BOEING

(NASA-CR-144048) THE 3.3K THRUST CHAMBER LIFE PREDICTION (Boeing Aerospace Co., Seattle, Wash.) 80 p HC $5.00 CSCL 12H

N76-11232

Unclas

G3/20 02202

3.3K Thrust Chamber Life Prediction

CONTRACT NAS8-30615

AUGUST 1, 1974

PREPARED BY
BOEING AEROSPACE COMPANY
(A DIVISION OF THE BOEING COMPANY)
RESEARCH AND ENGINEERING
SEATTLE, WASHINGTON

J. S. ANDREWS - PROGRAM MANAGER

W. H. ARMSTRONG - PRINCIPAL INVESTIGATOR

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

1.0 SUMMARY

The objective of this study was to determine the cause of low-cycle fatigue failure of the NASA/MSFC 3.3K Thrust Chamber. This thrust chamber typifies the current trend in rocket nozzle design which calls for high performance coupled with weight and volume limitations as well as the requirement of reusability.

The analysis was performed with the BOPACE finite-element computer program which provides capability to determine viscoplastic response of a structure subjected to cyclic thermal and mechanical loading. Results are presented which show the critical region for low-cycle fatigue and the history of strain within that region for each thermo-mechanical loading cycle in the 3.3K thrust chamber. The predicted behavior was used to evaluate the low-cycle fatigue life near the throat plane of the chamber. The results show that BOPACE provides an extremely accurate prediction of structural behavior; the critical region was identified and the life determined from computed strains was within 154 cycles of the observed failure at 1013 cycles.

BOPACE is the acronym for BOeing Plastic Analysis Capability for Engines.

2.0 INTRODUCTION

The advent of the Space Shuttle has brought a new era in the design and fabrication of rocket nozzles. The requirement of high-performance coupled with weight and volume limitations, has resulted in the design of rocket nozzles that operate at chamber pressures in excess of 3000 psia. This has elevated the throat heat flux from 20 Btu/in^2-sec for present day high performance rocket nozzles to the range of 80-100 Btu/in^2-sec for the Space Shuttle Main Engine (SSME). A further requirement for future high performance rocket nozzles is reusability. For example, the nozzle may have the requirement that it be capable of operating at 400 major thermal cycles for a total duration of up to 60 hours.

The combination of high performance and reusability has created major design problems. One of the critical aspects of the nozzle design is the fatigue life analysis. This has become a major design problem since a portion of the nozzle, particularly the throat section, is subjected to cyclic plastic strain due to the large temperature gradient between the hot inner wall and the relatively cool outer shell during the engine start-stop transients as well as during the sustained burn period. This has a major impact on nozzle life and creates the need to accurately predict when an engine may fail.

An essential part of any life analysis program is the availability of the appropriate physical and mechanical properties which are needed as functions of temperature for the materials used in fabrication of high performance rocket nozzles. Recognizing this need, NASA has initiated programs to obtain the necessary data; in particular, MSFC has an ongoing program to obtain high temperature low-cycle fatigue data on a copper-base alloy called NARloy-Z. This alloy, which is to be used in the SSME thrust chamber liner, has been fabricated into specimens consisting of the liner configuration of the SSME so the material can be subjected to a combustion environment. The ultimate

2.0 (Continued)

goal of the MSFC research test program is to simulate the cyclic viscoplastic strains in the full scale engine. Then with the appropriate material properties and a structural analysis program such as BOPACE, a correlation between the predicted engine life and the experimental results will be made. A cross section of the thrust chamber design used in the SSME and 3.3K engines is shown in Figure 2.0-1.

3.0 3.3K THRUST CHAMBER

Two configurations which represent a region of the 3.3K chamber 1.0-inch upstream from the throat plane were analyzed during this study. These configurations consisted of: (1) the cylinder wall and coolant channel geometry based on nominal drawing dimensions and (2) the as-built configuration of the outer wall and geometry of coolant channel number 35. Post test inspection of the chamber tested at MSFC revealed that coolant channel dimensions were off-nominal in all as-built channels. Thus, analysis of the nominal and off-nominal channels was performed to evaluate the geometry effect upon fatigue life. Channel number 35 of the test chamber was observed to have the maximum deviation from nominal dimensions in the region of the throat plane.

3.1 THRUST CHAMBER GEOMETRY

Cross sections of the configurations analyzed during this study are shown in Figures 3.1-1 and 3.1-2. The major difference between the two configurations is the shape of the channel wall in the NARloy-Z liner. Both cross sections are shown looking aft (downstream) at a section 1.0-inch forward of the throat plane. Note that the minimum thickness of the as-built configuration was 0.0005-inch greater than the nominal dimension, but is located near the fillet radius rather than the channel centerline.

3.2 MATERIAL PROPERTIES

The material properties required for the structural analysis are the stress-strain curves, modulus of elasticity, thermal expansion, Poisson's ratio, creep behavior and low-cycle fatigue life. These data, with the exception of creep and fatigue life information, were obtained from Reference 1 and are presented here in Figures 3.2-1 through 3.2-7.

3.2 (Continued)

Special consideration was given to the stress-strain curves. For the BOPACE program, stress-strain data is represented in terms of a combined hardening theory (Reference 2) which takes account of possible combined kinematic and isotropic hardening of the material. The plasticity data used to characterize NARloy-Z liner were assumed to include isotropic as well as kinematic hardening. An isotropic hardening curve (yield surface size versus cumulative plastic strain) was developed such that a moderate increase in yield point of NARloy-Z was included. Then curves of kinematic hardening versus plastic strain were developed for an assumed stable condition of the material. The third parameter (kinematic factor versus cumulative plastic strain) was then determined so the original stress-strain data were properly matched. Figures 3.2-8, 3.2-9, and 3.2-10 show these curves for several temperatures. Plastic behavior of the electrodeposited nickel (EDNI) outer shell was assumed to result from kinematic hardening only.

Creep data for NARloy-Z were included based on limited tests performed by Boeing in Huntsville (Reference 3). For input to BOPACE, creep information is represented as a reference curve of creep strain versus time (Figure 3.2-11) and a series of curves of creep factor versus stress for various temperatures. The creep factor curves used in this analysis are given in Figure 3.2-12.

The low-cycle fatigue life data used in this study was provided by MSFC. The life prediction curve (Figure 3.2-13) was developed from deflection controlled cyclic test data for uniaxial isothermal test specimens subjected to complete reversed loading. The uniaxial specimens were considered to have failed in low-cycle fatigue when a drop in tensile load carrying capability was observed. Thus, the failure criterion applied to this study was based on partial cracking of the liner rather than total separation of the material. The fatigue curve which is shown in Figure 3.2-13 can be expressed by the standard

3.2 (Continued)

relation of the form $\Delta\varepsilon = M N_f^c$ where $\Delta\varepsilon$ is the effective cyclic strain range, N_f is the number of cycles to failure and M and c are temperature dependent material constants. The values of M and c determined from Figure 3.2-13 are respectively 28.2 and -0.374. Substitution into the above equation gives the relation $N_f = (28.2/\Delta\varepsilon)^{2.674}$ for low-cycle fatigue life evaluation of NARloy-Z.

3.3 OPERATING CYCLE

The 3.3K thrust chamber loading cycle consists of a start transient, sustained burn, and shutdown transient with return to initial conditions. The initial conditions were assumed to consist of a uniform temperature of 70°F and zero pressure (0 psig) in the chamber and coolant passage. The chamber was assumed to be cooled from the fabrication temperature of 70°F to -120°F. Since the chilldown sequence was not defined, the chamber was subjected to a step change in temperature of -190°F with no pressure loading. The thermo-mechanical loading cycle was then characterized by the temperatures and pressures shown in Figures 3.3-1 and 3.3-2. Temperature distributions in the section were obtained from a heat transfer analysis of the 3.3K chamber. Some of the resulting temperature distributions at various times during the cycle are shown in Figures 3.3-3 through 3.3-10.

4.0 FINITE-ELEMENT MODELS

The finite element models used in the BOPACE analyses of the two coolant channel configurations are shown in Figures 4.0-1 and 4.0-2. Each figure shows the node identification (I.D.) number which corresponds to the nodal data given in Tables 4.0-I and 4.0-III. The nodal data are listed in four columns; the first column is simply a counter which lists the total number of nodes in the model. The second column lists node I.D.'s corresponding to the numbers in the finite-element mesh. The third and fourth columns list the nodal coordinates in the global cylindrical coordinate system where the radius R is given in millimeters and the angle θ is given in degrees.

Tables 4.0-II and 4.0-IV define the geometric characteristics of each finite element within the models. Here the first two columns count the number of elements and provide each element I.D. respectively. The next three columns list the global node numbers which define each finite element in terms of its three nodes.

The BOPACE program provides the constant-strain-triangle (CST) for viscoplastic analysis. Options are provided for plane-strain, plane-stress, or limited 3-dimensional analysis involving prescribed non-zero values of normal strain or stress; the appropriate model for the thrust chamber problem is the plane-strain CST.

Because of symmetry, it was possible to analyze the nominal configuration using a segment of 4.5° arc length. Although no symmetry exists for the channel 35 configuration, it was assumed that satisfactory results could be obtained with the 9.0° arc length segment shown. This assumption was verified by comparing results obtained near the boundaries of both models. Also the relative coarseness of the 9.0° model did not significantly affect the results obtained with the model. The coarse mesh was used only in regions that remained elastic or experienced very small plastic deformation during the operating cycle.

4.0 (Continued)

In summary, the models of the nominal and off-nominal configurations consisted respectively of 281 nodes with 477 elements and 256 nodes with 420 elements. Model characteristics were such that the model was constrained to displace along the radial boundaries, i.e., only one degree-of-freedom (R) was permitted at the radial boundary nodes. All other nodes were permitted two degrees-of-freedom (R,θ); this included nodes at the free boundaries of the chamber hot gas wall, coolant channel wall and outer wall as well as the interior nodes. Thus the nominal and off-nominal models were 522 and 472 degree-of-freedom models respectively.

5.0 LIFE ANALYSIS

The BOPACE analyses of loading conditions defined in Section 3.3 provide structural behavior of the entire model. Attention was focused however upon response in the region of the channel wall. It is in this region that the most damaging inelastic deformations occur.

5.1 NOMINAL CONFIGURATION RESULTS

Behavior of the nominal configuration is shown for one cycle of the loading conditions. Results are characterized by the strain and temperature histories shown in Figures 5.1-1, 5.1-2 and 5.1-3. These data show the response of the most highly strained region which is identified by the shaded finite-element (#238) in Figure 5.1-4.

The maximum strain range which occurred in element #238 reached the value of 1.63%. Use of $\Delta\varepsilon$ = 1.63% in the life prediction equation indicates that the nominal configuration should have a life of 2000 cycles under the thermomechanical loading defined in Section 3.3. This life is indicated by the dash-line in Figure 5.1-5.

Creep behavior was also computed, but cumulative creep was at least three orders of magnitude smaller than corresponding plastic strain components. Thus creep damage during each cycle would be small. There is some indication however that the creep strains tend to rachet because of the nature of the cycle. Values of stress and temperature decrease so rapidly during shutdown that the major portion of creep which occurs during start-up and sustained burn may tend

5.1 (Continued)

to accumulate. The racheting effect could be nullified, however by hardening that occurs during creep. The hardening that occurs during creep is determined by following the creep curve as long as temperature and stress remain constant. If either or both parameters change from one time increment to the next, the creep behavior will be defined by a new creep curve. The transfer from one curve to another requires an assumption for creep hardening. BOPACE provides options of age, strain, or work hardening. Details concerning these hardening assumptions are found in Reference 4. The strain hardening assumption was used to define creep hardening behavior of NARloy-Z. More investigation of the creep effect is warranted, and the investigation should include additional material testing which will permit application of Manson's strain range partitioning approach to evaluation of low cycle fatigue in these engines. This is particularly important in evaluation of engines such as the SSME which experience higher temperatures and longer sustained burn periods.

It should be noted that the most damaging strains occur on the cold side of the coolant channel wall. This effect was observed in both configurations analyzed. Post test inspection of the 3.3K thrust chamber tested at MSFC shows that all fatigue cracks propagated from the cold side of the coolant channel wall, but failure of the tested engine occurred much sooner than predicted for the nominal configuration. Post test inspection revealed that coolant channel dimensions were not nominal. Thus additional analyses were performed to study the effect of channel geometry upon fatigue life.

5.2 CHANNEL 35 RESULTS

Channel 35 was analyzed for the same loading conditions as applied to the nominal configuration. The results of the analysis are shown in Figures 5.2-1 through 5.2-5.

5.2 (Continued)

It was found that the change in shape of the cold side of the coolant channel 35 resulted in a significant increase in effective strain range over the maximum predicted value in the nominal configuration. The maximum value of effective strain range of 2.01% occurs during the time of strain reversal from sustained burn through shutdown. The region of maximum strain is indicated by the shaded element in Figure 5.2-4. Use of the computed value of 2.01% effective strain range in the low-cycle fatigue equation results in a predicted failure at 1167 cycles. A fatigue crack at this region was observed during post-test inspection after cycle #1013. A micrograph showing the low-cycle fatigue crack in channel 35 is presented in Figure 5.2-6.

6.0 CONCLUDING REMARKS

Results of the BOPACE analysis show that the critical region in the 3.3K thrust chamber is on the cold side of the channel wall. The life of the chamber was significantly affected by the shape of the channel wall. The as-built configuration of channel 35 had a fatigue life life of 51% of the predicted life of the nominal configuration even though the minimum thickness of the as-built configuration was 0.0005-inch greater than the nominal configuration. The reduced life was possibly caused by the fact that the thinnest section of channel 35 was near the fillet radius (a region of stress concentration) in the channel wall. It may be possible to extend the life of the engine by changing the shape of the cold side of the channel wall from a rectangular to a circular cross section. This shape should reduce stress concentration effects and result in extended life in the critical region of the chamber.

.0 REFERENCES

1. "Material Properties Manual", Rocketdyne, Canoga Park, California.

2. R. G. Vos and W. H. Armstrong, "Improved Hardening Theory for Cyclic Plasticity", Technical Note, AIAA Journal, March 1973.

3. "NARloy-Z Creep Test Report", Boeing Letter Report 5-9430-H-1357, July 1973.

4. BOPACE Program Documentation, Volumes 1 and 2, Boeing Document D5-17266-1 and -2, Contract NAS8-29821, July 1973.

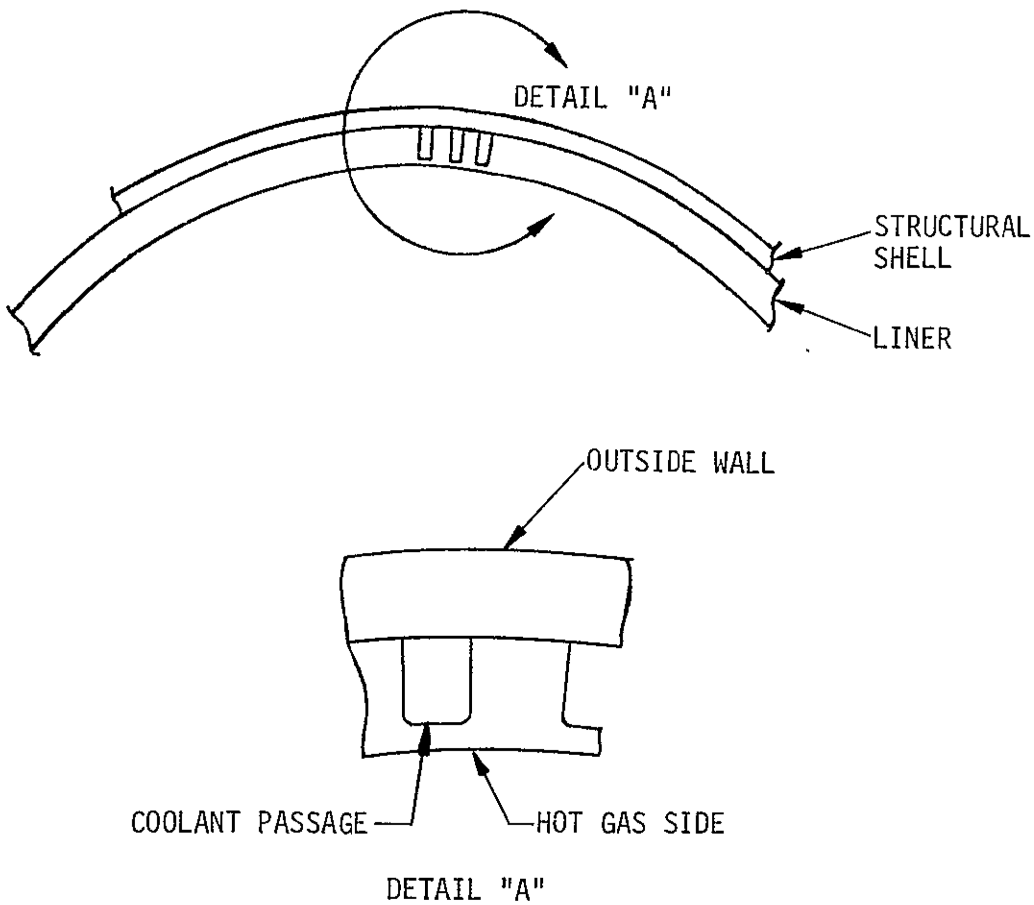
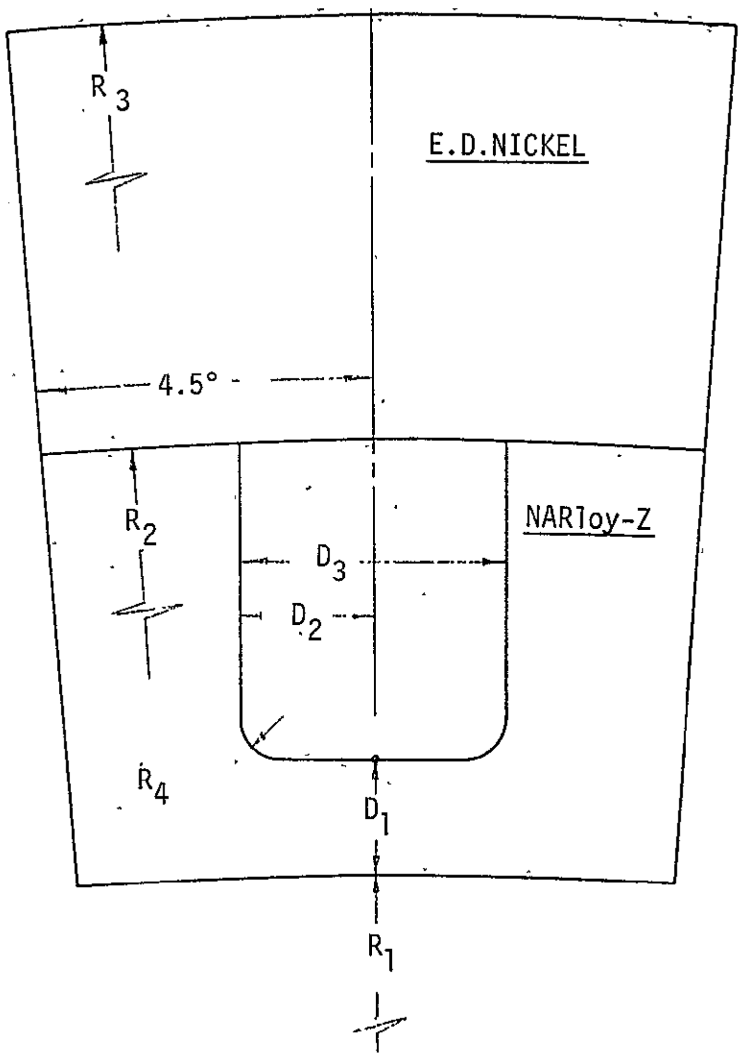
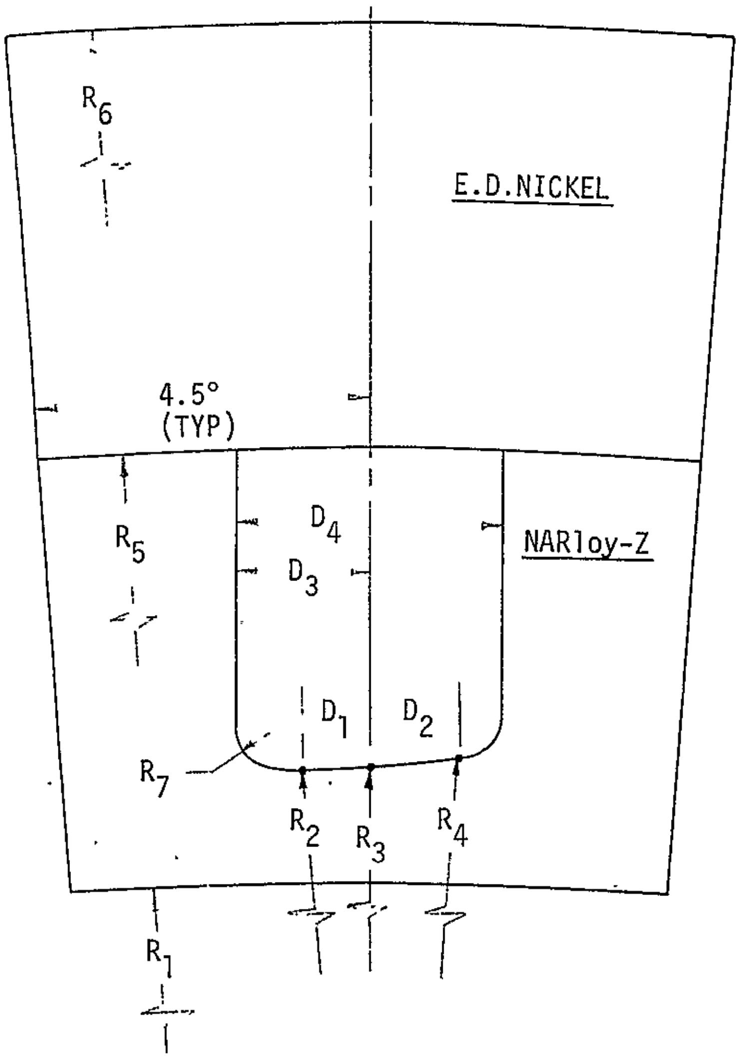


