	11 - 12	.001528
6	13 - 15	.035714
7	14 - 16	.033673
8	21 - 25	1260.4

CONVECTION CONDUCTORS - ANALYSIS D TEST 5.1

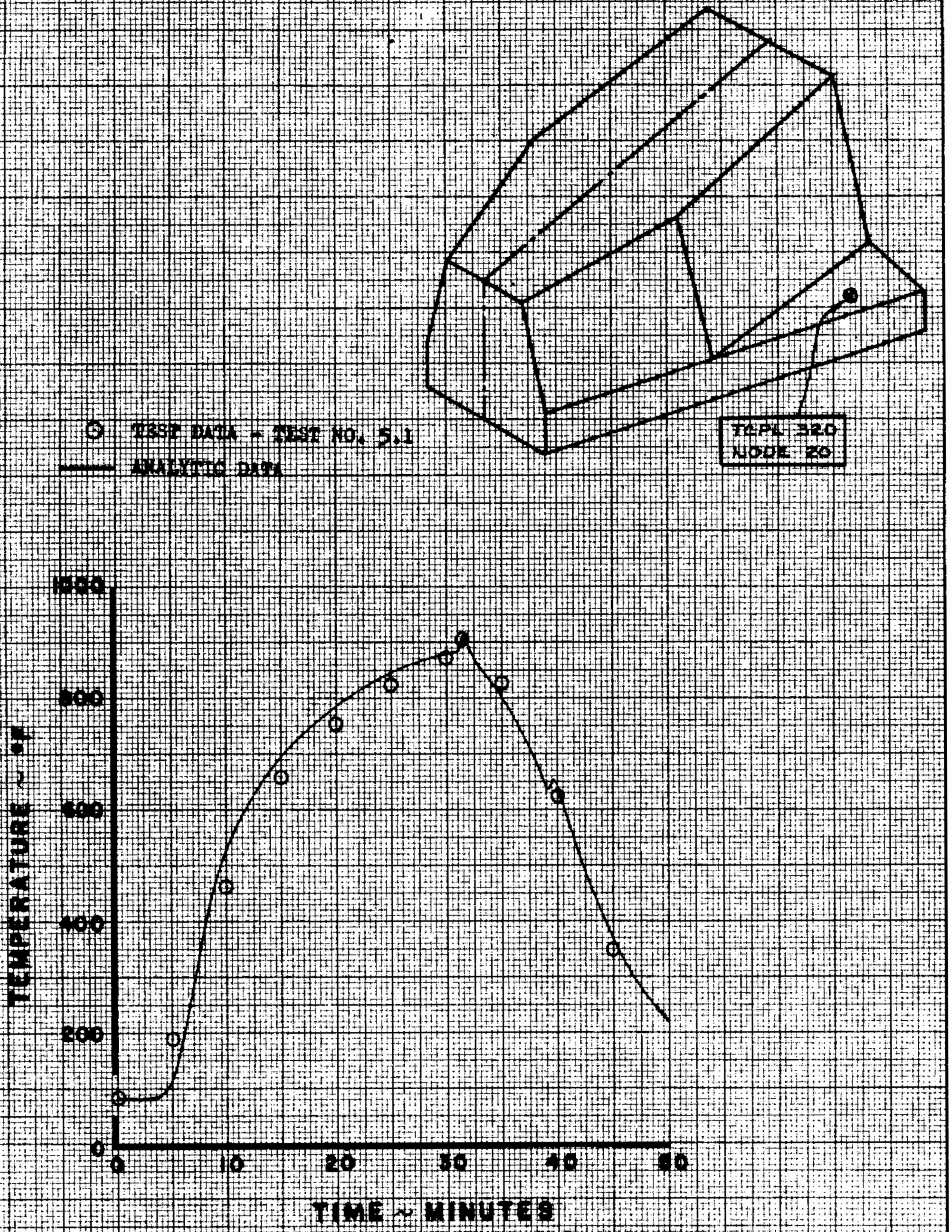
COND. NO.	NODE/NODE	A'	h'
10	11 - 24	236.0	SEE PAGE 21
11	25 - 24	190.85	
12	13 - 24	228.2	
13	14 - 24	345.5	
14	15 - 24	195.7	
15	16 - 24	300.0	
16	17 - 24	40.19	
17	18 - 24	61.06	

RADIATION CONDUCTOR MATRIX - ANALYSIS D TEST 5.1

NODE (j)	NODE (i) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	-					170																			
2		-					171																		
3			-					172																	
4				-					173																
5					-					174															
6	170					-					50	51	52	53	54	55	56	57	58		127	140			
7		171					-				59	60	61	62	63	64	65	66	67		128	141			
8			172					-			68	69	70	71	72	73	74	75	76		129	142			
9				173					-		77	78	79	80	81	82	83	84	85		130	143	154		
10					174					-	86	87	88	89	90	91	92	93	94		131	144	155		
11						50	59	68	77	86	-	95	96	97	98	99	100	101	102		132	145		160	
12						51	60	69	78	87	95	-	103	104	105	106	107	108	109		133	146	156	161	
13						52	61	70	79	88	96	103	-	110	111	112	113	114			134	147		162	
14						53	62	71	80	89	97	104	110	-	115	116	117	118	119	125	135	148		163	
15						54	63	72	81	90	98	105	111	115	-	120	121	122			136	149		164	
16						55	64	73	82	91	99	106	112	116	120	-	123	124		126	137	150		165	
17						56	65	74	83	92	100	107	113	117	121	123	-				138	151	157	166	
18						57	66	75	84	93	101	108	114	118	122	124		-			139	152	158	167	
19						58	67	76	85	94	102	109		119					-	175		153	159	168	
20														125		126			175	-				169	
21						127	128	129	130	131	132	133	134	135	136	137	138	139			-	177	178		
22						140	141	142	143	144	145	146	147	148	149	150	151	152	153		177	-			
23									154	155		156					157	158	159		178		-		
24											160	161	162	163	164	165	166	167	168	169		176		-	176
25																								176	-

RADIATION CONDUCTORS - ANALYSIS D TEST 5.1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
50	11.5088	100	9.9718	150	55.4888
51	1.2618	101	5.8323	151	11.6347
52	24.5130	102	.6750	152	77.3359
53	8.6182	103	3.0627	153	6.6040
54	15.9389	104	7.0859	154	4.0455
55	7.4514	105	2.5779	155	12.0705
56	24.4243	106	4.3005	156	9.8061
57	11.6463	107	1.1465	157	1.6272
58	.8193	108	3.0600	158	2.7707
59	3.3298	109	23.6926	159	10.4659
60	6.0942	110	8.6422	160	131.8977
61	11.0368	111	10.8677	161	146.1096
62	38.2600	112	6.8829	162	172.1466
63	10.2720	113	14.7887	163	240.8929
64	23.9568	114	1.9872	164	171.0140
65	16.1188	115	7.8297	165	245.8705
66	38.2655	116	17.0275	166	188.6343
67	6.9381	117	8.7700	167	286.5747
68	35.6094	118	25.7829	168	0
69	1.7586	119	.4366	169	88.9740
70	20.5094	120	8.9673	170	136.5
71	7.1310	121	35.8739	171	208.0
72	9.4698	122	6.5069	172	131.25
73	5.2728	123	7.3522	173	202.8
74	18.6241	124	56.3801	174	108.6
75	9.6728	125	19.6947	175	111.2967
76	1.2673	126	2.6280	176	157.55
77	4.5156	127	23.6834	177	15.9964
78	20.2709	128	4.1210	178	1.5649
79	8.6334	129	16.1341		
80	33.9333	130	3.3062		
81	6.7522	131	1.0801		
82	14.5961	132	14.0170		
83	12.5330	133	1.7078		
84	29.6931	134	21.1237		
85	25.3091	135	6.8720		
86	.3586	136	19.9178		
87	30.3864	137	5.9210		
88	1.1048	138	21.5129		
89	3.3969	139	4.5387		
90	1.3911	140	6.1287		
91	3.1367	141	47.3763		
92	3.1259	142	5.3712		
93	8.2931	143	37.2178		
94	30.3431	144	10.4110		
95	2.4616	145	9.4743		
96	9.0653	146	22.6854		
97	6.4058	147	13.0299		
98	6.4625	148	63.4284		
99	4.5923	149	13.2626		



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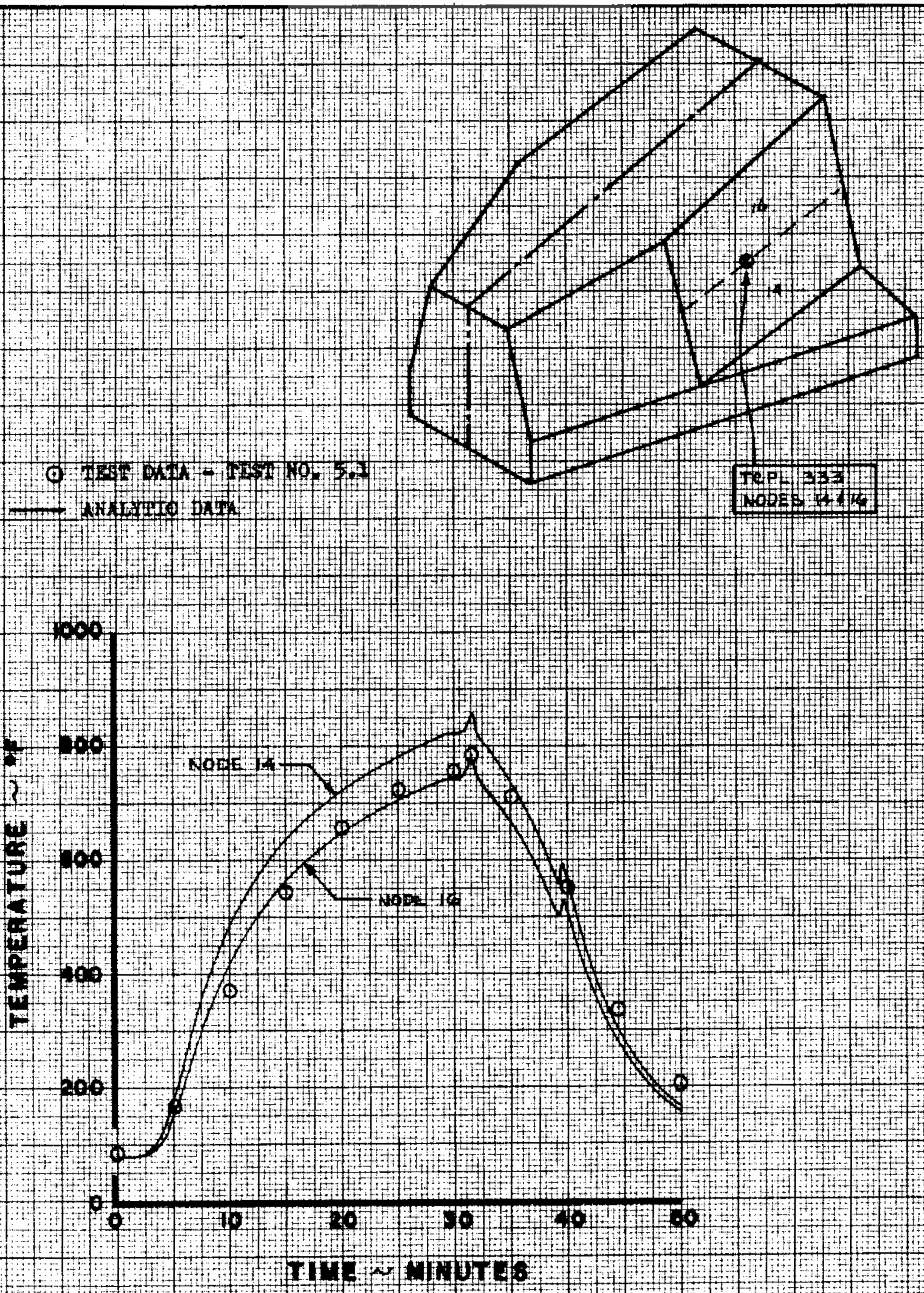
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS D
FORWARD BODY

THE BOEING COMPANY



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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS D
FORWARD BODY

THE BOEING COMPANY

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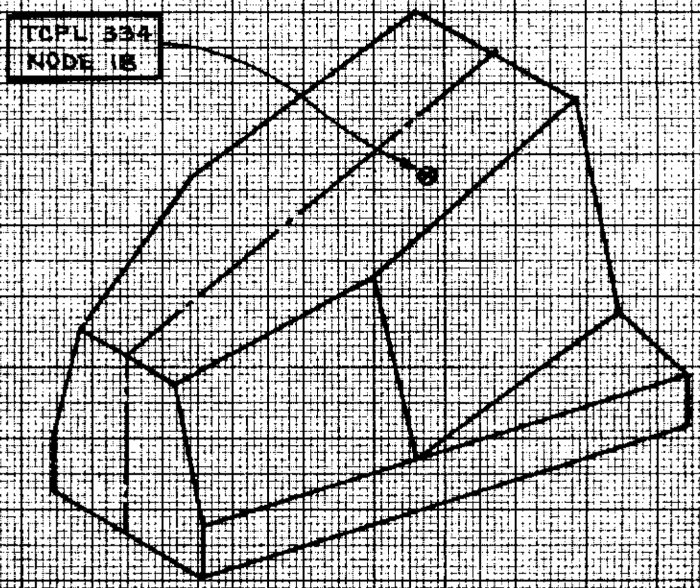

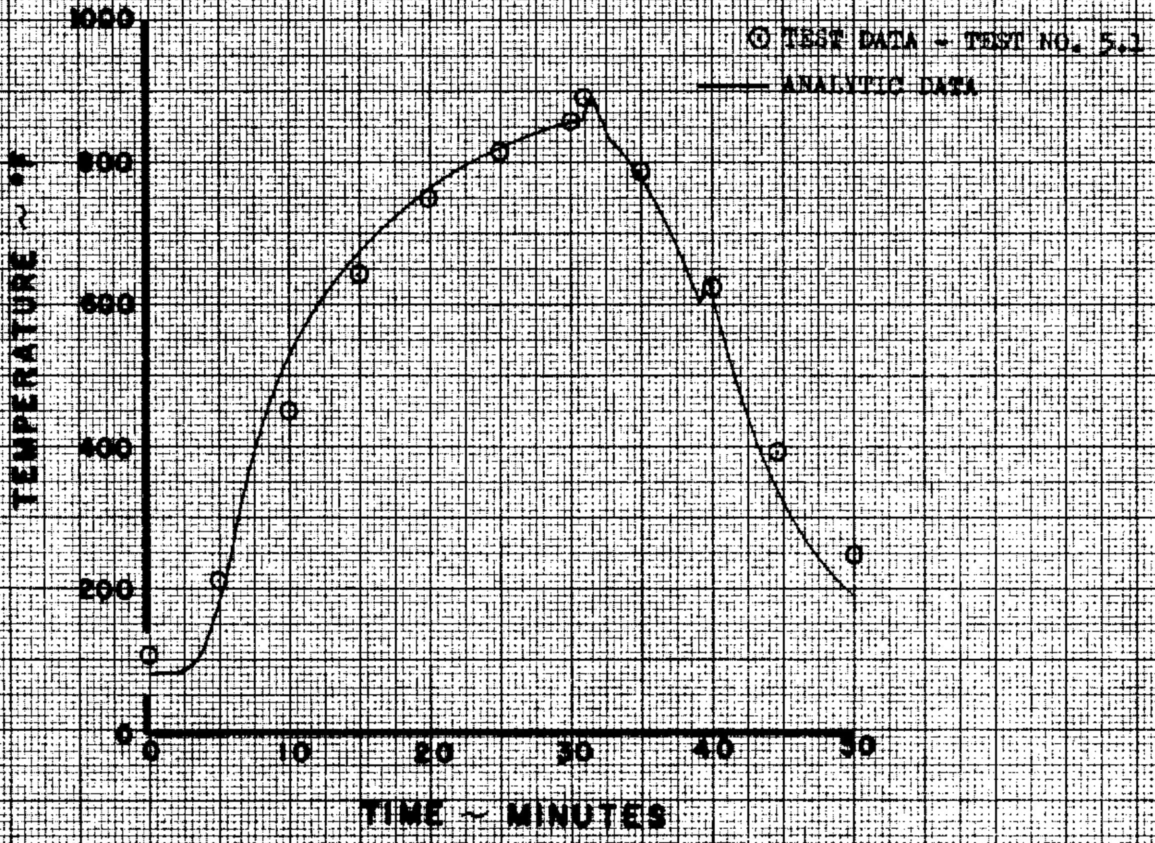

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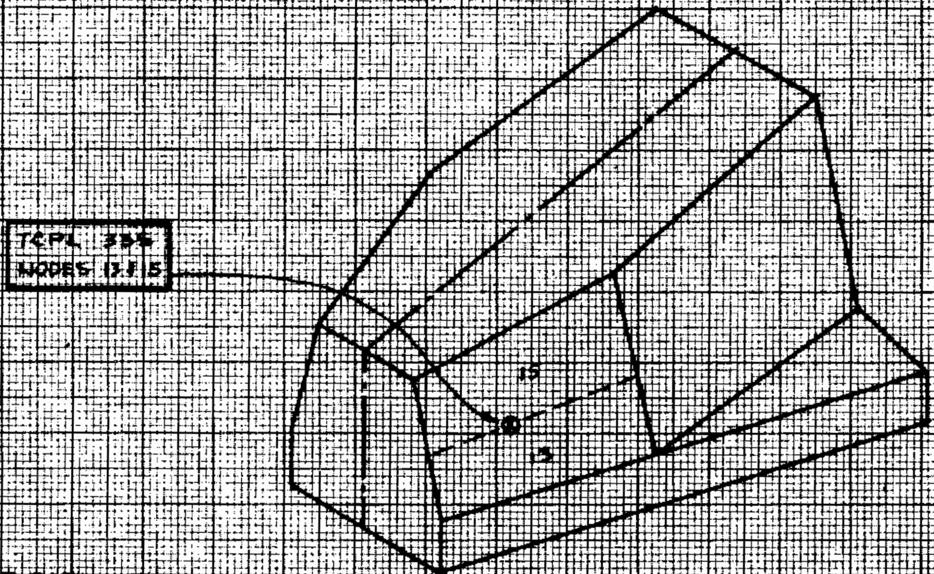
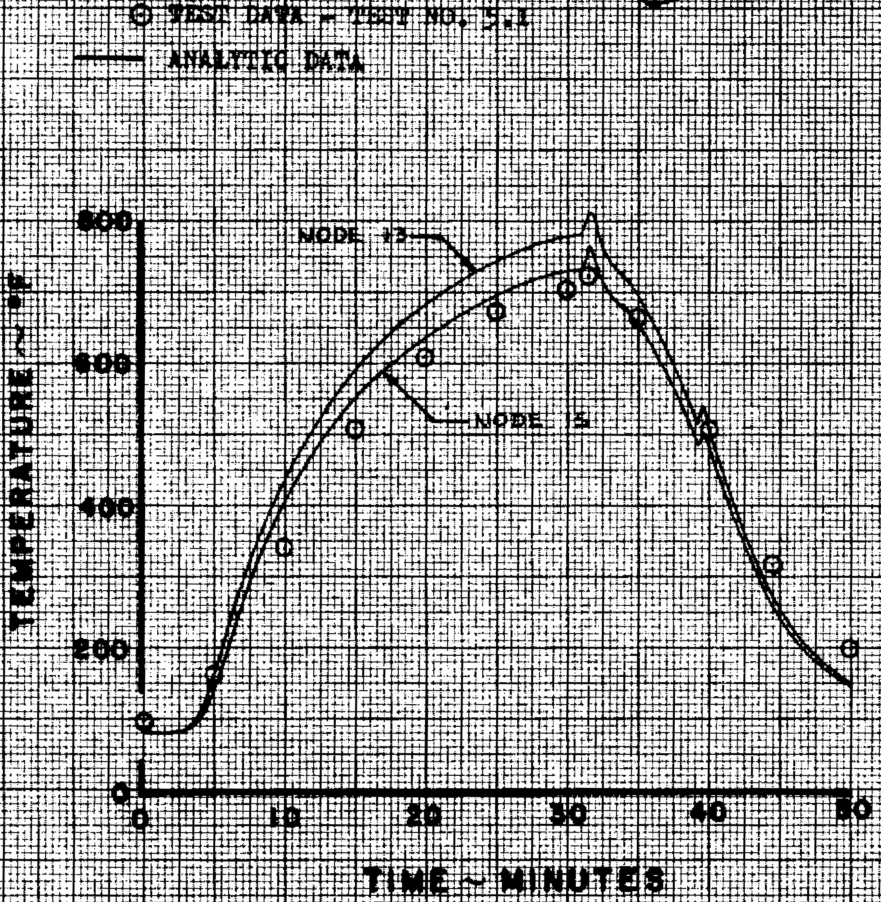
HOT STRUCTURES THERMAL CORRELATION
ANALYSIS D
FORWARD BODY

THE BOEING COMPANY

D2-90709
-1





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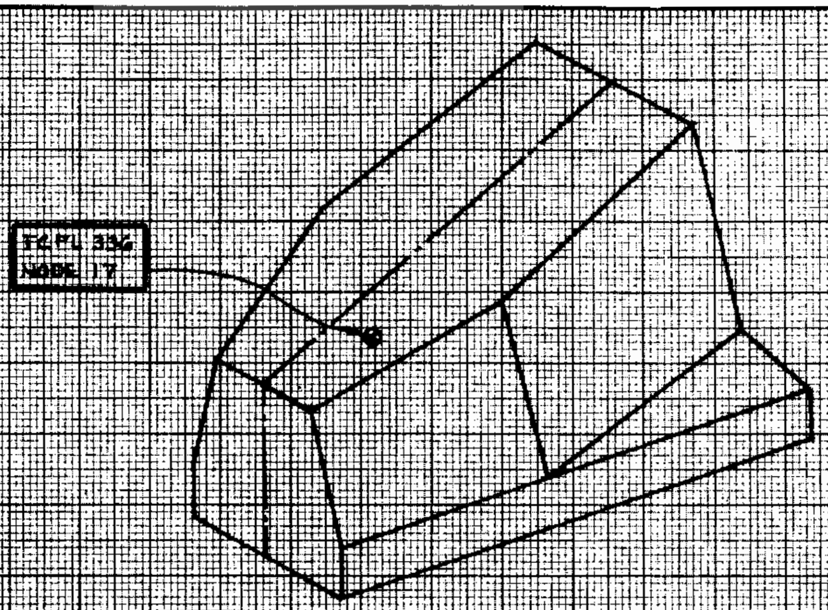
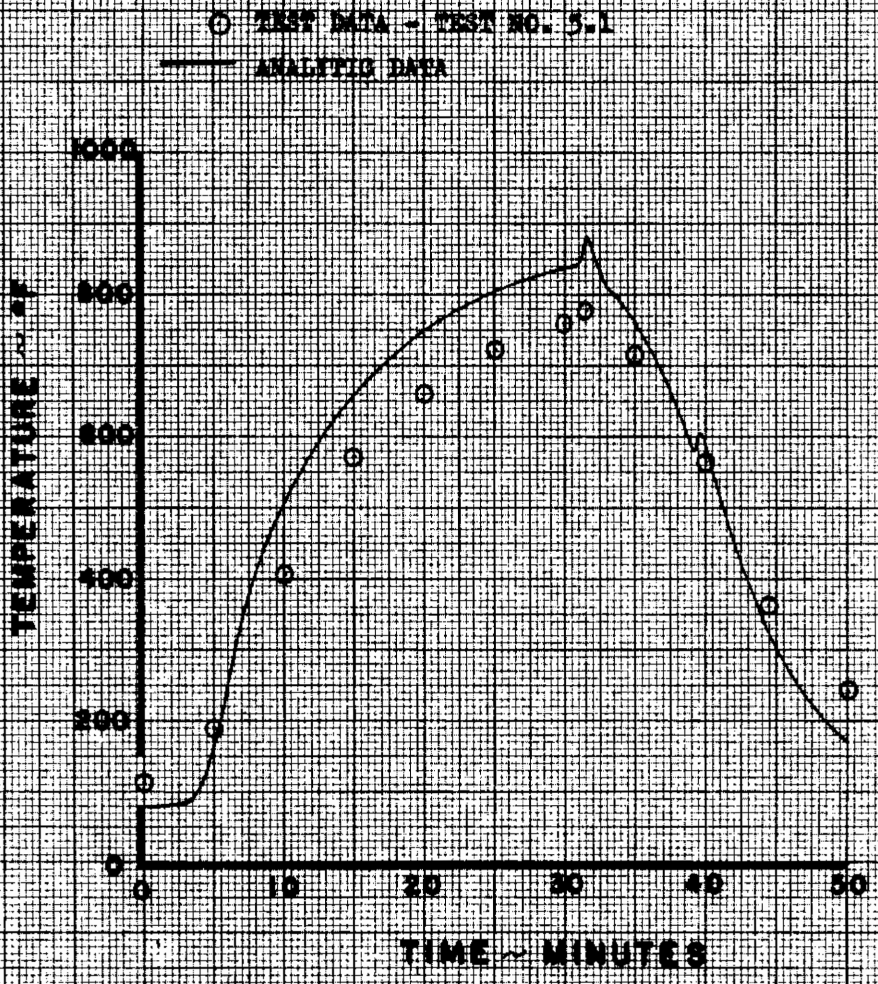
APR					THE BOEING COMPANY
APR					PAGE 143


TC PL 336
NODE 17


○ TEST DATA - TEST NO. 5.1
—— ANALYTIC DATA
TEMPERATURE ~ °F
1000
800
600
400
200
0
0
10
20
30
40
50
TIME ~ MINUTES

4.5.2.2 ANALYSIS D CORRELATION

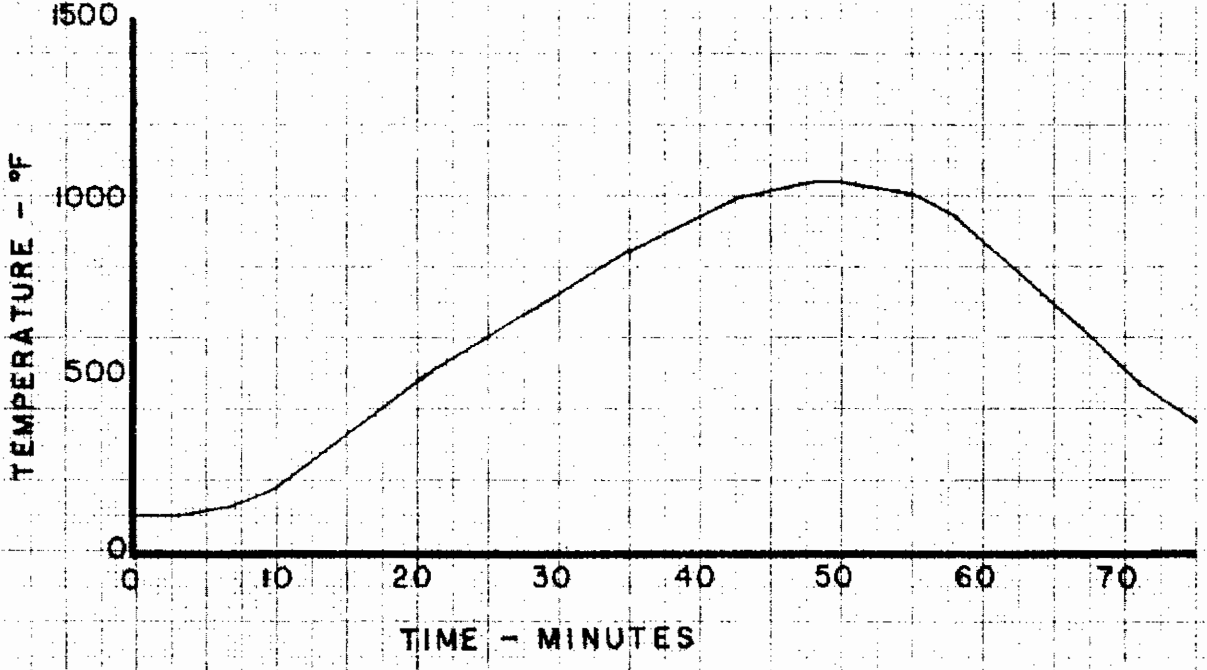
FORWARD BODY THREE-DIMENSIONAL ANALYSIS

TEST SERIES: B-1

BOUNDARY NODES	SOURCE	PAGE
1	CONTROL AREA 65 TEST B-1	37
2	CONTROL AREA 60 TEST B-1	37
3	CONTROL AREA 66 TEST B-1	37
4	CONTROL AREA 62 TEST B-1	37
5	CONTROL AREA 64 TEST B-1	38
22	THERMOCOUPLE 5A TEST B-1	146
23	TCPL'S 353 and 434 TEST B-1	147
24	ROOM TEMPERATURE	

THERMOCOUPLE 5A TEST B-1

DRIVE BOUNDARY NODE:
22 ANALYSIS D TEST B-1



CALC	Wrench	4/14/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS
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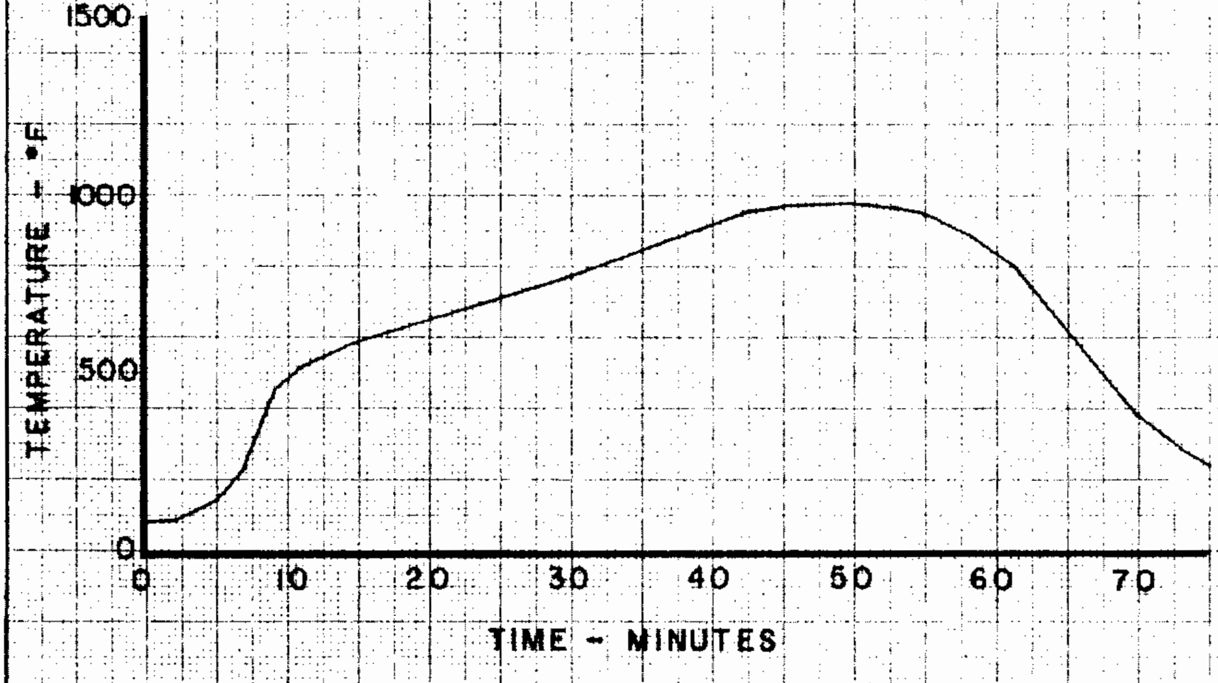
RESULTS FROM TEST B-1

48% OF THERMOCOUPLE #353
52% OF THERMOCOUPLE #434

DRIVE BOUNDARY NODE:

23 ANALYSIS D TEST B-1



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APR						
APR					THE BOEING COMPANY	PAGE 147

CAPACITORS - ANALYSIS D TEST B-1

NODE	MATERIAL	VOLUME	CAPACITANCE
1	HS-25	DRIVEN	--
2	↓	↓	↓
3	↓	↓	↓
4	↓	↓	↓
5	↓	DRIVEN	--
6	↓	2.27	.0704
7	↓	3.47	.1077
8	↓	2.19	.0679
9	↓	3.39	.1050
10	HS-25	1.36	.0421
11	RENE' 41	1.65	.0567
12	↓	1.83	.0628
13	↓	2.15	.0740
14	↓	3.32	.1121
15	↓	2.14	.0735
16	↓	3.11	.1069
17	↓	2.36	.0811
18	↓	3.58	.1232
19	↓	1.39	.0479
20	RENE' 41	1.11	.0383
21	ASBESTOS	9.85	.02225
22	CERAFELT	DRIVEN	--
23	BL'K BODY	DRIVEN	--
24	BL'K BODY	DRIVEN	--
25	ASBESTOS	9.85	.02225

CONDUCTION CONDUCTORS - ANALYSIS D TEST B-1

COND. NO.	NODE/NODE	A/L
1	6 - 7	.002038
2	6 - 8	.045674
3	7 - 9	.055488
4	8 - 9	.002038
5	11 - 12	.001528
6	13 - 15	.035714
7	14 - 16	.033673
8	21 - 25	1260.4