FIGURE 2.0-1: THRUST CHAMBER CROSS SECTION



DIMENSION	INCH	mm
D_1	0.035	0.889
D_2	0.040	1.016
D_3	0.080	2.032
R_1	1.137	28.88
R_2	1.266	32.16
R_3	1.393	35.38
R_4	0.012	0.305

FIGURE 3.1-1: NOMINAL CONFIGURATION, 3.3K THRUST CHAMBER



DIMENSION	INCH	mm
D_1	0.0208	0.528
D_2	0.0312	0.792
D_3	0.0415	1.054
D_4	0.0830	2.108
R_1	1.137	28.88
R_2	1.1725	29.78
R_3	1.1728	29.79
R_4	1.1753	29.85
R_5	1.266	32.16
R_6	1.393	35.38
R_7	0.012	0.305

FIGURE 3.1-2: CHANNEL #35 CONFIGURATION, 3.3K THRUST CHAMBER

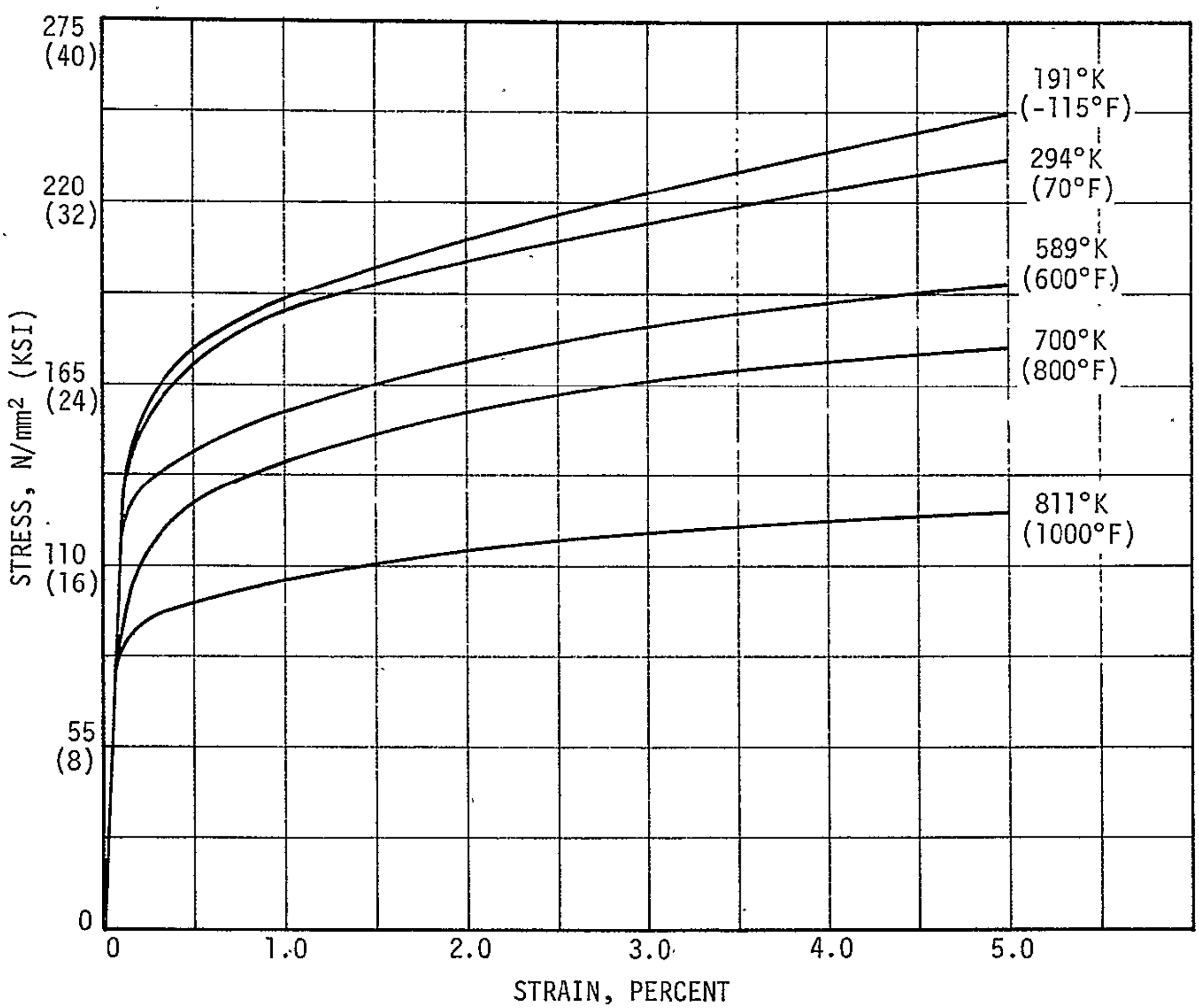


FIGURE 3.2-1: TYPICAL STRESS-STRAIN CURVES FOR WROUGHT NARloy-Z

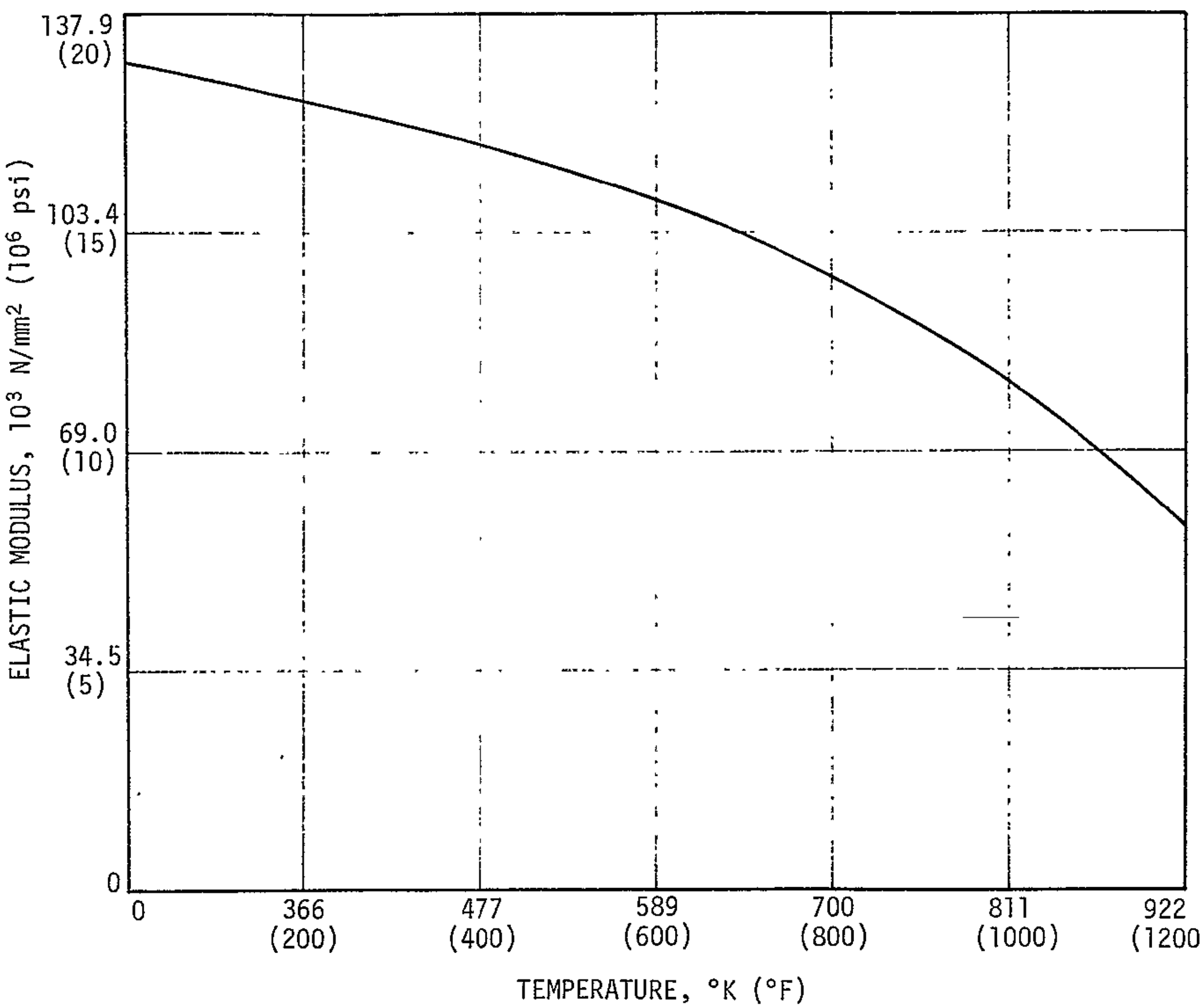


FIGURE 3.2-2: EFFECT OF TEMPERATURE ON ELASTIC MODULUS OF WROUGHT NARloy-Z

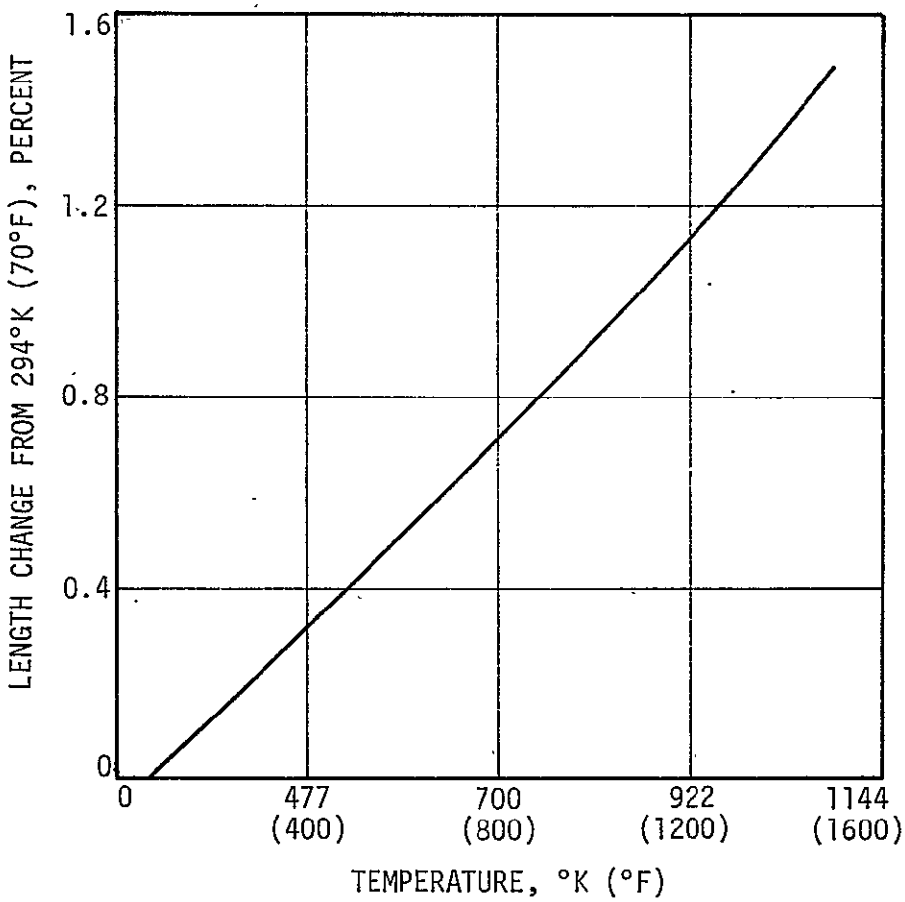


FIGURE 3.2-3: THERMAL EXPANSION OF WROUGHT NARloy-Z

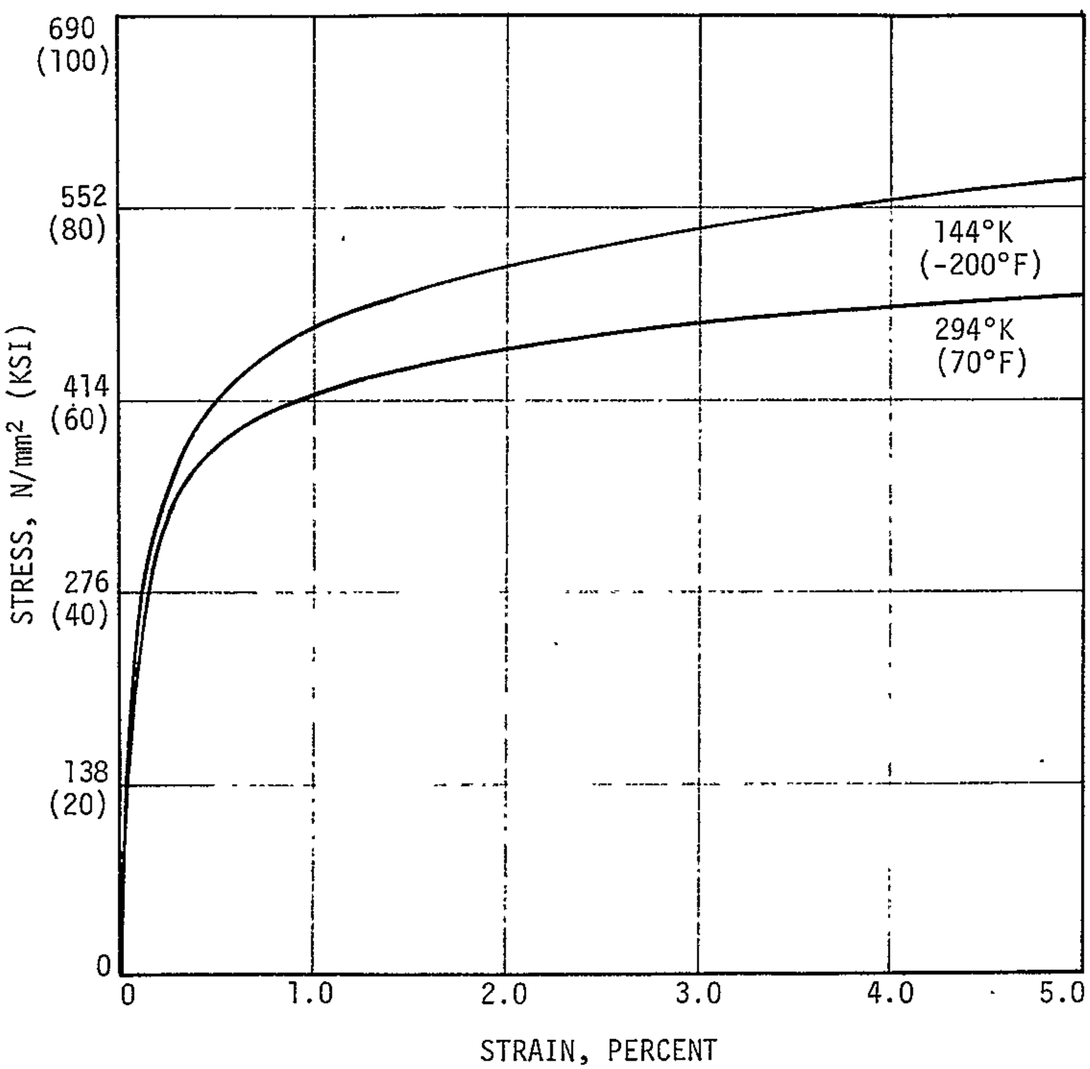


FIGURE 3.2-4: TYPICAL STRESS-STRAIN CURVES FOR ELECTRODEPOSITED NICKEL

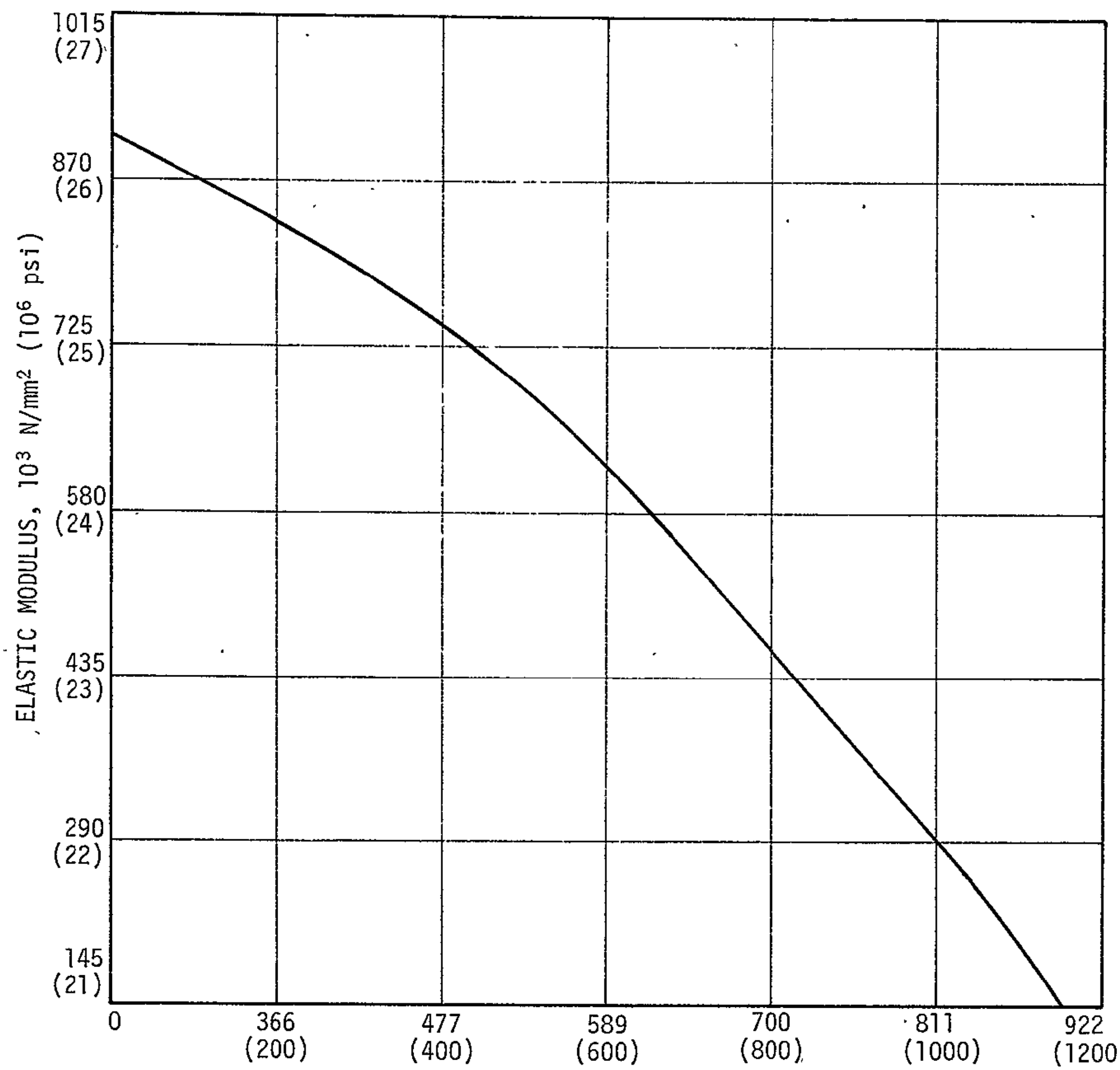


FIGURE 3.2-5: EFFECT OF TEMPERATURE ON ELASTIC MODULUS OF ELECTRODEPOSITED NICKEL

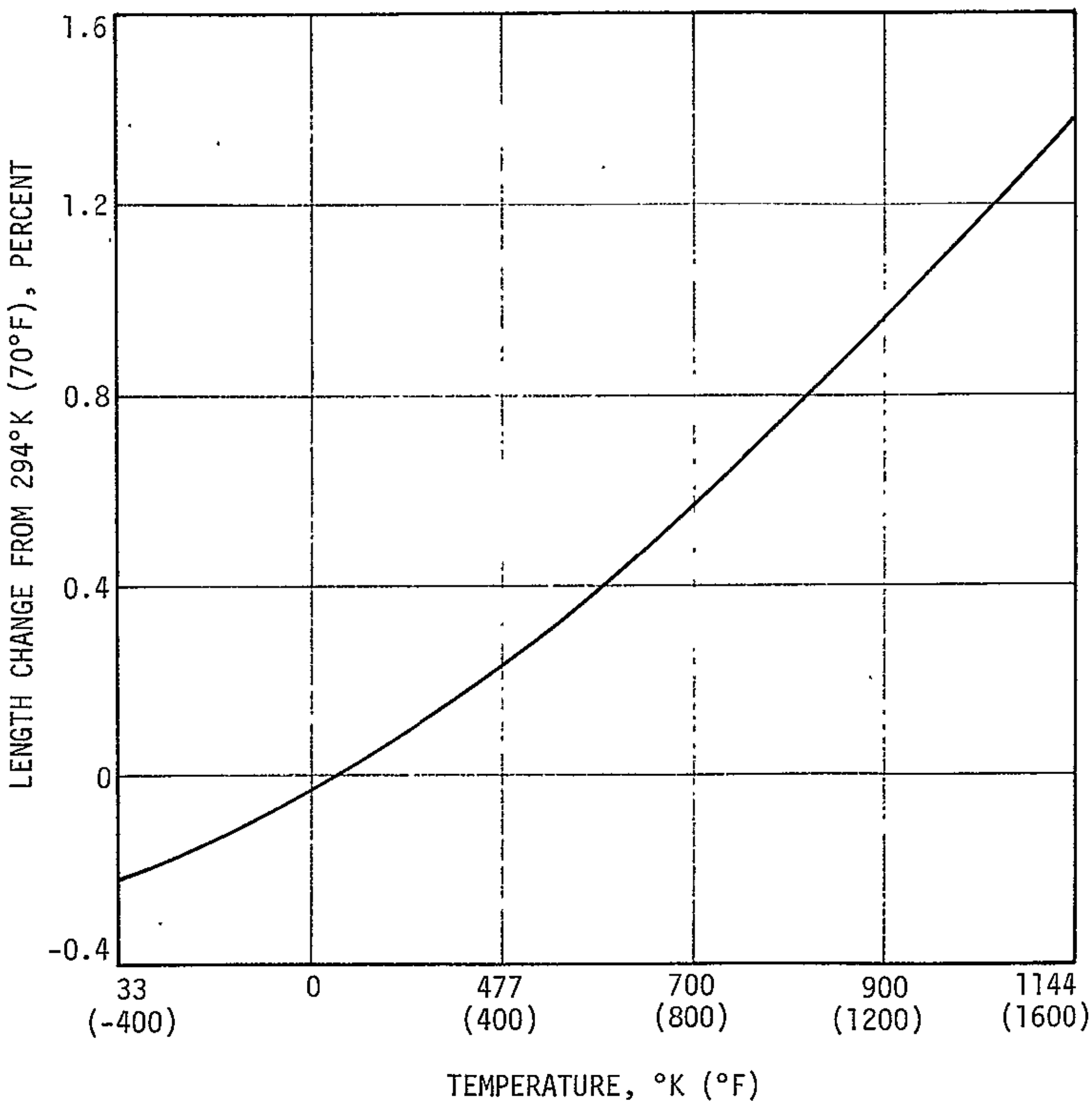


FIGURE 3.2-6: THERMAL EXPANSION OF ELECTRODEPOSITED NICKEL

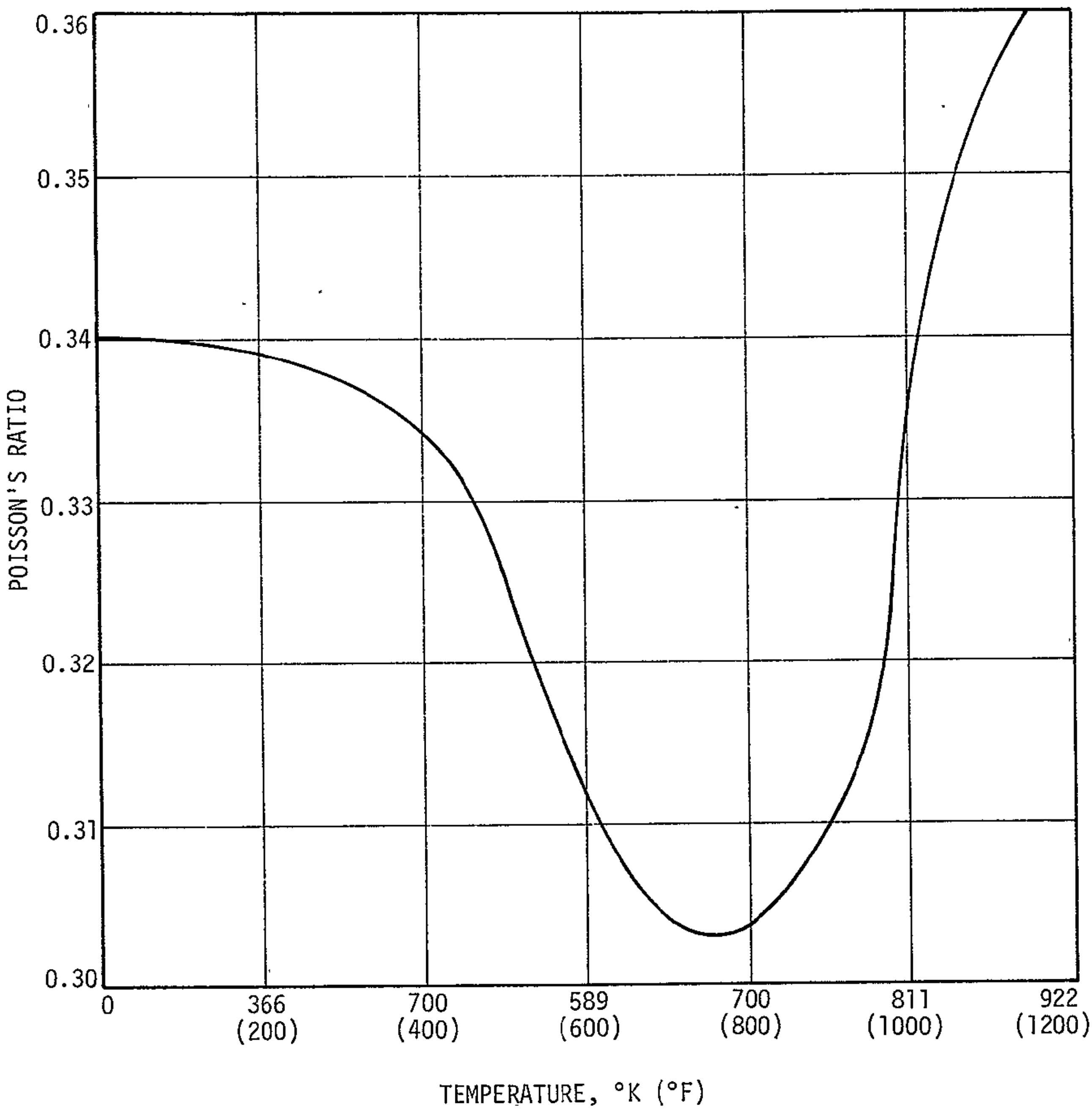


FIGURE 3.2-7: EFFECT OF TEMPERATURE ON POISSON'S RATIO FOR ELECTRODEPOSITED NICKEL

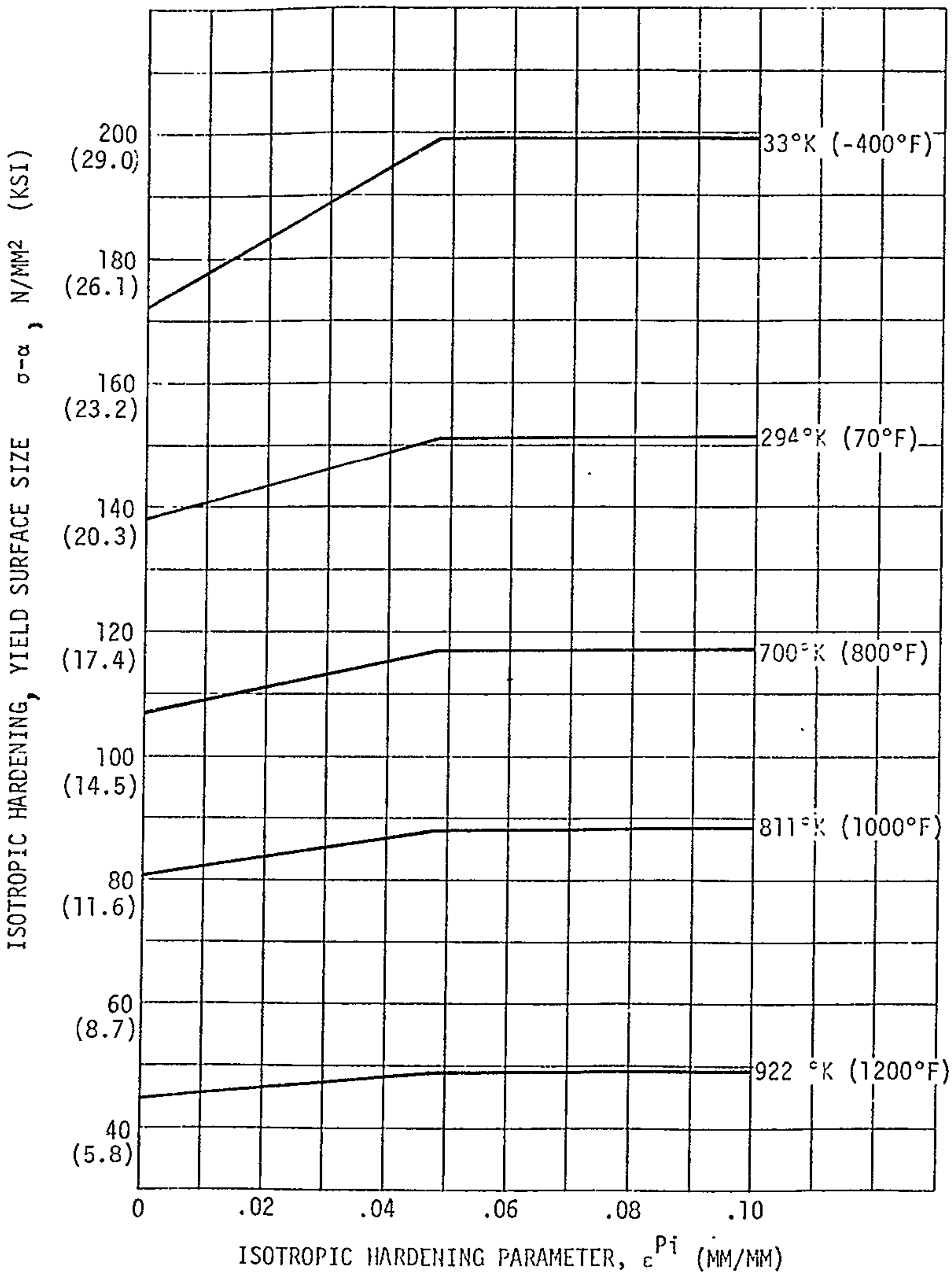


FIGURE 3.2-8: ASSUMED ISOTROPIC HARDENING FOR NARloy-Z

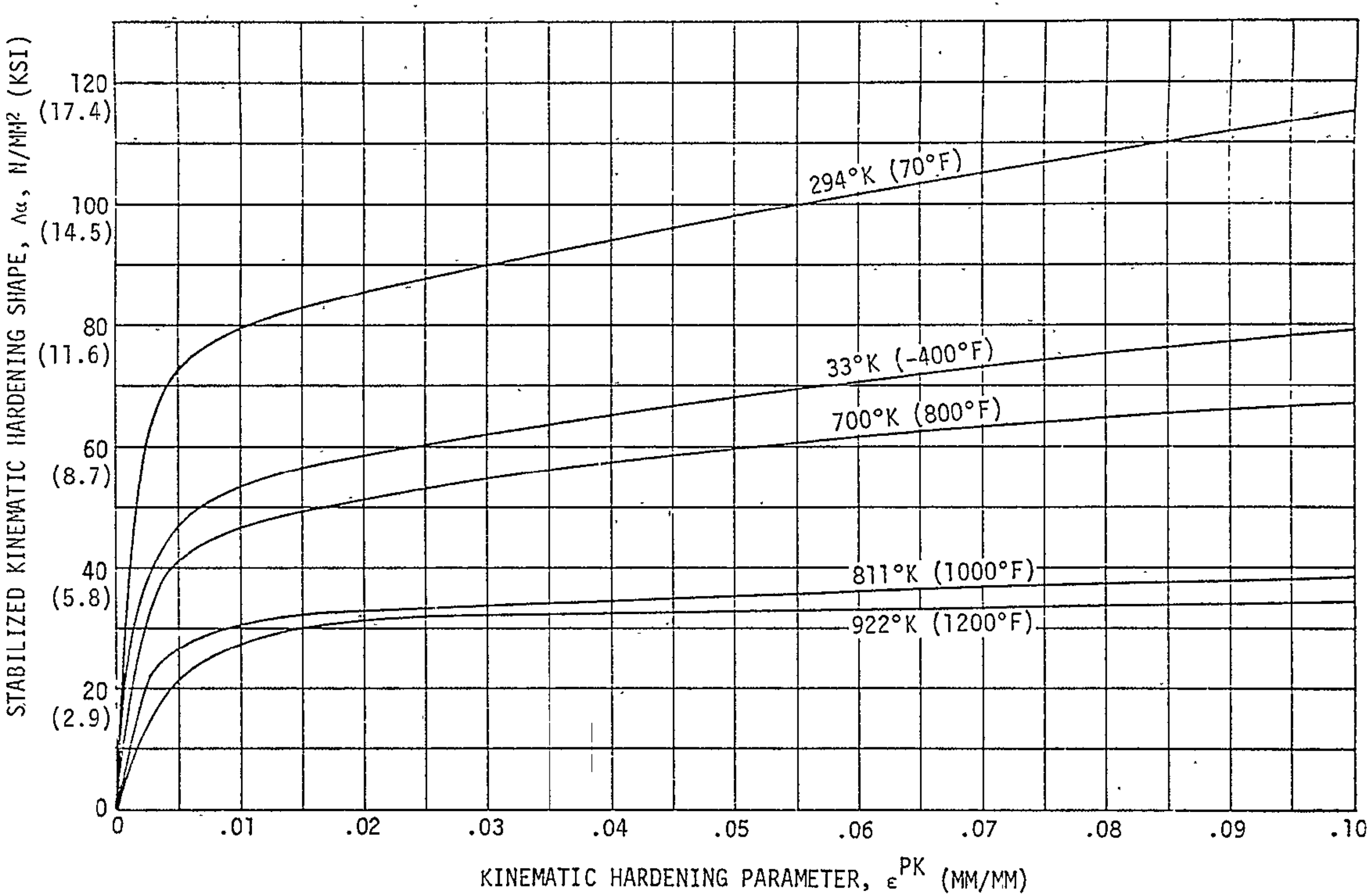


FIGURE 3.2-9: ASSUMED KINEMATIC HARDENING FOR NARloy-Z

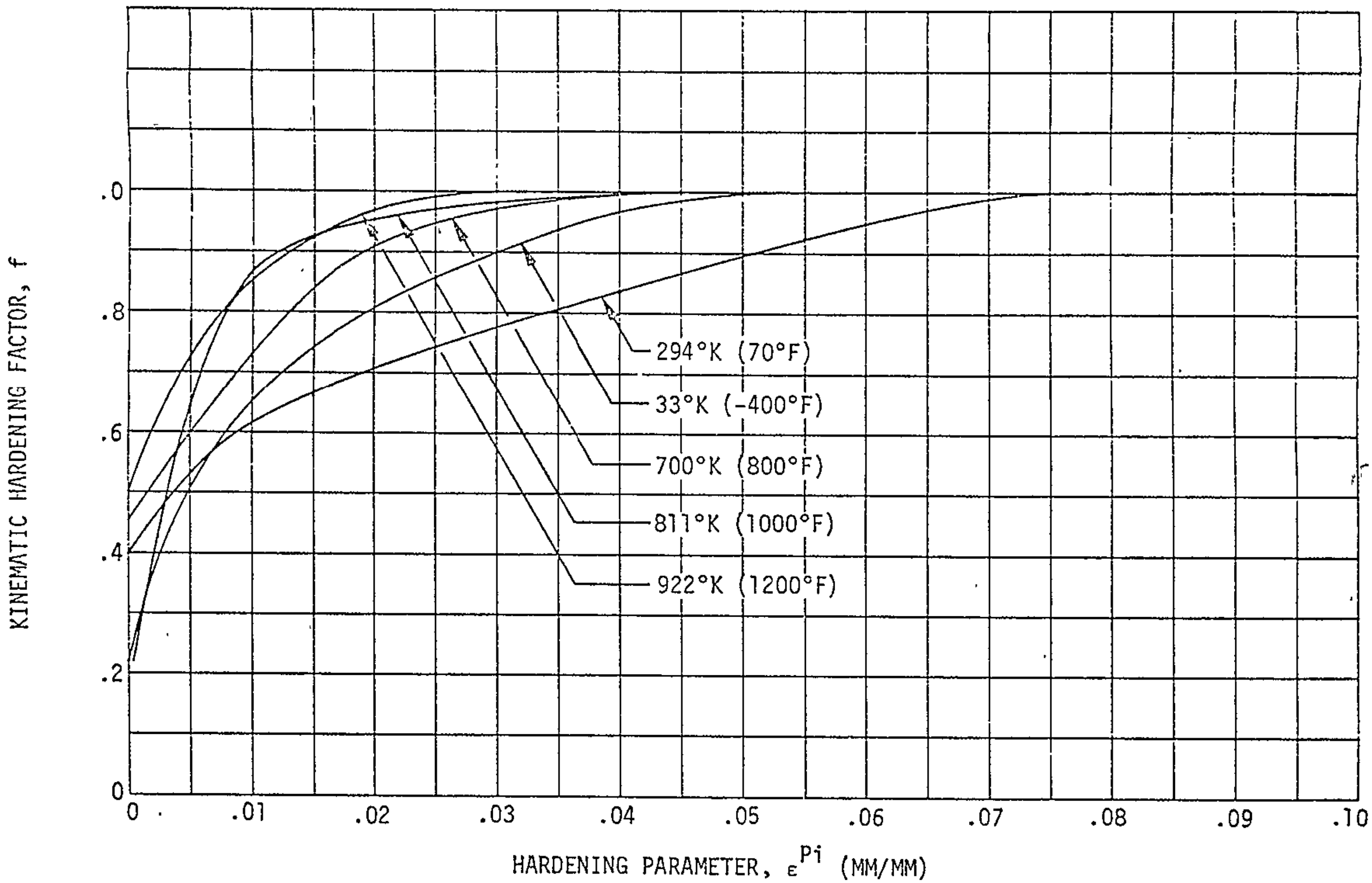


FIGURE 3.2-10: KINEMATIC HARDENING FACTOR FOR NARloy-Z

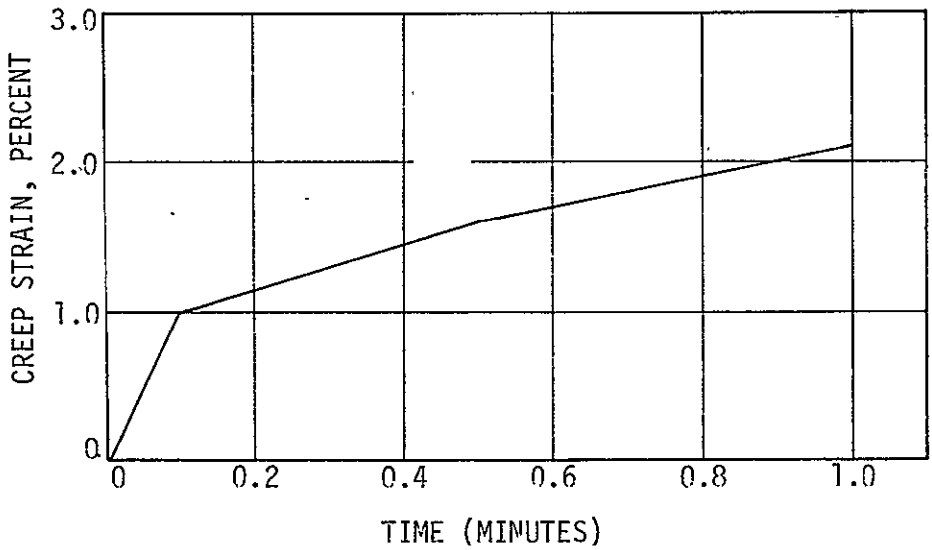


FIGURE 3.2-11: REFERENCE CREEP STRAIN VFRSUS TIME

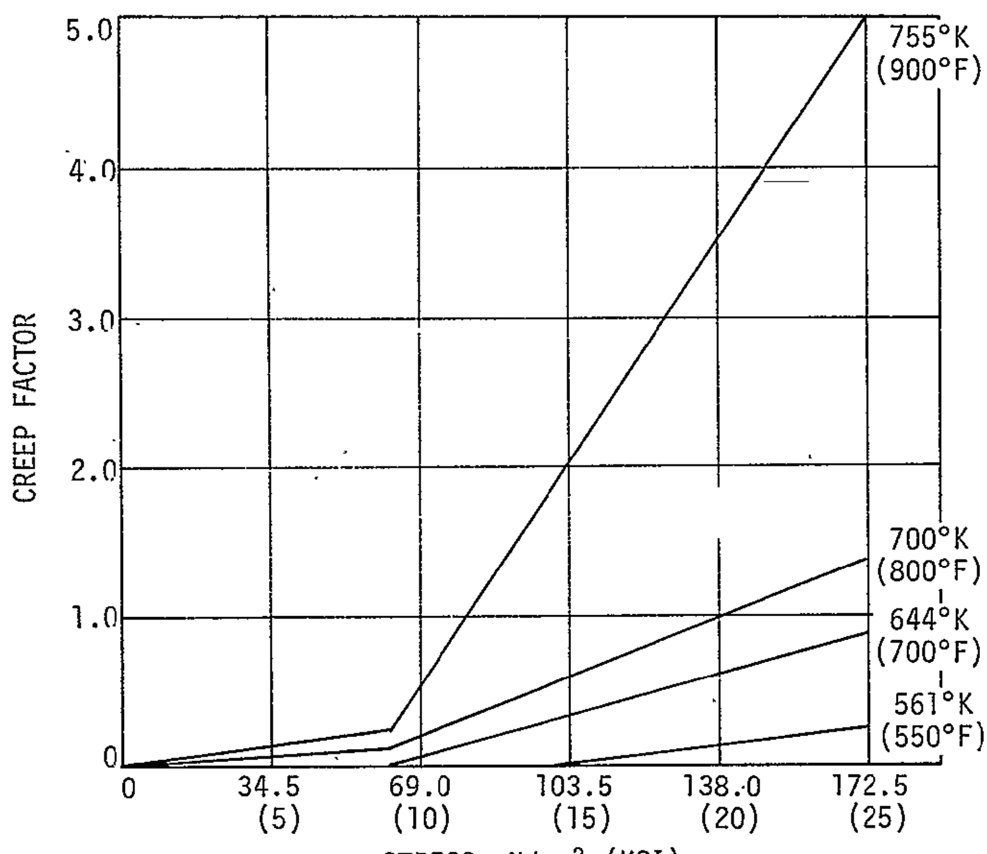


FIGURE 3.2-12: CREEP FACTOR VERSUS STRESS

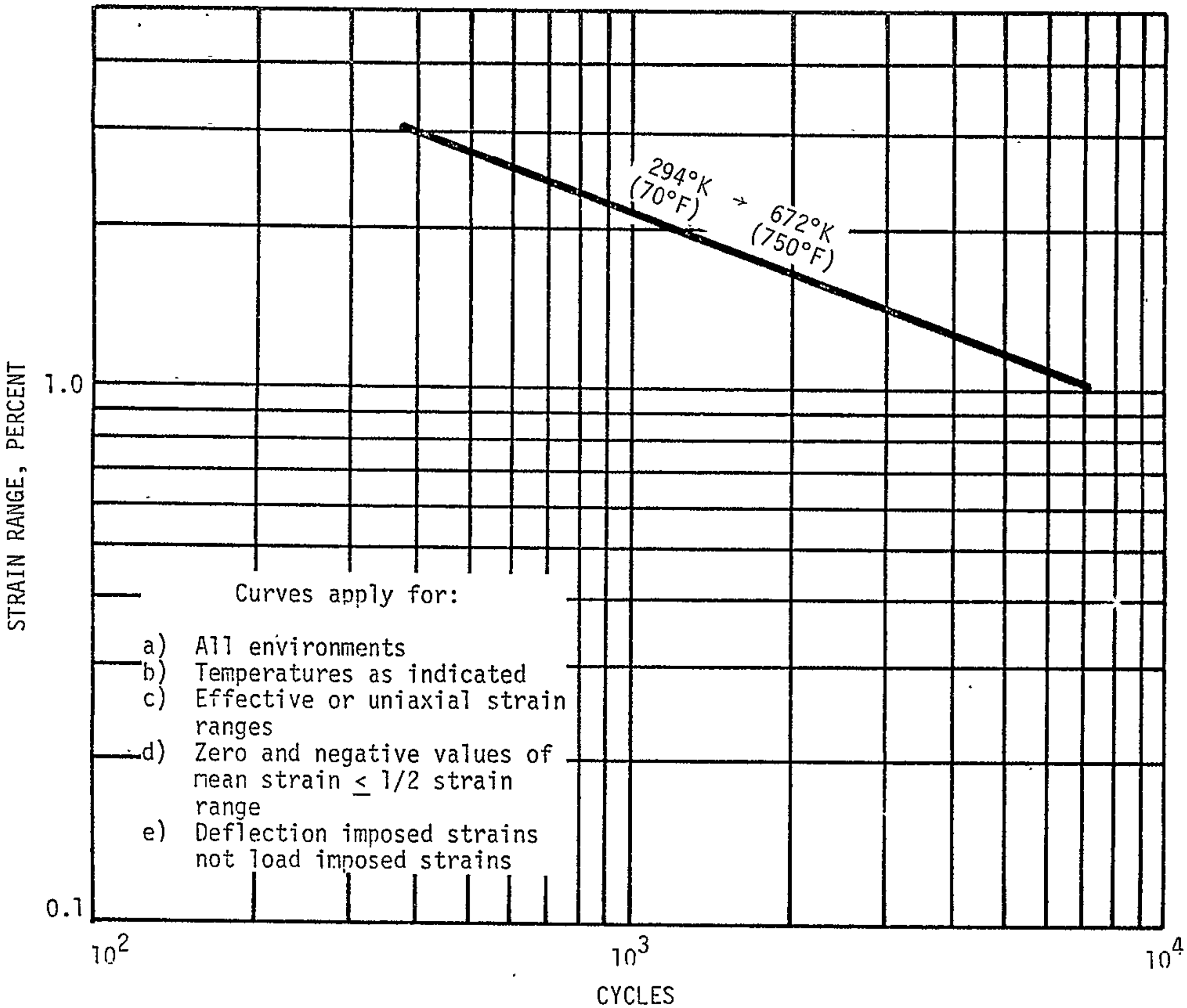


FIGURE 3.2-13: LOW-CYCLE FATIGUE LIFE OF NARloy-Z

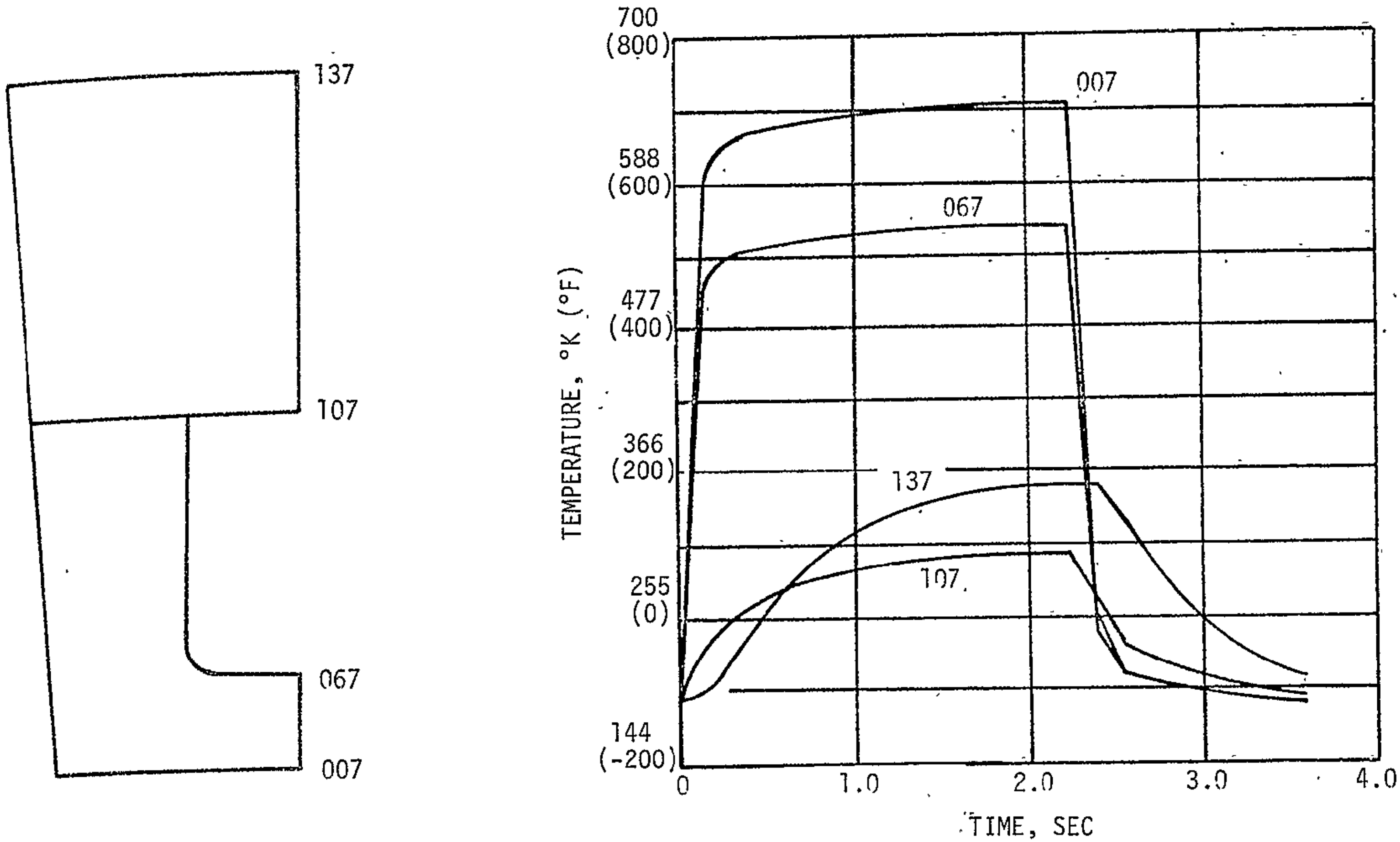


FIGURE 3.3-1: 3.3K TEMPERATURE CYCLE

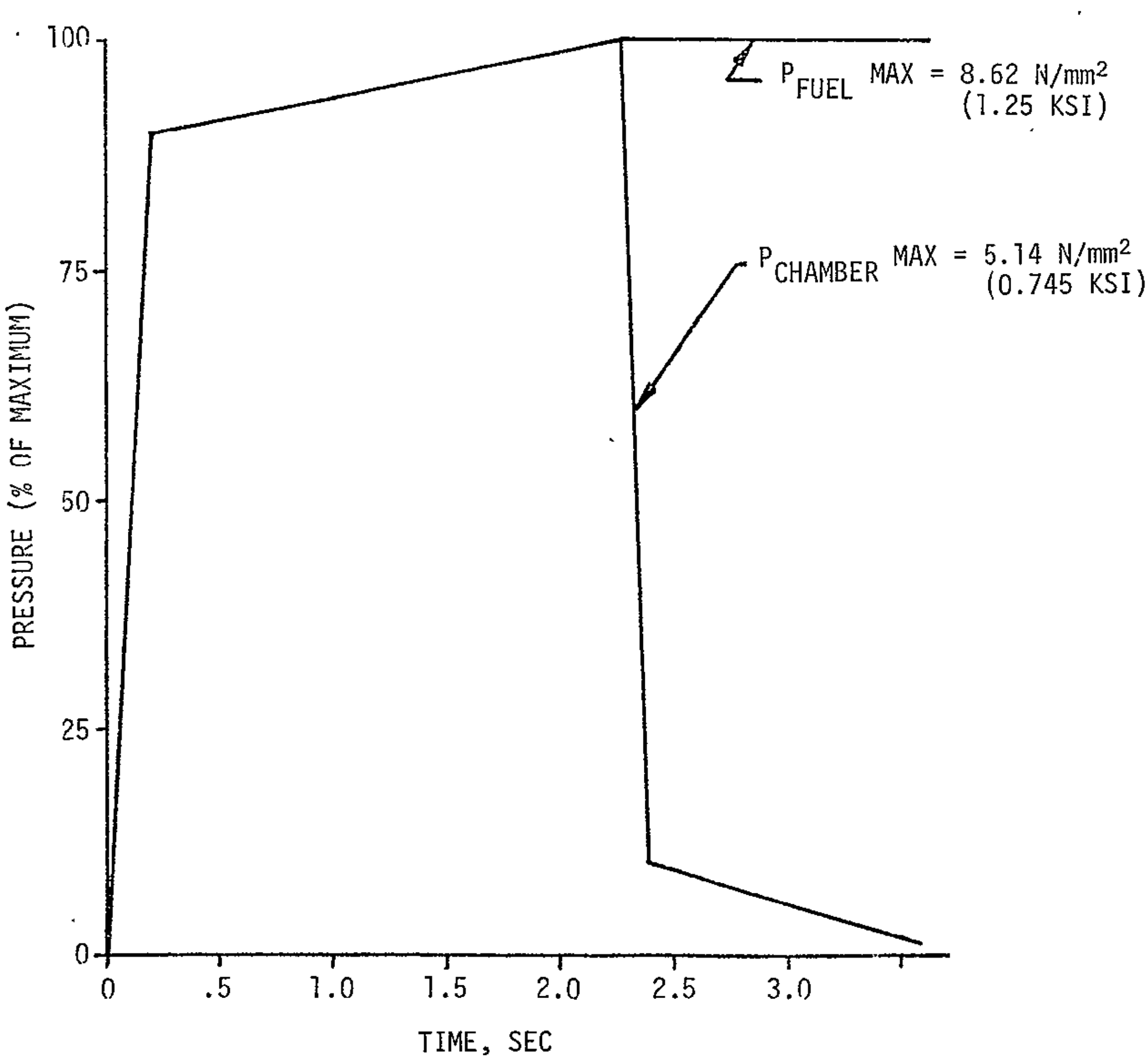


FIGURE 3.3-2: 3.3K PRESSURE CYCLE

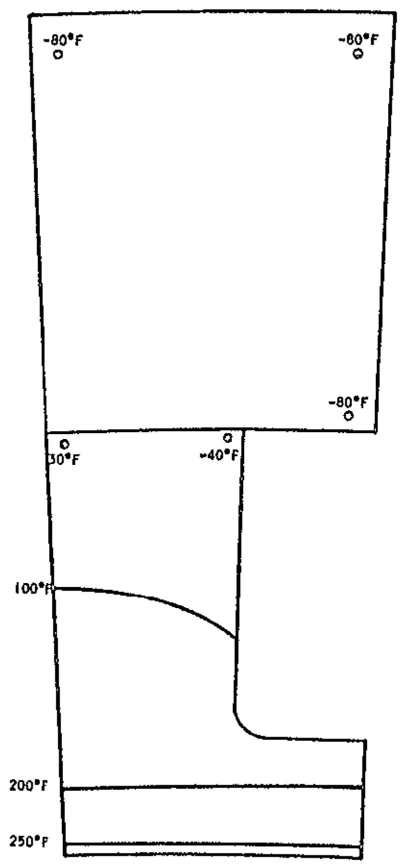


FIGURE 3.3-3: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 0.100 SECONDS

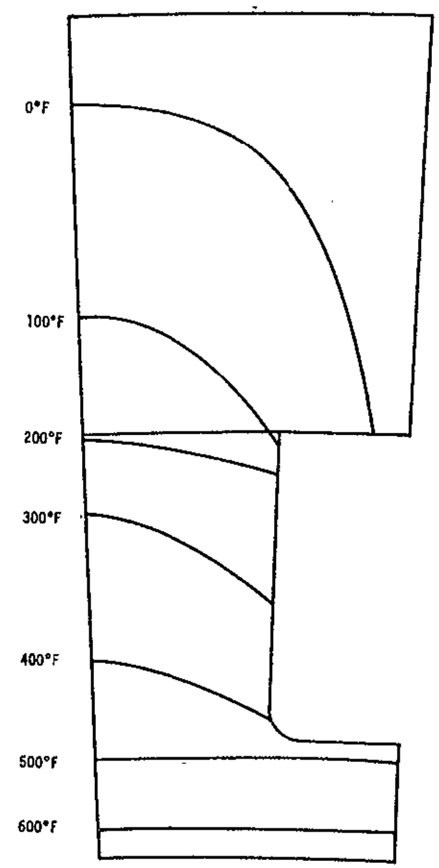


FIGURE 3.3-4: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 0.300 SECONDS

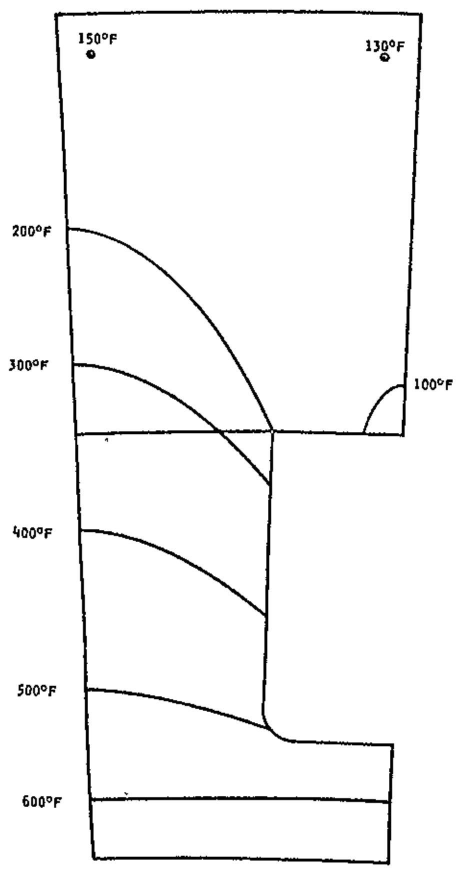


FIGURE 3.3-5: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 1.250 SECONDS

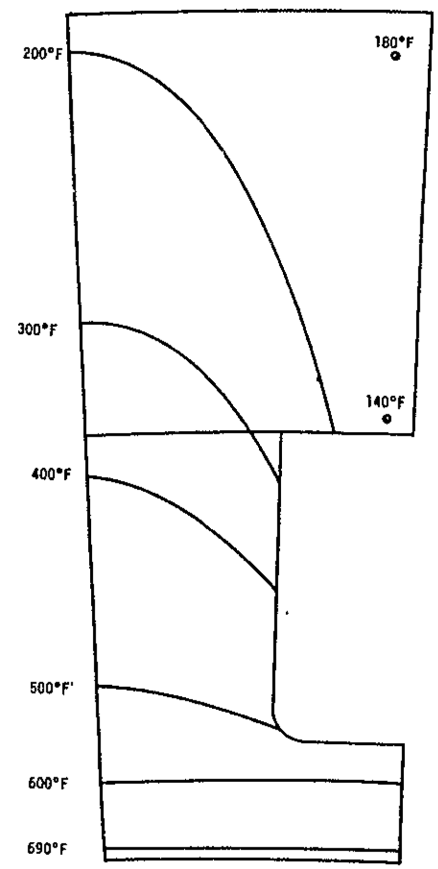


FIGURE 3.3-6: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 2.250 SECONDS

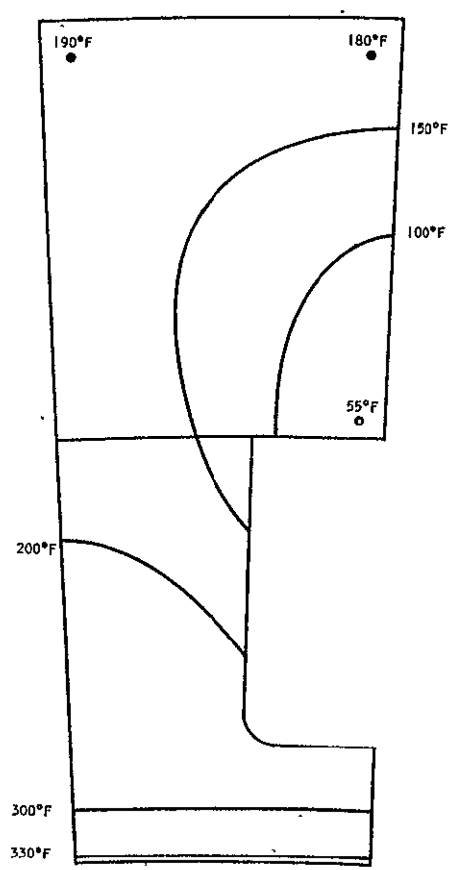


FIGURE 3.3-7: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 2.325 SECONDS

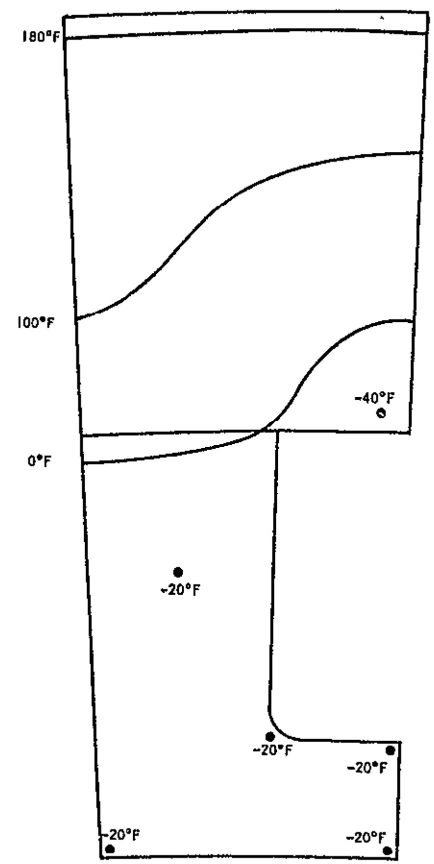


FIGURE 3.3-8: 3.3K THRUST CHAMBER ISOTHERMS,
TIME = 2.400 SECONDS

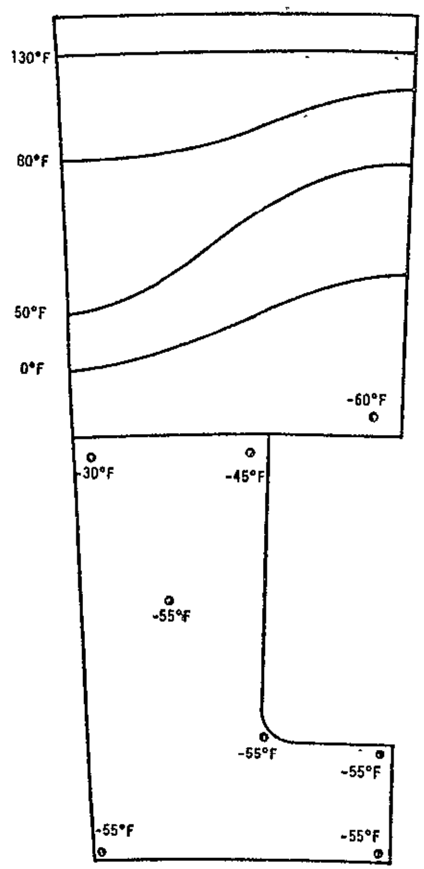


FIGURE 3.3-9 3.3K THRUST CHAMBER ISOTHERMS, TIME = 2.550 SECONDS

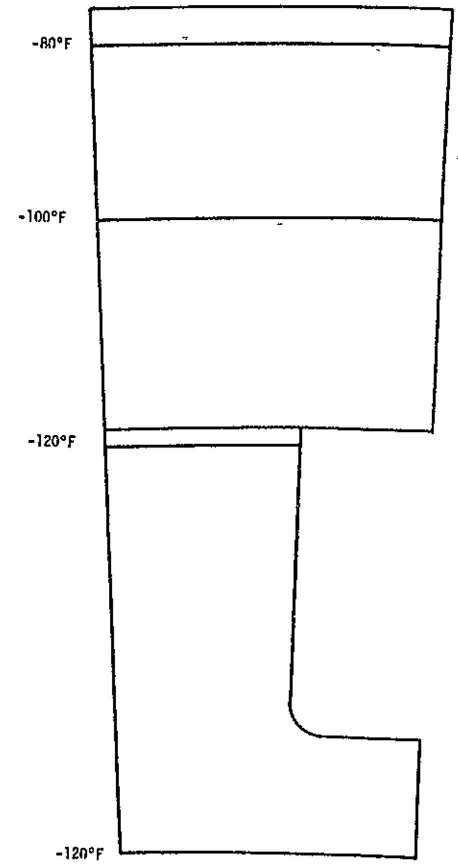


FIGURE 3.3-10: 3.3K THRUST CHAMBER ISOTHERMS, TIME = 3.600 SECONDS

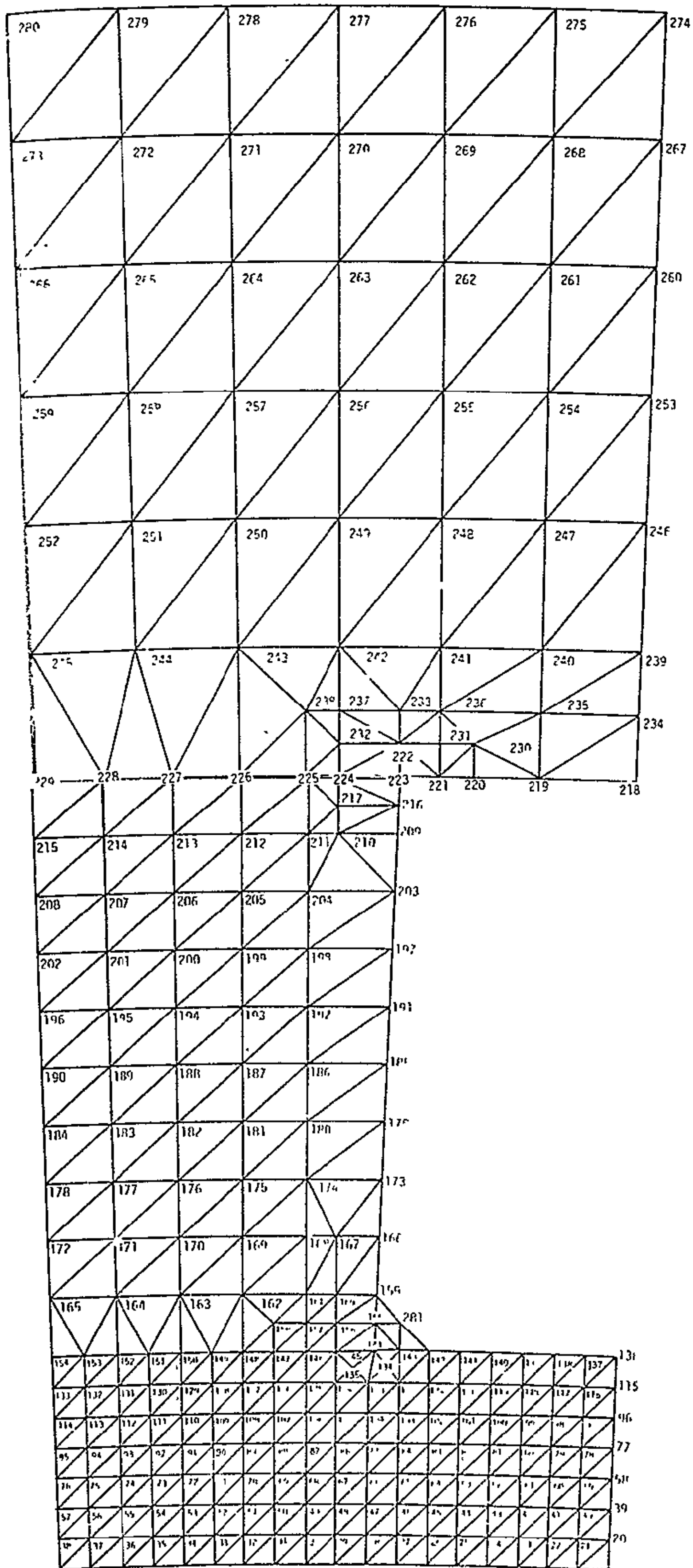


FIGURE 4.0-1: NOMINAL CONFIGURATION FINITE-ELEMENT MODEL SHOWING NODE I.D. NUMBERS

TABLE 4.0-I: NODE NUMBERS AND COORDINATES, NOMINAL CONFIGURATION

** NODE ** NO.	I.D.	R	THETA
1	1	0.28880D 02	0.0
2	2	0.28880D 02	0.25000D 00
3	3	0.28880D 02	0.50000D 00
4	4	0.28880D 02	0.75000D 00
5	5	0.28880D 02	0.10000D 01
6	6	0.28880D 02	0.12500D 01
7	7	0.28880D 02	0.15000D 01
8	8	0.28880D 02	0.17500D 01
9	9	0.28880D 02	0.20000D 01
10	10	0.28880D 02	0.22500D 01
11	11	0.28880D 02	0.25000D 01
12	12	0.28880D 02	0.27500D 01
13	13	0.28880D 02	0.30000D 01
14	14	0.28880D 02	0.32500D 01
15	15	0.28880D 02	0.35000D 01
16	16	0.28880D 02	0.37500D 01
17	17	0.28880D 02	0.40000D 01
18	18	0.28880D 02	0.42500D 01
19	19	0.28880D 02	0.45000D 01
20	20	0.29007D 02	0.0
21	21	0.29007D 02	0.25000D 00
22	22	0.29007D 02	0.50000D 00
23	23	0.29007D 02	0.75000D 00
24	24	0.29007D 02	0.10000D 01
25	25	0.29007D 02	0.12500D 01
26	26	0.29007D 02	0.15000D 01
27	27	0.29007D 02	0.17500D 01
28	28	0.29007D 02	0.20000D 01
29	29	0.29007D 02	0.22500D 01
30	30	0.29007D 02	0.25000D 01
31	31	0.29007D 02	0.27500D 01
32	32	0.29007D 02	0.30000D 01
33	33	0.29007D 02	0.32500D 01
34	34	0.29007D 02	0.35000D 01
35	35	0.29007D 02	0.37500D 01
36	36	0.29007D 02	0.40000D 01
37	37	0.29007D 02	0.42500D 01
38	38	0.29007D 02	0.45000D 01
39	39	0.29134D 02	0.0
40	40	0.29134D 02	0.25000D 00
41	41	0.29134D 02	0.50000D 00
42	42	0.29134D 02	0.75000D 00
43	43	0.29134D 02	0.10000D 01
44	44	0.29134D 02	0.12500D 01
45	45	0.29134D 02	0.15000D 01
46	46	0.29134D 02	0.17500D 01
47	47	0.29134D 02	0.20000D 01

TABLE 4.0-I (Continued)

48	48	0.29134D 02	0.22500D 01
49	49	0.29134D 02	0.25000D 01
50	50	0.29134D 02	0.27500D 01
51	51	0.29134D 02	0.30000D 01
52	52	0.29134D 02	0.32500D 01
53	53	0.29134D 02	0.35000D 01
54	54	0.29134D 02	0.37500D 01
55	55	0.29134D 02	0.40000D 01
56	56	0.29134D 02	0.42500D 01
57	57	0.29134D 02	0.45000D 01
58	58	0.29261D 02	0.0
59	59	0.29261D 02	0.25000D 00
60	60	0.29261D 02	0.50000D 00
61	61	0.29261D 02	0.75000D 00
62	62	0.29261D 02	0.10000D 01
63	63	0.29261D 02	0.12500D 01
64	64	0.29261D 02	0.15000D 01
65	65	0.29261D 02	0.17500D 01
66	66	0.29261D 02	0.20000D 01
67	67	0.29261D 02	0.22500D 01
68	68	0.29261D 02	0.25000D 01
69	69	0.29261D 02	0.27500D 01
70	70	0.29261D 02	0.30000D 01
71	71	0.29261D 02	0.32500D 01
72	72	0.29261D 02	0.35000D 01
73	73	0.29261D 02	0.37500D 01
74	74	0.29261D 02	0.40000D 01
75	75	0.29261D 02	0.42500D 01
76	76	0.29261D 02	0.45000D 01
77	77	0.29388D 02	0.0
78	78	0.29388D 02	0.25000D 00
79	79	0.29388D 02	0.50000D 00
80	80	0.29388D 02	0.75000D 00
81	81	0.29388D 02	0.10000D 01
82	82	0.29388D 02	0.12500D 01
83	83	0.29388D 02	0.15000D 01
84	84	0.29388D 02	0.17500D 01
85	85	0.29388D 02	0.20000D 01
86	86	0.29388D 02	0.22500D 01
87	87	0.29388D 02	0.25000D 01
88	88	0.29388D 02	0.27500D 01
89	89	0.29388D 02	0.30000D 01
90	90	0.29388D 02	0.32500D 01
91	91	0.29388D 02	0.35000D 01
92	92	0.29388D 02	0.37500D 01
93	93	0.29388D 02	0.40000D 01
94	94	0.29388D 02	0.42500D 01
95	95	0.29388D 02	0.45000D 01
96	96	0.29515D 02	0.0
97	97	0.29515D 02	0.25000D 00
98	98	0.29515D 02	0.50000D 00

TABLE 4.0-I (Continued)

99	99	0.29515D 02	0.75000D 00
100	100	0.29515D 02	0.10000D 01
101	101	0.29515D 02	0.12500D 01
102	102	0.29515D 02	0.15000D 01
103	103	0.29515D 02	0.17500D 01
104	104	0.29515D 02	0.20000D 01
105	105	0.29515D 02	0.22500D 01
106	106	0.29515D 02	0.25000D 01
107	107	0.29515D 02	0.27500D 01
108	108	0.29515D 02	0.30000D 01
109	109	0.29515D 02	0.32500D 01
110	110	0.29515D 02	0.35000D 01
111	111	0.29515D 02	0.37500D 01
112	112	0.29515D 02	0.40000D 01
113	113	0.29515D 02	0.42500D 01
114	114	0.29515D 02	0.45000D 01
115	115	0.29642D 02	0.0
116	116	0.29642D 02	0.25000D 00
117	117	0.29642D 02	0.50000D 00
118	118	0.29642D 02	0.75000D 00
119	119	0.29642D 02	0.10000D 01
120	120	0.29642D 02	0.12500D 01
121	121	0.29642D 02	0.15000D 01
122	122	0.29642D 02	0.17500D 01
123	123	0.29642D 02	0.20000D 01
124	124	0.29642D 02	0.22500D 01
125	125	0.29642D 02	0.25000D 01
126	126	0.29642D 02	0.27500D 01
127	127	0.29642D 02	0.30000D 01
128	128	0.29642D 02	0.32500D 01
129	129	0.29642D 02	0.35000D 01
130	130	0.29642D 02	0.37500D 01
131	131	0.29642D 02	0.40000D 01
132	132	0.29642D 02	0.42500D 01
133	133	0.29642D 02	0.45000D 01
134	134	0.29705D 02	0.18750D 01
135	135	0.29705D 02	0.21250D 01
136	136	0.29769D 02	0.0
137	137	0.29769D 02	0.25000D 00
138	138	0.29770D 02	0.50000D 00
139	139	0.29772D 02	0.75000D 00
140	140	0.29773D 02	0.10000D 01
141	141	0.29776D 02	0.12500D 01
142	142	0.29779D 02	0.15000D 01
143	143	0.29783D 02	0.17500D 01
144	144	0.29786D 02	0.19546D 01
145	145	0.29769D 02	0.22500D 01
146	146	0.29769D 02	0.25000D 01
147	147	0.29769D 02	0.27500D 01
148	148	0.29769D 02	0.30000D 01