CONVECTION CONDUCTORS - ANALYSIS D TEST B-1

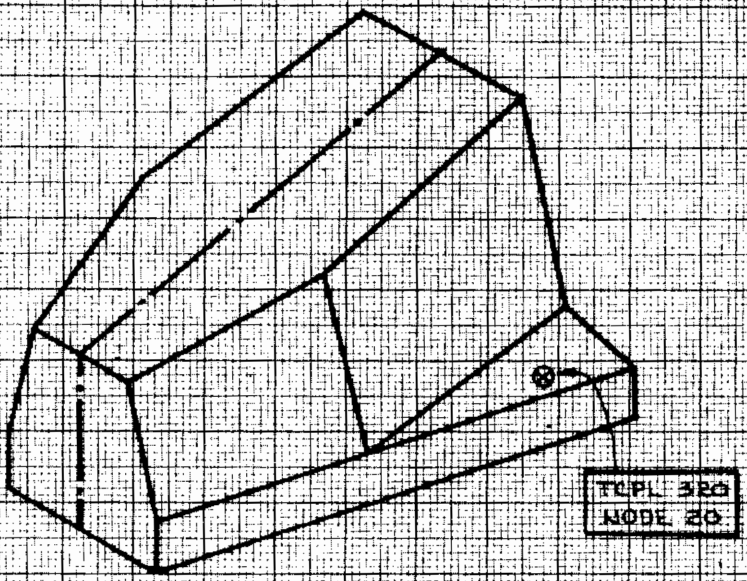
COND. NO.	NODE/NODE	A'	h'
10	11 - 24	236.0	SEE PAGE 21
11	25 - 24	190.85	
12	13 - 24	228.2	
13	14 - 24	345.5	
14	15 - 24	195.7	
15	16 - 24	300.0	
16	17 - 24	40.19	
17	18 - 24	61.06	

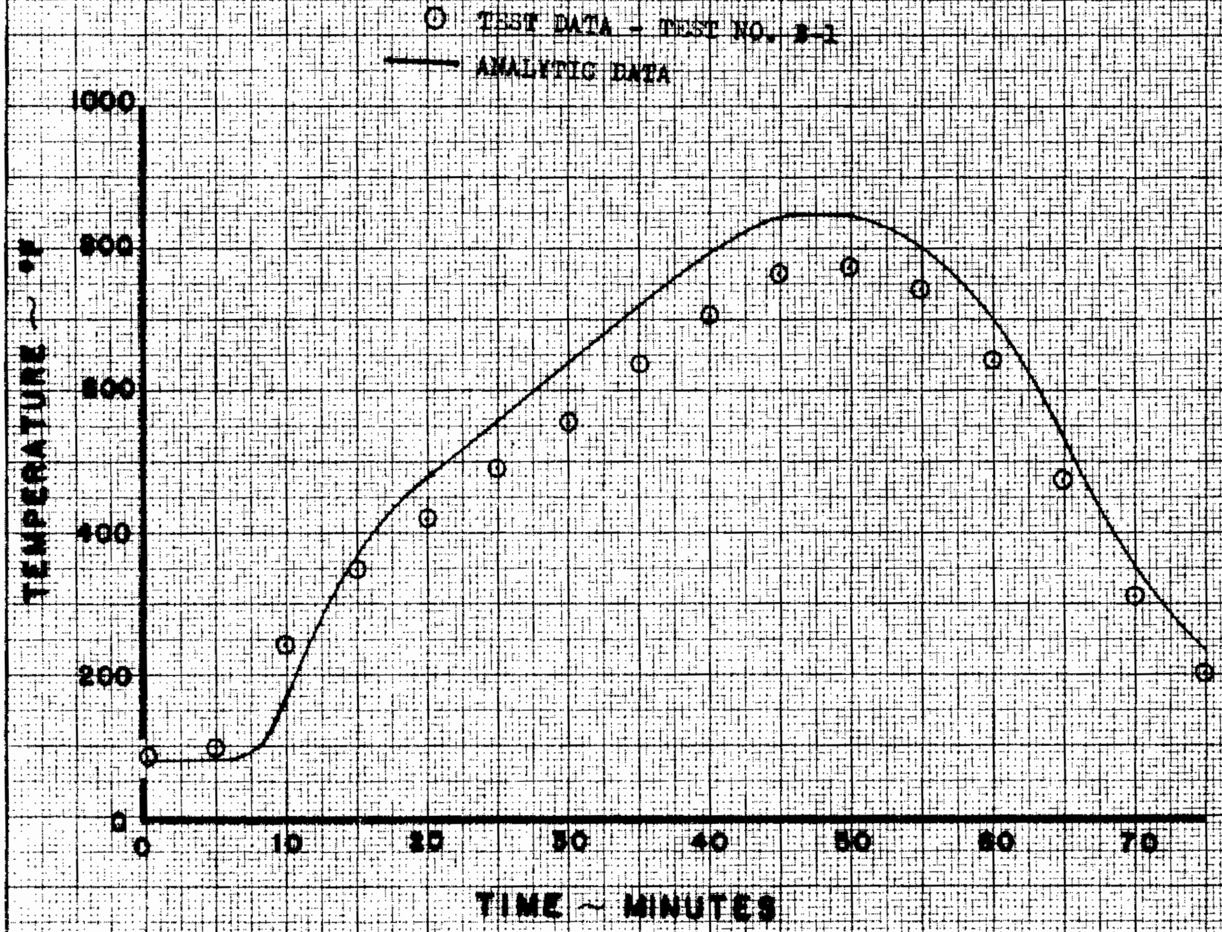
RADIATION CONDUCTOR MATRIX - ANALYSIS D TEST B-1

NODE (j)	NODE (i)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	-					170																			
2		-					171																		
3			-					172																	
4				-					173																
5					-					174															
6	170					-					50	51	52	53	54	55	56	57	58		127	140			
7		171					-				59	60	61	62	63	64	65	66	67		128	141			
8			172					-			68	69	70	71	72	73	74	75	76		129	142			
9				173					-		77	78	79	80	81	82	83	84	85		130	143	154		
10					174					-	86	87	88	89	90	91	92	93	94		131	144	155		
11						50	59	68	77	86	-	95	96	97	98	99	100	101	102		132	145		160	
12						51	60	69	78	87	95	-	103	104	105	106	107	108	109		133	146	156	161	
13						52	61	70	79	88	96	103	-	110	111	112	113	114			134	147		162	
14						53	62	71	80	89	97	104	110	-	115	116	117	118	119	125	135	148		163	
15						54	63	72	81	90	98	105	111	115	-	120	121	122			136	149		164	
16						55	64	73	82	91	99	106	112	116	120	-	123	124		126	137	150		165	
17						56	65	74	83	92	100	107	113	117	121	123	-				138	151	157	166	
18						57	66	75	84	93	101	108	114	118	122	124		-			139	152	158	167	
19						58	67	76	85	94	102	109		119					-	175		153	159	168	
20														125		126			175	-				169	
21						127	128	129	130	131	132	133	134	135	136	137	138	139			-	177	178		
22						140	141	142	143	144	145	146	147	148	149	150	151	152	153		177	-			
23									154	155		156					157	158	159		178		-		
24											160	161	162	163	164	165	166	167	168	169		176		-	176
25																								176	-

RADIATION CONDUCTORS - ANALYSIS D TEST B-1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
50	11.5088	100	9.9718	150	55.4888
51	1.2618	101	5.8323	151	11.6347
52	24.5130	102	.6750	152	77.3359
53	8.6182	103	3.0627	153	6.6040
54	15.9389	104	7.0859	154	4.0455
55	7.4514	105	2.5779	155	12.0705
56	24.4243	106	4.3005	156	9.8061
57	11.6463	107	1.1465	157	1.6272
58	.8193	108	3.0600	158	2.7707
59	3.3298	109	23.6926	159	10.4659
60	6.0942	110	8.6422	160	131.8977
61	11.0368	111	10.8677	161	146.1096
62	38.2600	112	6.8829	162	172.1466
63	10.2720	113	14.7887	163	240.8929
64	23.9568	114	1.9872	164	171.0140
65	16.1188	115	7.8297	165	245.8705
66	38.2655	116	17.0275	166	188.6343
67	6.9381	117	8.7700	167	286.5747
68	35.6094	118	25.7829	168	0
69	1.7586	119	.4366	169	88.9740
70	20.5094	120	8.9673	170	136.5
71	7.1310	121	35.8739	171	208.0
72	9.4698	122	6.5069	172	131.25
73	5.2728	123	7.3522	173	202.8
74	18.6241	124	56.3801	174	108.6
75	9.6728	125	19.6947	175	111.2967
76	1.2673	126	2.6280	176	157.55
77	4.5156	127	23.6834	177	15.9964
78	20.2709	128	4.1210	178	1.5649
79	8.6334	129	16.1341		
80	33.9333	130	3.3062		
81	6.7522	131	1.0801		
82	14.5961	132	14.0170		
83	12.5330	133	1.7078		
84	29.6931	134	21.1237		
85	25.3091	135	6.8720		
86	.3586	136	19.9178		
87	30.3864	137	5.9210		
88	1.1048	138	21.5129		
89	3.3969	139	4.5387		
90	1.3911	140	6.1287		
91	3.1367	141	47.3763		
92	3.1259	142	5.3712		
93	8.2931	143	37.2178		
94	30.3431	144	10.4110		
95	2.4616	145	9.4743		
96	9.0653	146	22.6854		
97	6.4058	147	13.0299		
98	6.4625	148	63.4284		
99	4.5923	149	13.2626		





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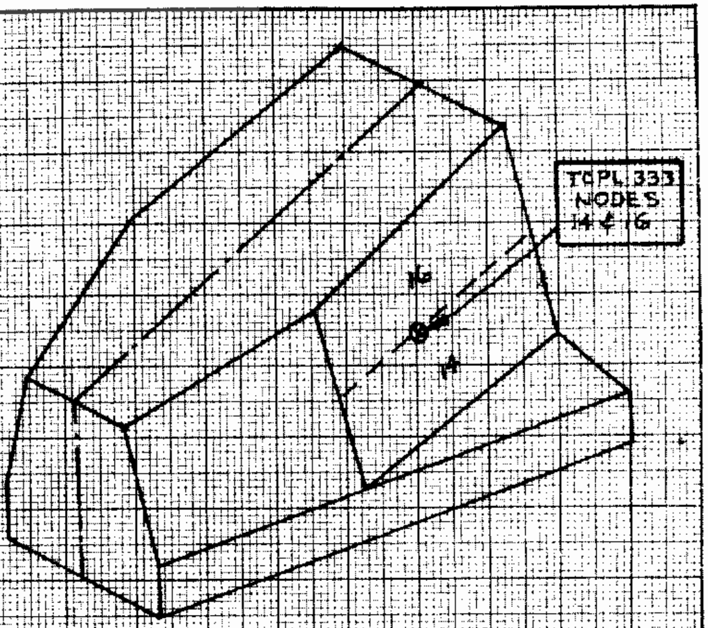
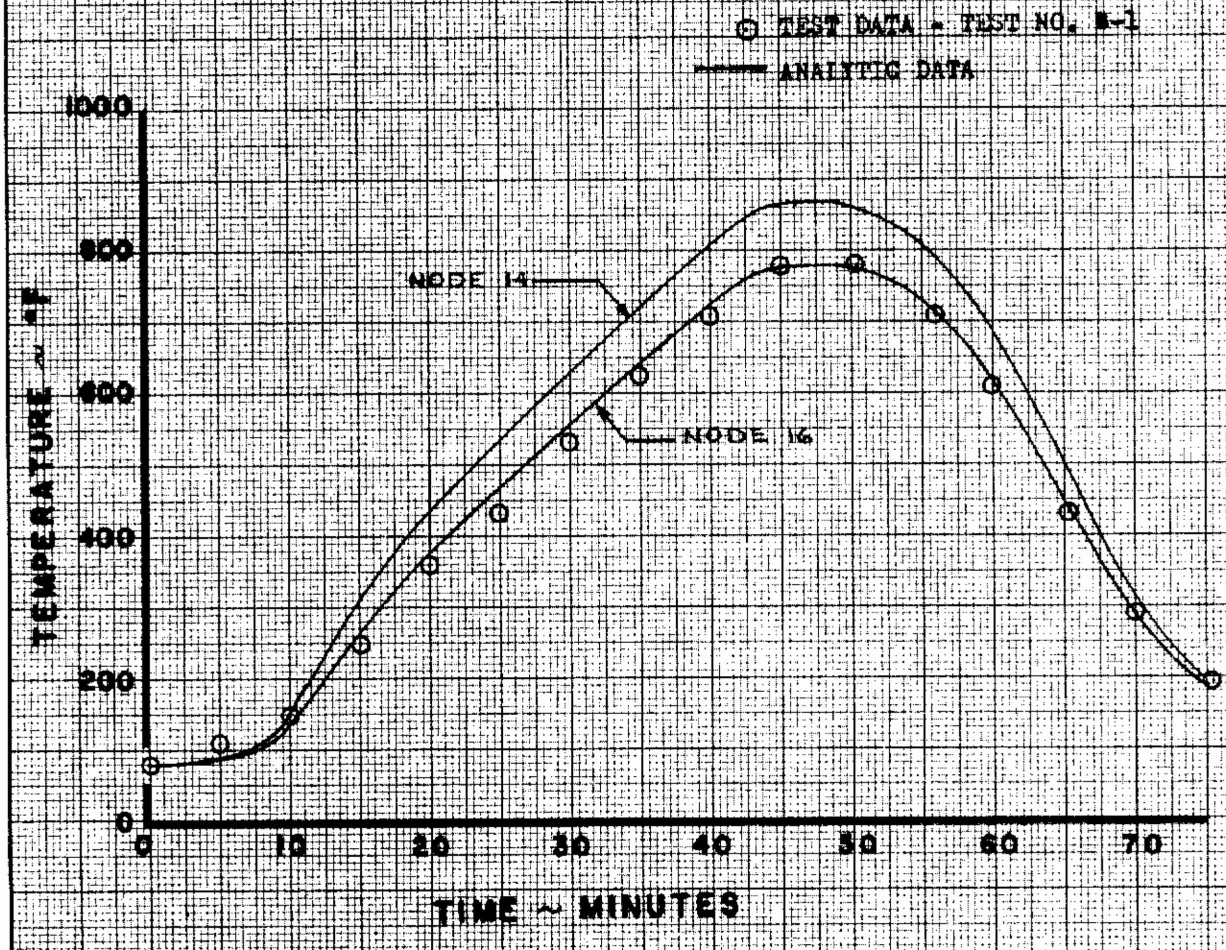
CHECK						
APR						
APR					THE BOEING COMPANY	PAGE 153





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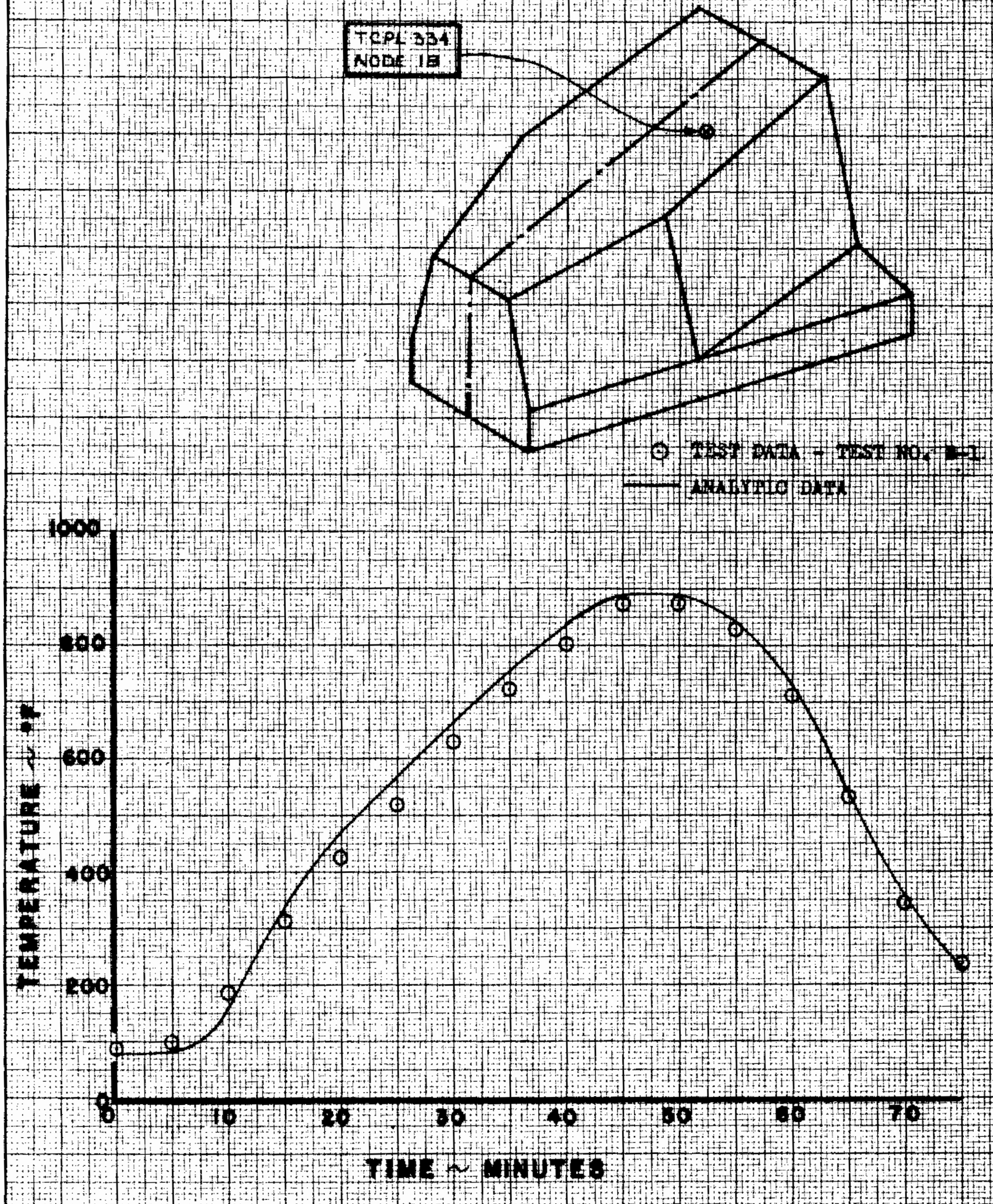
CHECK						
APR					THE BOEING COMPANY	PAGE 154
APR						



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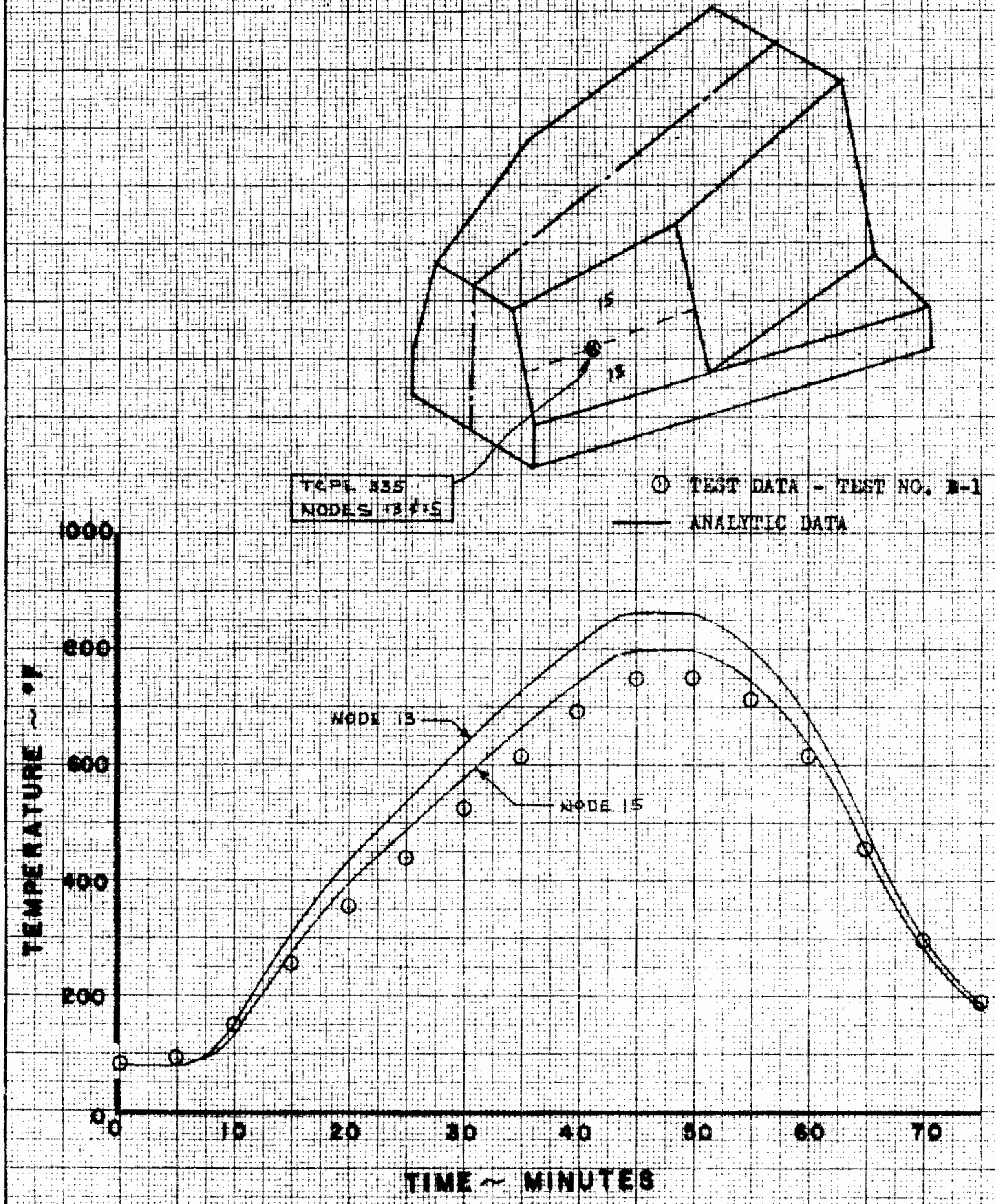
CHECK						
APR					THE BOEING COMPANY	PAGE 155
APR						



CALC	Wrensl	4/7/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS D - TEST B-1 FORWARD BODY
CHECK					
APR					THE BOEING COMPANY
APR					

D2-90709
-1

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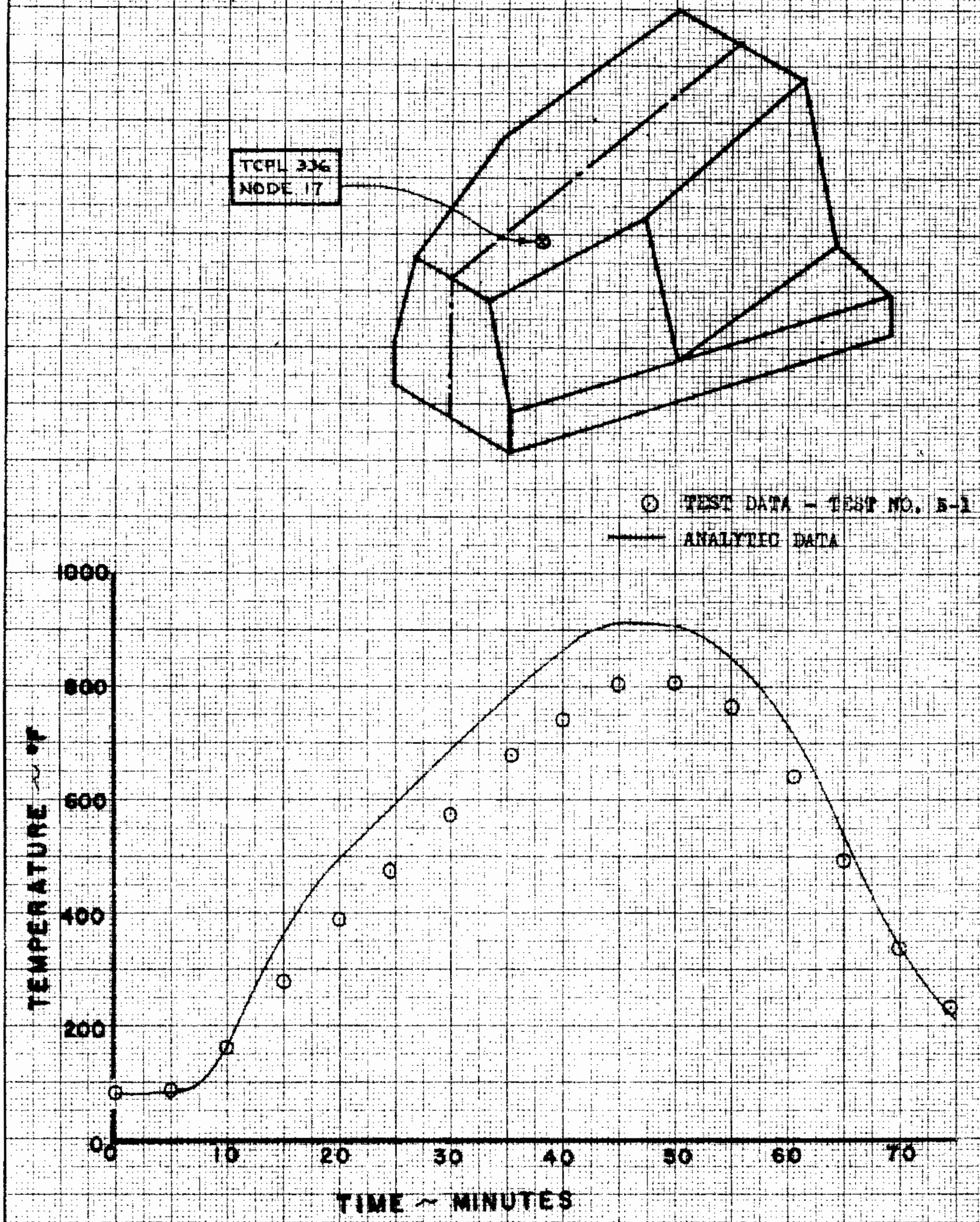

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4.5.3 Discussion (Analysis D)

Correlation of this three-dimensional analysis is quite good for Test 5.1 but of poorer overall quality for Test Bl. Discrepancies of the order of 100°F are seen in the area of the first fuselage bay for the latter test. This error is not exceedingly large, however, and can certainly be attributed to internal convective effects which have been noted previously in this test.

For this test model, which does not contain any large nose cap mass, the two-dimensional approach (as exhibited by Analysis A) appears equally valid as the three-dimensional assumption. The simple three-dimensional approach is not particularly poor, however, and probably would be sufficient for a design such as the X-20.

4.6 LONGERON JOINT THREE-DIMENSIONAL ANALYSIS (ANALYSIS E) (See Page 7)

4.6.1 Analysis Description

This analysis of a longeron structural joint is based on the utmost simplicity. Nodes are large and few, view factors were frequently estimates, and boundary conditions were held to a minimum. Normal techniques applied to such a joint might result in 100 nodes (a very large problem). Effort of this nature is not normally justifiable for such joints.

During the X-20 analysis program, similar methods were used, although the joint analysis effort was not completed.

The nodal system includes the basic joint (note usage of a simple massive node for the main fitting) and the immediate adjoining trusswork. Boundary conditions include the surrounding panel environment (some of which are "averaged" values) and the truss structure. A variety of sources was used for these boundary conditions (see boundary condition delineation at the beginning of the following section).

Assumptions 11 and 12 of Section 4.1 (page 9) apply. In addition, no interface effects are included.

Boundary conditions are referenced on page 160 for Test 5 and page 185 for Test B1.

The nodal system is shown in Figures 11 and 12, pages 172 and 173 for Test 5, and Figures 13 and 14, pages 201 and 202, for Test B1. Constants, conductors, capacitors, etc., are shown on pages 174 through 177 for Test 5, and pages 203 through 206 for Test B1.

Correlation for Test 5.6 is on pages 178 thru 184; Test B1 comparisons are shown on pages 207 through 208.

4.6.2.1 ANALYSIS E CORRELATION

LONGERON JOINT THREE-DIMENSIONAL ANALYSIS

TEST SERIES: 5 CONDITION: 5.6

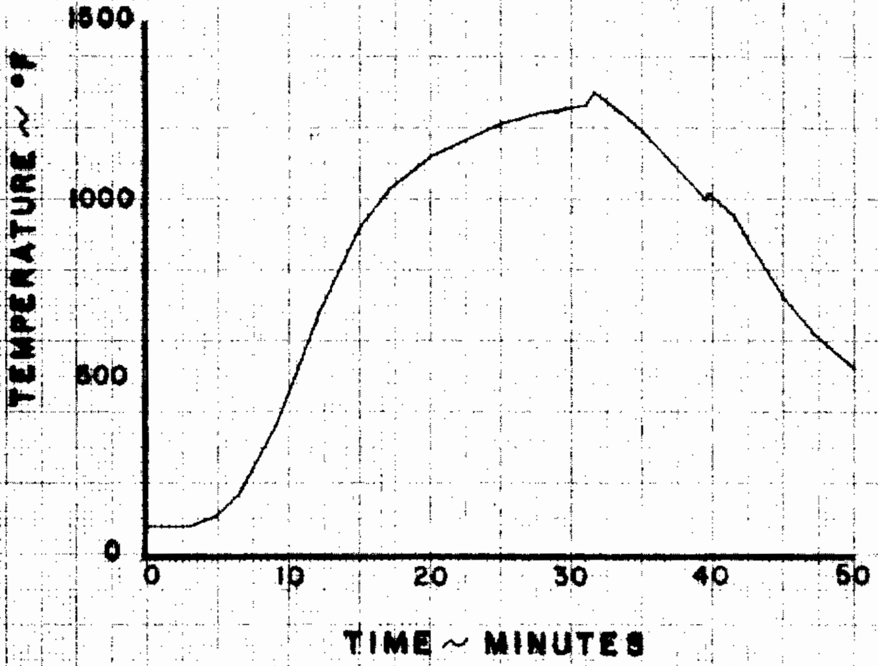
BOUNDARY NODES	SOURCE	PAGE
23	ANALYSIS B NODE 31	161
24	ANALYSIS B NODE 34	162
25	ANALYSIS B NODE 36	163
26	ANALYSIS B NODE 35	164
27	ANALYSIS B NODE 33	165
28	ANALYSIS B NODE 39 RUN 1	166
29	ANALYSIS B NODE 10	167
30	ANALYSIS B NODE 10	167
31	ANALYSIS B NODE 11	168
32	ANALYSIS B NODE 13	169
33	ANALYSIS B NODE 19	170
34	ANALYSIS B NODE 22	171

NOTE:

RUN 1 HAD THE DIAGONAL TRUSS TUBE LOCATED 10 INCHES AFT OF FRAME D AND GIVES BETTER APPROXIMATION OF THE BOUNDARY NODE THAN DOES THE FINAL RUN OF ANALYSIS B.