149	149	0.29769D 02	0.32500D 01

TABLE 4.0-I (Continued)

150	150	0.29769D 02	0.35000D 01
151	151	0.29769D 02	0.37500D 01
152	152	0.29769D 02	0.40000D 01
153	153	0.29769D 02	0.42500D 01
154	154	0.29769D 02	0.45000D 01
155	281	0.29888D 02	0.17500D 01
156	155	0.29888D 02	0.19477D 01
157	156	0.29888D 02	0.22500D 01
158	157	0.29888D 02	0.25000D 01
159	158	0.29888D 02	0.27500D 01
160	159	0.30008D 02	0.19402D 01
161	160	0.30008D 02	0.22500D 01
162	161	0.30008D 02	0.25000D 01
163	162	0.30008D 02	0.30000D 01
164	163	0.30008D 02	0.35000D 01
165	164	0.30008D 02	0.40000D 01
166	165	0.30008D 02	0.45000D 01
167	166	0.30246D 02	0.19247D 01
168	167	0.30246D 02	0.22500D 01
169	168	0.30246D 02	0.25000D 01
170	169	0.30246D 02	0.30000D 01
171	170	0.30246D 02	0.35000D 01
172	171	0.30246D 02	0.40000D 01
173	172	0.30246D 02	0.45000D 01
174	173	0.30485D 02	0.19098D 01
175	174	0.30485D 02	0.25000D 01
176	175	0.30485D 02	0.30000D 01
177	176	0.30485D 02	0.35000D 01
178	177	0.30485D 02	0.40000D 01
179	178	0.30485D 02	0.45000D 01
180	179	0.30724D 02	0.18950D 01
181	180	0.30724D 02	0.25000D 01
182	181	0.30724D 02	0.30000D 01
183	182	0.30724D 02	0.35000D 01
184	183	0.30724D 02	0.40000D 01
185	184	0.30724D 02	0.45000D 01
186	185	0.30963D 02	0.18805D 01
187	186	0.30963D 02	0.25000D 01
188	187	0.30963D 02	0.30000D 01
189	188	0.30963D 02	0.35000D 01
190	189	0.30963D 02	0.40000D 01
191	190	0.30963D 02	0.45000D 01
192	191	0.31201D 02	0.18661D 01
193	192	0.31201D 02	0.25000D 01
194	193	0.31201D 02	0.30000D 01
195	194	0.31201D 02	0.35000D 01
196	195	0.31201D 02	0.40000D 01
197	196	0.31201D 02	0.45000D 01
198	197	0.31440D 02	0.18523D 01
199	198	0.31440D 02	0.25000D 01
200	199	0.31440D 02	0.30000D 01

TABLE 4.0-I (Continued)

201	200	0.31440D 02	0.35000D 01
202	201	0.31440D 02	0.40000D 01
203	202	0.31440D 02	0.45000D 01
204	203	0.31679D 02	0.18379D 01
205	204	0.31679D 02	0.25000D 01
206	205	0.31679D 02	0.30000D 01
207	206	0.31679D 02	0.35000D 01
208	207	0.31679D 02	0.40000D 01
209	208	0.31679D 02	0.45000D 01
210	209	0.31918D 02	0.18241D 01
211	210	0.31918D 02	0.22500D 01
212	211	0.31918D 02	0.25000D 01
213	212	0.31918D 02	0.30000D 01
214	213	0.31918D 02	0.35000D 01
215	214	0.31918D 02	0.40000D 01
216	215	0.31918D 02	0.45000D 01
217	216	0.32037D 02	0.18125D 01
218	217	0.32037D 02	0.22500D 01
219	218	0.32156D 02	0.0
220	219	0.32156D 02	0.75000D 00
221	220	0.32156D 02	0.12500D 01
222	221	0.32156D 02	0.15000D 01
223	223	0.32156D 02	0.18109D 01
224	224	0.32156D 02	0.22500D 01
225	225	0.32156D 02	0.25000D 01
226	226	0.32156D 02	0.30000D 01
227	227	0.32156D 02	0.35000D 01
228	228	0.32156D 02	0.40000D 01
229	229	0.32156D 02	0.45000D 01
230	230	0.32291D 02	0.12500D 01
231	231	0.32291D 02	0.15000D 01
232	222	0.32291D 02	0.18033D 01
233	232	0.32291D 02	0.22500D 01
234	234	0.32426D 02	0.0
235	235	0.32426D 02	0.75000D 00
236	236	0.32426D 02	0.15000D 01
237	233	0.32426D 02	0.17959D 01
238	237	0.32426D 02	0.22500D 01
239	238	0.32426D 02	0.25000D 01
240	239	0.32694D 02	0.0
241	240	0.32694D 02	0.75000D 00
242	241	0.32694D 02	0.15000D 01
243	242	0.32694D 02	0.22500D 01
244	243	0.32694D 02	0.30000D 01
245	244	0.32694D 02	0.37500D 01
246	245	0.32694D 02	0.45000D 01
247	246	0.33232D 02	0.0
248	247	0.33232D 02	0.75000D 00
249	248	0.33232D 02	0.15000D 01
250	249	0.33232D 02	0.22500D 01
251	250	0.33232D 02	0.30000D 01

TABLE 4.0-I (Continued)

252	251	0.33232D 02	0.37500D 01
253	252	0.33232D 02	0.45000D 01
254	253	0.33770D 02	0.0
255	254	0.33770D 02	0.75000D 00
256	255	0.33770D 02	0.15000D 01
257	256	0.33770D 02	0.22500D 01
258	257	0.33770D 02	0.30000D 01
259	258	0.33770D 02	0.37500D 01
260	259	0.33770D 02	0.45000D 01
261	260	0.34307D 02	0.0
262	261	0.34307D 02	0.75000D 00
263	262	0.34307D 02	0.15000D 01
264	263	0.34307D 02	0.22500D 01
265	264	0.34307D 02	0.30000D 01
266	265	0.34307D 02	0.37500D 01
267	266	0.34307D 02	0.45000D 01
268	267	0.34845D 02	0.0
269	268	0.34845D 02	0.75000D 00
270	269	0.34845D 02	0.15000D 01
271	270	0.34845D 02	0.22500D 01
272	271	0.34845D 02	0.30000D 01
273	272	0.34845D 02	0.37500D 01
274	273	0.34845D 02	0.45000D 01
275	274	0.35382D 02	0.0
276	275	0.35382D 02	0.75000D 00
277	276	0.35382D 02	0.15000D 01
278	277	0.35382D 02	0.22500D 01
279	278	0.35382D 02	0.30000D 01
280	279	0.35382D 02	0.37500D 01
281	280	0.35382D 02	0.45000D 01

TABLE 4.0-II: ELEMENT NUMBERS AND CORRESPONDING NODE I.D. NUMBERS, NOMINAL CONFIGURATION

ELEMENT NO.	I.D.	NODE 1	NODE 2	NODE 3
1	1	1	20	2
2	2	2	21	3
3	3	3	22	4
4	4	4	23	5
5	5	5	24	6
6	6	6	25	7
7	7	7	26	8
8	8	8	27	9
9	9	9	28	10
10	10	10	29	11
11	11	11	30	12
12	12	12	31	13
13	13	13	32	14
14	14	14	33	15
15	15	15	34	16
16	16	16	35	17
17	17	17	36	18
18	18	18	37	19
19	19	21	2	20
20	20	22	3	21
21	21	23	4	22
22	22	24	5	23
23	23	25	6	24
24	24	26	7	25
25	25	27	8	26
26	26	28	9	27
27	27	29	10	28
28	28	30	11	29
29	29	31	12	30
30	30	32	13	31
31	31	33	14	32
32	32	34	15	33
33	33	35	16	34
34	34	36	17	35
35	35	37	18	36
36	36	38	19	37
37	37	20	39	21
38	38	21	40	22
39	39	22	41	23
40	40	23	42	24
41	41	24	43	25
42	42	25	44	26
43	43	26	45	27
44	44	27	46	28
45	45	28	47	29
46	46	29	48	30
47	47	30	49	31
48	48	31	50	32
49	49	32	51	33

TABLE 4.0-II (Continued)

50	50	33	52	34
51	51	34	53	35
52	52	35	54	36
53	53	36	55	37
54	54	37	56	38
55	55	40	21	39
56	56	41	22	40
57	57	42	23	41
58	58	43	24	42
59	59	44	25	43
60	60	45	26	44
61	61	46	27	45
62	62	47	28	46
63	63	48	29	47
64	64	49	30	48
65	65	50	31	49
66	66	51	32	50
67	67	52	33	51
68	68	53	34	52
69	69	54	35	53
70	70	55	36	54
71	71	56	37	55
72	72	57	38	56
73	73	39	58	40
74	74	40	59	41
75	75	41	60	42
76	76	42	61	43
77	77	43	62	44
78	78	44	63	45
79	79	45	64	46
80	80	46	65	47
81	81	47	66	48
82	82	48	67	49
83	83	49	68	50
84	84	50	69	51
85	85	51	70	52
86	86	52	71	53
87	87	53	72	54
88	88	54	73	55
89	89	55	74	56
90	90	56	75	57
91	91	59	40	58
92	92	60	41	59
93	93	61	42	60
94	94	62	43	61
95	95	63	44	62
96	96	64	45	63
97	97	65	46	64
98	98	66	47	65
99	99	67	48	66

TABLE 4.0-II (Continued)

100	100	68	49	67
101	101	69	50	68
102	102	70	51	69
103	103	71	52	70
104	104	72	53	71
105	105	73	54	72
106	106	74	55	73
107	107	75	56	74
108	108	76	57	75
109	109	58	77	59
110	110	59	78	60
111	111	60	79	61
112	112	61	80	62
113	113	62	81	63
114	114	63	82	64
115	115	64	83	65
116	116	65	84	66
117	117	66	85	67
118	118	67	86	68
119	119	68	87	69
120	120	69	88	70
121	121	70	89	71
122	122	71	90	72
123	123	72	91	73
124	124	73	92	74
125	125	74	93	75
126	126	75	94	76
127	127	78	59	77
128	128	79	60	78
129	129	80	61	79
130	130	81	62	80
131	131	82	63	81
132	132	83	64	82
133	133	84	65	83
134	134	85	66	84
135	135	86	67	85
136	136	87	68	86
137	137	88	69	87
138	138	89	70	88
139	139	90	71	89
140	140	91	72	90
141	141	92	73	91
142	142	93	74	92
143	143	94	75	93
144	144	95	76	94
145	145	77	96	78
146	146	78	97	79
147	147	79	98	80
148	148	80	99	81
149	149	81	100	82

TABLE 4.0-II (Continued)

150	150	82	101	83
151	151	83	102	84
152	152	84	103	85
153	153	85	104	86
154	154	86	105	87
155	155	87	106	88
156	156	88	107	89
157	157	89	108	90
158	158	90	109	91
159	159	91	110	92
160	160	92	111	93
161	161	93	112	94
162	162	94	113	95
163	163	97	78	96
164	164	98	79	97
165	165	99	80	98
166	166	100	81	99
167	167	101	82	100
168	168	102	83	101
169	169	103	84	102
170	170	104	85	103
171	171	105	86	104
172	172	106	87	105
173	173	107	88	106
174	174	108	89	107
175	175	109	90	108
176	176	110	91	109
177	177	111	92	110
178	178	112	93	111
179	179	113	94	112
180	180	114	95	113
181	181	96	115	97
182	182	97	116	98
183	183	98	117	99
184	184	99	118	100
185	185	100	119	101
186	186	101	120	102
187	187	102	121	103
188	188	103	122	104
189	189	104	123	105
190	190	105	124	106
191	191	106	125	107
192	192	107	126	108
193	193	108	127	109
194	194	109	128	110
195	195	110	129	111
196	196	111	130	112
197	197	112	131	113
198	198	113	132	114
199	199	116	97	115