RESULTS OF ANALYSIS B TEST 5.1:
NODE 31

DRIVE BOUNDARY NODE:
23 ANALYSIS E TEST 5.6



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D2-90709
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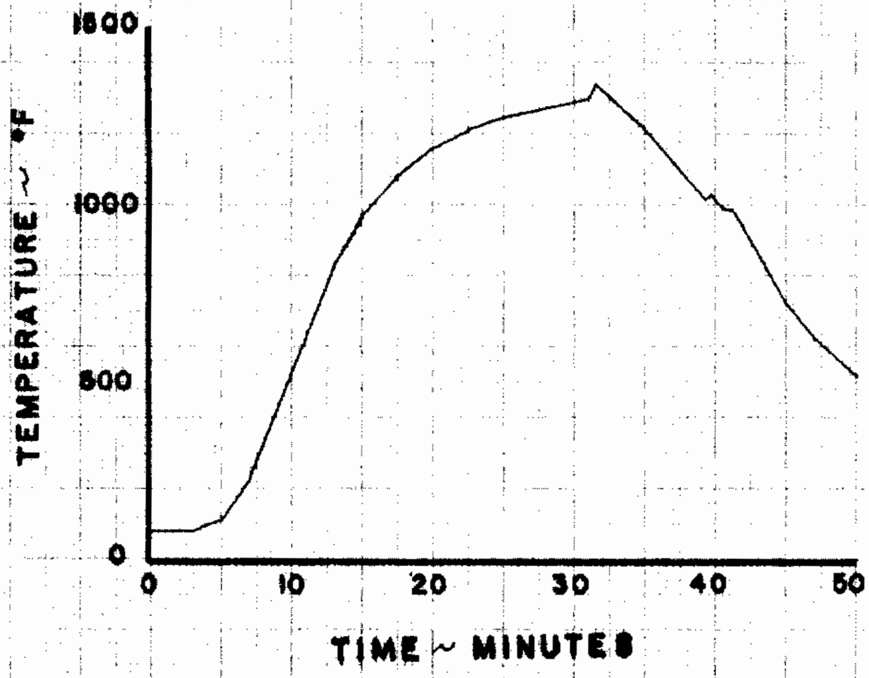
RESULTS OF ANALYSIS B TEST 5.1:
NODE 34

DRIVE BOUNDARY NODE:
24 ANALYSIS E TEST 5.6

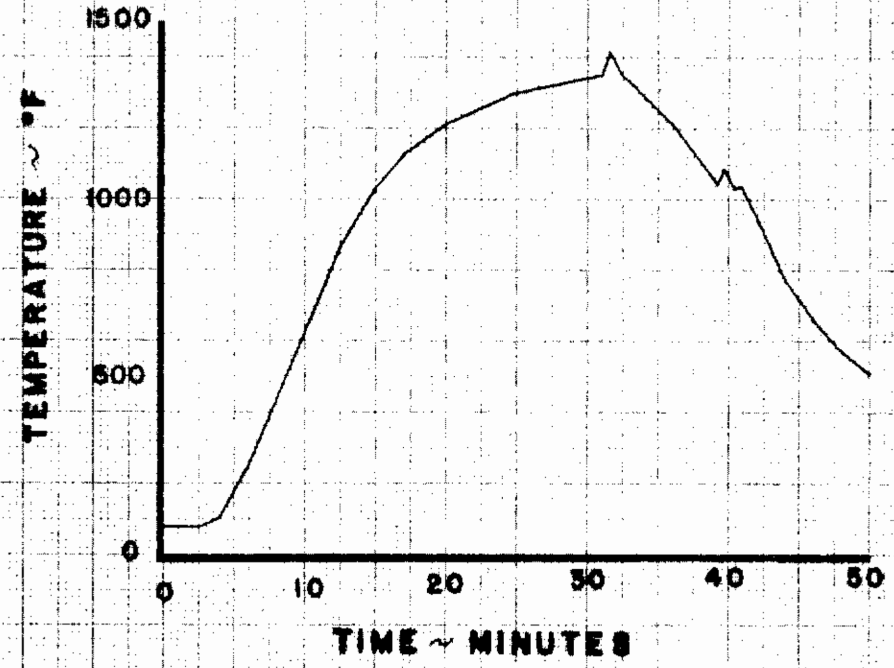


RESULTS OF ANALYSIS B TEST 5.1:

NODE 36

DRIVE BOUNDARY NODE:

25 ANALYSIS E TEST 5.6



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BOUNDARY CONDITIONS

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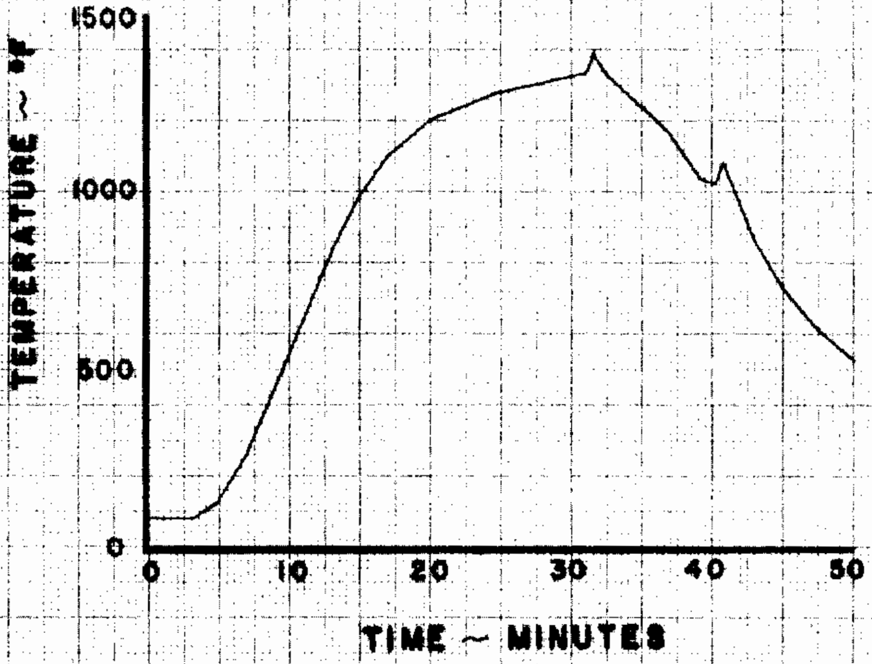
RESULTS OF ANALYSIS B TEST 5.1:
NODE 35

DRIVE BOUNDARY NODE:
26 ANALYSIS E TEST 5.6



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BOUNDARY CONDITIONS

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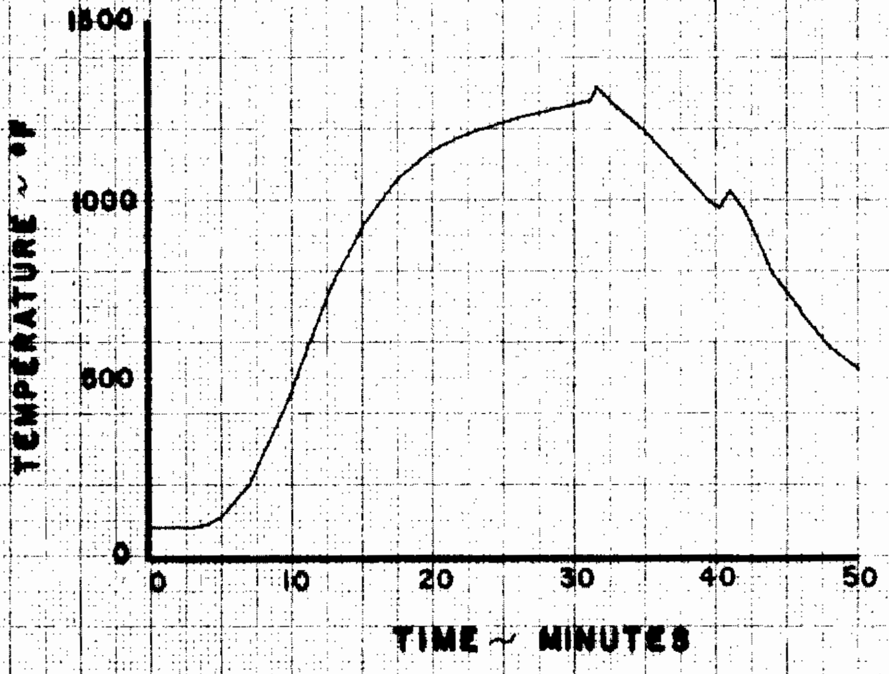
RESULTS OF ANALYSIS B TEST 5.1:
NODE 33

DRIVE BOUNDARY NODE:
27 ANALYSIS E TEST 5.6



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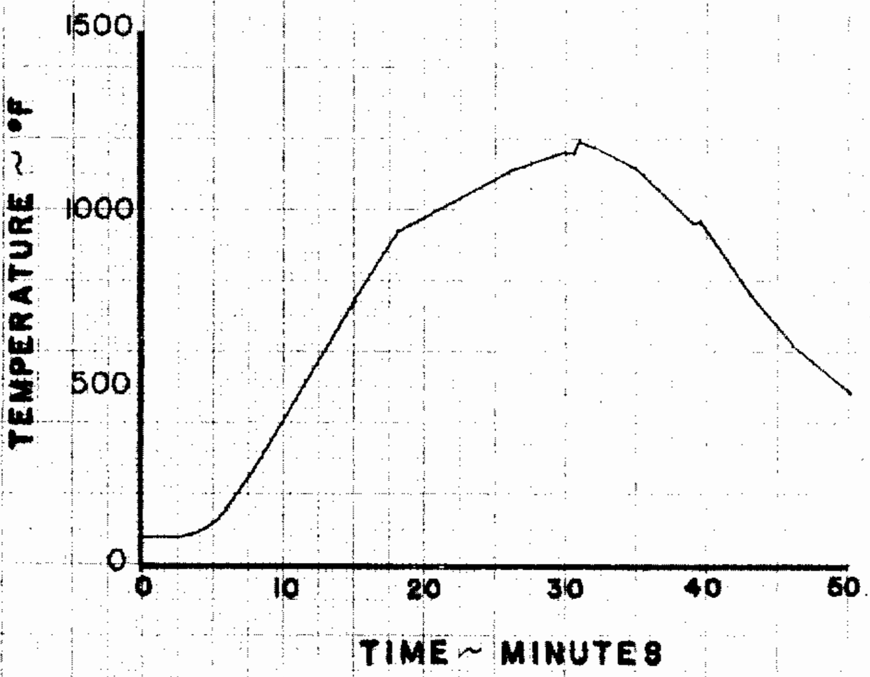
RESULTS OF ANALYSIS B TEST 9.1:
NODE 39 RUN NO. 1

DRIVE BOUNDARY NODES:
28 ANALYSIS E TEST 5.6



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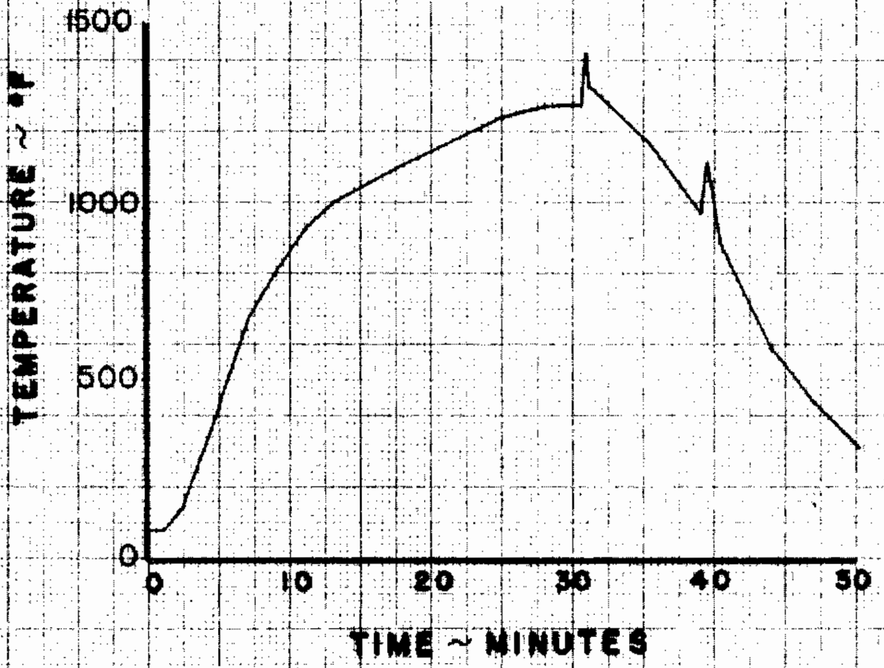
				THE BOEING COMPANY	

RESULTS OF ANALYSIS B TEST 5.1:
NODE 10

DRIVE BOUNDARY NODES:
29 ANALYSIS E TEST 5.6
30 ANALYSIS E TEST 5.6



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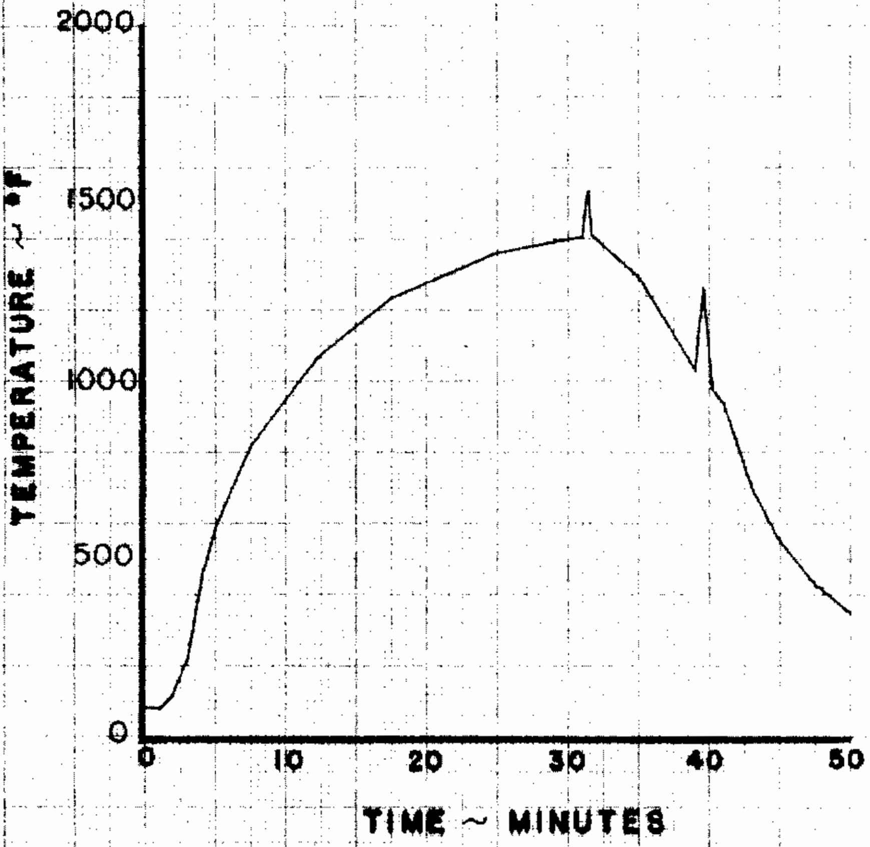
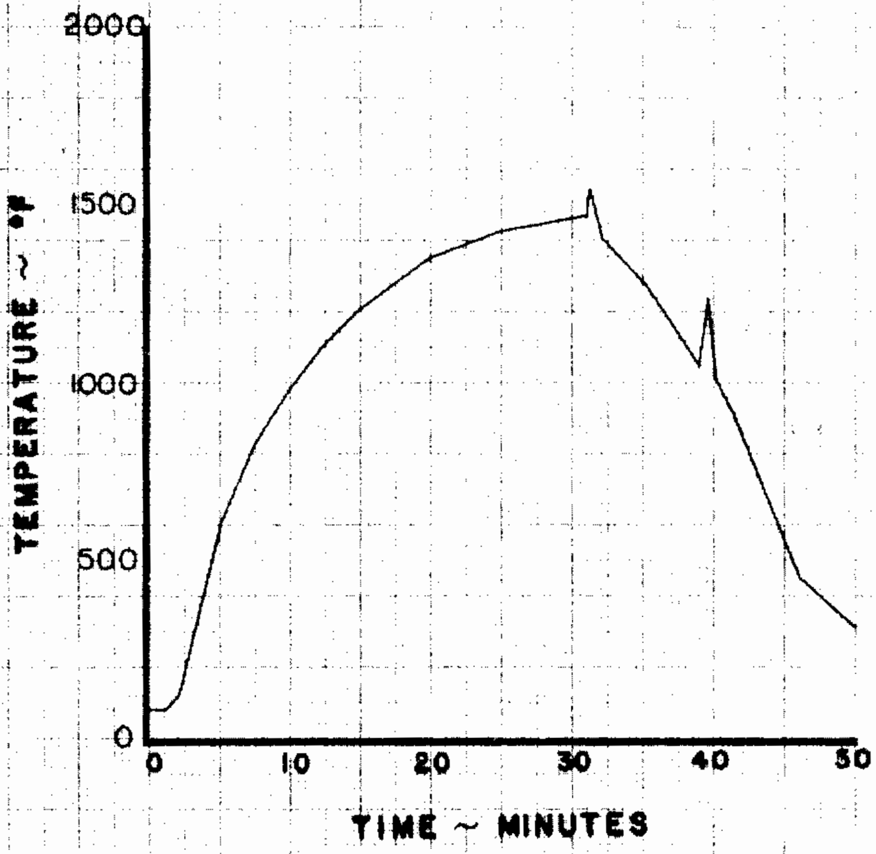
RESULTS OF ANALYSIS B TEST 5.1:
NODE 11

DRIVE BOUNDARY NODE:
31 ANALYSIS E TEST 5.6



RESULTS OF ANALYSIS B TEST 5.1:
NODE 13

DRIVE BOUNDARY NODE:
32 ANALYSIS E TEST 5.6



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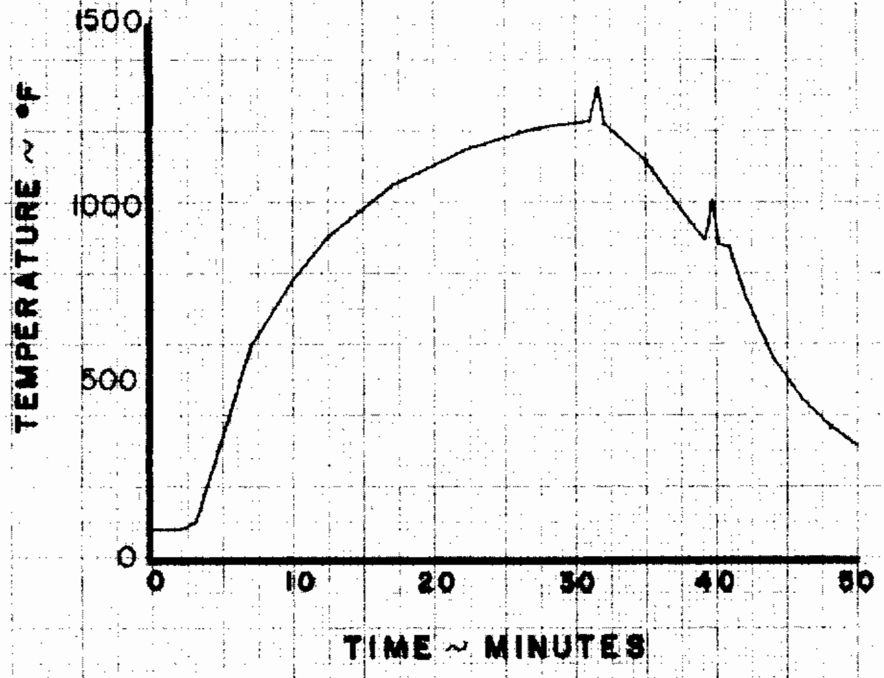
BOUNDARY CONDITIONS

THE BOEING COMPANY

RESULTS OF ANALYSIS B TEST 5.1:
NODE 19

DRIVE BOUNDARY NODE:
33 ANALYSIS E TEST 5.6



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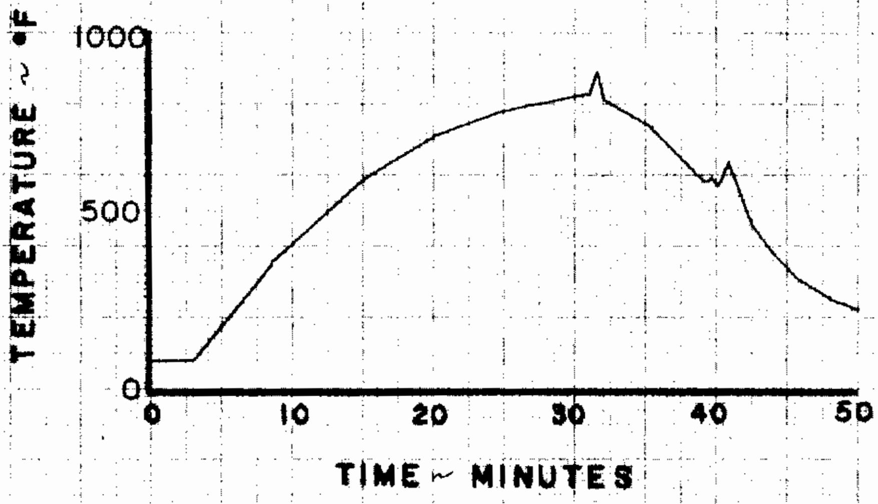
HCT STRUCTURES THERMAL CORRELATION
BOUNDARY CONDITIONS

RESULTS OF ANALYSIS B TEST 5.1:
NODE 22

DRIVE BOUNDARY NODE:
34 ANALYSIS E TEST 5.6



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ANALYSIS E
LONGERON JOINT
3-DIMENSIONAL

NODAL DIAGRAM

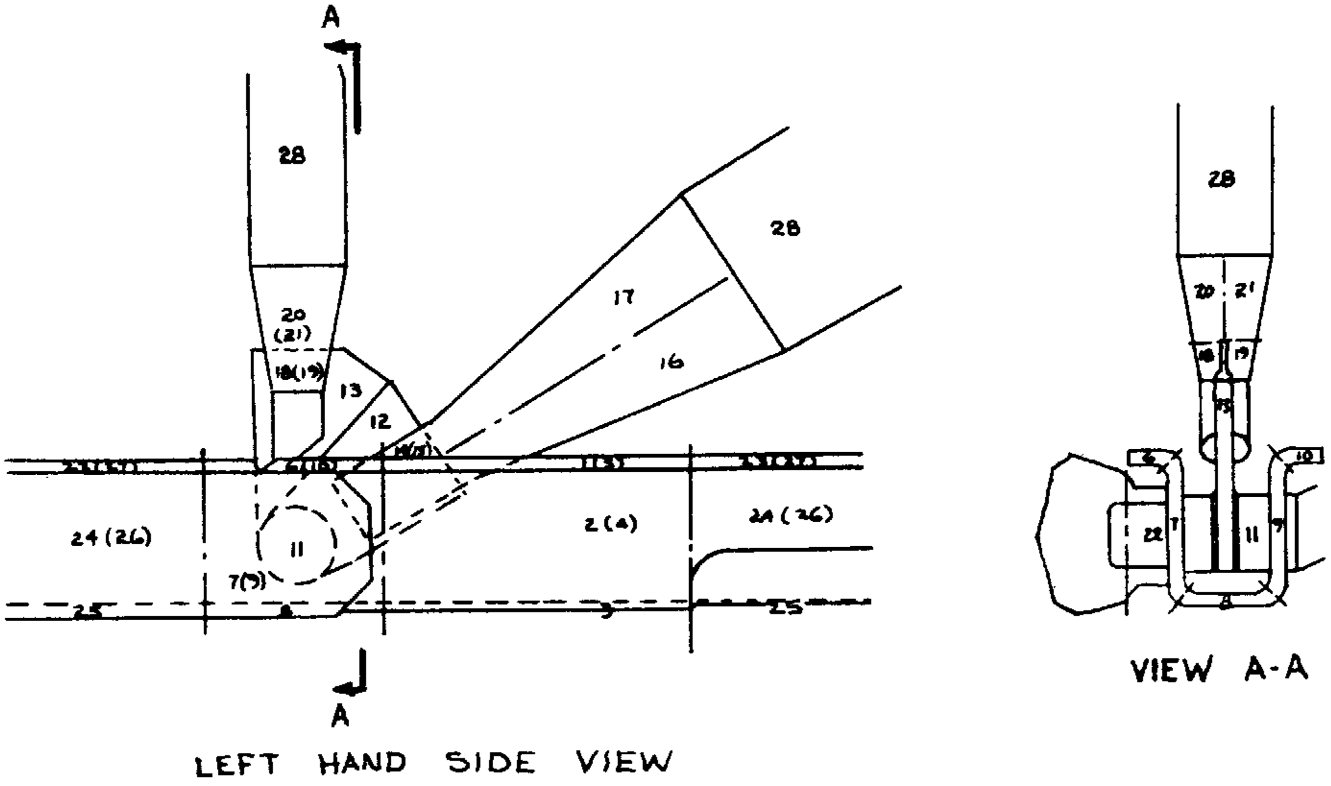

FIGURE 11 - ANALYSIS E NODAL DIAGRAM - TEST 5

ANALYSIS E
LONGERON JOINT
3-DIMENSIONAL

NODAL DIAGRAM

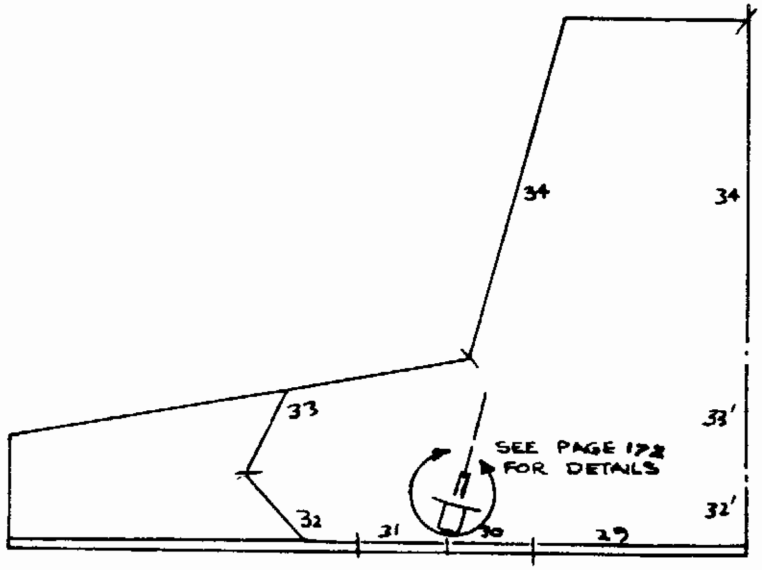

FIGURE 12 - ANALYSIS E BOUNDARY CONDITION DIAGRAM - TEST 5

CAPACITORS - ANALYSIS E TEST 5.1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	RENE' 41	0.124	4.266×10^{-3}
2	↓	0.434	1.493×10^{-2}
3		0.310	1.0664×10^{-2}
4		0.434	1.493×10^{-3}
5		0.124	4.266×10^{-3}
6		0.136	4.678×10^{-3}
7		0.476	1.6374×10^{-2}
8		0.300	1.032×10^{-2}
9		0.476	1.6374×10^{-2}
10		0.136	4.678×10^{-3}
11		0.452	1.5559×10^{-2}
12		0.386	9.838×10^{-3}
13		0.408	1.4035×10^{-2}
14		0.0694	2.384×10^{-3}
15		0.0694	2.384×10^{-3}
16		0.492	1.693×10^{-2}
17		0.492	1.693×10^{-2}
18		0.0364	1.252×10^{-3}
19		0.0364	1.252×10^{-3}
20		0.0513	1.765×10^{-3}
21		0.0513	1.765×10^{-3}
22	RENE' 41	0.234	8.050×10^{-3}
23 thru 28	RENE' 41	DRIVEN	--
29 thru 32	HS-25	DRIVEN	--
33	RENE' 41	DRIVEN	--
34	RENE' 41	DRIVEN	--

CONDUCTION CONDUCTORS - ANALYSIS E TEST 5.1

CONDUCTOR	CONNECTING NODES	A/L
1	1 - 2	.3444
2	2 - 3	.2583
3	3 - 4	.2583
4	4 - 5	.3444
5	6 - 7	.3778
6	7 - 8	.2667
7	8 - 9	.2667
8	9 - 10	.3778
9	1 - 6	.0157
10	2 - 7	.0549
11	3 - 8	.0392
12	4 - 9	.0549
13	5 - 10	.0157
14	11 - 7	.43
15	11 - 9	.43
16	11 - 12	.2095
17	11 - 13	.1920
18	12 - 13	.2609
19	12 - 14	.1867
20	12 - 15	.1867
21	14 - 16	.0174
22	15 - 16	.0174
23	14 - 17	.0174
24	15 - 17	.0174
25	16 - 17	.2000
26	13 - 18	.1891
27	13 - 19	.1891
28	18 - 20	.0357
29	19 - 21	.0357
30	22 - 11	.0833
31	1 - 23	.0157
32	2 - 24	.0384
33	3 - 25	.0157
34	4 - 26	.0384
35	5 - 27	.0157
36	6 - 23	.0140
37	7 - 24	.119
38	8 - 25	.075
39	9 - 26	.119
40	10 - 27	.014
41	16 - 28	.0707
42	17 - 28	.0707
43	20 - 28	.0420
44	21 - 28	.0420

RADIATION CONDUCTOR MATRIX

NODE (J)	NODE (I)																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1	-	50														85															101	102	103	
2	50	-	51	52							60	67		81											160	161					104	105		
3		51	-	53							61					86								162		163				106	107			
4		52	53	-	54						62	68			83									164	165				108	109				
5				54	-											87													110	111			112	113
6						-	55					69	75																		114	115	116	
7						55	-	56	57		63	70	76	82											166	167					117	118		
8							56	-	58		64													168		169				119	120			
9							57	58	-	59	65	71	77		84									170	171				121	122				
10									59	-		72	78																123	124			125	126
11		60	61	62			63	64	65		-	66												172	173	174								127
12		67		68		69	70		71	72	66	-		73	74																			
13						75	76		77	78			-					79	80										128			129	130	131
14		81					82					73		-																			132	
15				83					84			74			-																		133	134
16	85		86		87											-	88						175		176		177	178	135			136		
17																88	-											179					137	138
18													79					-														139	141	
19													80						-										143				145	146
20																				-	89							180				140	142	
21																				89	-							181	144				147	148
22																						-									149	150		
23																175							-											
24			162	164				168	170		172													-										
25		160		165			166		171		173					176									-									
26		161	163				167	169			174															-								
27																177											-							
28																178	179			180	181							-						
29				108	110				121	123			128			135			143		144								-					
30			106	109	111			119	122	124																				-				
31	101	104	107			114	117	120														149									-			
32	102	105				115	118						129			136		139		140		150										-		
33	103				112	116				125			130	132	133		137	141	145	142	147												-	
34					113					126	127		131		134		138		146		148													-

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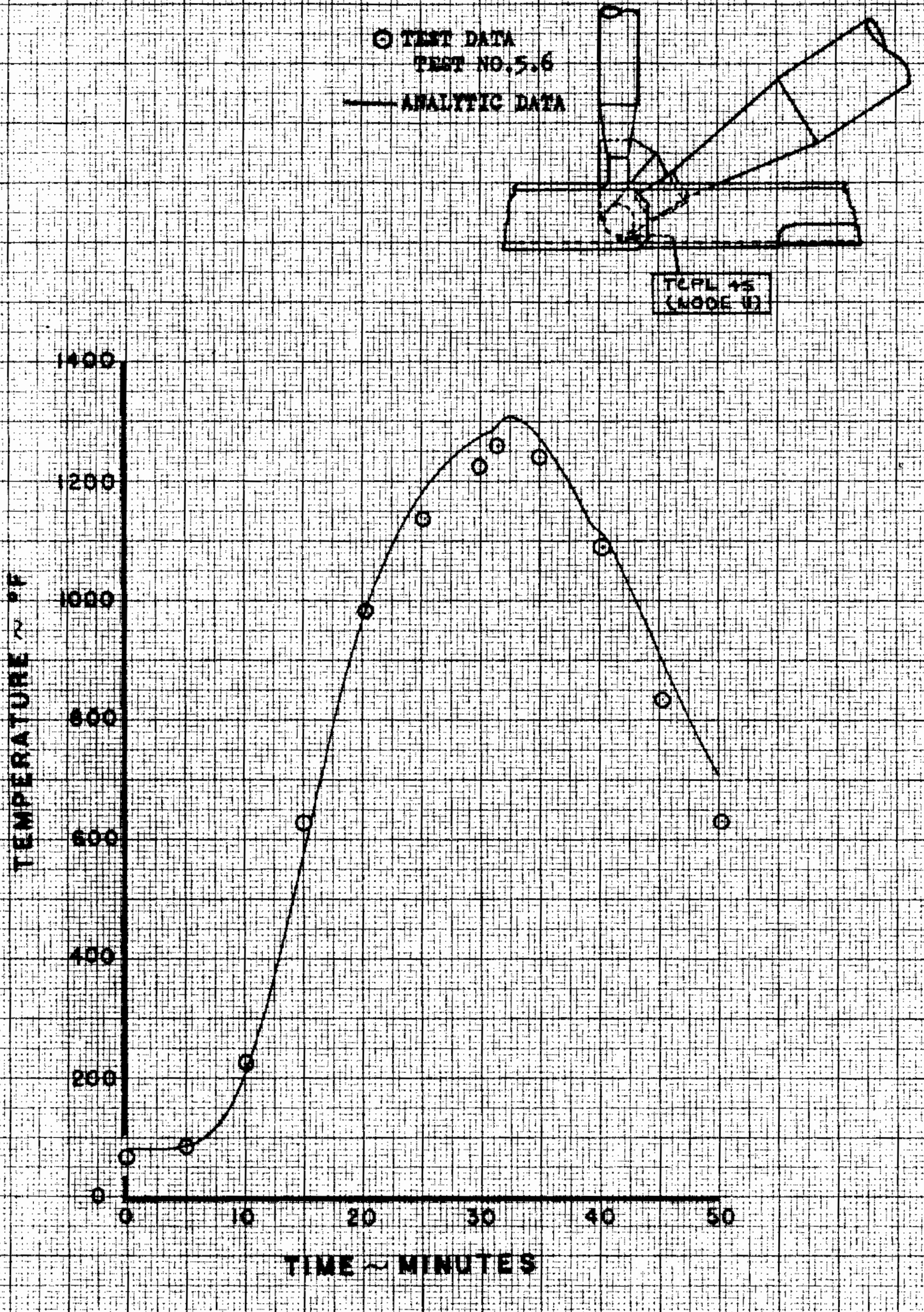
PAGE