TABLE 4.0-II (Continued)

200	200	117	98	116
201	201	118	99	117
202	202	119	100	118
203	203	120	101	119
204	204	121	102	120
205	205	122	103	121
206	206	123	104	122
207	207	124	105	123
208	208	125	106	124
209	209	126	107	125
210	210	127	108	126
211	211	128	109	127
212	212	129	110	128
213	213	130	111	129
214	214	131	112	130
215	215	132	113	131
216	216	133	114	132
217	217	115	136	116
218	218	116	137	117
219	219	117	138	118
220	220	118	139	119
221	221	119	140	120
222	222	120	141	121
223	223	121	142	122
224	224	123	122	134
225	225	124	123	135
226	226	124	145	125
227	227	125	146	126
228	228	126	147	127
229	229	127	148	128
230	230	128	149	129
231	231	129	150	130
232	232	130	151	131
233	233	131	152	132
234	234	132	153	133
235	235	137	116	136
236	236	138	117	137
237	237	139	118	138
238	238	140	119	139
239	239	141	120	140
240	240	142	121	141
241	241	143	122	142
242	242	122	143	134
243	243	144	123	134
244	244	123	144	135
245	245	145	124	135
246	246	146	125	145
247	247	147	126	146
248	248	148	127	147
249	249	149	128	148

TABLE 4.0-II (Continued)

250	250	150	129	149
251	251	151	130	150
252	252	152	131	151
253	253	153	132	152
254	254	154	133	153
255	255	144	155	145
256	256	145	156	146
257	257	146	157	147
258	258	147	158	148
259	259	148	162	149
260	260	163	150	149
261	261	150	163	151
262	262	164	152	151
263	263	152	164	153
264	264	165	154	153
265	265	156	145	155
266	266	157	146	156
267	267	158	147	157
268	268	162	148	158
269	269	162	163	149
270	270	163	164	151
271	271	164	165	153
272	272	155	159	156
273	273	156	160	157
274	274	157	161	158
275	275	160	156	159
276	276	161	157	160
277	277	161	162	158
278	278	159	166	160
279	279	160	167	161
280	280	161	168	162
281	281	162	169	163
282	282	163	170	164
283	283	164	171	165
284	284	167	160	166
285	285	168	161	167
286	286	169	162	168
287	287	170	163	169
288	288	171	164	170
289	289	172	165	171
290	290	166	173	167
291	291	174	168	167
292	292	168	174	169
293	293	169	175	170
294	294	170	176	171
295	295	171	177	172
296	296	173	174	167
297	297	175	169	174
298	298	176	170	175
299	299	177	171	176

TABLE 4.0-II (Continued)

300	300	178	172	177
301	301	173	179	174
302	302	174	180	175
303	303	175	181	176
304	304	176	182	177
305	305	177	183	178
306	306	180	174	179
307	307	181	175	180
308	308	182	176	181
309	309	183	177	182
310	310	184	178	183
311	311	179	185	180
312	312	180	186	181
313	313	181	187	182
314	314	182	188	183
315	315	183	189	184
316	316	186	180	185
317	317	187	181	186
318	318	188	182	187
319	319	189	183	188
320	320	190	184	189
321	321	185	191	186
322	322	186	192	187
323	323	187	193	188
324	324	188	194	189
325	325	189	195	190
326	326	192	186	191
327	327	193	187	192
328	328	194	188	193
329	329	195	189	194
330	330	196	190	195
331	331	191	197	192
332	332	192	198	193
333	333	193	199	194
334	334	194	200	195
335	335	195	201	196
336	336	198	192	197
337	337	199	193	198
338	338	200	194	199
339	339	201	195	200
340	340	202	196	201
341	341	197	203	198
342	342	198	204	199
343	343	199	205	200
344	344	200	206	201
345	345	201	207	202
346	346	204	198	203
347	347	205	199	204
348	348	206	200	205
349	349	207	201	206

TABLE 4.0-II (Continued)

350	350	208	202	207
351	351	204	203	210
352	352	204	211	205
353	353	205	212	206
354	354	206	213	207
355	355	207	214	208
356	356	203	209	210
357	357	211	204	210
358	358	212	205	211
359	359	213	206	212
360	360	214	207	213
361	361	215	208	214
362	362	209	216	210
363	363	210	217	211
364	364	211	225	212
365	365	212	226	213
366	366	213	227	214
367	367	214	228	215
368	368	217	210	216
369	369	225	211	217
370	370	226	212	225
371	371	227	213	226
372	372	228	214	227
373	373	229	215	228
374	374	223	224	216
375	375	217	216	224
376	376	217	224	225
377	377	218	234	219
378	378	230	220	219
379	379	220	230	221
380	380	223	221	222
381	381	224	223	222
382	382	231	222	221
383	383	222	232	224
384	384	225	238	226
385	385	226	243	227
386	386	228	227	244
387	387	245	229	228
388	388	235	219	234
389	389	219	235	230
390	390	231	221	230
391	391	222	231	236
392	392	232	222	237
393	393	236	233	222
394	394	233	237	222
395	395	243	226	238
396	396	243	244	227
397	397	244	245	228
398	398	235	236	230
399	399	236	231	230

TABLE 4.0-II (Continued)

400	400	225	224	232
401	401	238	225	232
402	402	234	239	235
403	403	235	240	236
404	404	233	236	241
405	405	237	242	238
406	406	240	235	239
407	407	241	236	240
408	408	241	242	233
409	409	242	243	238
410	410	239	246	240
411	411	240	247	241
412	412	241	248	242
413	413	242	249	243
414	414	243	250	244
415	415	244	251	245
416	416	247	240	246
417	417	248	241	247
418	418	249	242	248
419	419	250	243	249
420	420	251	244	250
421	421	252	245	251
422	422	246	253	247
423	423	247	254	248
424	424	248	255	249
425	425	249	256	250
426	426	250	257	251
427	427	251	258	252
428	428	254	247	253
429	429	255	248	254
430	430	256	249	255
431	431	257	250	256
432	432	258	251	257
433	433	259	252	258
434	434	253	260	254
435	435	254	261	255
436	436	255	262	256
437	437	256	263	257
438	438	257	264	258
439	439	258	265	259
440	440	261	254	260
441	441	262	255	261
442	442	263	256	262
443	443	264	257	263
444	444	265	258	264
445	445	266	259	265
446	446	260	267	261
447	447	261	268	262
448	448	262	269	263
449	449	263	270	264

TABLE 4.0-II (Continued)

450	450	264	271	265
451	451	265	272	266
452	452	268	261	267
453	453	269	262	268
454	454	270	263	269
455	455	271	264	270
456	456	272	265	271
457	457	273	266	272
458	458	267	274	268
459	459	268	275	269
460	460	269	276	270
461	461	270	277	271
462	462	271	278	272
463	463	272	279	273
464	464	275	268	274
465	465	276	269	275
466	466	277	270	276
467	467	278	271	277
468	468	279	272	278
469	469	280	273	279
470	470	237	238	232
471	471	143	144	134
472	472	144	145	135
473	473	237	233	242
474	474	144	143	155
475	475	155	281	159
476	476	281	155	143
477	477	143	142	281

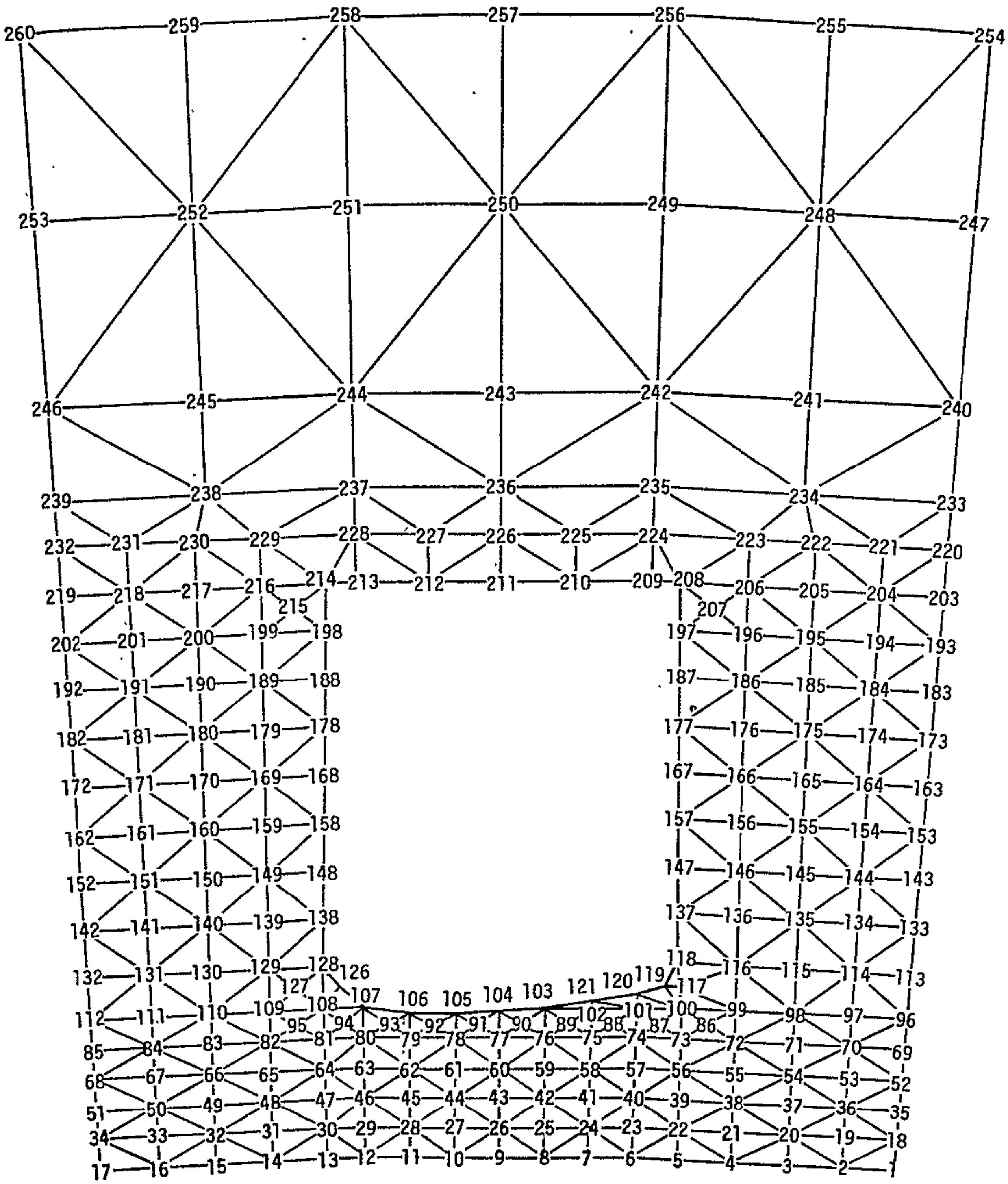


FIGURE 4.0-2: CHANNEL 35 FINITE-ELEMENT MODEL SHOWING NODE I.D. NUMBERS

TABLE 4.0-III: NODE NUMBERS AND COORDINATES, CHANNEL 35 CONFIGURATION

** NODE ** NO.	I.D.	R	THETA
1	1	0.288800D 02	-0.450000D 01
2	2	0.288800D 02	-0.390710D 01
3	3	0.288800D 02	-0.331420D 01
4	4	0.288800D 02	-0.272130D 01
5	5	0.288800D 02	-0.212840D 01
6	6	0.288800D 02	-0.159630D 01
7	7	0.288800D 02	-0.106420D 01
8	8	0.288800D 02	-0.532100D 00
9	9	0.288800D 02	0.0
10	10	0.288800D 02	0.532100D 00
11	11	0.288800D 02	0.106420D 01
12	12	0.288800D 02	0.159630D 01
13	13	0.288800D 02	0.212840D 01
14	14	0.288800D 02	0.272130D 01
15	15	0.288800D 02	0.331420D 01
16	16	0.288800D 02	0.390710D 01
17	17	0.288800D 02	0.450000D 01
18	18	0.290580D 02	-0.450000D 01
19	19	0.290580D 02	-0.390710D 01
20	20	0.290580D 02	-0.331420D 01
21	21	0.290580D 02	-0.272130D 01
22	22	0.290580D 02	-0.212840D 01
23	23	0.290580D 02	-0.159630D 01
24	24	0.290580D 02	-0.106420D 01
25	25	0.290580D 02	-0.532100D 00
26	26	0.290580D 02	0.0
27	27	0.290580D 02	0.532100D 00
28	28	0.290580D 02	0.106420D 01
29	29	0.290580D 02	0.159630D 01
30	30	0.290580D 02	0.212840D 01
31	31	0.290580D 02	0.272130D 01
32	32	0.290580D 02	0.331420D 01
33	33	0.290580D 02	0.390710D 01
34	34	0.290580D 02	0.450000D 01
35	35	0.292350D 02	-0.450000D 01
36	36	0.292350D 02	-0.390710D 01
37	37	0.292350D 02	-0.331420D 01
38	38	0.292350D 02	-0.272130D 01
39	39	0.292350D 02	-0.212840D 01
40	40	0.292350D 02	-0.159630D 01
41	41	0.292350D 02	-0.106420D 01
42	42	0.292350D 02	-0.532100D 00
43	43	0.292350D 02	0.0
44	44	0.292350D 02	0.532100D 00
45	45	0.292350D 02	0.106420D 01
46	46	0.292350D 02	0.159630D 01
47	47	0.292350D 02	0.212840D 01
48	48	0.292350D 02	0.272130D 01
49	49	0.292350D 02	0.331420D 01
50	50	0.292350D 02	0.390710D 01

TABLE 4.0-III (Continued)

51	51	0.29235D 02	0.45000D 01
52	52	0.29413D 02	-0.45000D 01
53	53	0.29413D 02	-0.39071D 01
54	54	0.29413D 02	-0.33142D 01
55	55	0.29413D 02	-0.27213D 01
56	56	0.29413D 02	-0.21284D 01
57	57	0.29413D 02	-0.15963D 01
58	58	0.29413D 02	-0.10642D 01
59	59	0.29413D 02	-0.53210D 00
60	60	0.29413D 02	0.0
61	61	0.29413D 02	0.53210D 00
62	62	0.29413D 02	0.10642D 01
63	63	0.29413D 02	0.15963D 01
64	64	0.29413D 02	0.21284D 01
65	65	0.29413D 02	0.27213D 01
66	66	0.29413D 02	0.33142D 01
67	67	0.29413D 02	0.39071D 01
68	68	0.29413D 02	0.45000D 01
69	69	0.29591D 02	-0.45000D 01
70	70	0.29591D 02	-0.39071D 01
71	71	0.29591D 02	-0.33142D 01
72	72	0.29591D 02	-0.27213D 01
73	73	0.29591D 02	-0.21284D 01
74	74	0.29591D 02	-0.15963D 01
75	75	0.29591D 02	-0.10642D 01
76	76	0.29591D 02	-0.53210D 00
77	77	0.29591D 02	0.0
78	78	0.29591D 02	0.53210D 00
79	79	0.29591D 02	0.10642D 01
80	80	0.29591D 02	0.15963D 01
81	81	0.29591D 02	0.21284D 01
82	82	0.29591D 02	0.27213D 01
83	83	0.29591D 02	0.33142D 01
84	84	0.29591D 02	0.39071D 01
85	85	0.29591D 02	0.45000D 01
86	86	0.29677D 02	-0.24248D 01
87	87	0.29677D 02	-0.18624D 01
88	88	0.29677D 02	-0.13302D 01
89	89	0.29677D 02	-0.78920D 00
90	90	0.29677D 02	-0.26600D 00
91	91	0.29677D 02	0.26600D 00
92	92	0.29677D 02	0.78920D 00
93	93	0.29677D 02	0.13302D 01
94	94	0.29677D 02	0.18624D 01
95	95	0.29677D 02	0.24248D 01
96	96	0.29764D 02	-0.45000D 01
97	97	0.29764D 02	-0.39071D 01
98	98	0.29764D 02	-0.33142D 01
99	99	0.29764D 02	-0.27213D 01
100	100	0.29801D 02	-0.20277D 01
101	101	0.29793D 02	-0.15246D 01
102	102	0.29787D 02	-0.10164D 01
103	103	0.29799D 02	-0.50820D 00

TABLE 4.0-III (Continued)

104	104	0.29788D	02	0.0	
105	105	0.29782D	02	0.50760D	00
106	106	0.29782D	02	0.10153D	01
107	107	0.29816D	02	0.15218D	01
108	108	0.29824D	02	0.20288D	01
109	109	0.29764D	02	0.27213D	01
110	110	0.29764D	02	0.33142D	01
111	111	0.29764D	02	0.39071D	01
112	112	0.29764D	02	0.45000D	01
113	113	0.30040D	02	-0.45000D	01
114	114	0.30040D	02	-0.39071D	01
115	115	0.30040D	02	-0.33142D	01
116	116	0.30040D	02	-0.27213D	01
117	117	0.29910D	02	-0.20202D	01
118	118	0.30057D	02	-0.20105D	01
119	119	0.29907D	02	-0.18375D	01
120	120	0.29853D	02	-0.15218D	01
121	121	0.29820D	02	-0.10153D	01
122	126	0.29898D	02	0.18633D	01
123	127	0.29884D	02	0.24248D	01
124	128	0.30057D	02	0.20105D	01
125	129	0.30040D	02	0.27213D	01
126	130	0.30040D	02	0.33142D	01
127	131	0.30040D	02	0.39071D	01
128	132	0.30040D	02	0.45000D	01
129	133	0.30308D	02	-0.45000D	01
130	134	0.30308D	02	-0.39071D	01
131	135	0.30308D	02	-0.33142D	01
132	136	0.30308D	02	-0.27213D	01
133	137	0.30324D	02	-0.19927D	01
134	138	0.30324D	02	0.19927D	01
135	139	0.30308D	02	0.27213D	01
136	140	0.30308D	02	0.33142D	01
137	141	0.30308D	02	0.39071D	01
138	142	0.30308D	02	0.45000D	01
139	143	0.30574D	02	-0.45000D	01
140	144	0.30574D	02	-0.39071D	01
141	145	0.30574D	02	-0.33142D	01
142	146	0.30574D	02	-0.27213D	01
143	147	0.30591D	02	-0.19756D	01
144	148	0.30591D	02	0.19756D	01
145	149	0.30574D	02	0.27213D	01
146	150	0.30574D	02	0.33142D	01
147	151	0.30574D	02	0.39071D	01
148	152	0.30574D	02	0.45000D	01
149	153	0.30841D	02	-0.45000D	01
150	154	0.30841D	02	-0.39071D	01
151	155	0.30841D	02	-0.33142D	01
152	156	0.30841D	02	-0.27213D	01
153	157	0.30858D	02	-0.19584D	01
154	158	0.30858D	02	0.19584D	01
155	159	0.30841D	02	0.27213D	01
156	160	0.30841D	02	0.33142D	01

TABLE 4.0-III (Continued)

157	161	0.30841D 02	0.39071D 01
158	162	0.30841D 02	0.45000D 01
159	163	0.31108D 02	-0.45000D 01
160	164	0.31108D 02	-0.39071D 01
161	165	0.31108D 02	-0.33142D 01
162	166	0.31108D 02	-0.27213D 01
163	167	0.31126D 02	-0.19417D 01
164	168	0.31126D 02	0.19417D 01
165	169	0.31108D 02	0.27213D 01
166	170	0.31108D 02	0.33142D 01
167	171	0.31108D 02	0.39071D 01
168	172	0.31108D 02	0.45000D 01
169	173	0.31375D 02	-0.45000D 01
170	174	0.31375D 02	-0.39071D 01
171	175	0.31375D 02	-0.33142D 01
172	176	0.31375D 02	-0.27213D 01
173	177	0.31393D 02	-0.19251D 01
174	178	0.31393D 02	0.19251D 01
175	179	0.31375D 02	0.27213D 01
176	180	0.31375D 02	0.33142D 01
177	181	0.31375D 02	0.39071D 01
178	182	0.31375D 02	0.45000D 01
179	183	0.31642D 02	-0.45000D 01
180	184	0.31642D 02	-0.39071D 01
181	185	0.31642D 02	-0.33142D 01
182	186	0.31642D 02	-0.27213D 01
183	187	0.31660D 02	-0.18982D 01
184	188	0.31660D 02	0.18982D 01
185	189	0.31642D 02	0.27213D 01
186	190	0.31642D 02	0.33142D 01
187	191	0.31642D 02	0.39071D 01
188	192	0.31642D 02	0.45000D 01
189	193	0.31909D 02	-0.45000D 01
190	194	0.31909D 02	-0.39071D 01
191	195	0.31909D 02	-0.33142D 01
192	196	0.31909D 02	-0.27213D 01
193	197	0.31926D 02	-0.18925D 01
194	198	0.31926D 02	0.18925D 01
195	199	0.31909D 02	0.27213D 01
196	200	0.31909D 02	0.33142D 01
197	201	0.31909D 02	0.39071D 01
198	202	0.31909D 02	0.45000D 01
199	203	0.32175D 02	-0.45000D 01
200	204	0.32175D 02	-0.39071D 01
201	205	0.32175D 02	-0.33142D 01
202	206	0.32175D 02	-0.27213D 01
203	207	0.32042D 02	-0.24248D 01
204	208	0.32193D 02	-0.18770D 01
205	209	0.32193D 02	-0.15000D 01
206	210	0.32193D 02	-0.75000D 00
207	211	0.32193D 02	0.0
208	212	0.32193D 02	0.75000D 00
209	213	0.32193D 02	0.15000D 01