RADIATION CONDUCTORS - ANALYSIS E TEST 5.1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
50	.496	112	.124	172	.090
51	.868	113	.744	173	.090
52	1.736	114	.32	174	.090
53	.868	115	.16	175	.234
54	.496	116	.56	176	.156
55	.280	117	.60	177	.234
56	.280	118	1.00	178	.780
57	.420	119	1.40	179	.780
58	.300	120	.60	180	.218
59	.280	121	1.40	181	.218
60	.090	122	.84		
61	.090	123	.08		
62	.090	124	.40		
63	.360	125	.08		
64	.270	126	.48		
65	.360	127	.144		
66	.126	128	.70		
67	.070	129	.42		
68	.070	130	1.19		
69	.035	131	.21		
70	.070	132	.44		
71	.070	133	.275		
72	.035	134	.165		
73	.075	135	1.56		
74	.075	136	1.56		
75	.070	137	3.90		
76	.070	138	3.90		
77	.070	139	.2835		
78	.070	140	.5265		
79	.650	141	.384		
80	.650	142	.896		
81	.385	143	.4455		
82	.275	144	.640		
83	.385	145	.2025		
84	.275	146	.162		
85	.390	147	.320		
86	.500	148	.320		
87	.390	149	.312		
88	5.04	150	.458		
89	.760	160	.217		
101	.496	161	.434		
102	.248	162	.186		
103	.868	163	.186		
104	1.302	164	.434		
105	2.170	165	.217		
106	.930	166	.084		
107	2.170	167	.196		
108	2.170	168	.100		
109	1.302	169	.100		
110	.124	170	.196		
111	.620	171	.084		



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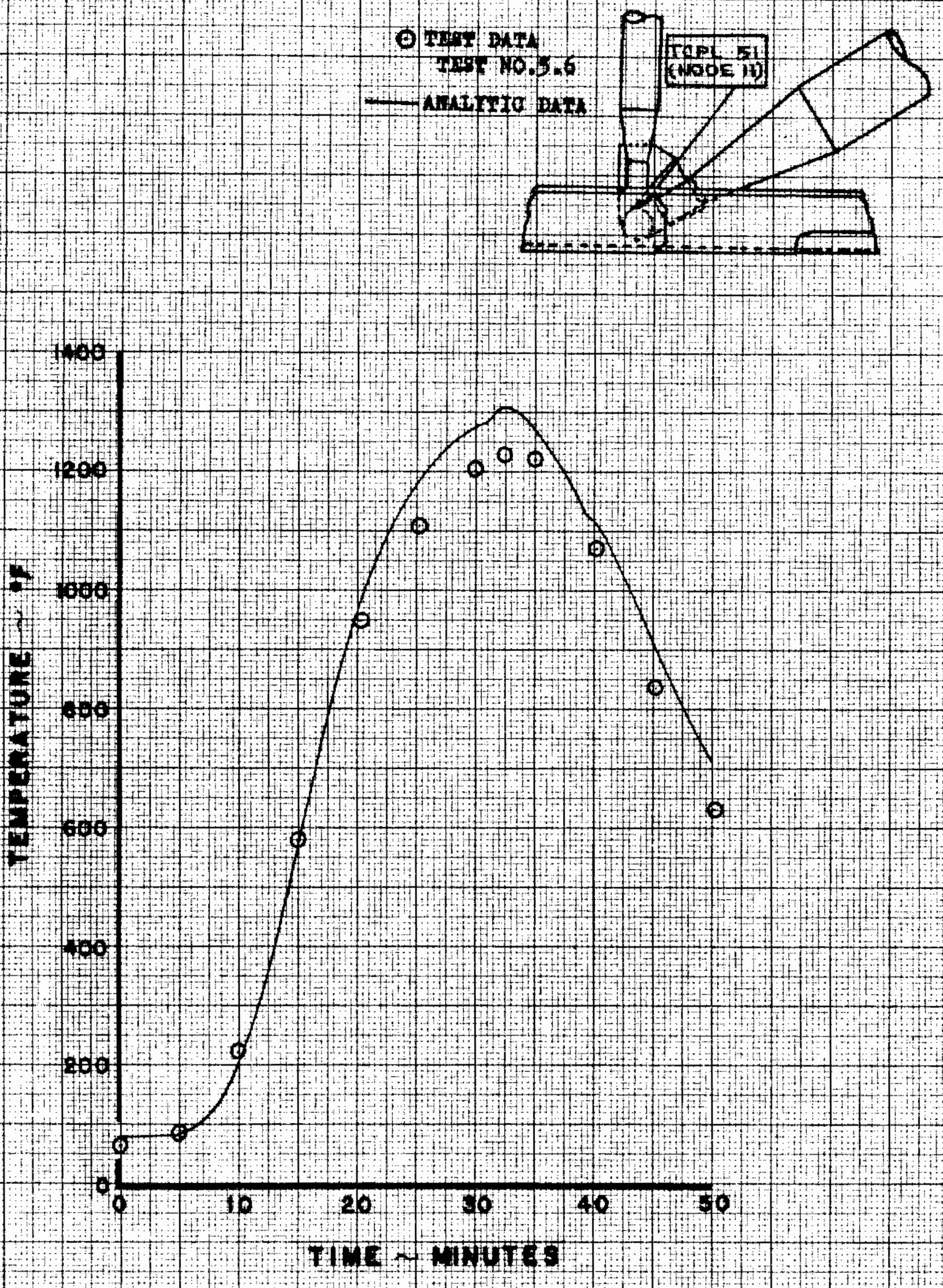

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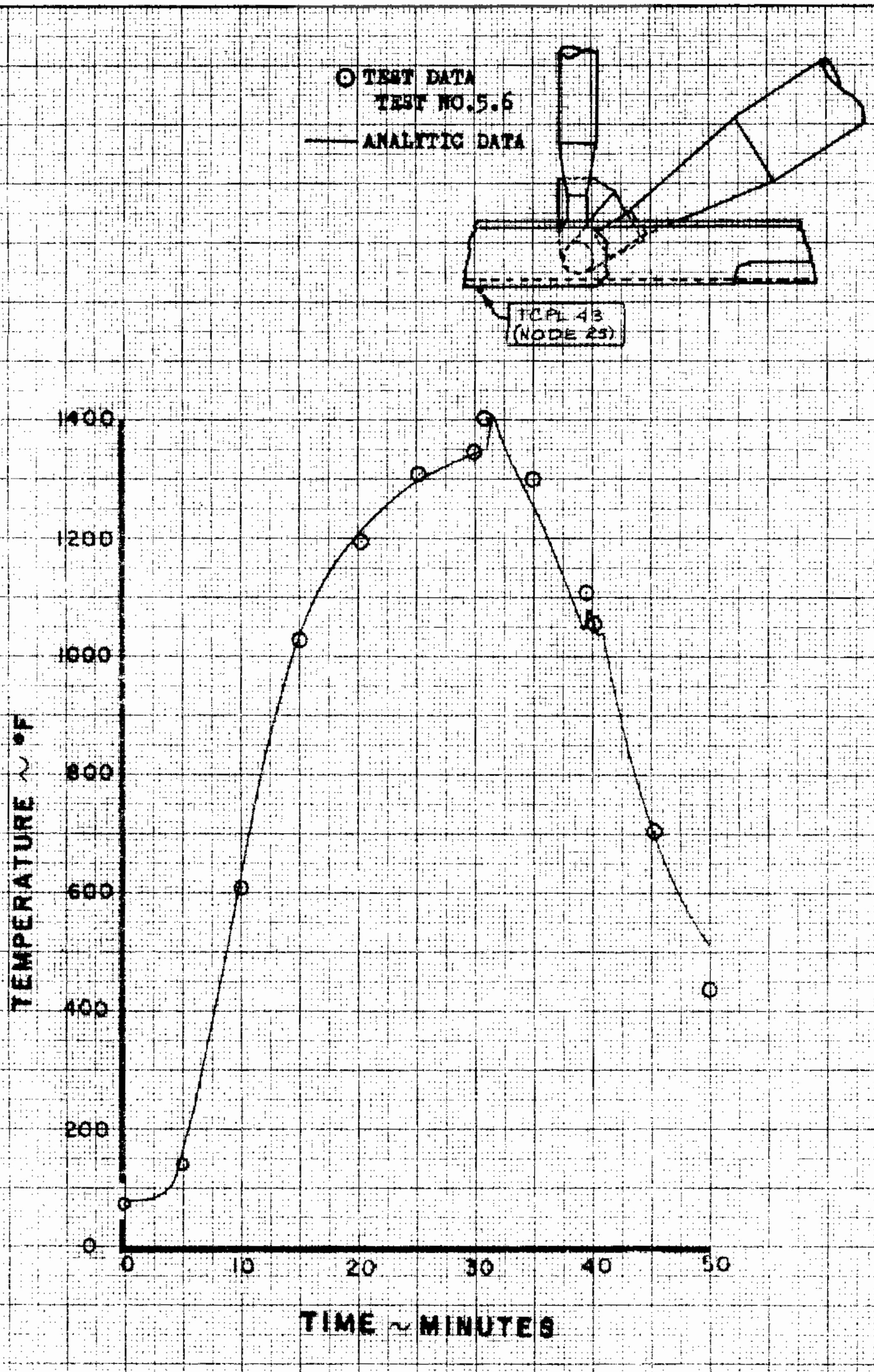

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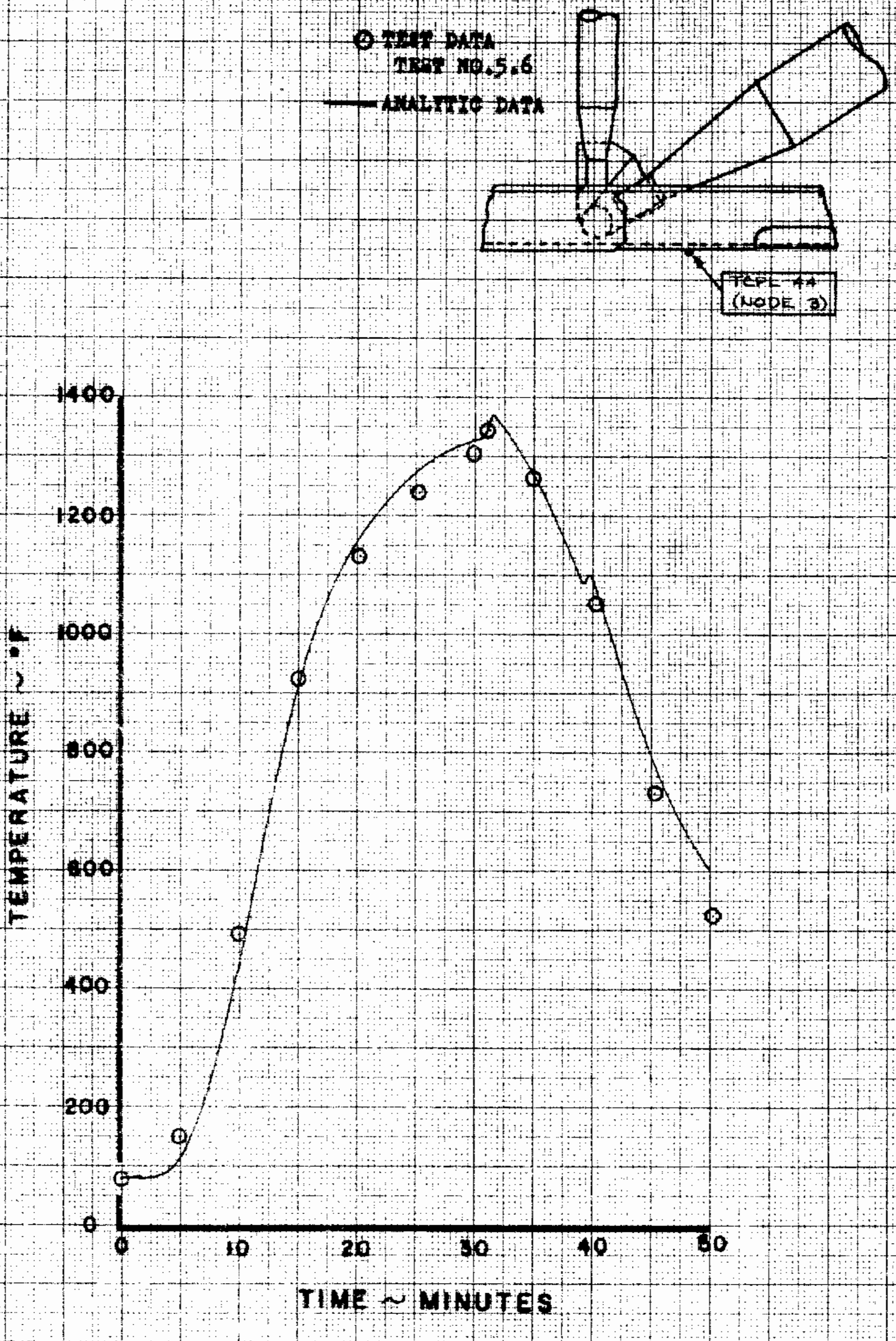

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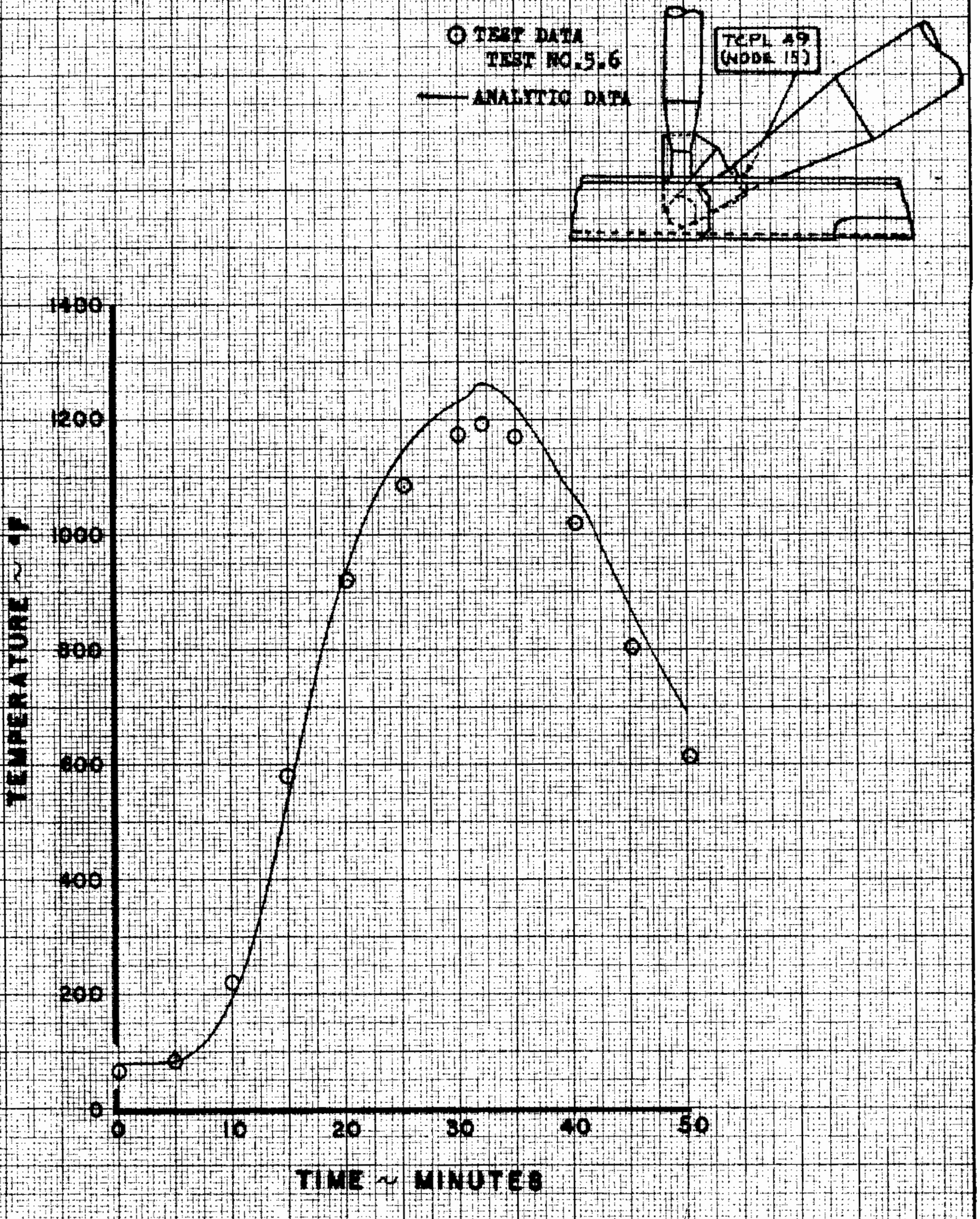

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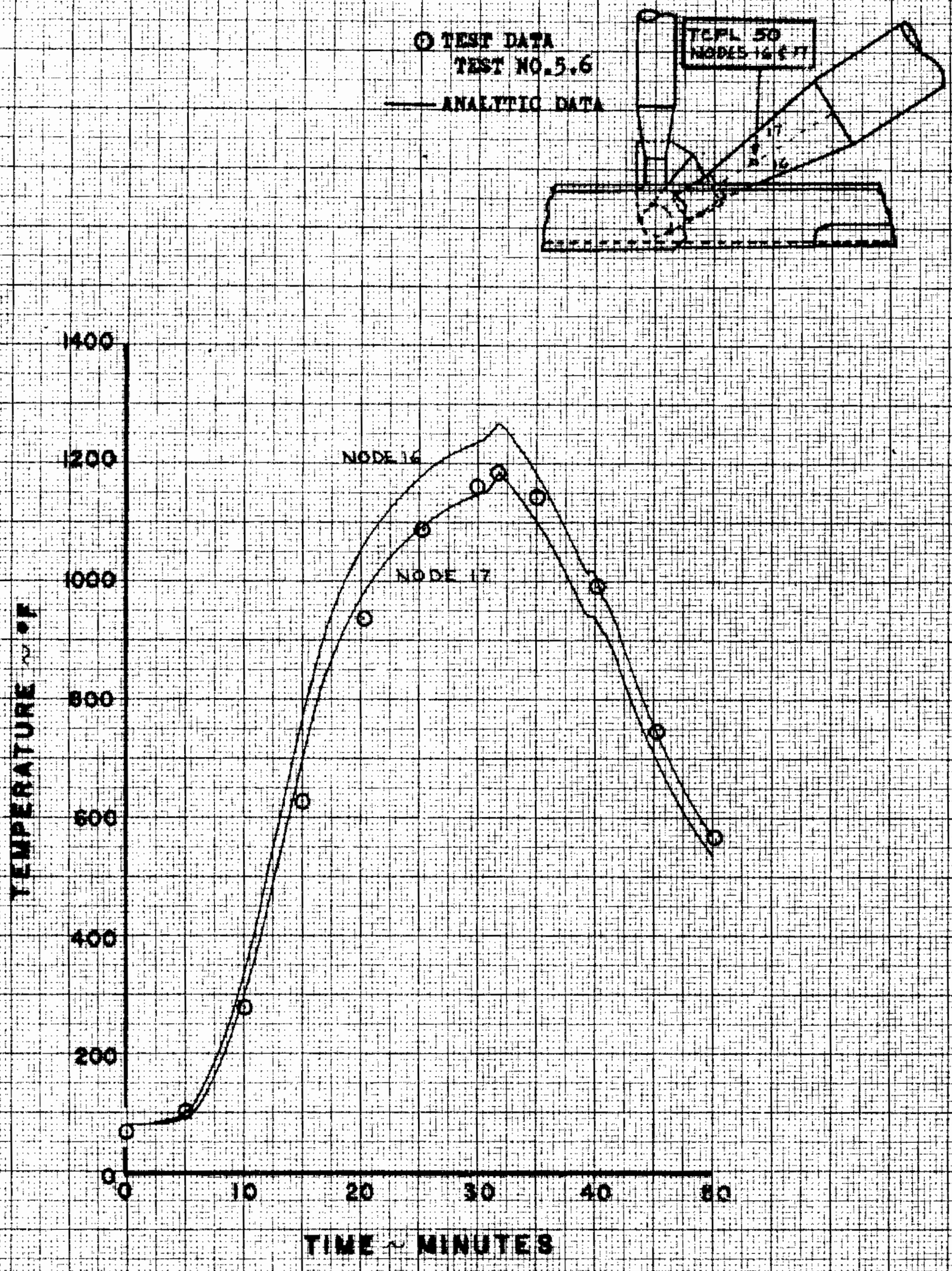

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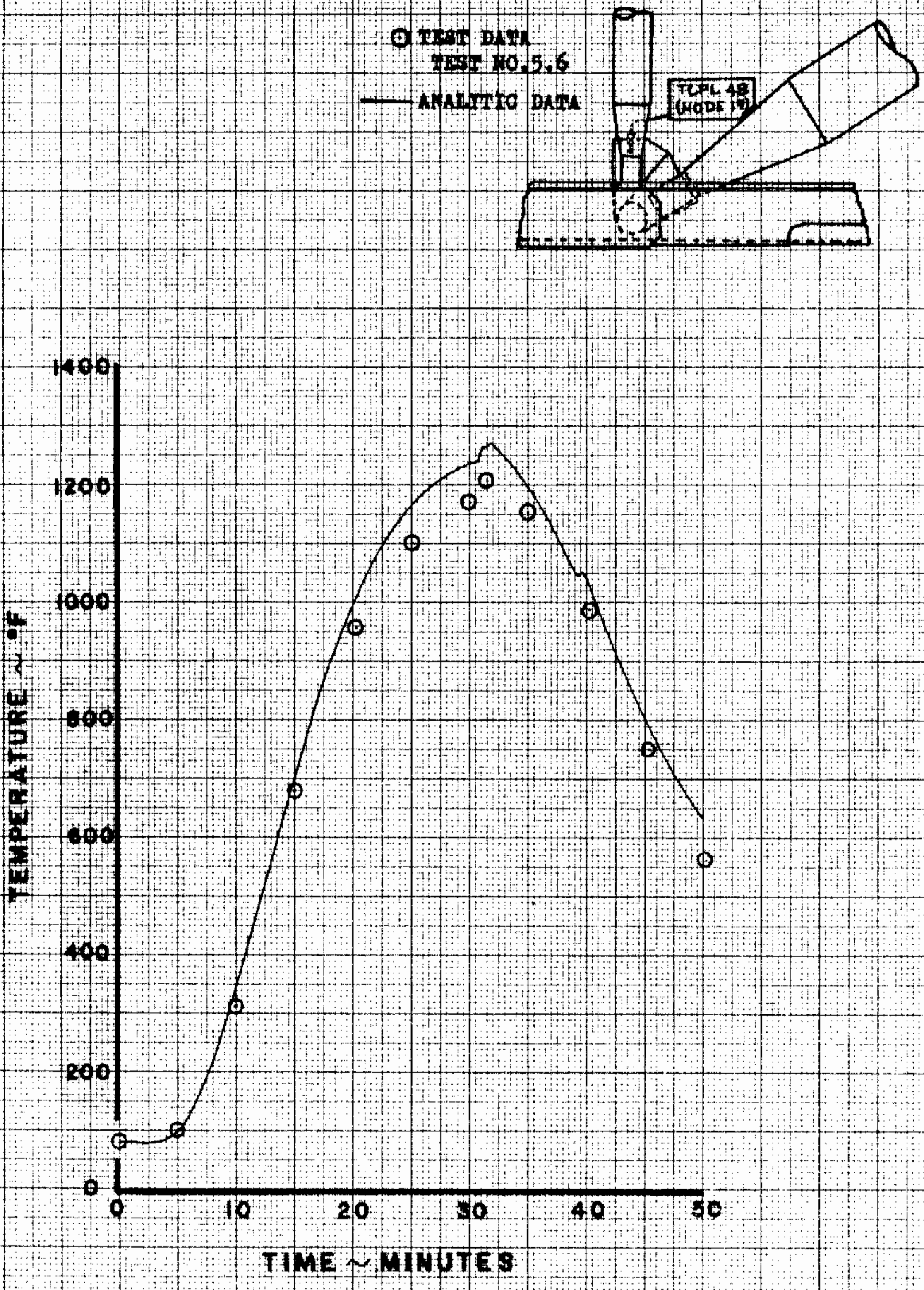

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D2-90709
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PAGE

4.6.2.2 ANALYSIS E CORRELATION

LONGERON JOINT THREE-DIMENSIONAL ANALYSIS

TEST SERIES: B-1

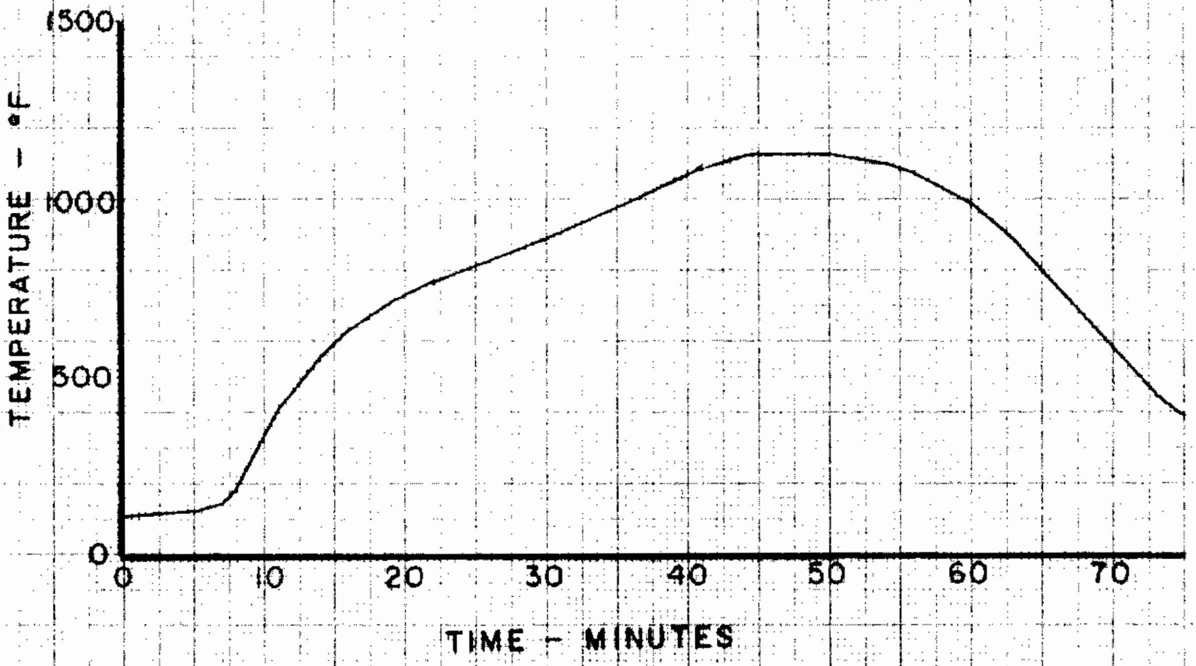
BOUNDARY NODES	SOURCE	PAGE
23	THERMOCOUPLE 40 TEST B-1	186
24	THERMOCOUPLE 38 TEST B-1	187
25	THERMOCOUPLE 60 TEST B-1	188
26	THERMOCOUPLE 37 TEST B-1	189
27	THERMOCOUPLE 39 TEST B-1	190
28	THERMOCOUPLE 90 TEST B-1	191
29	ANALYSIS B TEST B-1 NODE 8	192
30	THERMOCOUPLE 348 TEST B-1	193
31	THERMOCOUPLE 344 TEST B-1	194
32	THERMOCOUPLE 344 TEST B-1	194
33	THERMOCOUPLE 434 TEST B-1	195
34	THERMOCOUPLE 327 TEST B-1	196
35	THERMOCOUPLE 3AS TEST B-1	197
36	ANALYSIS B TEST B-1 NODE 56	198
37	THERMOCOUPLE 3B TEST B-1	199
38	THERMOCOUPLE 7A TEST B-1	200

NOTE:

THERMOCOUPLE 39 WAS NOT RECORDED FOR TEST B-1, SO BOUNDARY NODE 27 WAS APPROXIMATED BY THE FORMULA SHOWN ON PAGE 190.

THERMOCOUPLE #40 TEST B-1

DRIVE BOUNDARY NODE:
23 ANALYSIS E TEST B-1



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HOT STRUCTURES THERMAL CORRELATION
BOUNDARY CONDITIONS

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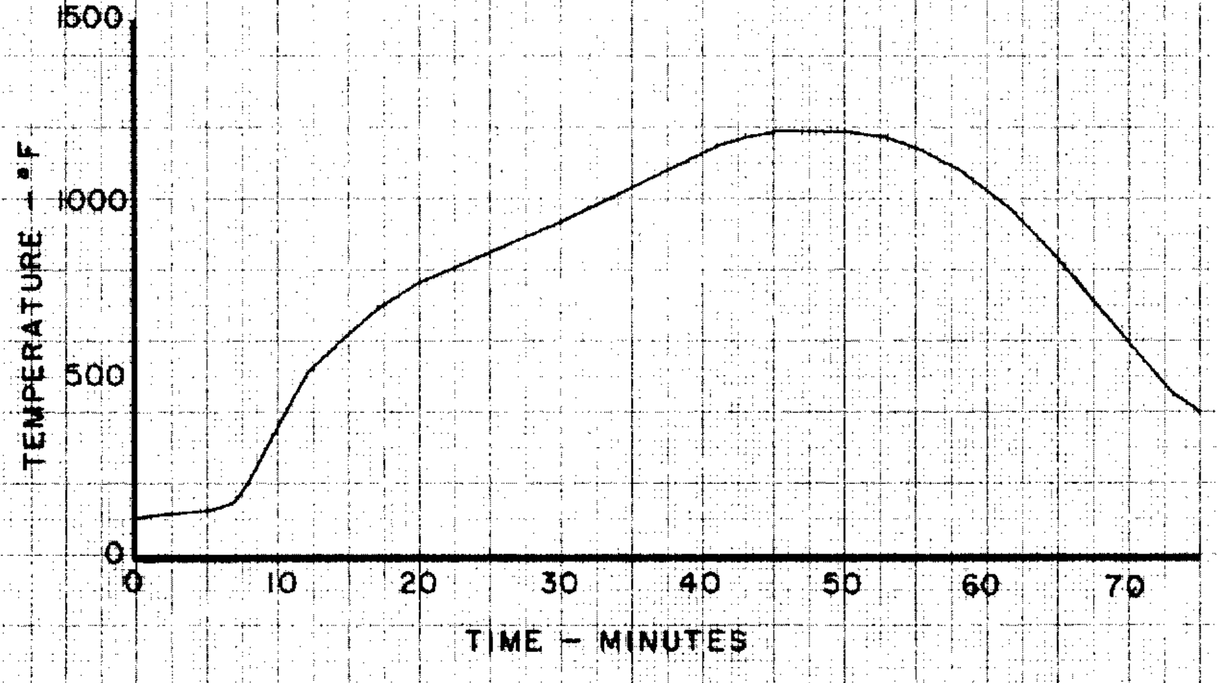
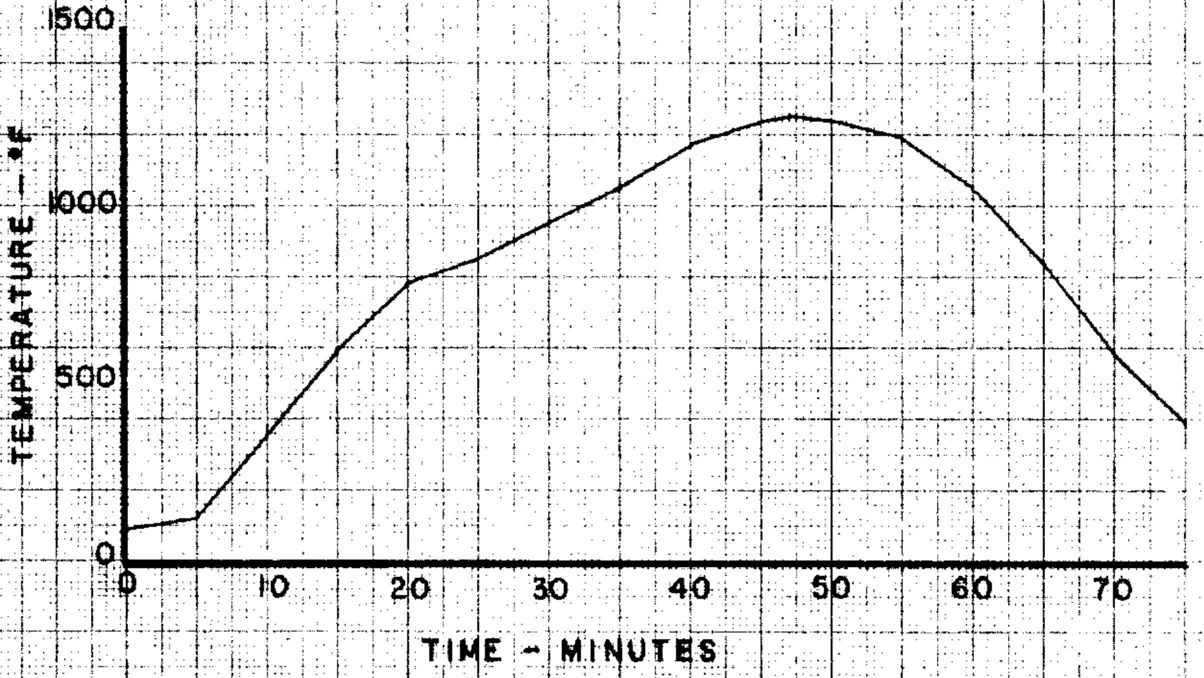
THERMOCOUPLE #38 TEST B-1