TABLE 4.0-III (Continued)

210	214	0.32193D	02	0.18770D	01
211	215	0.32042D	02	0.24248D	01
212	216	0.32175D	02	0.27213D	01
213	217	0.32175D	02	0.33142D	01
214	218	0.32175D	02	0.39071D	01
215	219	0.32175D	02	0.45000D	01
216	220	0.32426D	02	-0.45000D	01
217	221	0.32426D	02	-0.39071D	01
218	222	0.32426D	02	-0.33142D	01
219	223	0.32426D	02	-0.27213D	01
220	224	0.32426D	02	-0.15000D	01
221	225	0.32426D	02	-0.75000D	00
222	226	0.32426D	02	0.0	
223	227	0.32426D	02	0.75000D	00
224	228	0.32426D	02	0.15000D	01
225	229	0.32426D	02	0.27213D	01
226	230	0.32426D	02	0.33142D	01
227	231	0.32426D	02	0.39071D	01
228	232	0.32426D	02	0.45000D	01
229	233	0.32694D	02	-0.45000D	01
230	234	0.32694D	02	-0.30000D	01
231	235	0.32694D	02	-0.15000D	01
232	236	0.32694D	02	0.0	
233	237	0.32694D	02	0.15000D	01
234	238	0.32694D	02	0.30000D	01
235	239	0.32694D	02	0.45000D	01
236	240	0.33232D	02	-0.45000D	01
237	241	0.33232D	02	-0.30000D	01
238	242	0.33232D	02	-0.15000D	01
239	243	0.33232D	02	0.0	
240	244	0.33232D	02	0.15000D	01
241	245	0.33232D	02	0.30000D	01
242	246	0.33232D	02	0.45000D	01
243	247	0.34307D	02	-0.45000D	01
244	248	0.34307D	02	-0.30000D	01
245	249	0.34307D	02	-0.15000D	01
246	250	0.34307D	02	0.0	
247	251	0.34307D	02	0.15000D	01
248	252	0.34307D	02	0.30000D	01
249	253	0.34307D	02	0.45000D	01
250	254	0.35382D	02	-0.45000D	01
251	255	0.35382D	02	-0.30000D	01
252	256	0.35382D	02	-0.15000D	01
253	257	0.35382D	02	0.0	
254	258	0.35382D	02	0.15000D	01
255	259	0.35382D	02	0.30000D	01
256	260	0.35382D	02	0.45000D	01

TABLE 4.0-IV: ELEMENT NUMBERS AND CORRESPONDING NODE I.D. NUMBERS, CHANNEL 35 CONFIGURATION

ELEMENT NO.	I.D.	NODE 1	NODE 2	NODE 3
1	1	2	1	18
2	2	18	19	2
3	3	19	20	2
4	4	3	2	20
5	5	4	3	20
6	6	20	21	4
7	7	21	22	4
8	8	5	4	22
9	9	6	5	22
10	10	22	23	6
11	11	23	24	6
12	12	7	6	24
13	13	8	7	24
14	14	24	25	8
15	15	25	26	8
16	16	9	8	26
17	17	10	9	26
18	18	26	27	10
19	19	27	28	10
20	20	11	10	28
21	21	12	11	28
22	22	28	29	12
23	23	29	30	12
24	24	13	12	30
25	25	14	13	30
26	26	30	31	14
27	27	31	32	14
28	28	15	14	32
29	29	16	15	32
30	30	32	33	16
31	31	33	34	16
32	32	17	16	34
33	33	35	36	18
34	34	19	18	36
35	35	20	19	36
36	36	36	37	20
37	37	37	38	20
38	38	21	20	38
39	39	22	21	38
40	40	38	39	22
41	41	39	40	22
42	42	23	22	40
43	43	24	23	40
44	44	40	41	24
45	45	41	42	24
46	46	25	24	42
47	47	26	25	42
48	48	42	43	26
49	49	43	44	26
50	50	27	26	44
51	51	28	27	44

TABLE 4.0-IV (Continued)

52	52	44	45	28
53	53	45	46	28
54	54	29	28	46
55	55	30	29	46
56	56	46	47	30
57	57	47	48	30
58	58	31	30	48
59	59	32	31	48
60	60	48	49	32
61	61	49	50	32
62	62	33	32	50
63	63	34	33	50
64	64	50	51	34
65	65	36	35	52
66	66	52	53	36
67	67	53	54	36
68	68	37	36	54
69	69	38	37	54
70	70	54	55	38
71	71	55	56	38
72	72	39	38	56
73	73	40	39	56
74	74	56	57	40
75	75	57	58	40
76	76	41	40	58
77	77	42	41	58
78	78	58	59	42
79	79	59	60	42
80	80	43	42	60
81	81	44	43	60
82	82	60	61	44
83	83	61	62	44
84	84	45	44	62
85	85	46	45	62
86	86	62	63	46
87	87	63	64	46
88	88	47	46	64
89	89	48	47	64
90	90	64	65	48
91	91	65	66	48
92	92	49	48	66
93	93	50	49	66
94	94	66	67	50
95	95	67	68	50
96	96	51	50	68
97	97	69	70	52
98	98	53	52	70
99	99	54	53	70
100	100	70	71	54
101	101	71	72	54
102	102	55	54	72
103	103	56	55	72
104	104	72	73	56

TABLE 4.0-IV (Continued)

105	105	73	74	56
106	106	57	56	74
107	107	58	57	74
108	108	74	75	58
109	109	75	76	58
110	110	59	58	76
111	111	60	59	76
112	112	76	77	60
113	113	77	78	60
114	114	61	60	78
115	115	62	61	78
116	116	78	79	62
117	117	79	80	62
118	118	63	62	80
119	119	64	63	80
120	120	80	81	64
121	121	81	82	64
122	122	65	64	82
123	123	66	65	82
124	124	82	83	66
125	125	83	84	66
126	126	67	66	84
127	127	68	67	84
128	128	84	85	68
129	129	70	69	96
130	130	96	97	70
131	131	97	98	70
132	132	71	70	98
133	133	72	71	98
134	134	98	99	72
135	135	72	99	86
136	136	99	100	86
137	137	73	72	86
138	138	100	73	86
139	139	73	100	87
140	140	100	101	87
141	141	74	73	87
142	142	101	74	87
143	143	74	101	88
144	144	101	102	88
145	145	75	74	88
146	146	102	75	88
147	147	75	102	89
148	148	102	103	89
149	149	76	75	89
150	150	103	76	89
151	151	76	103	90
152	152	103	104	90
153	153	77	76	90
154	154	104	77	90
155	155	77	104	91
156	156	104	105	91
157	157	78	77	91

TABLE 4.0-IV (Continued)

158	158	105	78	91
159	159	78	105	92
160	160	105	106	92
161	161	79	78	92
162	162	106	79	92
163	163	79	106	93
164	164	106	107	93
165	165	80	79	93
166	166	107	80	93
167	167	80	107	94
168	168	107	108	94
169	169	81	80	94
170	170	108	81	94
171	171	81	108	95
172	172	108	109	95
173	173	82	81	95
174	174	109	82	95
175	175	109	110	82
176	176	83	82	110
177	177	84	83	110
178	178	110	111	84
179	179	111	112	84
180	180	85	84	112
181	181	113	114	96
182	182	97	96	114
183	183	98	97	114
184	184	114	115	98
185	185	115	116	98
186	186	99	98	116
187	187	99	116	117
188	188	116	118	117
189	189	100	99	117
190	190	119	117	118
191	191	117	119	100
192	192	119	120	100
193	193	101	100	120
194	194	120	121	101
195	195	102	101	121
196	196	103	102	121
197	204	108	107	126
198	205	128	108	126
199	206	108	128	127
200	207	128	129	127
201	208	109	108	127
202	209	129	109	127
203	210	110	109	129
204	211	129	130	110
205	212	130	131	110
206	213	111	110	131
207	214	112	111	131
208	215	131	132	112
209	216	114	113	133
210	217	133	134	114

TABLE 4.0-IV (Continued)

211	218	134	135	114
212	219	115	114	135
213	220	116	115	135
214	221	135	136	116
215	222	136	137	116
216	223	118	116	137
217	224	129	128	138
218	225	138	139	129
219	226	139	140	129
220	227	130	129	140
221	228	131	130	140
222	229	140	141	131
223	230	141	142	131
224	231	132	131	142
225	232	143	144	133
226	233	134	133	144
227	234	135	134	144
228	235	144	145	135
229	236	145	146	135
230	237	136	135	146
231	238	137	136	146
232	239	146	147	136
233	240	148	149	138
234	241	139	138	149
235	242	140	139	149
236	243	149	150	140
237	244	150	151	140
238	245	141	140	151
239	246	142	141	151
240	247	151	152	142
241	248	144	143	153
242	249	153	154	144
243	250	154	155	144
244	251	145	144	155
245	252	146	145	155
246	253	155	156	146
247	254	156	157	146
248	255	147	146	157
249	256	149	148	158
250	257	158	159	149
251	258	159	160	149
252	259	150	149	160
253	260	151	150	160
254	261	160	161	151
255	262	161	162	151
256	263	152	151	162
257	264	163	164	153
258	265	154	153	164
259	266	155	154	164
260	267	164	165	155
261	268	165	166	155
262	269	156	155	166
263	270	157	156	166

TABLE 4.0-IV (Continued)

264	271	166	167	156
265	272	168	169	158
266	273	159	158	169
267	274	160	159	169
268	275	169	170	160
269	276	170	171	160
270	277	161	160	171
271	278	162	161	171
272	279	171	172	162
273	280	164	163	173
274	281	173	174	164
275	282	174	175	164
276	283	165	164	175
277	284	166	165	175
278	285	175	176	166
279	286	176	177	166
280	287	167	166	177
281	288	169	168	178
282	289	178	179	169
283	290	179	180	169
284	291	170	169	180
285	292	171	170	180
286	293	180	181	171
287	294	181	182	171
288	295	172	171	182
289	296	183	184	173
290	297	174	173	184
291	298	175	174	184
292	299	184	185	175
293	300	185	186	175
294	301	176	175	186
295	302	177	176	186
296	303	186	187	177
297	304	188	189	178
298	305	179	178	189
299	306	180	179	189
300	307	189	190	180
301	308	190	191	180
302	309	181	180	191
303	310	182	181	191
304	311	191	192	182
305	312	184	183	193
306	313	193	194	184
307	314	194	195	185
308	315	185	184	195
309	316	186	185	195
310	317	195	196	186
311	318	196	197	186
312	319	187	186	197
313	320	189	188	198
314	321	198	199	189
315	322	199	200	189
316	323	190	189	200

TABLE 4.0-IV (Continued)

317	324	191	190	200
318	325	200	201	191
319	326	201	202	191
320	327	192	191	202
321	328	203	204	193
322	329	194	193	204
323	330	195	194	204
324	331	204	205	195
325	332	205	206	195
326	333	196	195	206
327	334	196	206	207
328	335	206	208	207
329	336	197	196	207
330	337	208	197	207
331	338	198	214	215
332	339	214	216	215
333	340	199	198	215
334	341	216	199	215
335	342	200	199	216
336	343	216	217	200
337	344	217	218	200
338	345	201	200	218
339	346	202	201	218
340	347	218	219	202
341	348	204	203	220
342	349	220	221	204
343	350	221	222	204
344	351	205	204	222
345	352	206	205	222
346	353	222	223	206
347	354	208	206	223
348	355	223	224	208
349	356	209	208	224
350	357	210	209	224
351	358	224	225	210
352	359	225	226	210
353	360	211	210	226
354	361	212	211	226
355	362	226	227	212
356	363	227	228	212
357	364	213	212	228
358	365	214	213	228
359	366	228	229	214
360	367	216	214	229
361	368	229	230	216
362	369	217	216	230
363	370	218	217	230
364	371	230	231	218
365	372	231	232	218
366	373	219	218	232
367	374	221	220	233
368	375	233	234	221
369	376	222	221	234

TABLE 4.0-IV (Continued)

370	377	223	222	234
371	378	234	235	223
372	379	224	223	235
373	380	225	224	235
374	381	235	236	225
375	382	226	225	236
376	383	227	226	236
377	384	236	237	227
378	385	228	227	237
379	386	229	228	237
380	387	237	238	229
381	388	230	229	238
382	389	231	230	238
383	390	238	239	231
384	391	232	231	239
385	392	234	233	240
386	393	240	241	234
387	394	241	242	234
388	395	235	234	242
389	396	236	235	242
390	397	242	243	236
391	398	243	244	236
392	399	237	236	244
393	400	238	237	244
394	401	244	245	238
395	402	245	246	238
396	403	239	238	246
397	404	247	248	240
398	405	241	240	248
399	406	242	241	248
400	407	248	249	242
401	408	249	250	242
402	409	243	242	250
403	410	244	243	250
404	411	250	251	244
405	412	251	252	244
406	413	245	244	252
407	414	246	245	252
408	415	252	253	246
409	416	248	247	254
410	417	254	255	248
411	418	255	256	248
412	419	249	248	256
413	420	250	249	256
414	421	256	257	250
415	422	257	258	250
416	423	251	250	258
417	424	252	251	258
418	425	258	259	252
419	426	259	260	252
420	427	253	252	260