DRIVE BOUNDARY NODE:
24 ANALYSIS E TEST B-1



THERMOCOUPLE #60 TEST B-1

DRIVE BOUNDARY NODE:
25 ANALYSIS E TEST B-1



CALC	Drenel	9/13/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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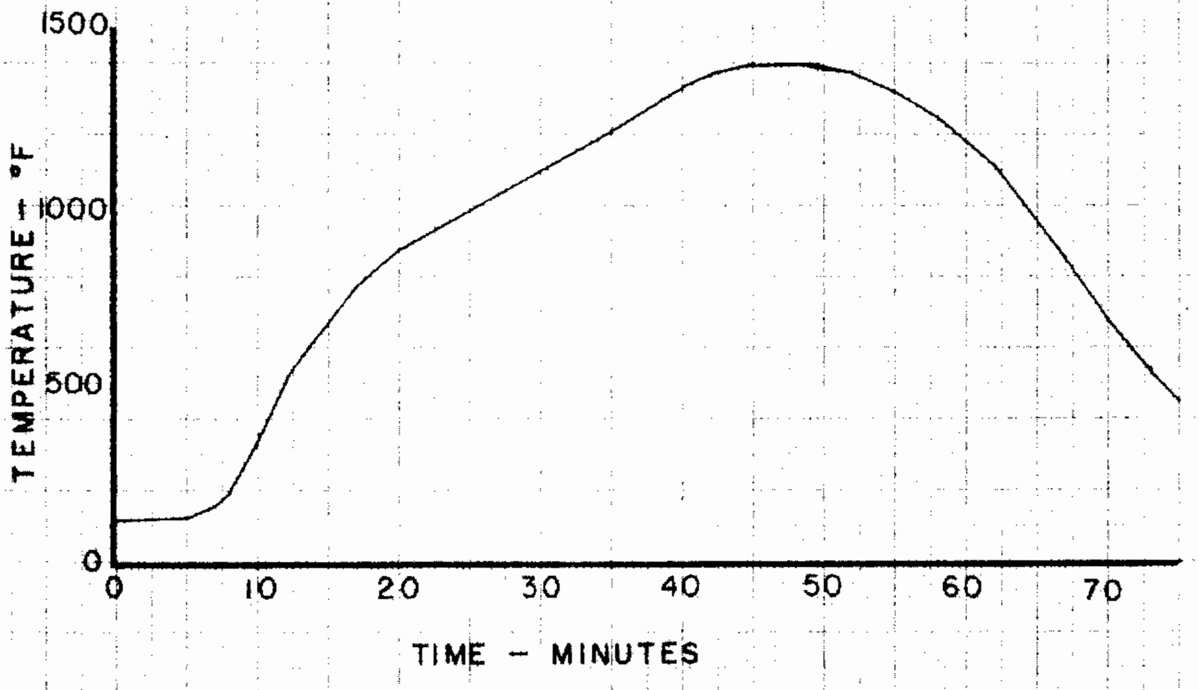
APR					THE BOEING COMPANY	PAGE

THERMOCOUPLE #37 TEST B-1

DRIVE BOUNDARY NODE:
26 ANALYSIS E TEST B-1



CALC	4/13/65	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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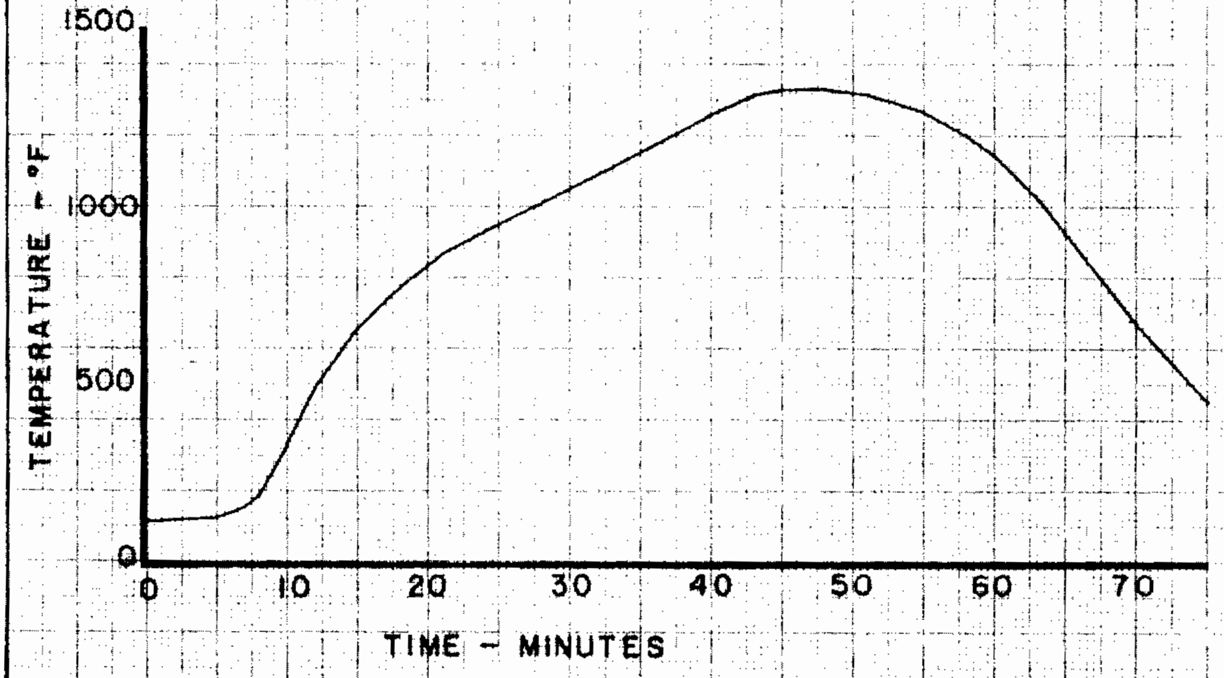
APD		THE BOEING COMPANY	

THERMOCOUPLE #39 TEST B-1 (APPROXIMATED)

$T_{39} = T_{37} - (T_{38} - T_{40})$

DRIVE BOUNDARY NODE:

27 ANALYSIS E TEST B-1



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APR					THE BOEING COMPANY

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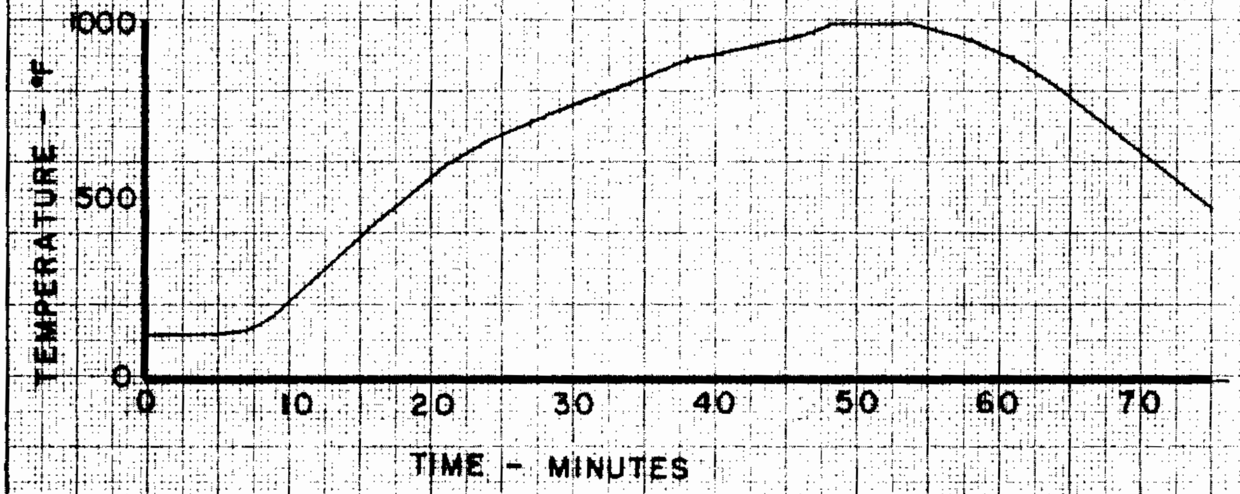
THERMOCOUPLE #90 TEST B-1

DRIVE BOUNDARY NODE:
28 ANALYSIS E TEST B-1



CALC	Drench	4/13/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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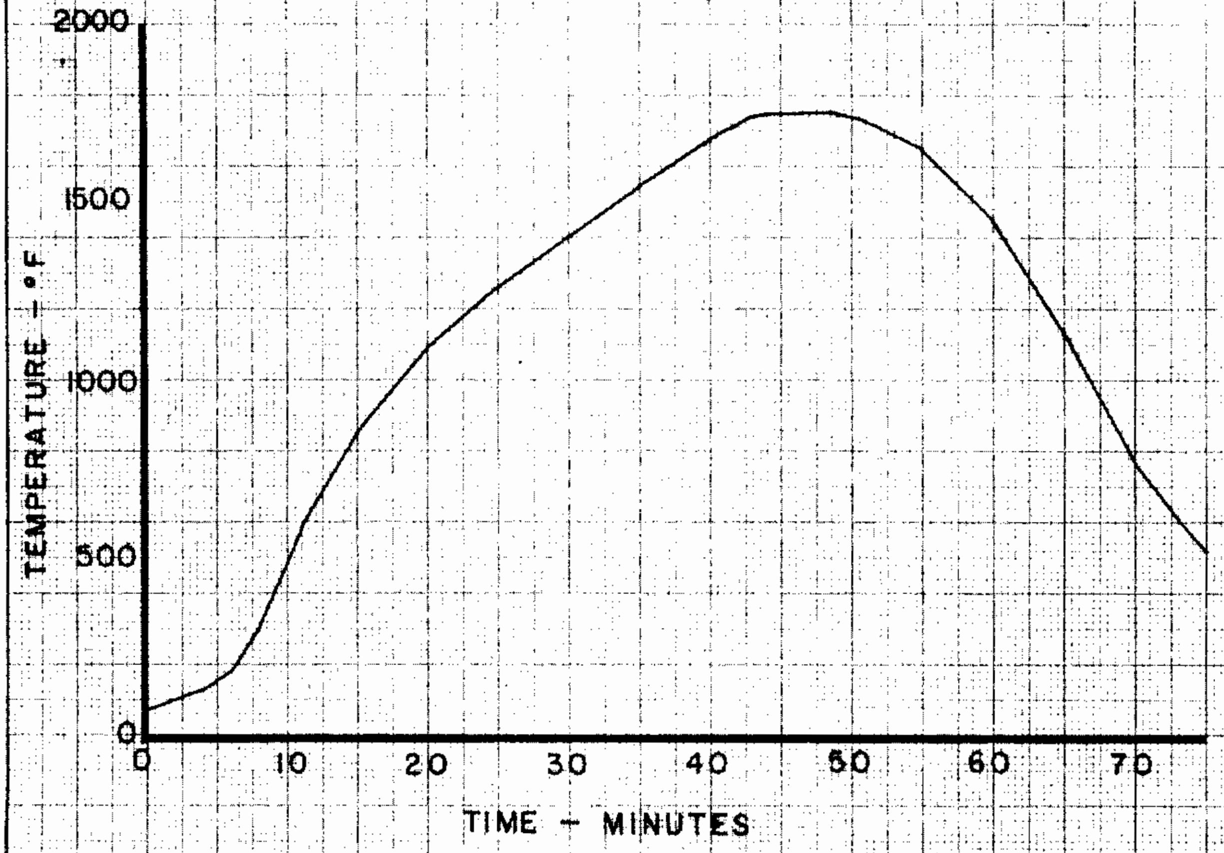
APR					THE BOEING COMPANY	PAGE 191

RESULTS FROM ANALYSIS B TEST B-1
NODE 8

DRIVE BOUNDARY NODE:
29 ANALYSIS E TEST B-1



CALC	Branch	4/13/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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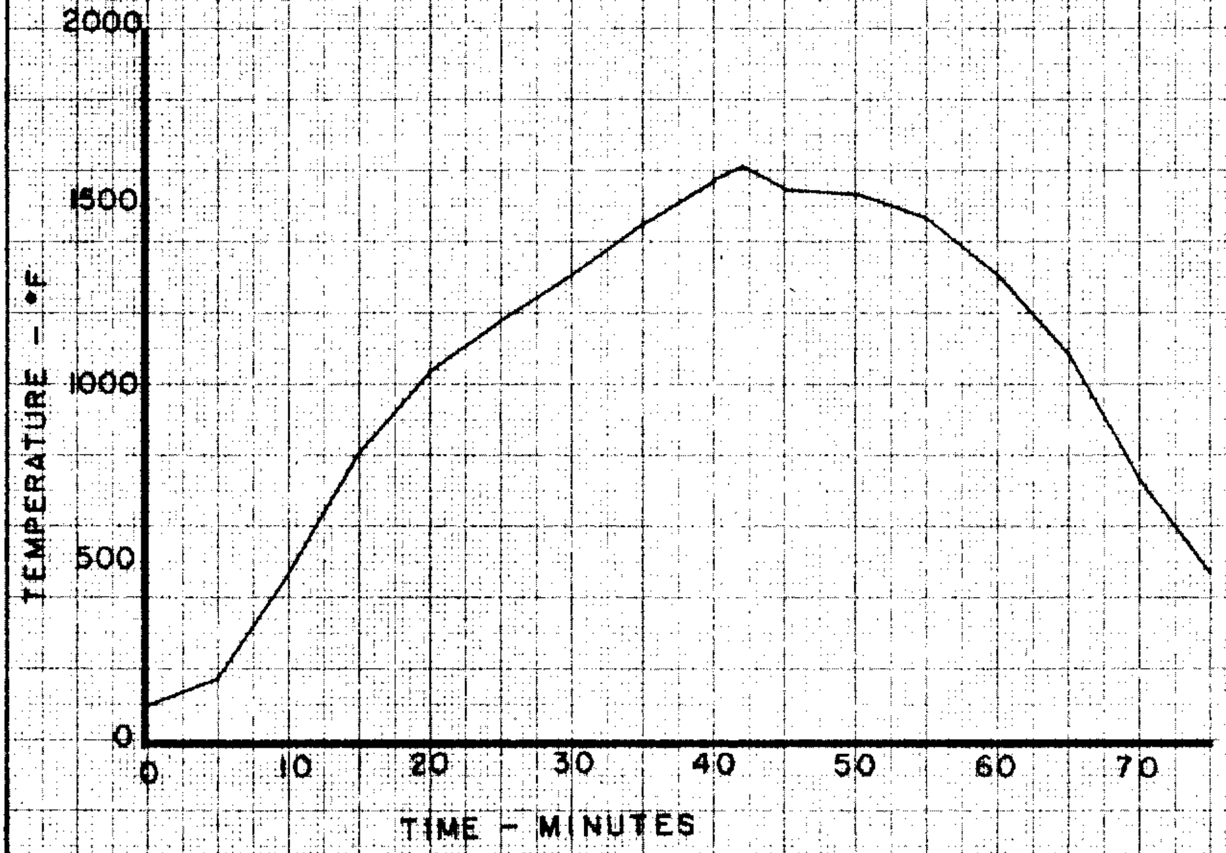
APR						
APR					THE BOEING COMPANY	PAGE 192

THERMOCOUPLE #348 TEST B-1

DRIVE BOUNDARY NODE:
30 ANALYSIS E TEST B-1



CALC		4/13/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS
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APR					
APR					THE BOEING COMPANY

D2-90709
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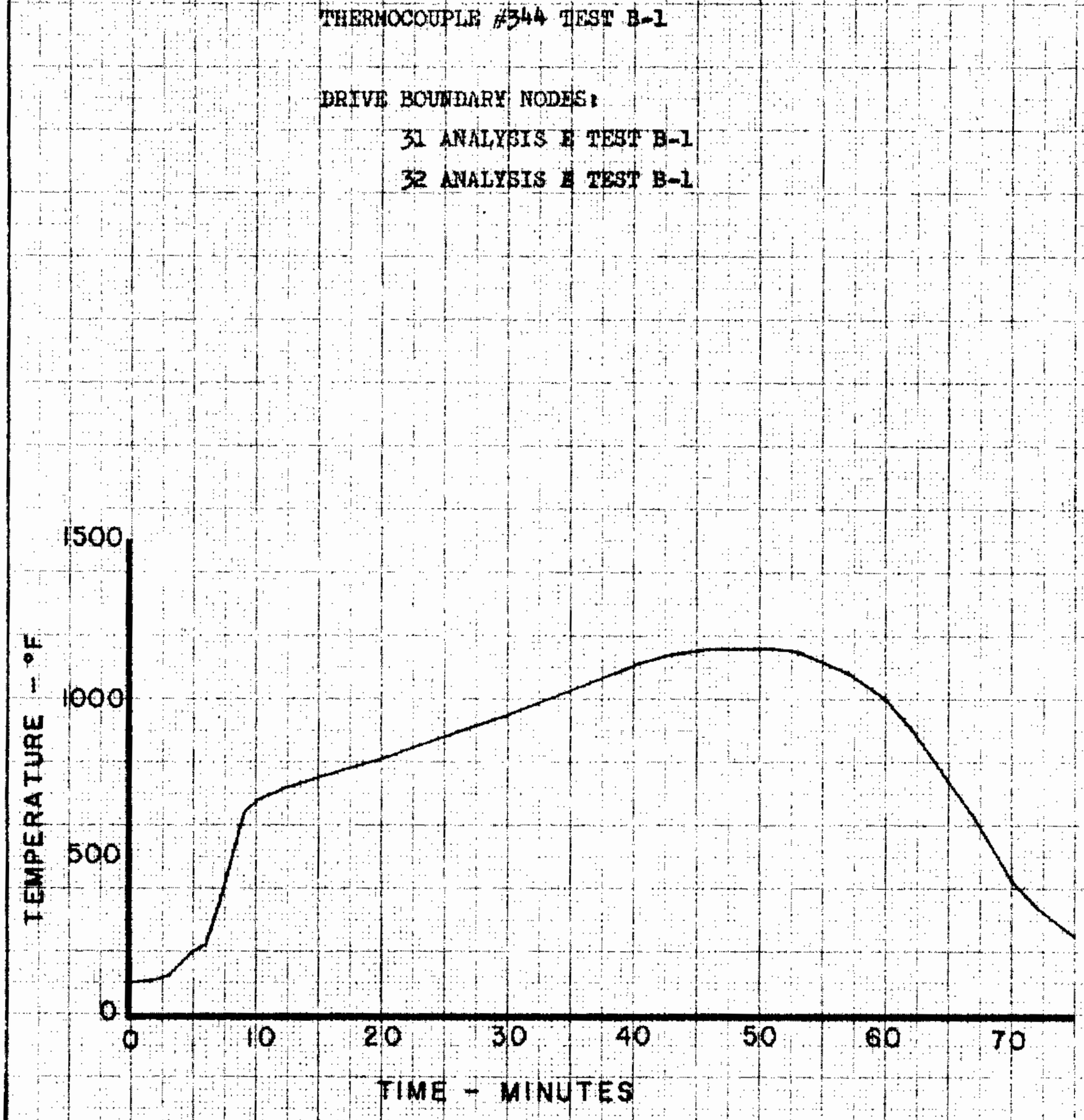

THERMOCOUPLE #344 TEST B-1

DRIVE BOUNDARY NODES:
31 ANALYSIS E TEST B-1
32 ANALYSIS E TEST B-1

CALC		4/13/66	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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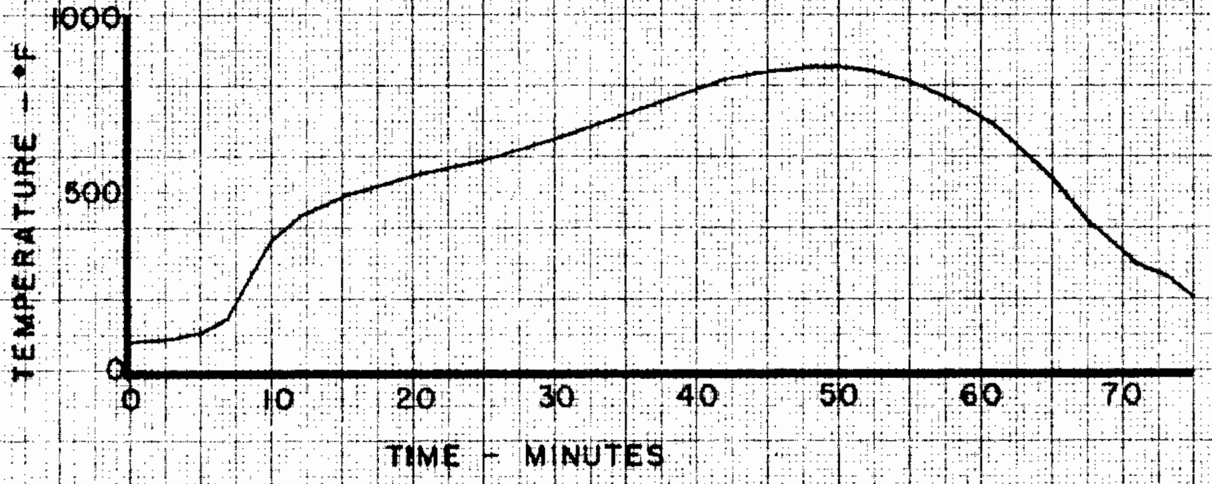
APR					THE BOEING COMPANY	PAGE

THERMOCOUPLE #434 TEST B-1

DRIVE BOUNDARY NODE:

33 ANALYSIS E TEST B-1



CALC		4/13/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS
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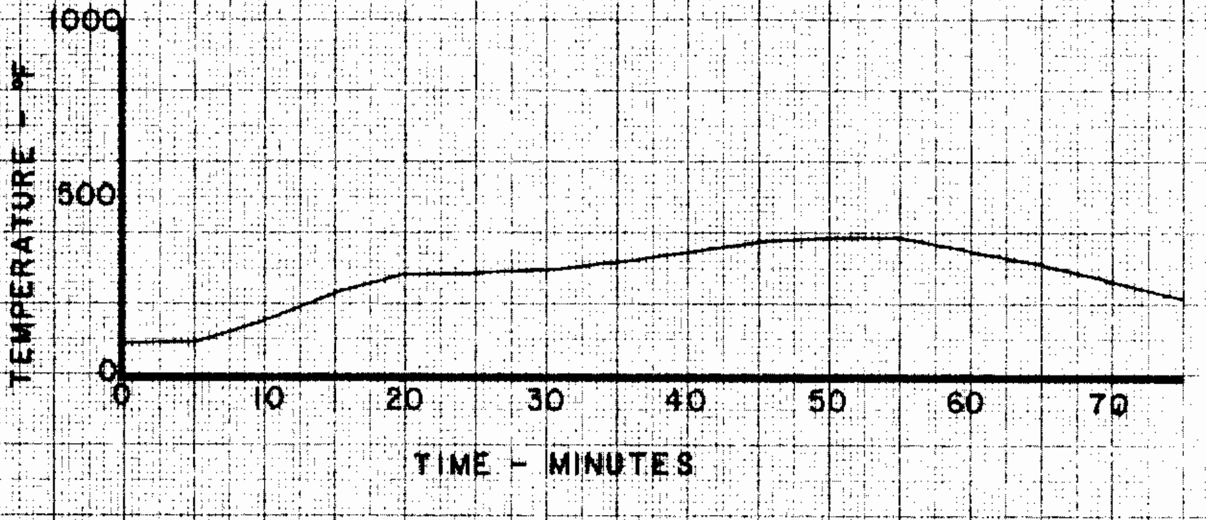
APR					THE BOEING COMPANY

THERMOCOUPLE #327 TEST B-1

DRIVE BOUNDARY NODE:
34 ANALYSIS & TEST B-1



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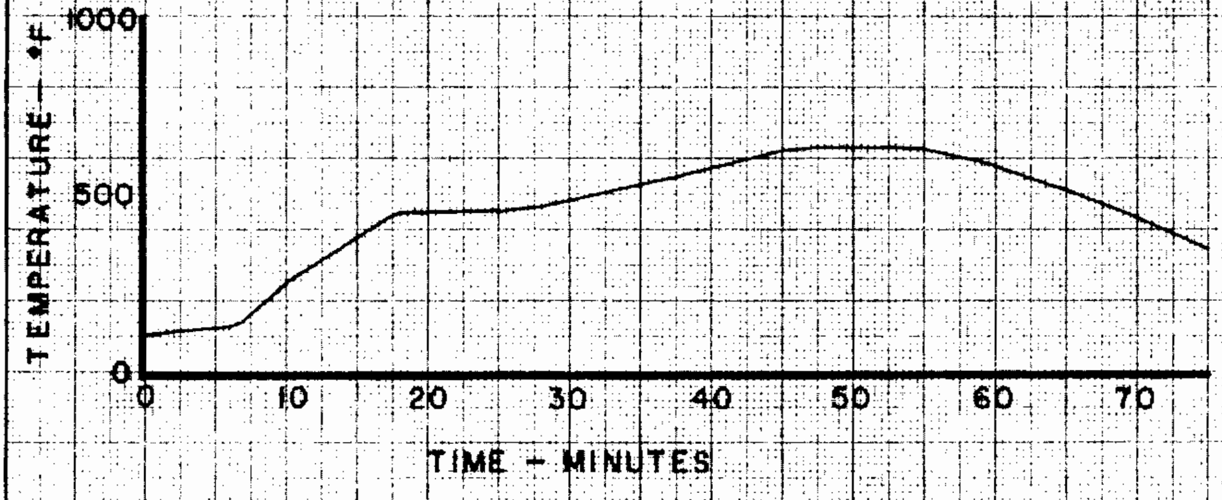
APR						
APR					THE BOEING COMPANY	PAGE 196

THERMOCOUPLE #3AS TEST B-1

DRIVE BOUNDARY NODE:
35 ANALYSIS E TEST B-1



CALC AFrench 4/13/65 REVISED DATE
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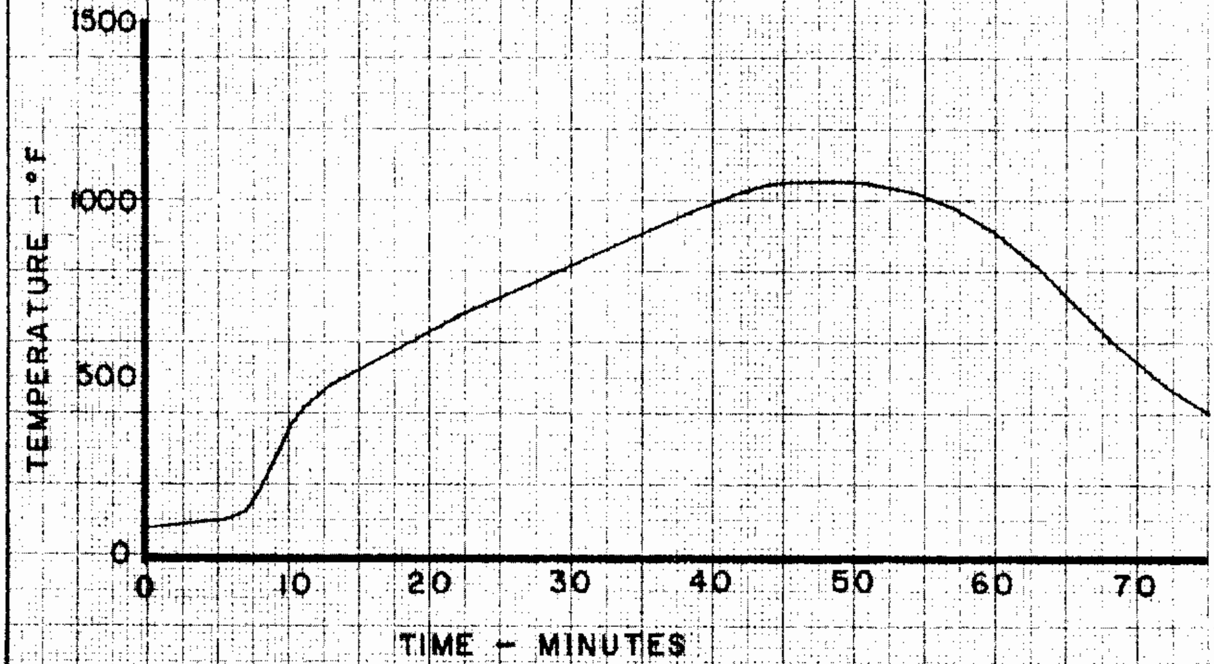
HOT STRUCTURES THERMAL CORRELATION
BOUNDARY CONDITIONS

THE BOEING COMPANY

RESULTS FROM ANALYSIS B TEST B-1:
NODE 56

DRIVE BOUNDARY NODE:
56 ANALYSIS B TEST B-1



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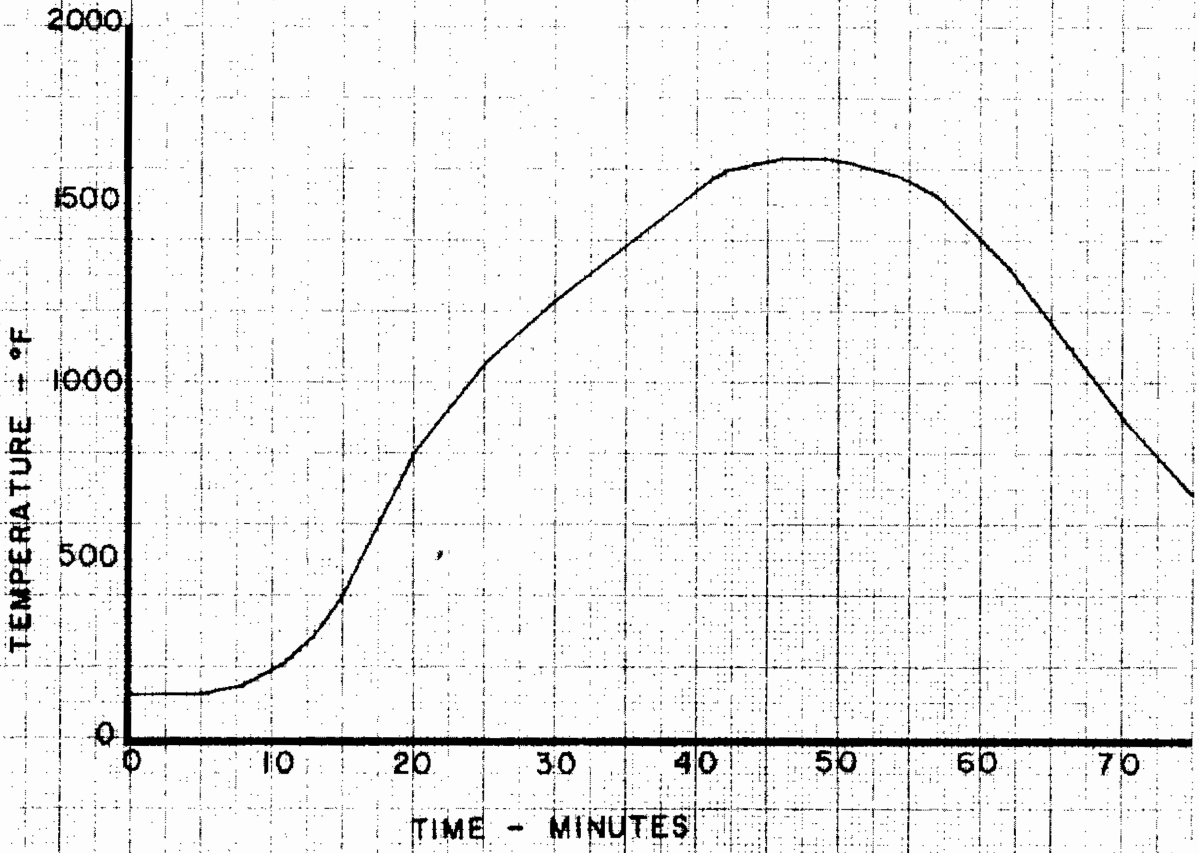
APR					THE BOEING COMPANY
APR					

THERMOCOUPLE #3B TEST B-1

DRIVE BOUNDARY NODE:

57 ANALYSIS E TEST B-1



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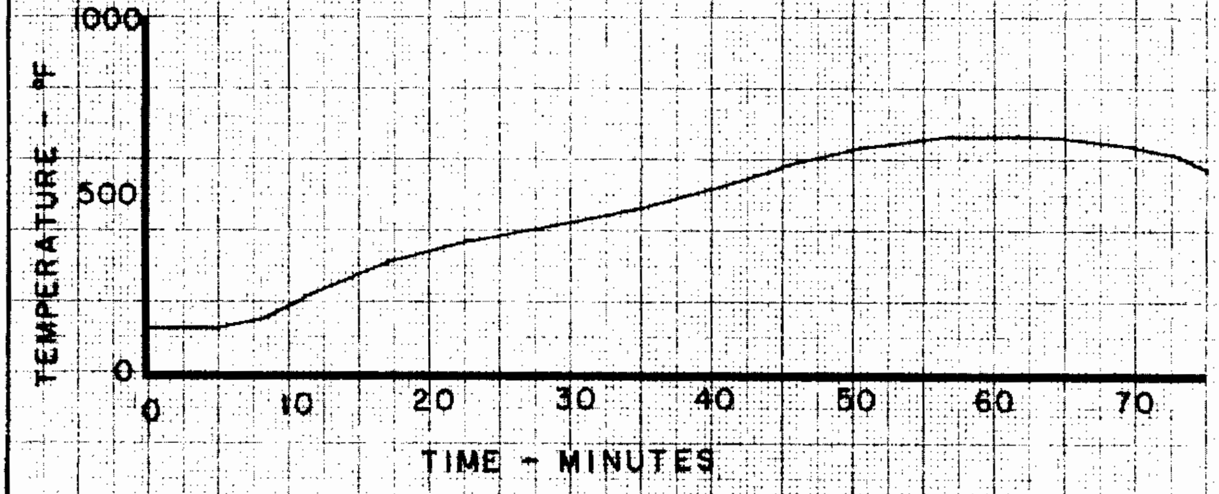
APR						
APR					THE BOEING COMPANY	PAGE 199

THERMOCOUPLE #7A TEST B-1

DRIVE BOUNDARY NODE:

58 ANALYSIS E TEST B-1



			REVISED	DATE		
CALC	Drench	4/13/65			HOT STRUCTURES THERMAL CORRELATION BOUNDARY CONDITIONS	D2-90709 -1
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APR						
APR					THE BOEING COMPANY	PAGE 200

ANALYSIS E
LONGERON JOINT
3-DIMENSIONAL

NODAL DIAGRAM

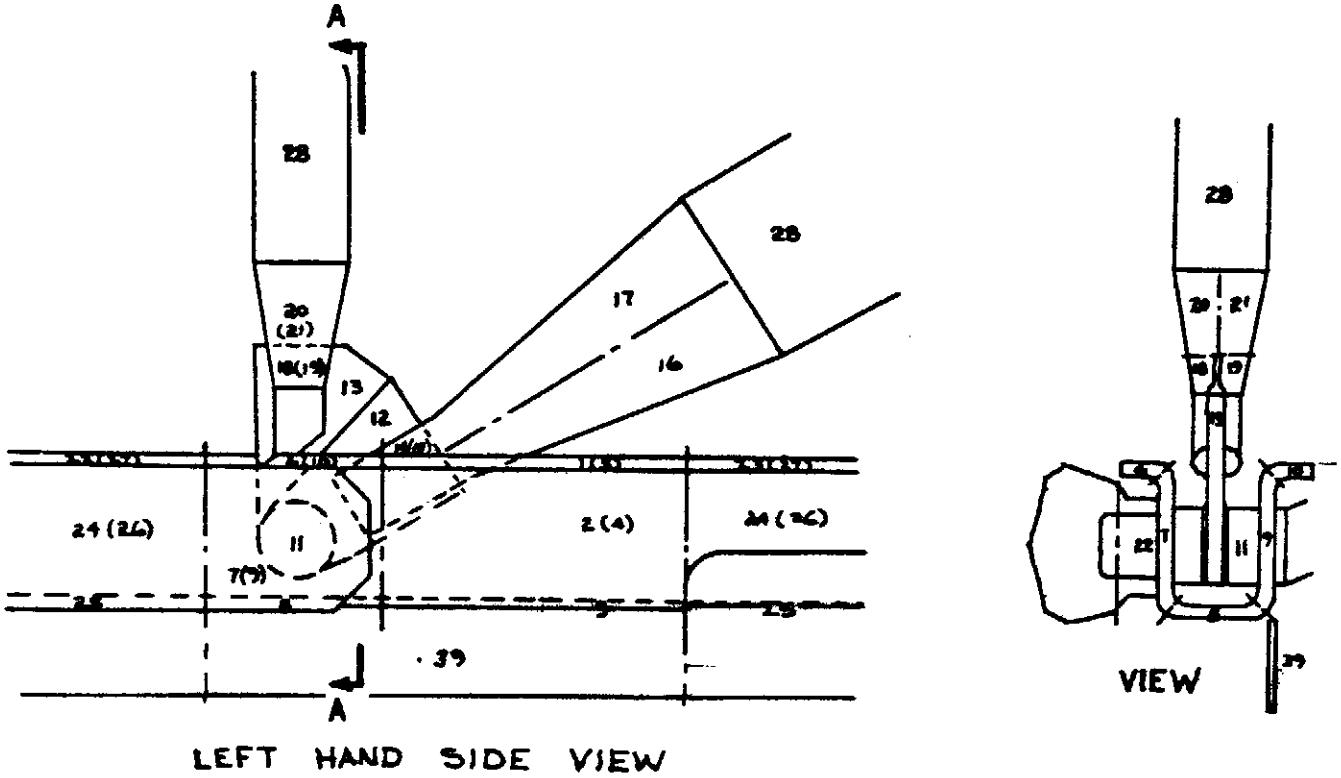

FIGURE 13 - ANALYSIS E NODAL DIAGRAM - TEST B1

ANALYSIS E - B1
LONGERON JOINT
3-DIMENSIONAL

NODAL DIAGRAM

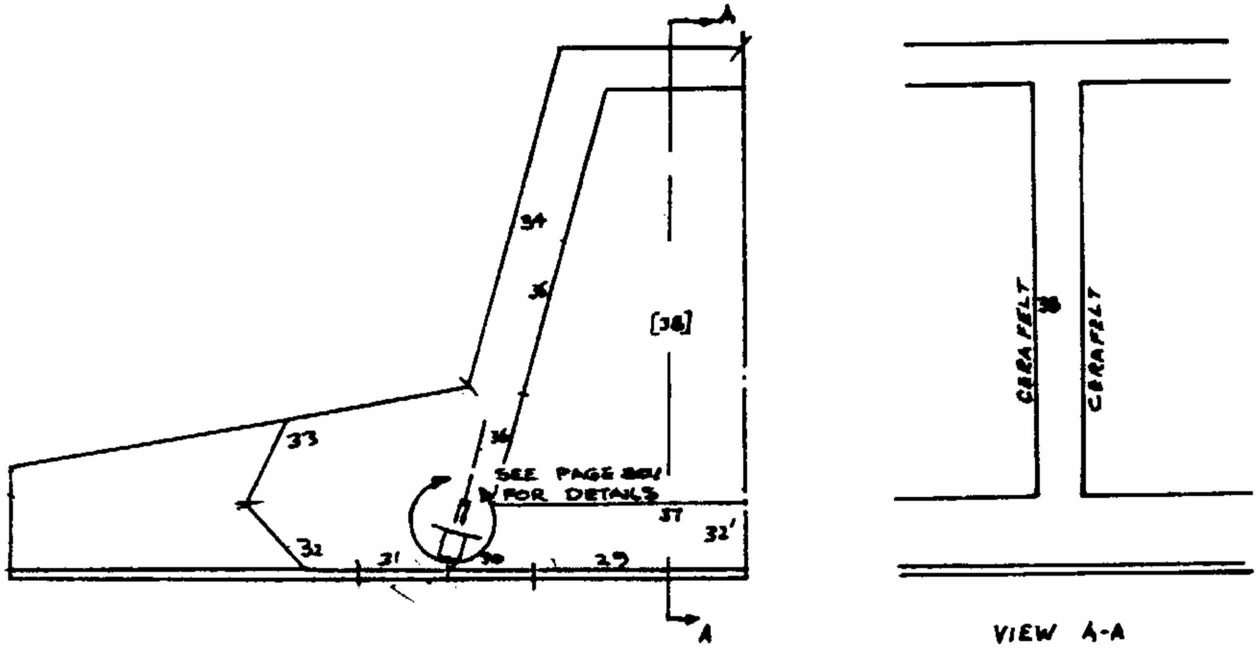

FIGURE 14 - ANALYSIS E BOUNDARY CONDITION DIAGRAM - TEST B1

CAPACITORS - ANALYSIS E TEST B-1

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	RENE' 41	0.124	4.266×10^{-3}
2		0.434	1.493×10^{-2}
3		0.310	1.0664×10^{-2}
4		0.434	1.493×10^{-3}
5		0.124	4.266×10^{-3}
6		0.136	4.678×10^{-3}
7		0.476	1.6374×10^{-2}
8		0.300	1.032×10^{-2}
9		0.476	1.6374×10^{-2}
10		0.136	4.678×10^{-3}
11		0.452	1.5559×10^{-2}
12		0.386	9.838×10^{-3}
13		0.408	1.4035×10^{-2}
14		0.0694	2.384×10^{-3}
15		0.0694	2.384×10^{-3}
16		0.492	1.693×10^{-2}
17		0.492	1.693×10^{-2}
18		0.0364	1.252×10^{-3}
19		0.0364	1.252×10^{-3}
20		0.0513	1.765×10^{-3}
21		0.0513	1.765×10^{-3}
22	RENE' 41	0.234	8.050×10^{-3}
23 thru 28	RENE' 41	DRIVEN	--
29 thru 32	HS-25	DRIVEN	--
33	RENE' 41	DRIVEN	--
34	RENE' 41	DRIVEN	--
35 thru 38	CERAFELT	DRIVEN	--
39	RENE' 41	0.081	2.78×10^{-3}

CONDUCTION CONDUCTORS - ANALYSIS E TEST B-1

CONDUCTOR	CONNECTING NODES	A/L
1	1 - 2	.3444
2	2 - 3	.2583
3	3 - 4	.2583
4	4 - 5	.3444
5	6 - 7	.3778
6	7 - 8	.2667
7	8 - 9	.2667
8	9 - 10	.3778
9	1 - 6	.0157
10	2 - 7	.0549
11	3 - 8	.0392
12	4 - 9	.0549
13	5 - 10	.0157
14	11 - 7	.43
15	11 - 9	.43
16	11 - 12	.2095
17	11 - 13	.1920
18	12 - 13	.2609
19	12 - 14	.1867
20	12 - 15	.1867
21	14 - 16	.0174
22	15 - 16	.0174
23	14 - 17	.0174
24	15 - 17	.0174
25	16 - 17	.2000
26	13 - 18	.1891
27	13 - 19	.1891
28	18 - 20	.0357
29	19 - 21	.0357
30	22 - 11	.0833
31	1 - 23	.0157
32	2 - 24	.0384
33	3 - 25	.0157
34	4 - 26	.0384
35	5 - 27	.0157
36	6 - 23	.0140
37	7 - 24	.119
38	8 - 25	.075
39	9 - 26	.119
40	10 - 27	.014
41	16 - 28	.0707
42	17 - 28	.0707
43	20 - 28	.0420
44	21 - 28	.0420

RADIATION CONDUCTOR MATRIX

NODE (j)	NODE (i)																																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1	-	50														85															101	102	103						
2	50	-	51	52							60	67		81											160	161					104	105							
3		51	-	53							61					86								162		163					107								106
4		52	53	-	54						62	68			83									164	165				108	109									
5				54	-											87													110	111				113	190	193	202		
6						-	55					69	75																		114	115	116						
7						55	-	56	57		63	70	76	82											166	167					117	118							
8							56	-	58		64													168		169					120								119
9							57	58	-	59	65	71	77		84									170	171				121	122									
10									59	-		72	78																123	124				126	191	194	203	204	
11		60	61	62			63	64	65		-	66												172	173	174								127		195		205	
12		67		68		69	70		71	72	66	-		73	74																					196			
13						75	76		77	78			-					79	80										128			129	130			197		206	
14		81					82					73		-																			132						
15				83					84			74			-																		133			198			
16	85		86		87											-	88						175		176		177	178	135			136							
17																88	-											179					137	138	192	199			
18													79					-														139	141						
19													80						-										143							200		207	
20																				-	89							180				140	142						
21																				89	-							181	144							201		208	
22																						-									149	150							
23																175							-																
24			162	164				168	170		172													-															
25		160		165			166		171		173					176									-														212
26		161	163				167	169			174															-													
27																177											-												
28																178	179			180	181							-											
29				108	110				121	123			128			135			143		144								-										
30				109	111				122	124																				-									210
31	101	104	107			114	117	120														149									-								211
32	102	105				115	118						129			136		139		140		150										-							213
33	103					116							130	132	133		137	141		142													-						
34					113					126	127						138																	-					
35					190					191							192																		-				
36					193					194	195	196	197		198		199		200		201															-			
37					802					203																											-		
38										204	205		206						207		208																	-	
39			106					119																	212					210	211	213							-

CALC		4/7/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION RADIATION CONDUCTOR MATRIX ANALYSIS E - TEST B-1
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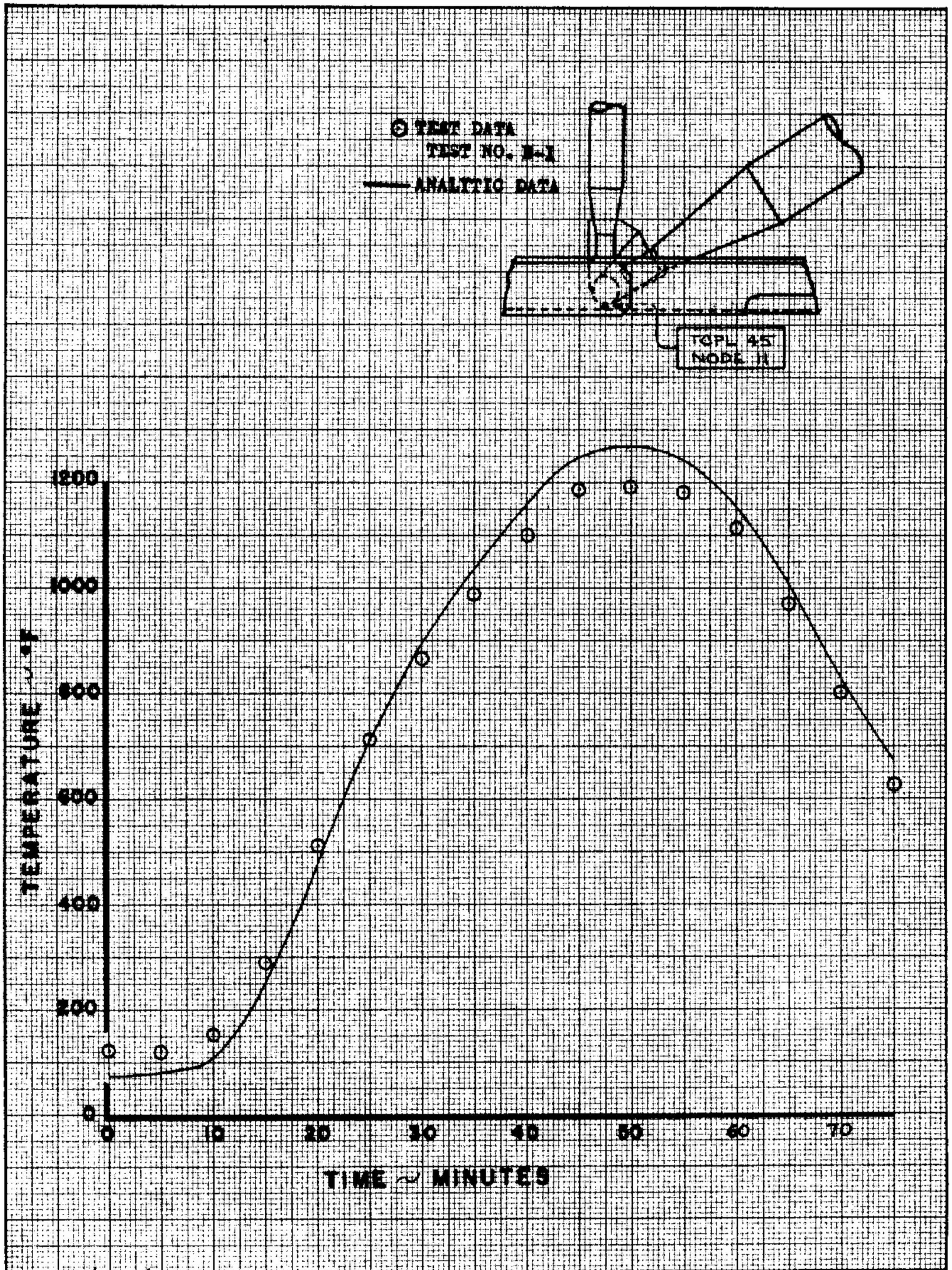
APPR					

D2-90709
-1

PAGE 205

RADIATION CONDUCTORS - ANALYSIS E TEST B-1

COND. NO.	AF	COND. NO.	AF	COND. NO.	AF
50	.496	113	.124	180	.218
51	.868	114	.32	181	.218
52	1.736	115	.16	190	.124
53	.868	116	.56	191	.040
54	.496	117	.60	192	.78
55	.280	118	1.00	193	.558
56	.280	119	.50	194	.2
57	.420	120	1.50	195	.54
58	.300	121	1.40	196	.35
59	.280	122	.84	197	.28
60	.090	123	.08	198	.22
61	.090	124	.40	199	3.12
62	.090	126	.08	200	.162
63	.360	127	.036	201	.2944
64	.270	128	.70	202	.124
65	.360	129	.28	203	.04
66	.126	130	.7	204	.28
67	.070	132	.44	205	.54
68	.070	133	.22	206	.35
69	.035	135	1.56	207	.2025
70	.070	136	1.56	208	.3456
71	.070	137	3.12	210	4.05
72	.035	138	.78	211	1.33
73	.075	139	.2835	212	.202
74	.075	140	.5265	213	1.21
75	.070	141	.384		
76	.070	142	.896		
77	.070	143	.4455		
78	.070	144	.640		
79	.650	149	.312		
80	.650	150	.458		
81	.385	160	.217		
82	.275	161	.434		
83	.385	162	.186		
84	.275	163	.186		
85	.390	164	.434		
86	.500	165	.217		
87	.390	166	.084		
88	5.04	167	.196		
89	.760	168	.100		
101	.496	169	.100		
102	.248	170	.196		
103	.868	171	.084		
104	1.302	172	.090		
105	2.170	173	.090		
106	.775	174	.090		
107	2.325	175	.234		
108	2.170	176	.156		
109	1.302	177	.234		
110	.124	178	.780		
111	.620	179	.780		



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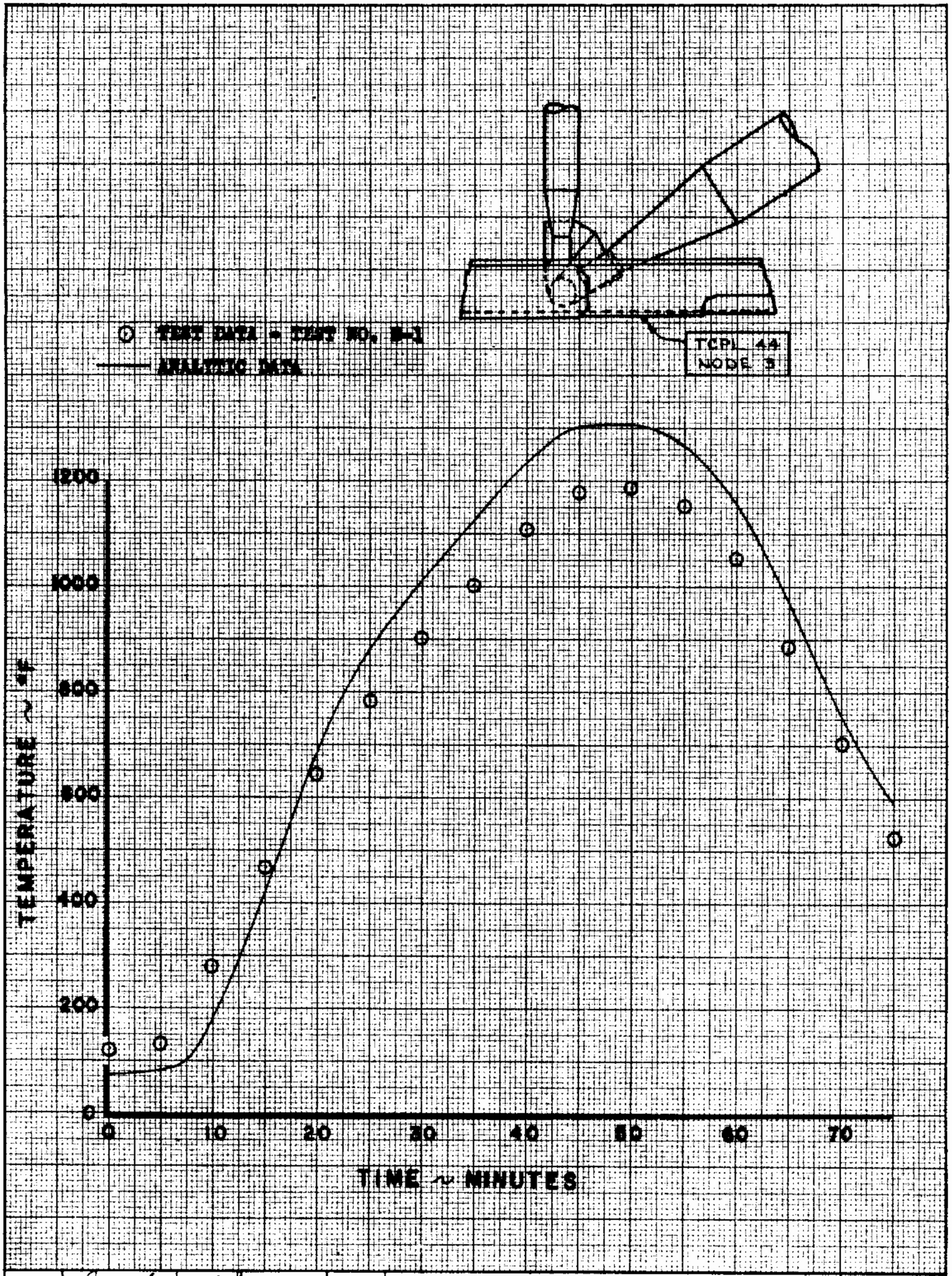

CALC	Dench	3/16/65	REVISED	DATE	HOT STRUCTURES THERMAL CORRELATION ANALYSIS E - B1 LONGERON JOINT	D2-90709 -1
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4.6.3 Discussion (Analysis E)

Although useful data is somewhat limited on this joint, that which can be fairly compared with the analysis indicates good agreement. The analysis does not predict the vertical gradient through the main cylindrical block (Node 11 of the analysis); the test data indicates that this is quite small.

Significant data from the blocked case (Test B1) is limited to two thermocouples, neither of which correlate too closely. However, unusual convective effects in this region were noted in the Analysis B effort.

4.7 WING JOINT THREE-DIMENSIONAL ANALYSIS (ANALYSIS F) (See Page 7)

4.7.1 Analysis Description

Similar in philosophy to Analysis E, this analysis is of a welded and bolted wing joint. Of primary interest in such a region are gradients between bolts, tabs, and tubes. These gradients are largest early in reentry and during the latter phases near landing. Such gradients can cause local stress concentration and/or material structural weakness.

Techniques and assumptions similar to those of Analysis E were used: large nodes, simple boundary conditions, and simplified view factor determination methods.

Boundary conditions are referenced on page 211.

The nodal system is shown in Figure 15, page 216. Constants, conductors, capacitors, etc., are shown on pages 217 through 219.

Correlation for Test 5.8 is shown on pages 220 through 224. Correlation with Test B1 seemed unnecessary and is not shown.

4.7.2 ANALYSIS F CORRELATION

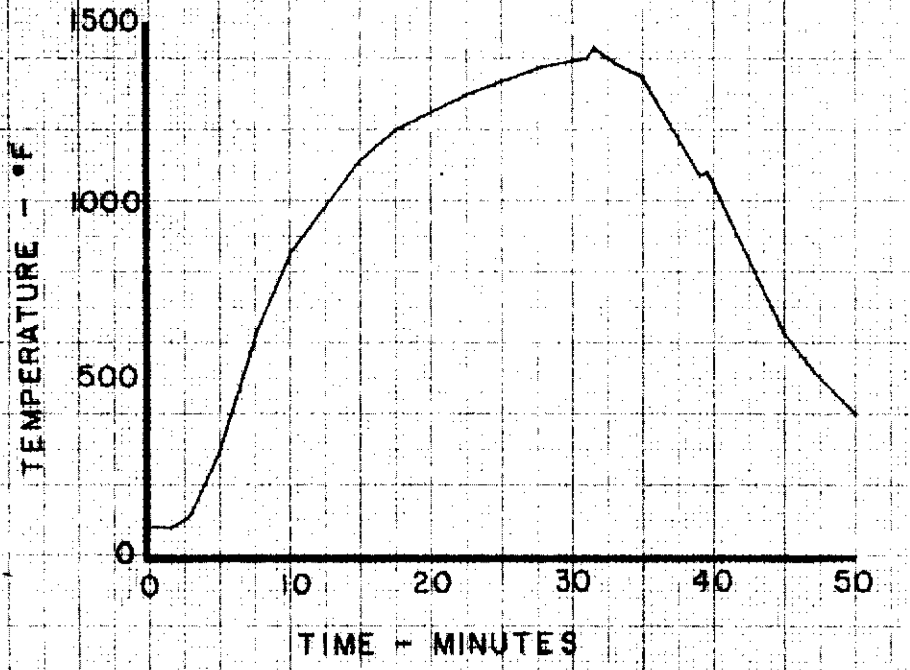
WING JOINT THREE-DIMENSIONAL ANALYSIS

TEST SERIES: 5 CONDITION: 5.8

BOUNDARY NODES	SOURCE	PAGE
14	THERMOCOUPLE 263 TEST 5.1	212
15	THERMOCOUPLE 268 TEST 5.8	213
16	THERMOCOUPLE 344 TEST 5.6	214
17	THERMOCOUPLE 434 TEST 5.6	215

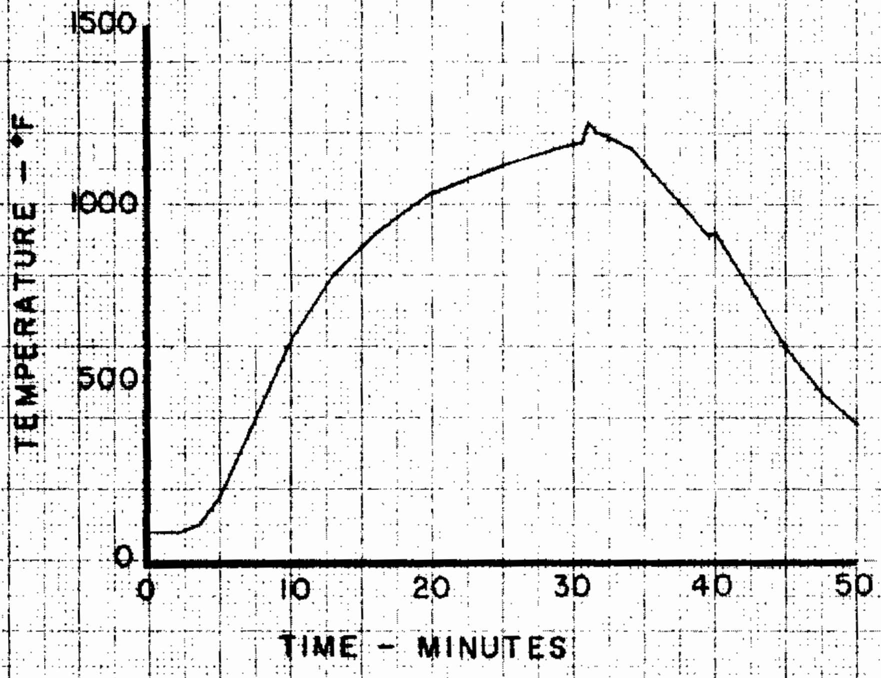
THERMOCOUPLE #263 TEST 5.1

DRIVE BOUNDARY NODE:
14 ANALYSIS F TEST 5.8



THERMOCOUPLE #268 TEST 5.8

DRIVE BOUNDARY NODE:
15 ANALYSIS F TEST 5.8



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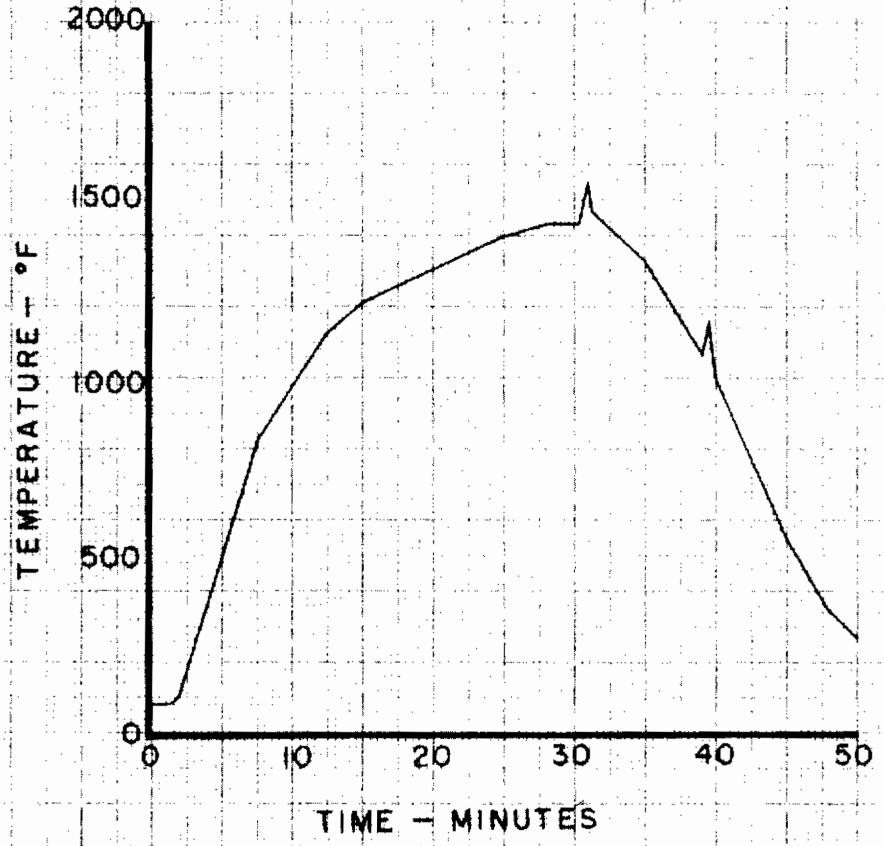
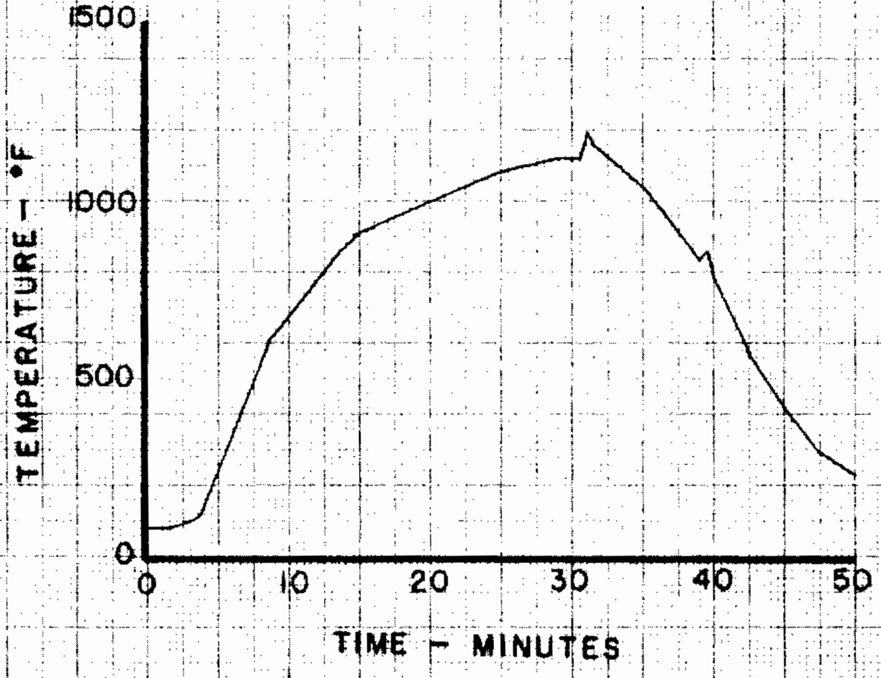
THERMOCOUPLE #344 TEST 5.6

DRIVE BOUNDARY NODE:
16 ANALYSIS F TEST 5.8



THERMOCOUPLE #434 TEST 5.6

DRIVE BOUNDARY NODE:
17 ANALYSIS F TEST 5.8



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HOT STRUCTURES THERMAL CORRELATION
BOUNDARY CONDITIONS

THE BOEING COMPANY

ANALYSIS F
WING JOINT -D2
3-DIMENSIONAL

NODAL DIAGRAM

DRIVEN NODES:
- 14
- 15
- 16
- 17

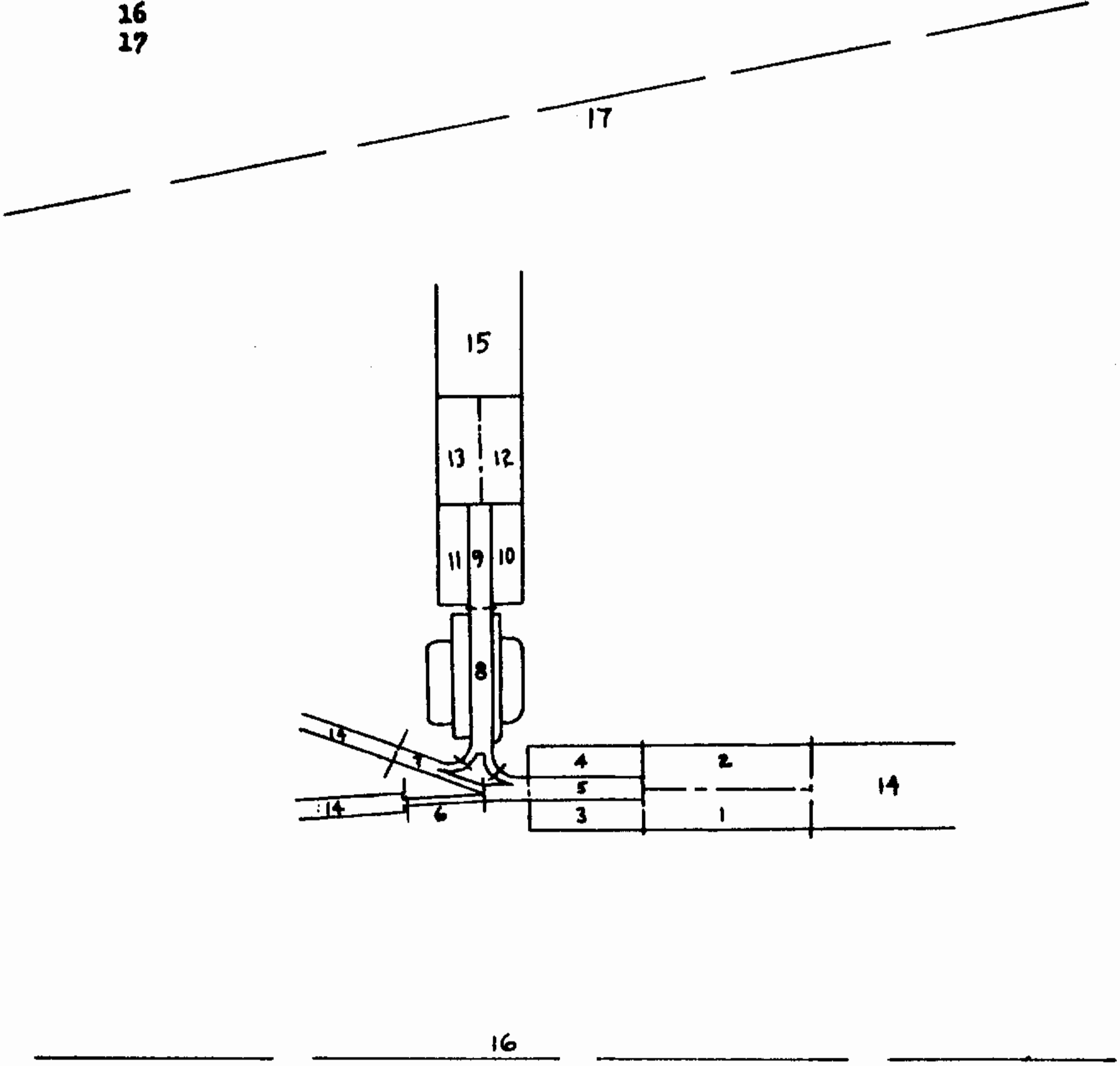


FIGURE 15

ANALYSIS F NODAL DIAGRAM

CAPACITANCE - ANALYSIS F

NODE	MATERIAL	VOLUME (INCHES^3)	CAPACITANCE (BTU/°F)
1	RENE' 41	0.016	0.5504×10^{-3}
2	│	0.016	0.5504×10^{-3}
3	│	0.0098	0.3371×10^{-3}
4	│	0.0098	0.3371×10^{-3}
5	│	0.070	2.4080×10^{-3}
6	│	0.014	0.4816×10^{-3}
7	│	0.0273	0.9391×10^{-3}
8	│	0.2640	9.0820×10^{-3}
9	│	0.042	1.4450×10^{-3}
10	│	0.0084	0.2290×10^{-3}
11	│	0.0084	0.2290×10^{-3}
12	│	0.0104	0.3578×10^{-3}
13	│	0.0104	0.3578×10^{-3}
14	↓	DRIVEN	--
15	RENE' 41	DRIVEN	--
16	HS-25	DRIVEN	--
17	RENE' 41	DRIVEN	--

CONDUCTION CONDUCTORS - ANALYSIS F

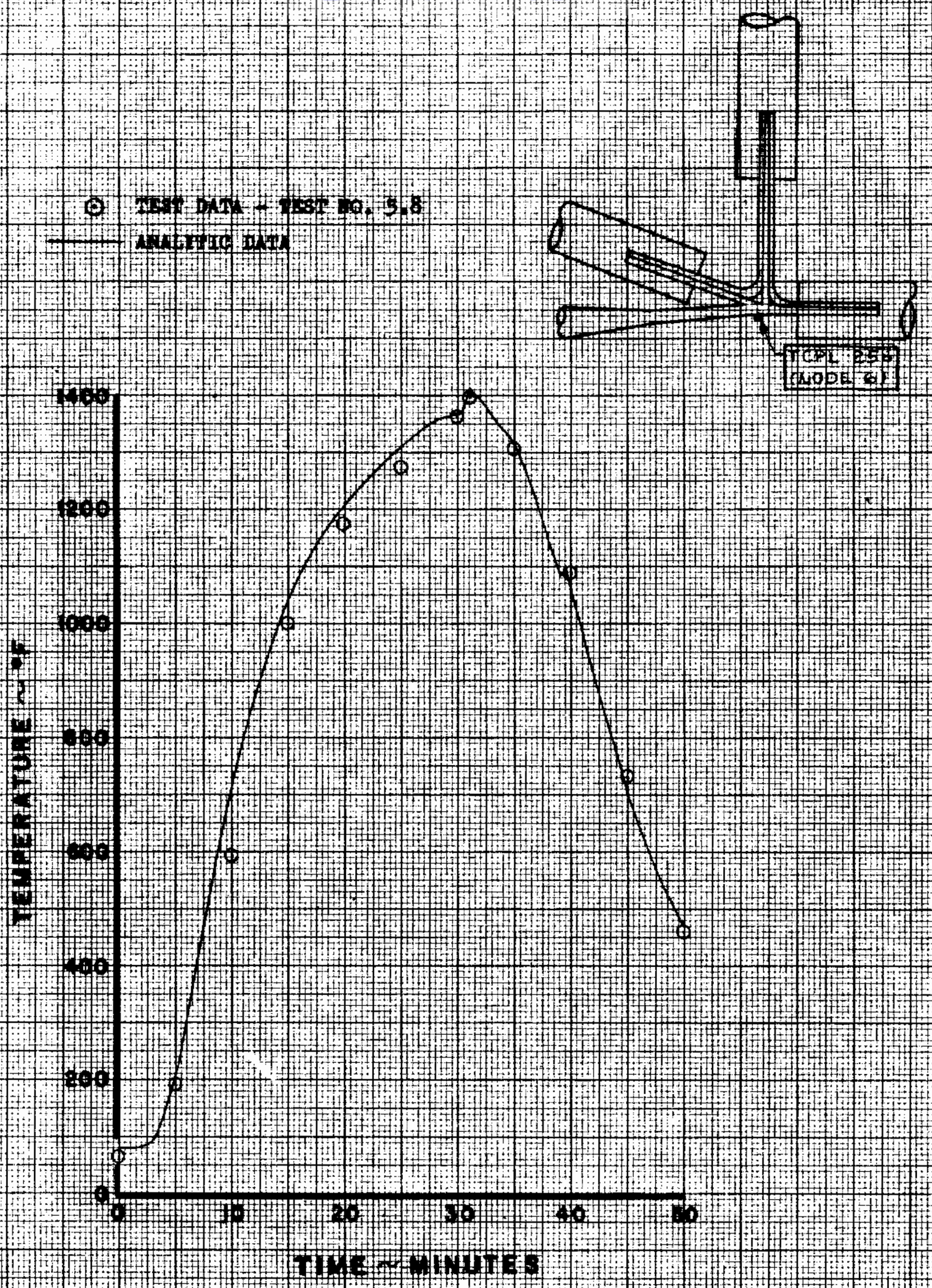
CONDUCTOR	CONNECTING NODES	A/L	k CURVE
1	1 - 2	0.050	RENE' 41
2	1 - 3	0.0176	
3	2 - 4	0.0176	
4	3 - 5	0.056	
5	4 - 5	0.056	
6	5 - 6	0.0373	
7	5 - 7	0.0175	
8	5 - 8	0.028	
9	7 - 8	0.035	
10	8 - 9	0.0933	
11	9 - 10	0.048	
12	9 - 11	0.048	
13	10 - 12	0.025	
14	11 - 13	0.025	
15	12 - 13	0.0325	
16	14 - 1	0.016	
17	14 - 2	0.016	
18	14 - 6	0.056	
19	14 - 7	0.028	
20	15 - 12	0.016	
21	15 - 13	0.016	RENE' 41

RADIATION CONDUCTOR MATRIX - ANALYSIS F

NODE (j)	NODE (i)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	-	30												39		43	
2	30	-												40			45
3			-		31											44	
4				-	32			33									46
5			31	32	-												
6						-	34									47	
7						34	-	35								48	55
8				33			35	-								49	56
9									-	36	37					50	57
10									36	-						51	58
11									37		-					52	59
12												-	38		41	53	60
13												38	-		42	54	61
14	39	40												-			
15												41	42		-		
16	43		44			47	48	49	50	51	52	53	54			-	
17		45		46			55	56	57	58	59	60	61				-

RADIATION CONDUCTORS

COND. NO.	AF	COND. NO.	AF
30	.500	47	.350
31	.350	49	.510
32	.350	51	.084
33	.098	52	.084
34	.350	53	.104
35	.270	54	.104
36	.300	55	.180
37	.300	56	.850
38	.325	57	0
39	.080	58	.252
40	.080	59	.252
41	.052	60	.312
42	.052	61	.312
43	.800	48	0
44	.490	50	0
45	.800		
46	.343		



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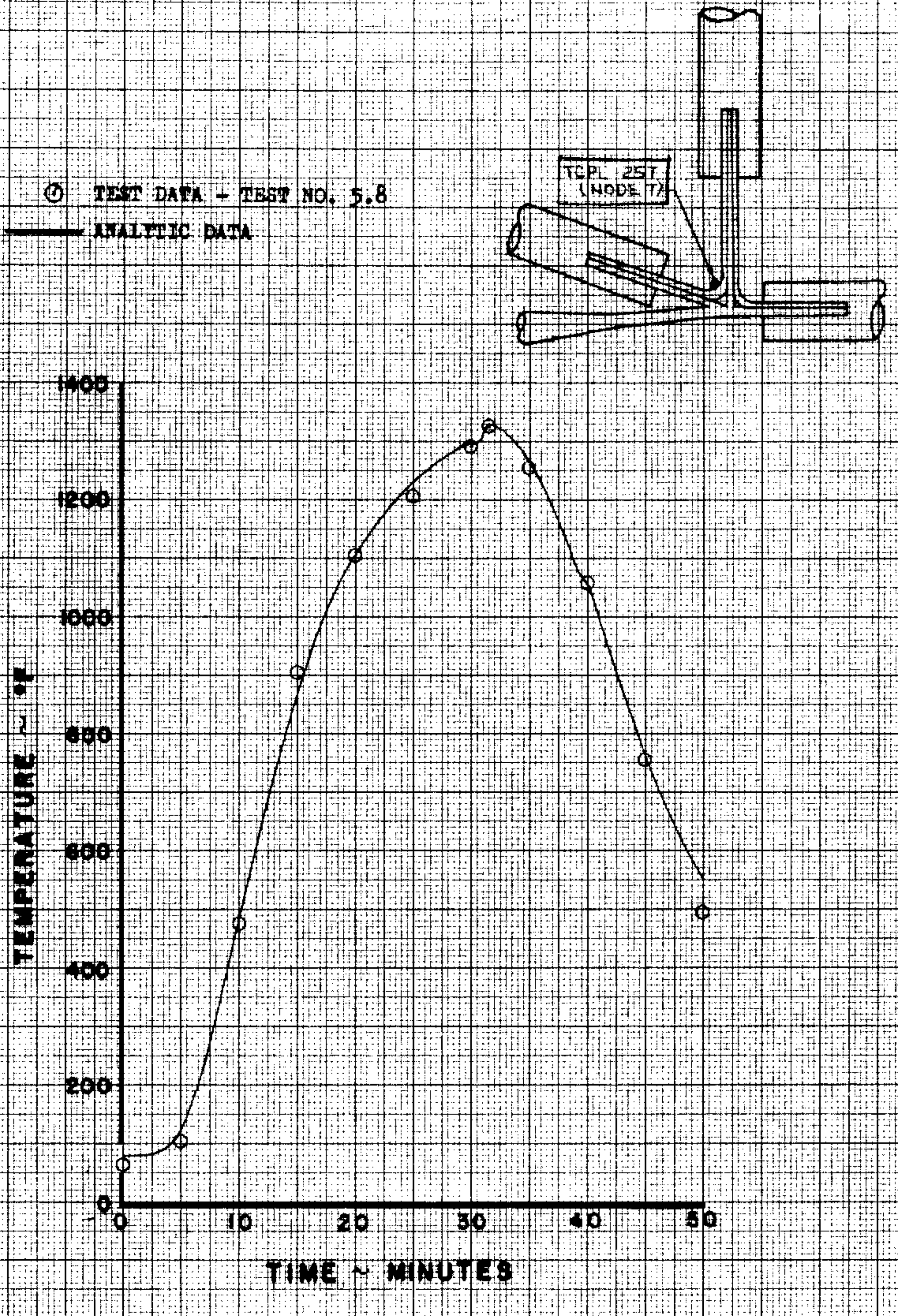

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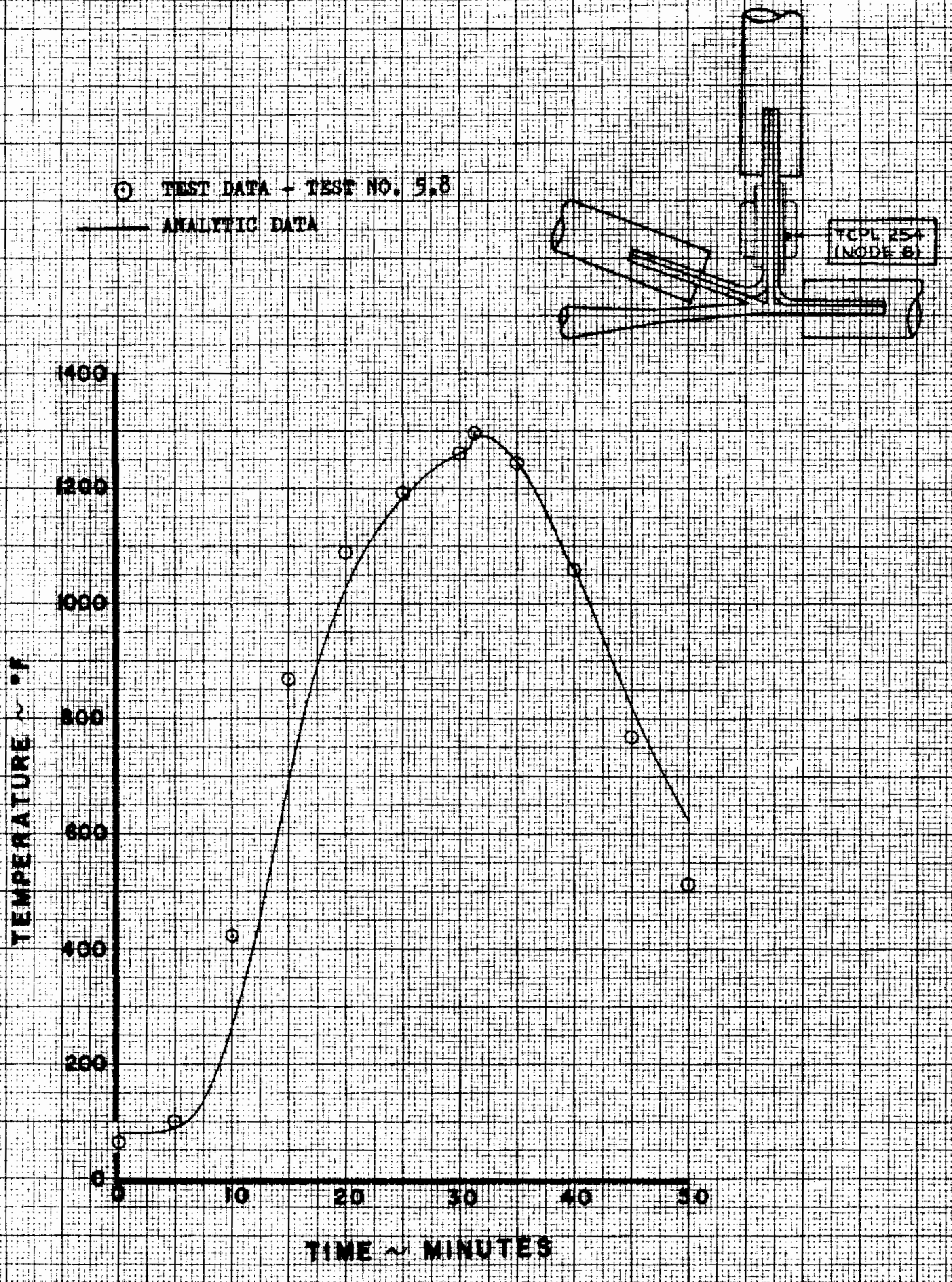

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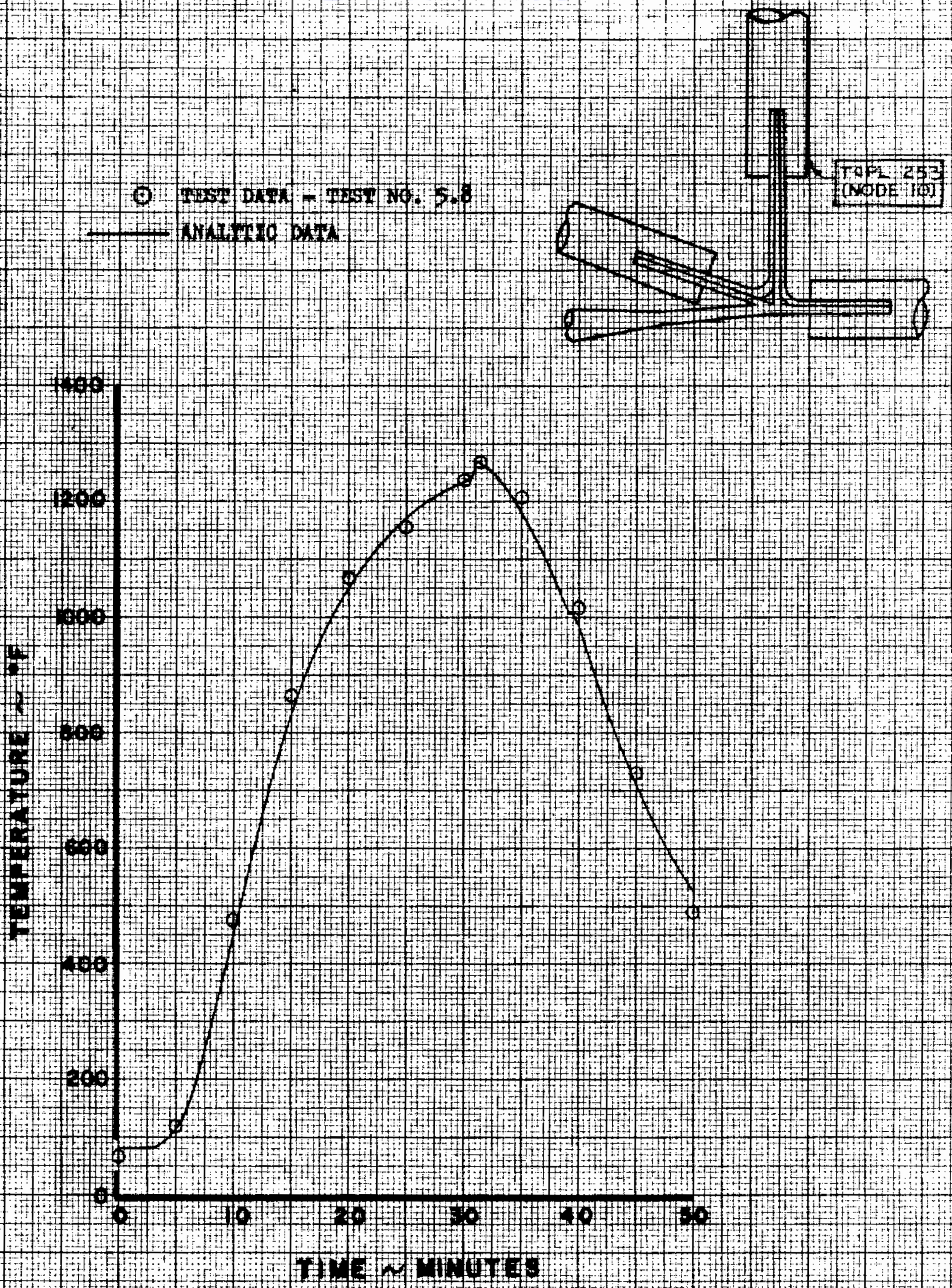

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ANALYSIS F
WING SPAR JOINT

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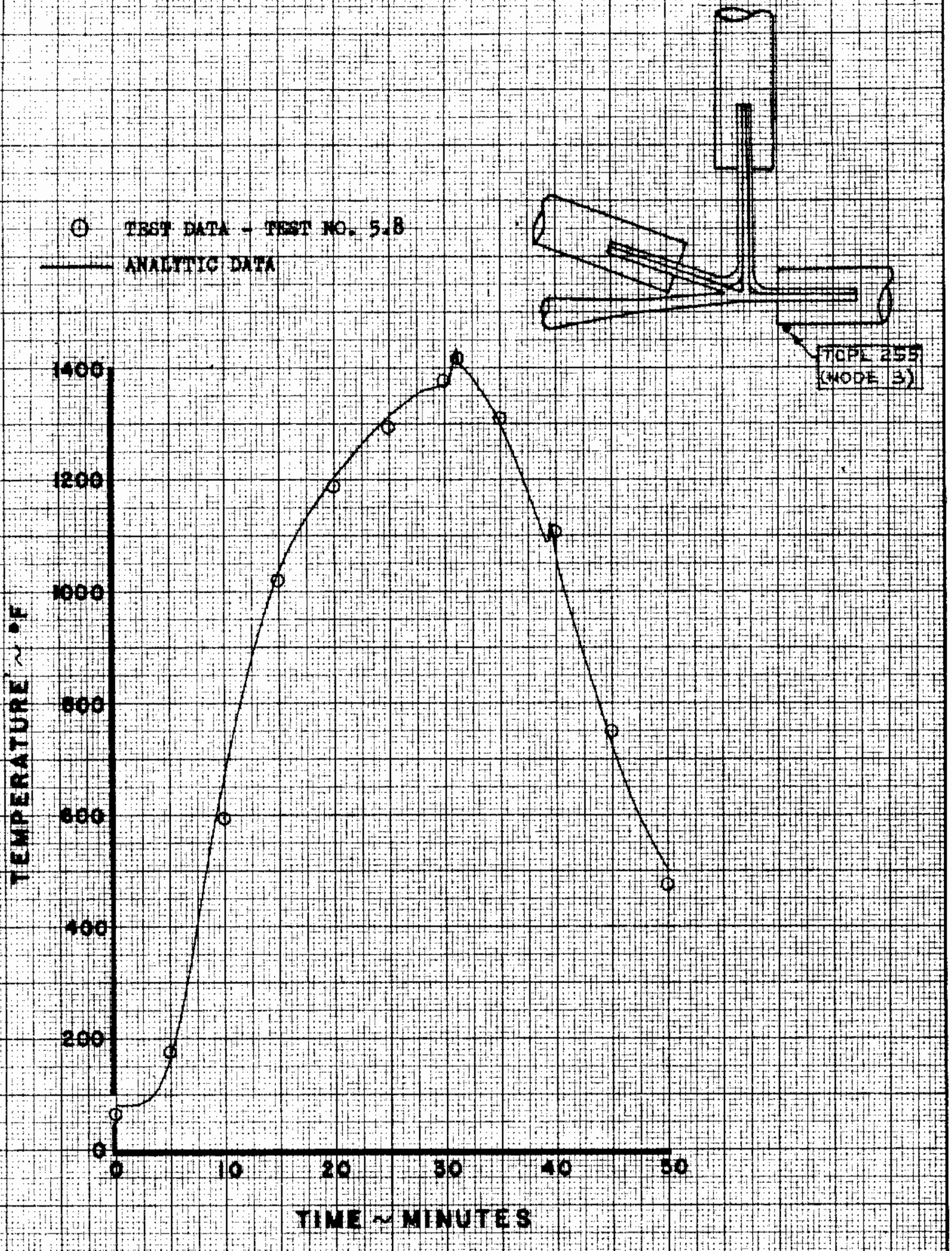

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS F
WING SPAR JOINT

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4.7.3 Discussion (Analysis F)

Excellent correlation of all available data from Test 5.1 is shown.

During the analysis it was noted that care in the calculation of capacitance and effective radiating area of the somewhat massive bolt was necessary. Similar parameters of other nodes of lesser mass may be less accurate. The conclusion here is that for a joint analysis where bolt-tube gradients are of interest, better accuracy is required in the calculation of parameters for that bolt than for the rest of the nodal system.

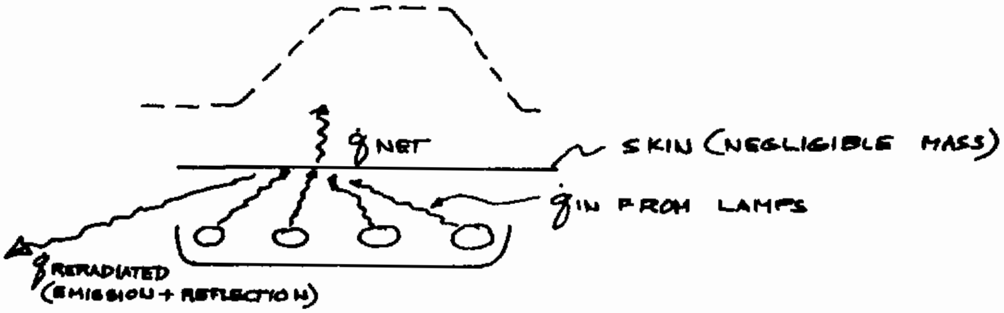
4.8 CORRUGATION DETAIL TWO-DIMENSIONAL ANALYSIS (ANALYSIS G) (See Page 7)

4.8.1 Analysis Description

This two-dimensional analysis was added to the original grouping to provide additional information on skin-corrugation gradients, and conduction characteristics. All other analyses assume no spotweld conduction, just radiation between the skin and corrugated panel. Also the previous analyses predict only "mean" corrugation temperatures since the corrugation is replaced by an equivalent flat plate.

This analysis is of the lower body panel just forward of Frame D and was run only for Test 5.6 (no blockage).

Symmetry was used to reduce the size to effectively one-half of a corrugation pitch. An unusual forcing function was used, since little was known of the actual local skin temperature distribution. Node 1 of the skin was driven to the test temperature associated with it (Thermocouple 346). The energy radiated from Node 1 to the corrugation nodes (1 through 12) was then integrated and this term was then applied as a heat source to the other skin nodes (2 through 5). The basic assumption here is that the energy emitted from the backside effectively represents the balance between the heat lamp interchange energy and emitted energy from the skin frontside (see below); and that same balance is applicable to the surrounding area.



The boundary conditions behind the corrugation are two: one (Node 13) represents a mean upper fuselage and wing temperature level; the other (Node 14) represents the effect of a nearby truss tube. They are referenced on page 227.

The nodal system is shown in Figs.16&17, pages 231&232. Constants, conductors, capacitors, etc., are shown on pages 233 through 234.

Correlation for Test 5.6 with various contact area assumptions is shown on pages 235 through 237.

4.8.2.1 ANALYSIS G CORRELATION

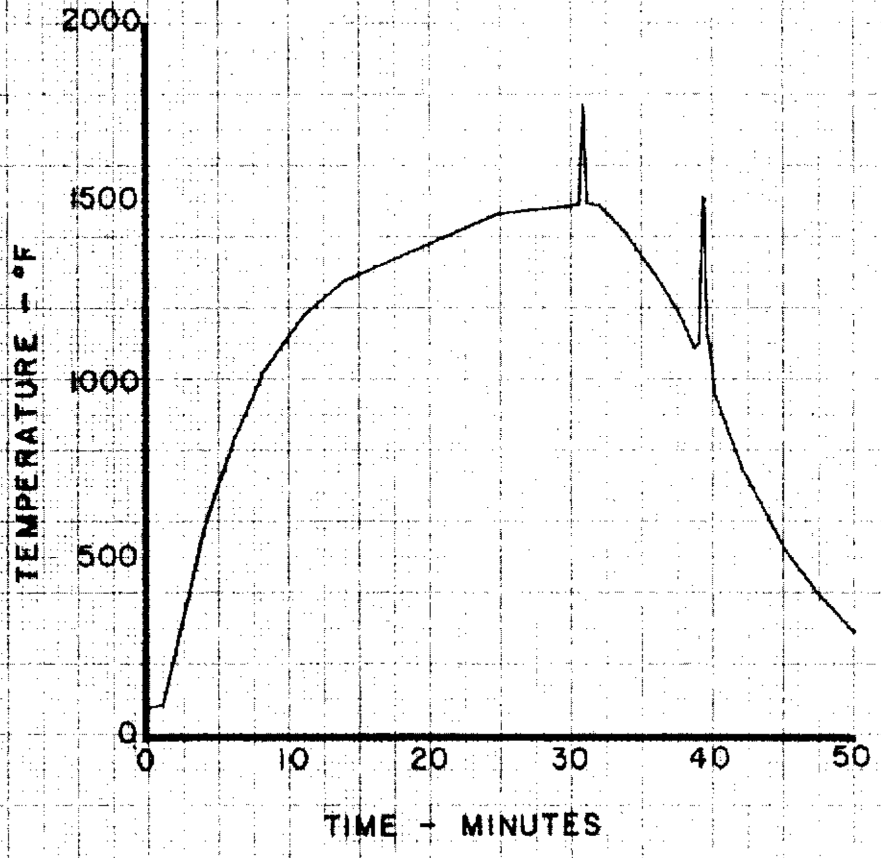
CORRUGATION DETAIL TWO-DIMENSIONAL ANALYSIS

TEST SERIES: 5 CONDITION: 5.6

BOUNDARY NODES	SOURCE	PAGE
1	THERMOCOUPLE 346 TEST 5.6	228
13	APPROXIMATED	229
14	APPROXIMATED	230

THERMOCOUPLE #346 TEST 5.6

DRIVE BOUNDARY NODE:
1 ANALYSIS G TEST 5.6



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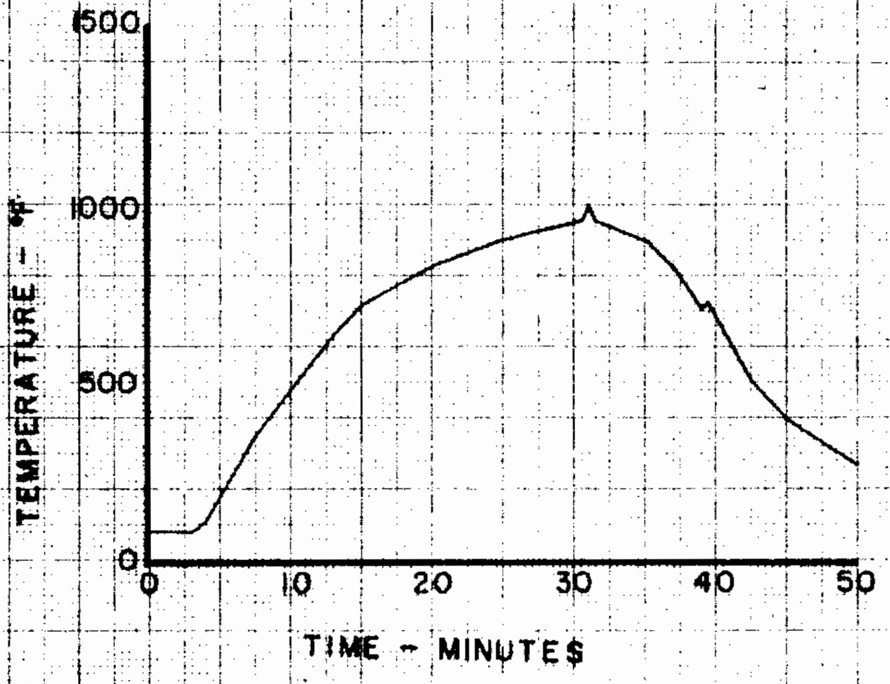
RESULTS FROM ANALYSIS B TEST 5.1:
2.1%(NODE 35 - 100°F)
56.0% THERMOCOUPLE #329 TEST 5.1
14.6% THERMOCOUPLE #332 TEST 5.6
27.3% THERMOCOUPLE #432 TEST 5.6

DRIVE BOUNDARY NODE:
13 ANALYSIS G TEST 5.6



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BOUNDARY CONDITIONS

D2-90709
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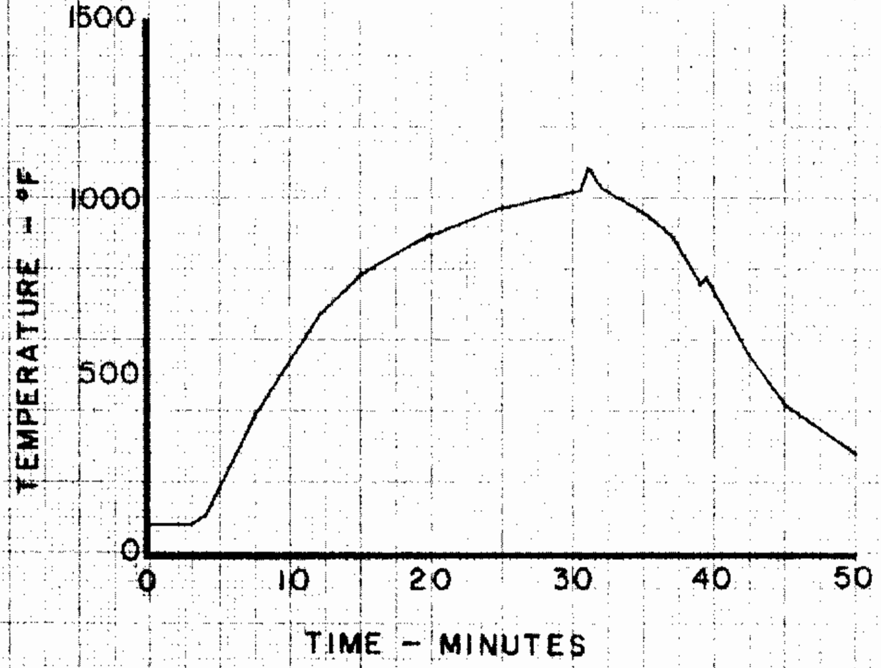
RESULTS FROM:

70.0% NODE 13 ANALYSIS G TEST 5.6
30.0% THERMOCOUPLE #223 TEST 5.6

DRIVE BOUNDARY NODE:

14 ANALYSIS G TEST 5.6



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HOT STRUCTURES THERMAL CORRELATION

ANALYSIS G
CORRUGATION ANALYSIS

NODAL DIAGRAM

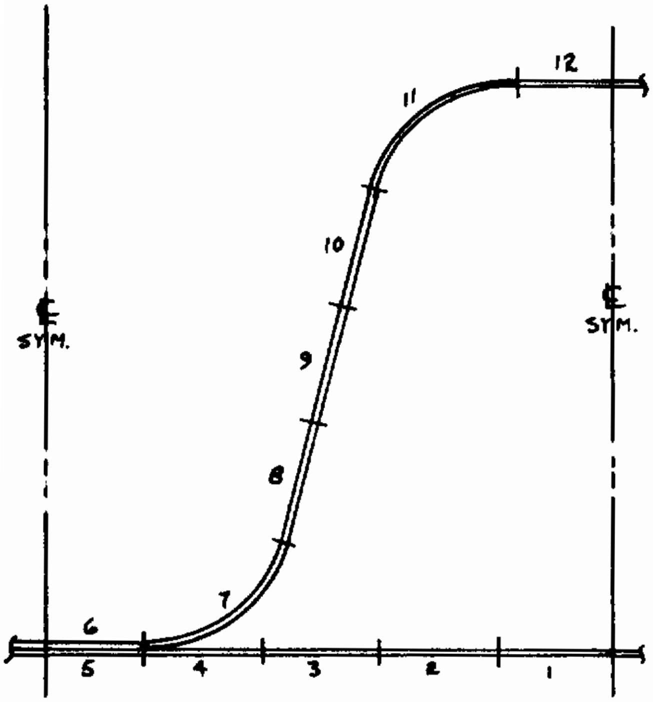


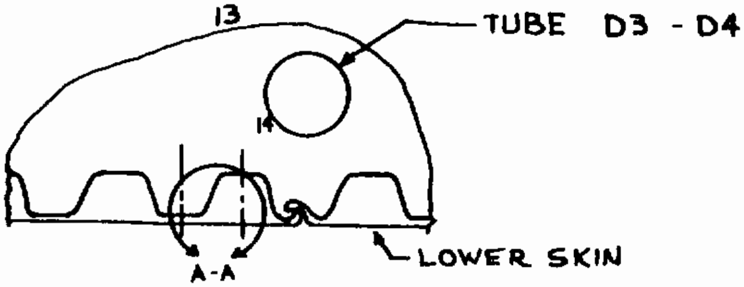
FIGURE 16

ANALYSIS G NODAL DIAGRAM

HOT STRUCTURES THERMAL CORRELATION

ANALYSIS G
CORRUGATION ANALYSIS

NODAL DIAGRAM



SEE PAGE 231
FOR DETAILS OF A-A

FIGURE 17

ANALYSIS G BOUNDARY CONDITION DIAGRAM

CAPACITANCE - ANALYSIS G

NODE	MATERIAL	VOLUME	CAPACITANCE	
1	HS-25	DRIVEN	--	
2	↓	.00125	3.875×10^{-5}	
3		.00125	3.875 ↓	
4		.00125	3.875	
5		.001	3.100	(0)
6		.00125	3.875	(0)
7		.002505	7.766	
8		.0016	4.96	
9		.0016	4.96	
10		.0016	4.96	
11		.002505	7.766	
12	HS-25	.00125	3.875×10^{-5}	
13	RENE' 41	DRIVEN	--	
14	RENE' 41	DRIVEN	--	

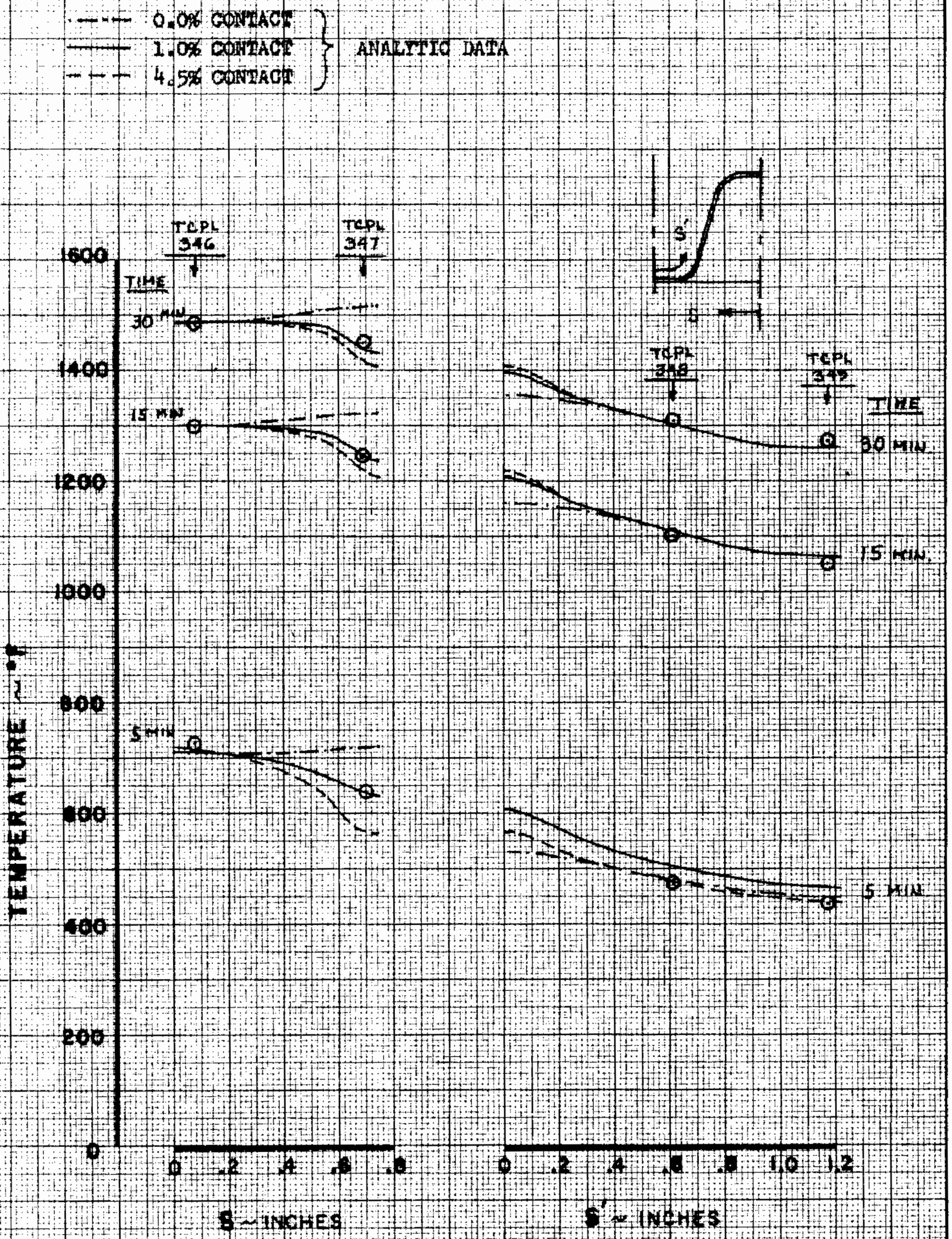
CONDUCTION CONDUCTORS

COND. NO.	NODE/NODE	A/L	
1	1 - 2	.0512	
2	2 - 3	.0512	
3	3 - 4	.0512	
4	4 - 5	.0569	
5	5 - 6	.1389	(1% CONTACT)
6	6 - 7	.05326	
7	7 - 8	.04872	
8	8 - 9	.0625	
9	9 - 10	.0625	
10	10 - 11	.04872	
11	11 - 12	.05326	

RADIATION CONDUCTOR MATRIX

NODE (j)	NODE (i)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	-						50	51	52	53	54	55		
2		-					56	57	58	59	60	61		
3			-				62	63	64	65	66	67		
4				-			68	69	70	71	72	73		
5					-	74								
6					74	-	75	76	77	78	79		95	
7	50	56	62	68		75	-	80	81	82	83	84	96	
8	51	57	63	69		76	80	-	85	86	87	88	97	
9	52	58	64	70		77	81	85	-	89	90	91	98	
10	53	59	65	71		78	82	86	89	-	92	93	99	
11	54	60	66	72		79	83	87	90	92	-	94	100	
12	55	61	67	73			84	88	91	93	94	-		101
13						95	96	97	98	99	100		-	
14												101		-

RADIATION CONDUCTOR	AF VALUE	RADIATION CONDUCTOR	AF VALUE	RADIATION CONDUCTOR	AF VALUE
50	.0083	74	.1238	98	.0731
51	.0251	75	.0126	99	.0857
52	.0288	76	.0181	100	.2164
53	.0249	77	.0124	101	.1250
54	.0437	78	.0088		
55	.0255	79	.0048		
56	.0163	80	.0399		
57	.0326	81	.0301		
58	.0261	82	.0210		
59	.0202	83	.0218		
60	.0384	84	.0048		
61	.0226	85	.0295		
62	.0565	86	.0252		
63	.0255	87	.0210		
64	.0144	88	.0088		
65	.0117	89	.0295		
66	.0298	90	.0301		
67	.0183	91	.0124		
68	.1353	92	.0399		
69	.0025	93	.0181		
70	.0038	94	.0126		
71	.0038	95	.0714		
72	.0069	96	.1188		
73	.0050	97	.0606		



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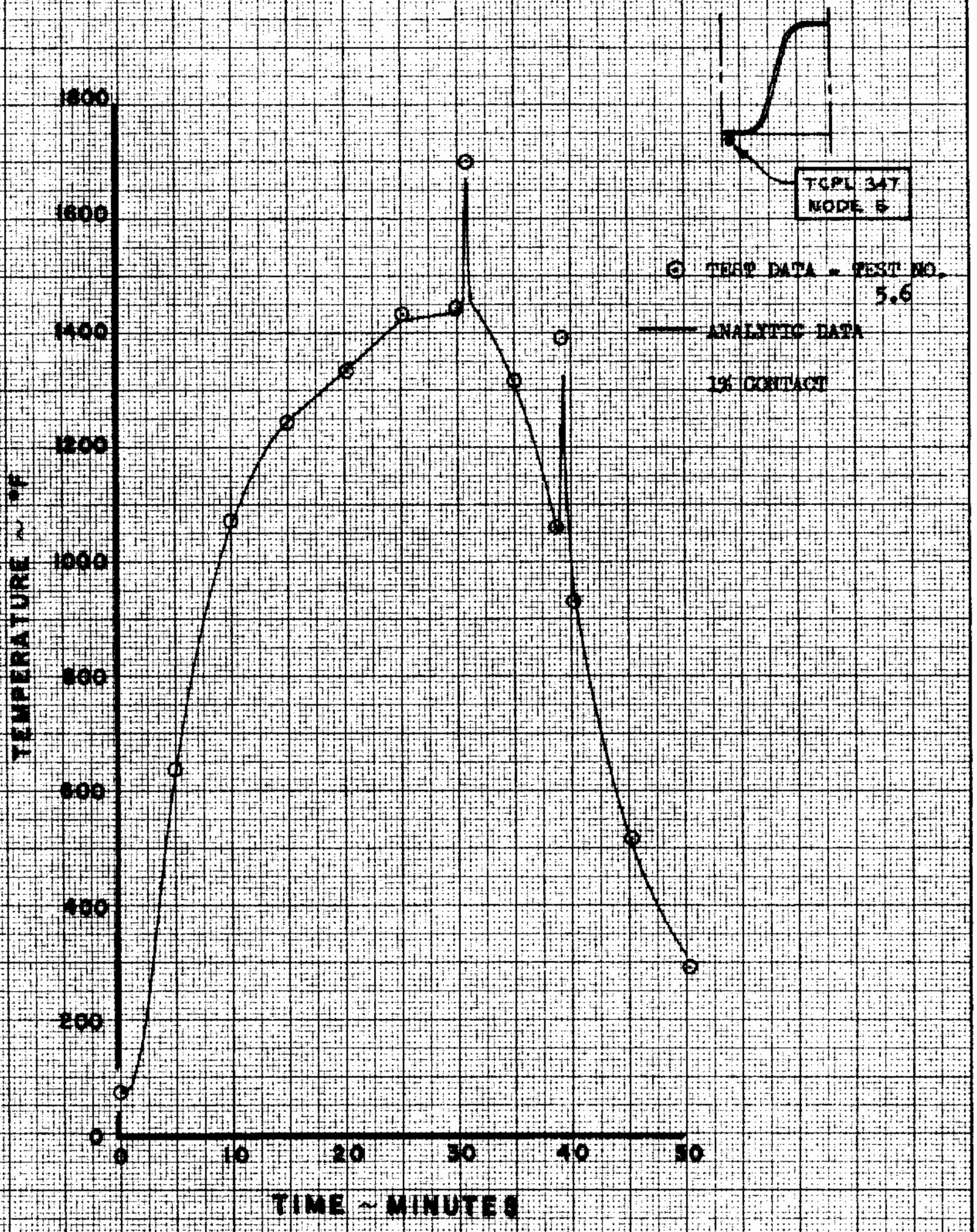

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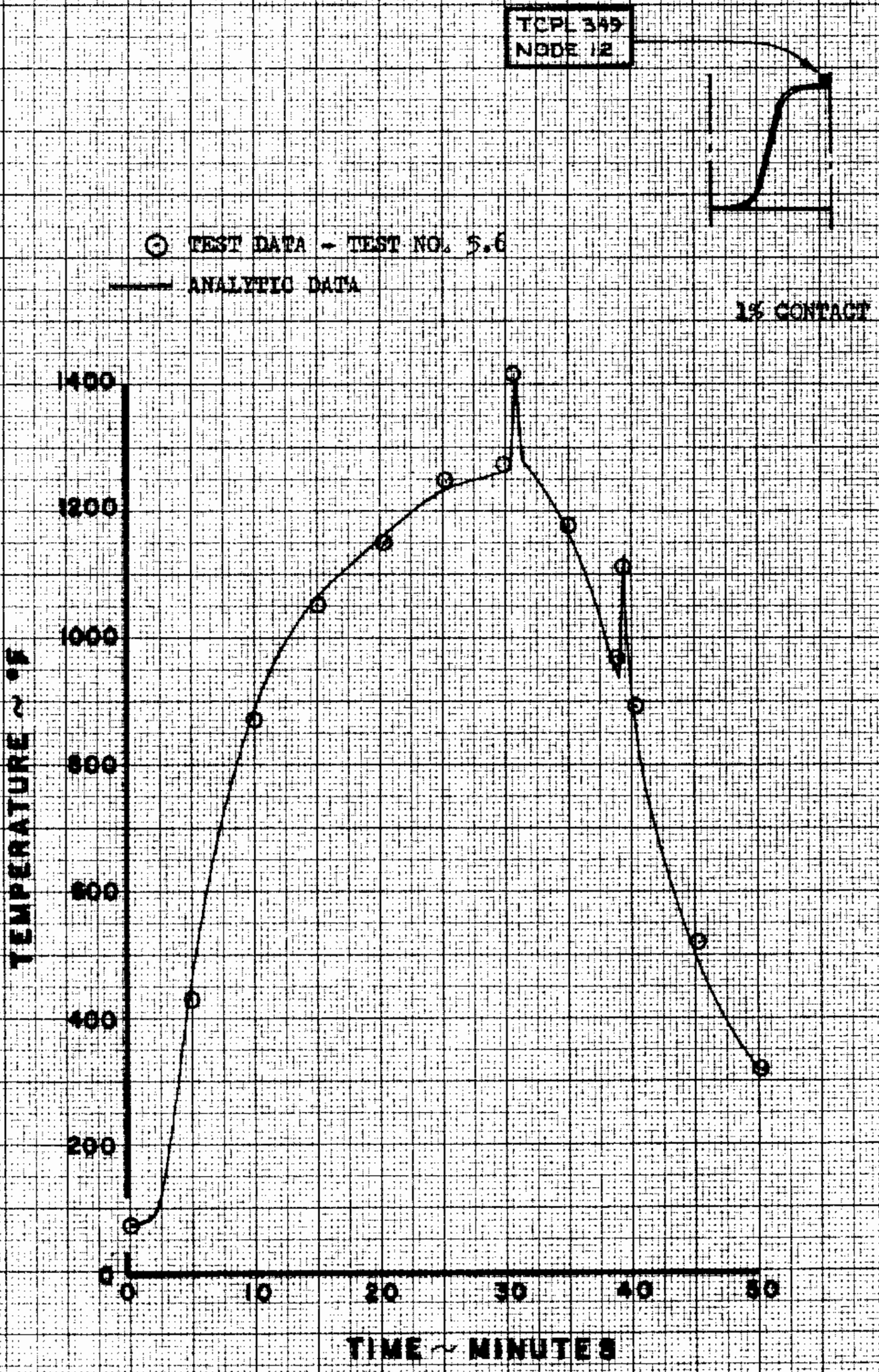

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HOT STRUCTURES THERMAL CORRELATION
ANALYSIS G
LOWER BODY CORRUGATION

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4.8.3 Discussion (Analysis G)

This analysis indicates that conduction through the spotwelds between the skin and corrugation is somewhat significant if detailed corrugation temperatures are desired. For general panel temperatures, however, the assumptions of no conduction and equivalent flat plates used by Analyses A, B, C and D would appear valid.

Three cases with varying conduction contact area percentages are compared with test data. The actual spotweld area amounted to approximately 4.5% but the best results are shown for a 1% assumption. Thus interface resistance in the spotweld area would seem quite significant. A 0% (equivalent to Analyses A, B, C and D) case produces gradient directions that seem unrealistic, though supporting data is sparse. Note again however, that these are small gradients and that gross temperature levels do not seem particularly affected by such an assumption.

SECTION V

GENERAL PROGRAM CONCLUSIONS

5.1 THERMAL CORRELATION CONCLUSIONS

Similar to Reference (4), the overall correlation shown between predictions based on X-20A thermal analysis methods and the Hot Structures test data is quite good. Generally, predictions are somewhat conservative (50°F to 100°F), but this is to be desired.

General agreement exists throughout the trajectories, thus indicating reasonable transient method capability. Of particular note, the maneuvers of the Test 5 series were in good agreement in an unusual number of cases; this was not anticipated.

The following detail methods, techniques, and assumptions appear validated by this program:

1) Two-dimensional cross-section cuts of large glide reentry vehicles.

2) Replacement of corrugations with equivalent flat plates (where mean panel temperatures are desired).

3) Neglect of conduction (through spotwelds or probably, bolts and rivets) between the outer skin and the corrugated panel, i.e., radiation only. (This would be restricted to oxidized surfaces without further data.)

4) Use of fairly simple internal radiation equations and factors (no unusually complex networks were required).

5) Simple large node three-dimensional approaches in these regions:

    a) Open nose-section region (further data is necessary on this point).

    b) Truss structure joints (where care in the use of massive nodes is exercised).

    This is of particular interest since many constants (view factors in particular) are based on engineering judgement rather than hours of computer and/or handbook lookup time. Requirements, of course, would influence the decision to use such methods.

6) Neglect of all trusswork (except major longerons and occasionally large diagonal tubes) in two-dimensional cross-sections. Note, however, that the lower longerons, in the case of Test B1, were sensitive to the panel attachment details as a result of stepped spanwise panel gradients near the longerons.

7) Inclusion of natural convection on unheated vertical or near vertical surfaces (and, in this case the top surface) is necessary on sea level test specimens. This, of course, is somewhat a function of test orientation and technique.

8) Neglect of internal convection currents in a closed sea level test specimen (except where internal compartments create narrow flow passages thus reducing the "random" nature of such currents).

9) Use of a large digital computer program (BETA) for the actual temperature calculation and integration task.

10) The use of mean cavity temperature boundary conditions (particularly as seen in Section 4.5.2.1) is interesting but not proven.

No conclusions relative to X-20 thermal analysis methods may be drawn for temperatures much below 500°F. Corrugation detail gradients are well correlated in Section 4.8, but the conduction interface effects are too strong and too unpredictable to draw any far reaching conclusions.

Between this program and the Heat Protection System Test Program (Reference 4), general correlation of internal structural temperature prediction methods exists for the following:

1) Overall structural system
    a) Insulated panel systems (at altitude)
    b) Uninsulated panel systems
    c) Structural trusswork
    d) Large open-cavity regions
2) Detail areas
    a) Structural joints
    b) Insulated panel attachments

5.2 RECOMMENDATIONS

The correlation shown by this program and by Reference 4 is sufficient to warrant usage of X-20 thermal analysis methods (as further detailed in Reference 3) on all similar vehicles. Obviously, engineering judgement is required, and one must constantly watch for variances in boundary conditions, geometry, structural concept, environment, and materials that might invalidate such methods.

Future sea level tests of large or full scale vehicles, where possible, should be conducted with an eye towards reduction of convective effects (both internally and externally). If all surfaces are to be heated, then the problem essentially disappears. For a vehicle, such as the "Hot Structures Models",where only the lower surface is heated, the test specimen could be inverted. This would eliminate the convection "forcing functions",since the coolest surfaces are also the lowest. Note again that such currents do not influence temperatures during reentry due to lower air density.

APPENDIX

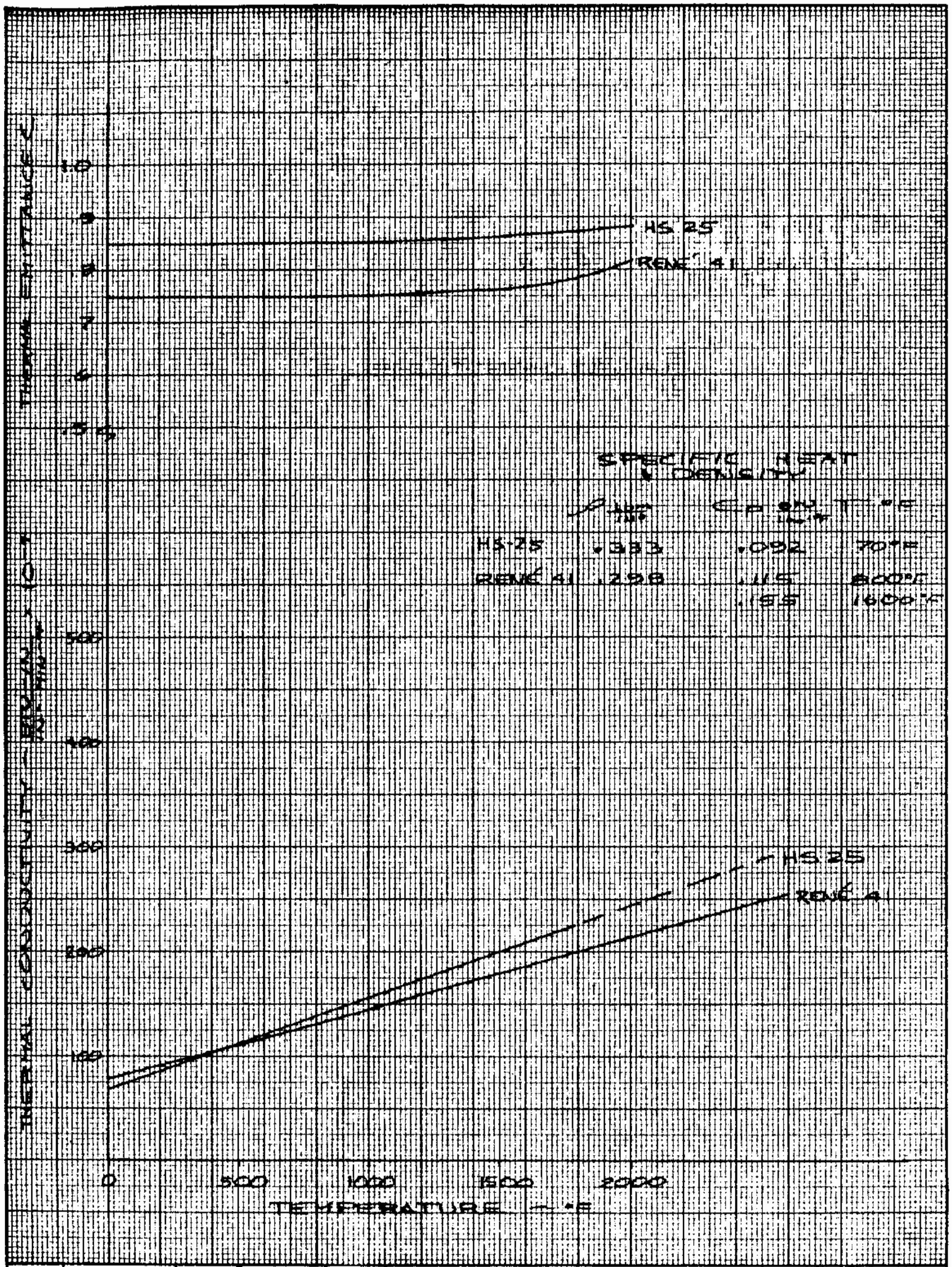
PROPERTY VALUES

MATERIALS USED

RENE' 41
HS-25
CERAFELT(THERMOFLEX)
TRANSITE
ASBESTOS

PROPERTIES SHOWN INCLUDE:

ρ - DENSITY
Cp - SPECIFIC HEAT
k - THERMAL CONDUCTIVITY
ϵ - THERMAL EMITTANCE



SPECIFIC HEAT & DENSITY

	ρ LB/IN³	Cp BTU/LB°F	T °F
HS-25	.333	.092	70°F
RENÉ 41	.298	.115	800°F
		.155	1600°F

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PLOT	HFC	8-12-4		

HOT STRUCTURES
THERMAL ANALYSIS
MATERIAL PROPERTIES

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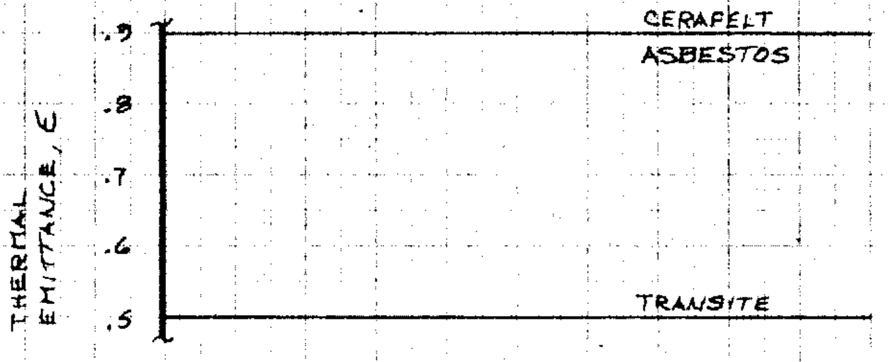
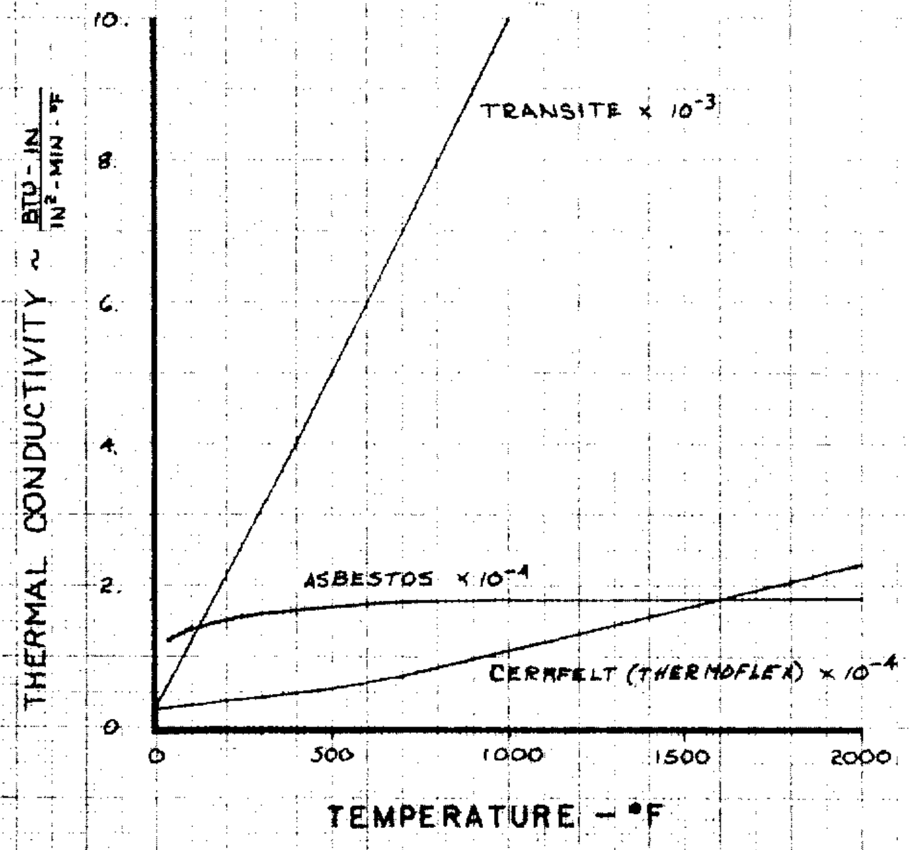


	$\rho \frac{LB_m}{IN^3}$	$C_p \sim \frac{BTU}{LB_m \cdot °F}$
TRANSITE	.0579	.20
CERAFELT	3.472×10^{-3}	.24
ASBESTOS	1.16×10^{-2}	.195



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HOT STRUCTURES THERMAL CORRELATION
MATERIAL PROPERTIES

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5. AUTHOR(S) *(Last name, first name, initial)*

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13. ABSTRACT

Test data generated during the early X-20 (Dyna-Soar) phases is compared with thermal analysis methods evolved throughout the X-20 Program.

Data is taken from the "Hot Structures" concept model test program. This model was similar in shape and concept to the X-20 design.

The thermal analysis approach and methods used follow closely those which created the X-20 design temperatures.

Generally good correlation is shown for two-dimensional cross-sectional cuts, a simple three-dimensional nose region analysis, simple structural joint analyses, and certain other detail areas. Some additional light is shed on joint interface effects. The only major problem evolved was convection currents in and around the test specimen.

This program in combination with an earlier insulated panel correlation program provides general confidence in the X-20 thermal analysis approach and methods.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Thermal Correlation						
Thermal Analysis Methods						
Grey Body Radiation						
Radiation View Factors						
Thermal Test Data						
Hot Structures						
Boeing Engineering Thermal Analyzer Computer Program (BETA)						

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