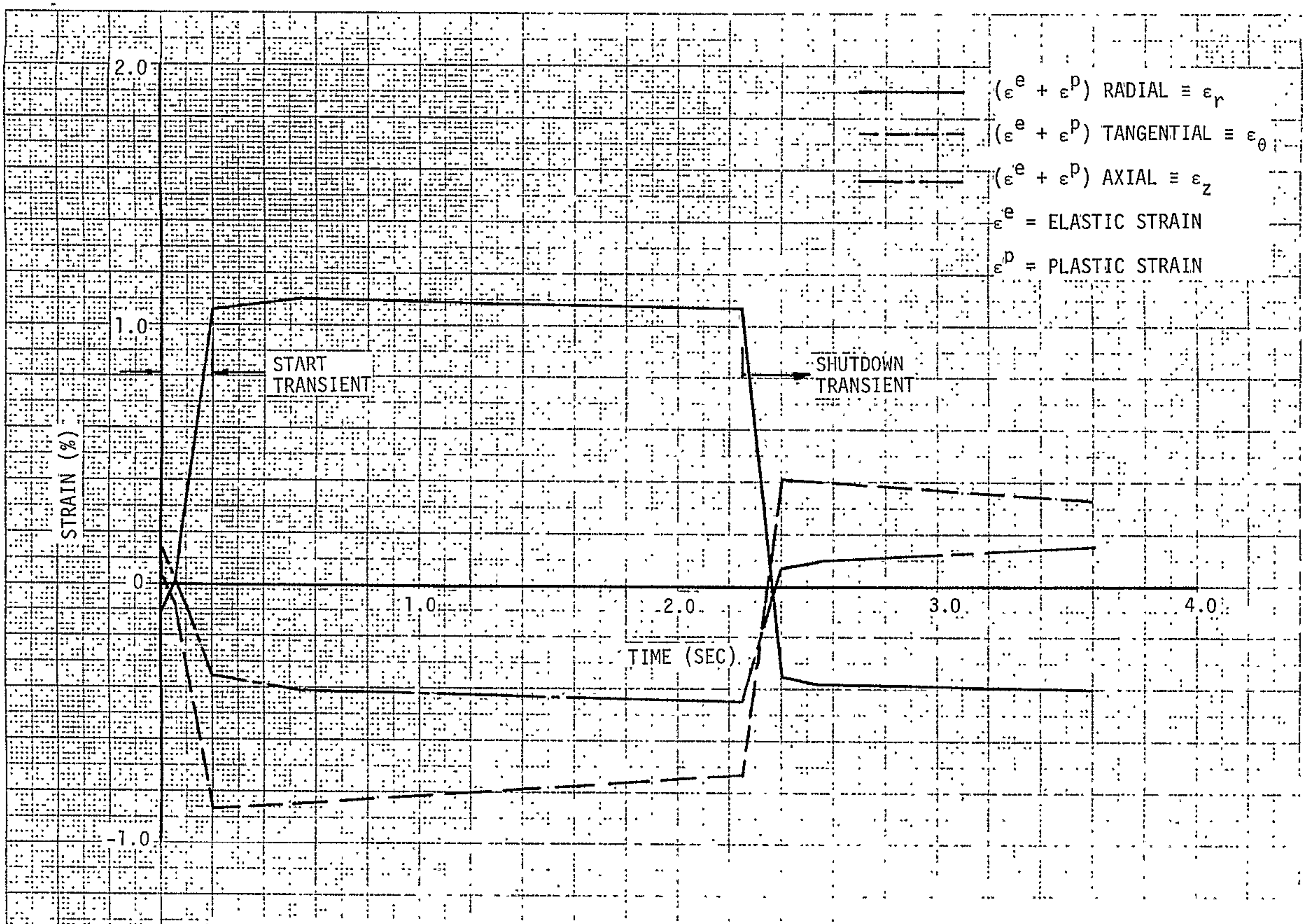


FIGURE 5.1-1: STRAIN VS. TIME, ELEMENT #238, NOMINAL CONFIGURATION 3.3K THRUST CHAMBER

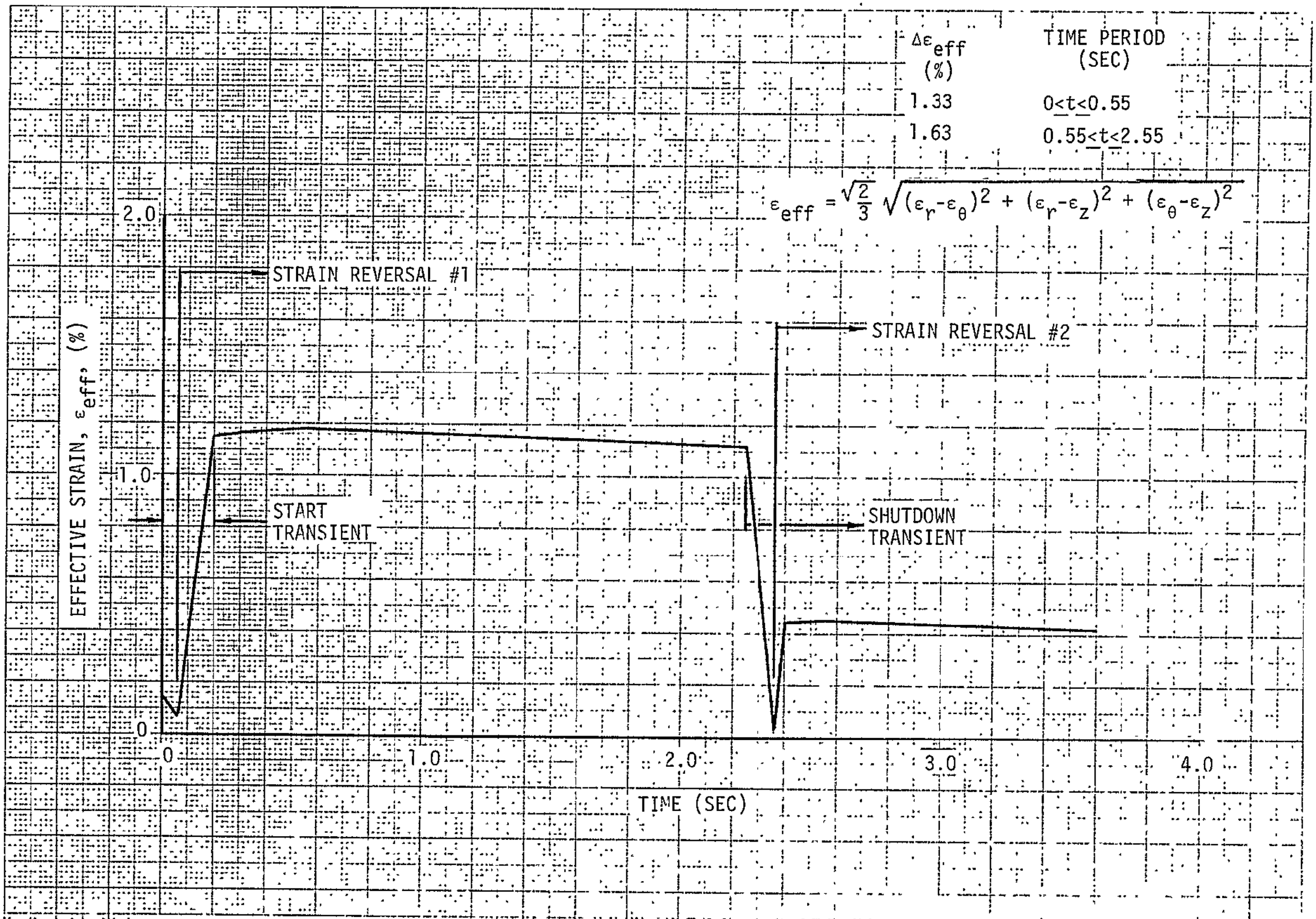


FIGURE 5.1-2: EFFECTIVE STRAIN VS. TIME, ELEMENT #238, NOMINAL CONFIGURATION 3.3K THRUST CHAMBER

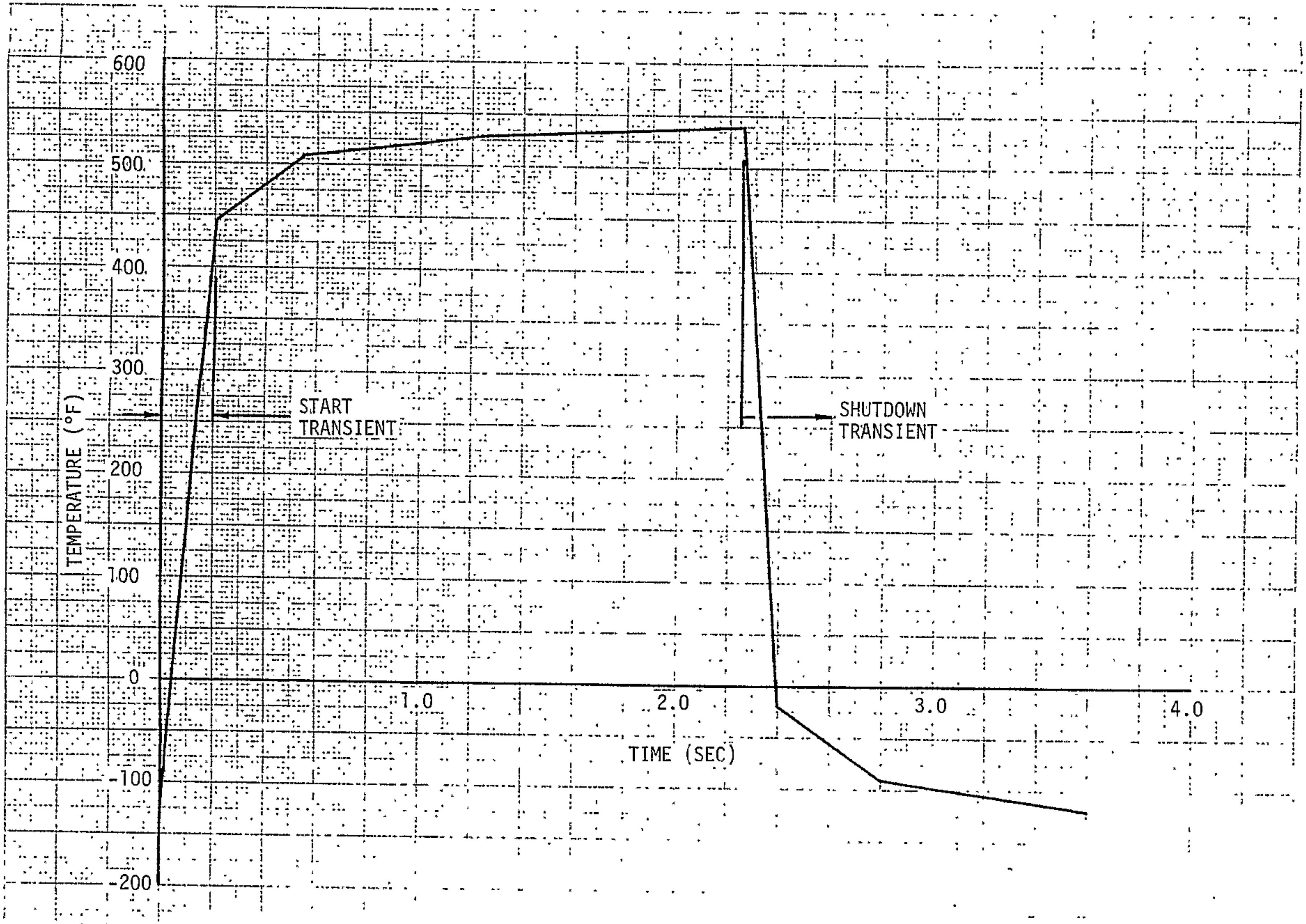


FIGURE 5.1-3: TEMPERATURE VS. TIME, ELEMENT #238, NOMINAL CONFIGURATION 3.3K THRUST CHAMBER

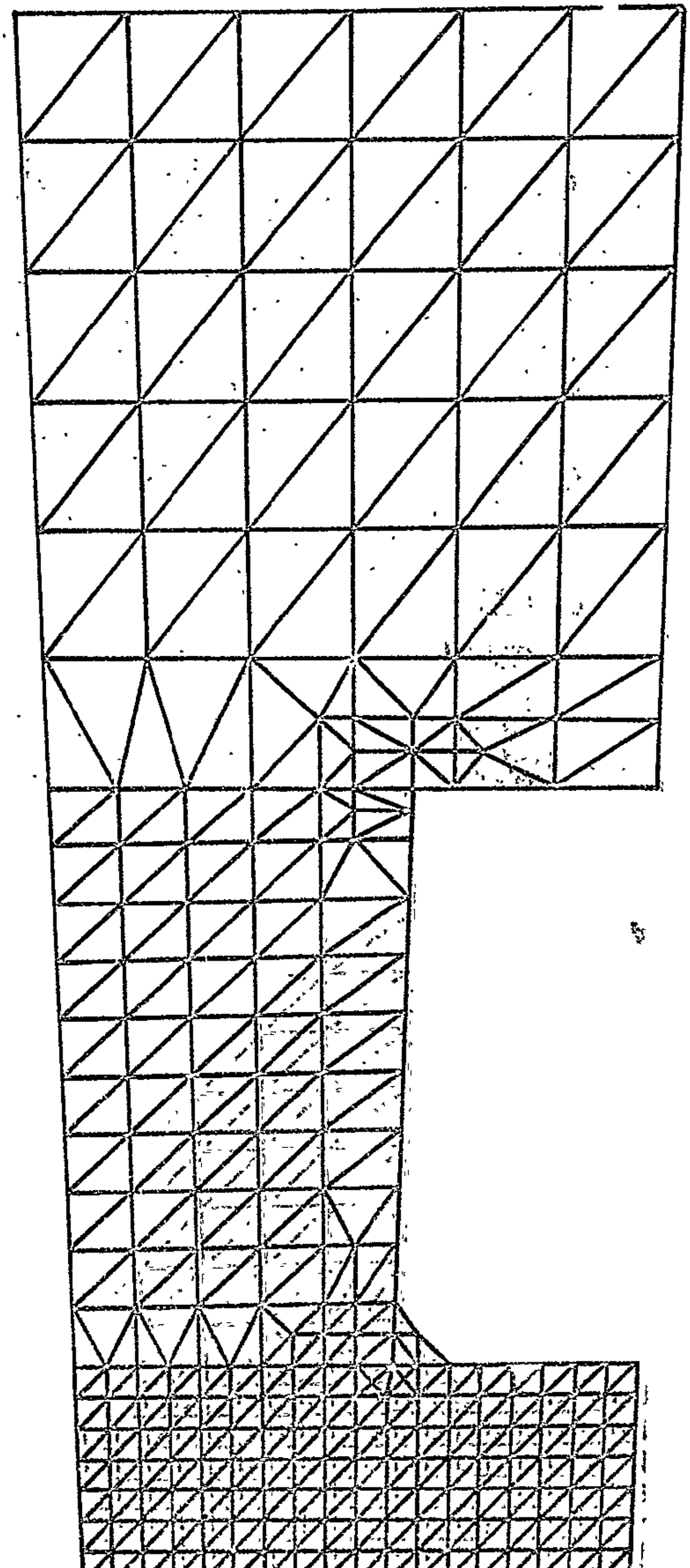


FIGURE 5.1-4: CRITICAL REGION, NOMINAL CONFIGURATION

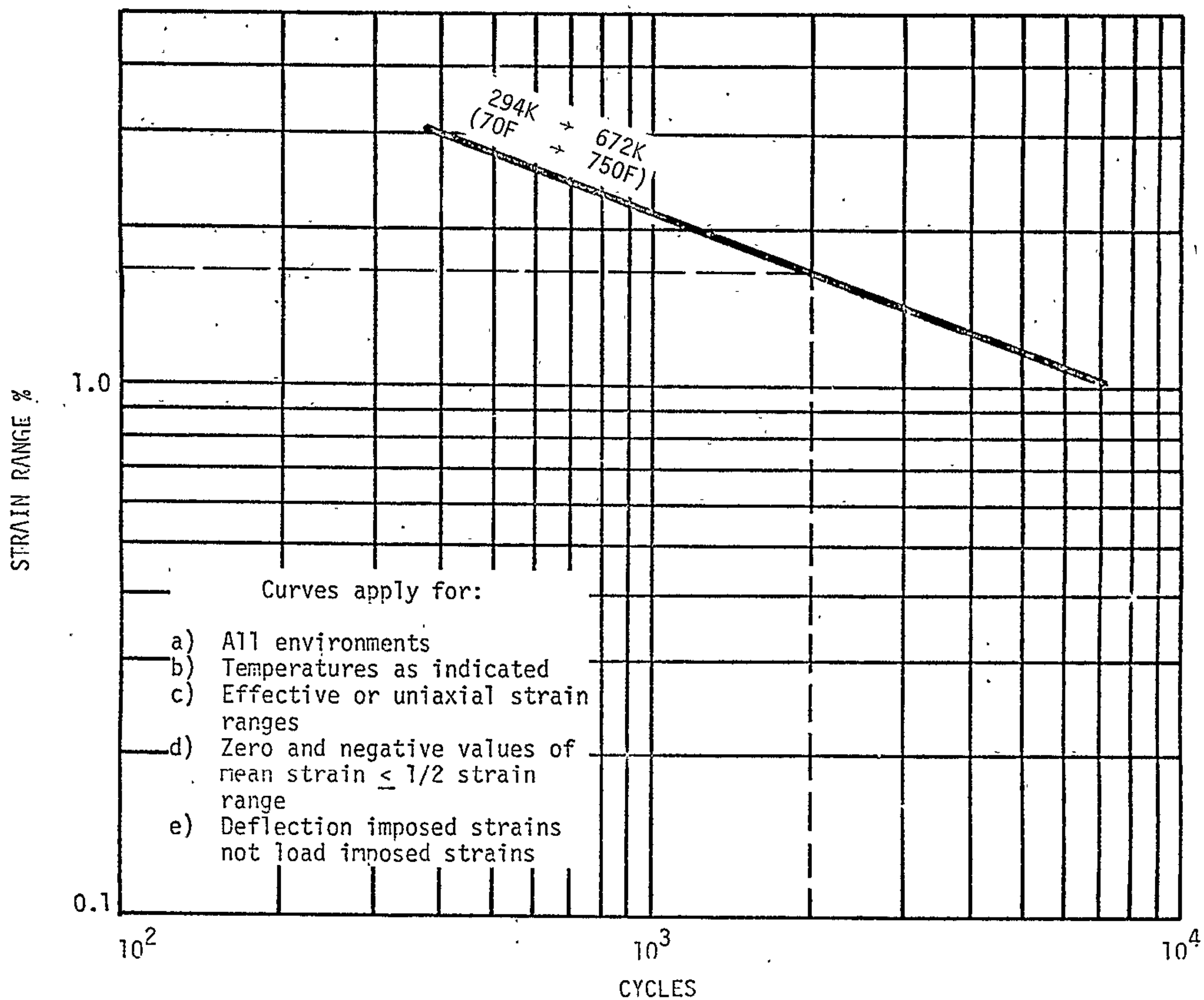


FIGURE 5.1-5: LOW-CYCLE FATIGUE LIFE OF NARloy-Z, ELEMENT #238, NOMINAL CONFIGURATION 3.3K THRUST CHAMBER

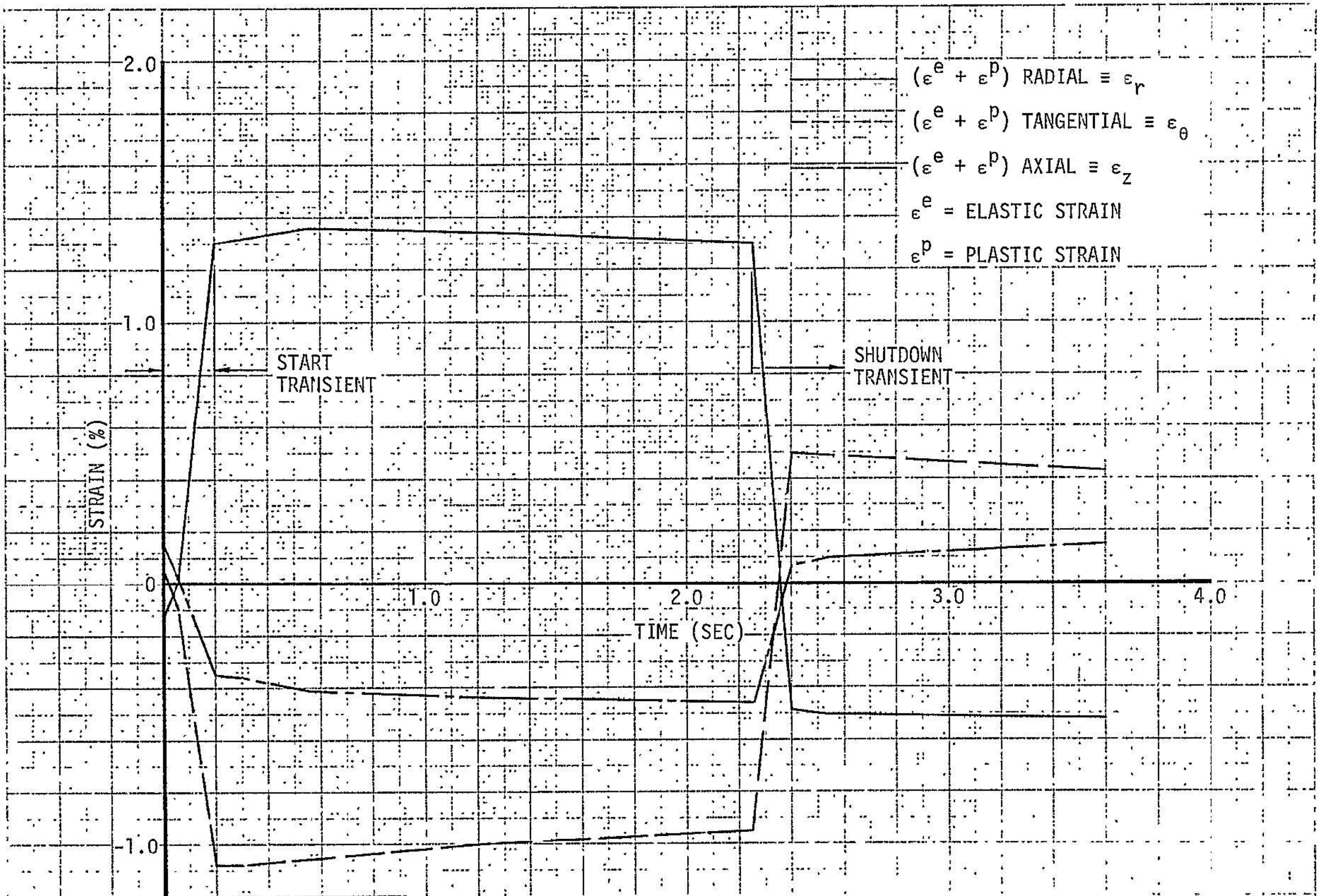


FIGURE 5.2-1: STRAIN VS. TIME, ELEMENT #160, CHANNEL #35, 3.3K THRUST CHAMBER

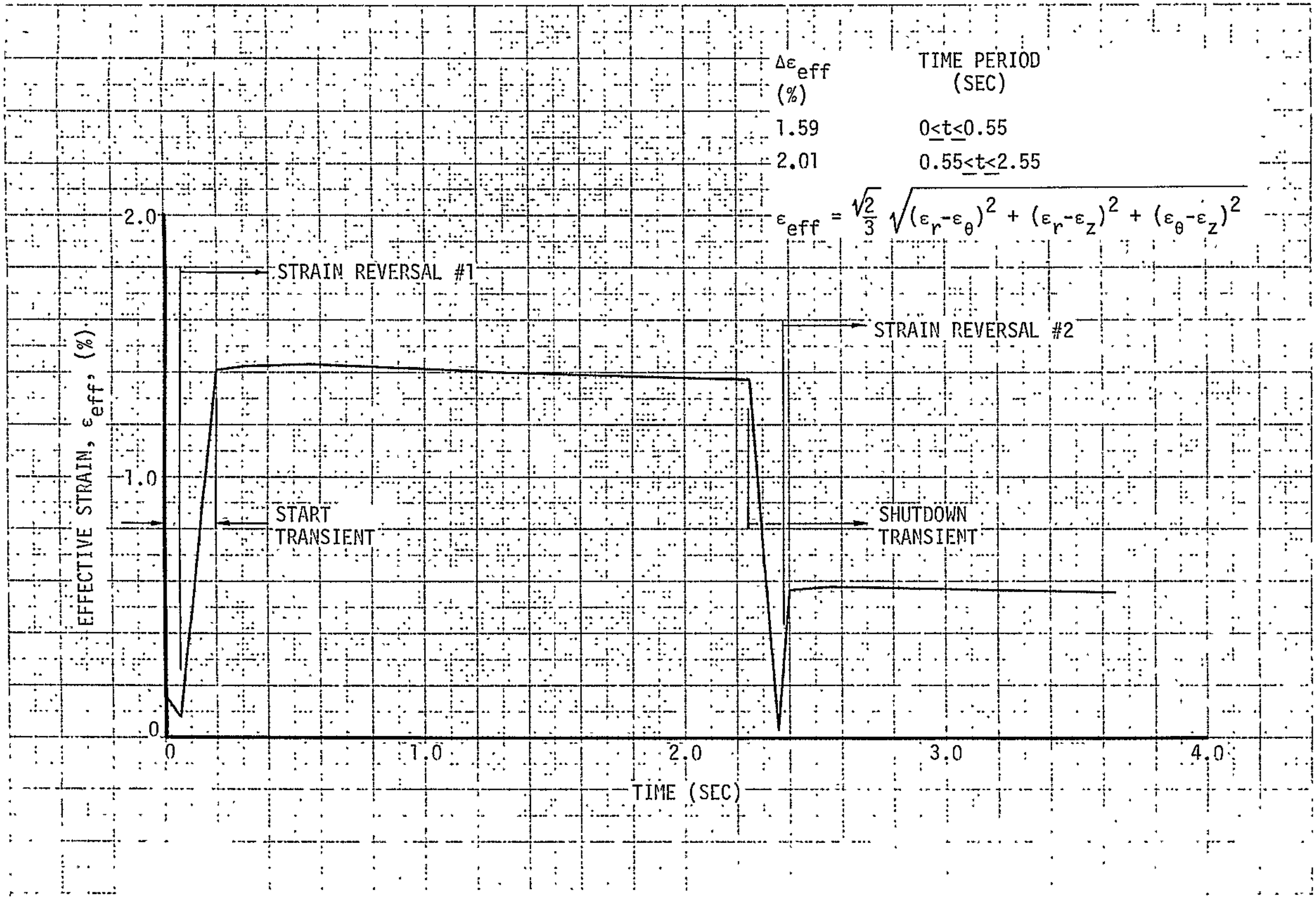


FIGURE 5.2-2: EFFECTIVE STRAIN VS. TIME, ELEMENT #160, CHANNEL #35, 3.3K THRUST CHAMBER

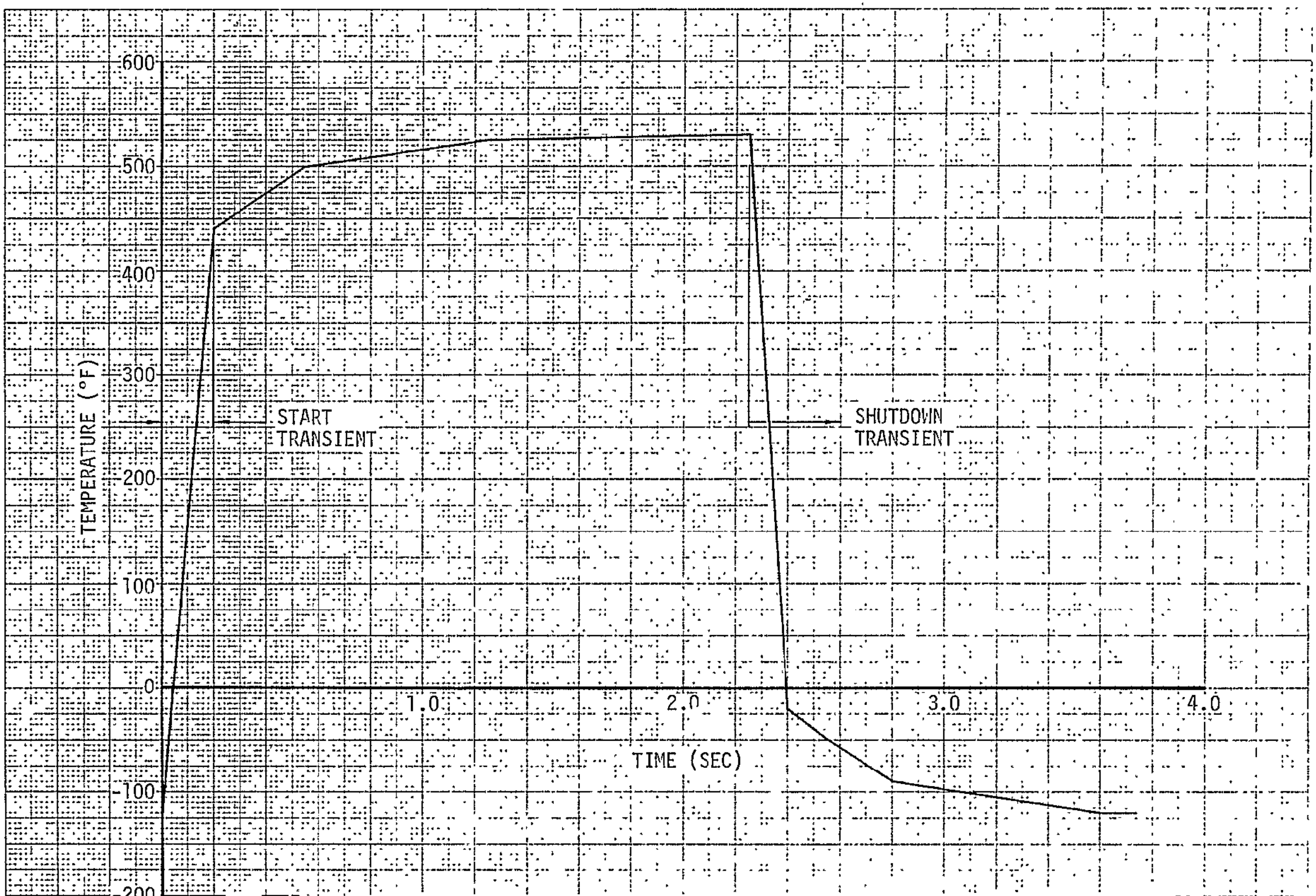


FIGURE 5.2-3: TEMPERATURE VS. TIME, ELEMENT #160, CHANNEL #35, 3.3K THRUST CHAMBER

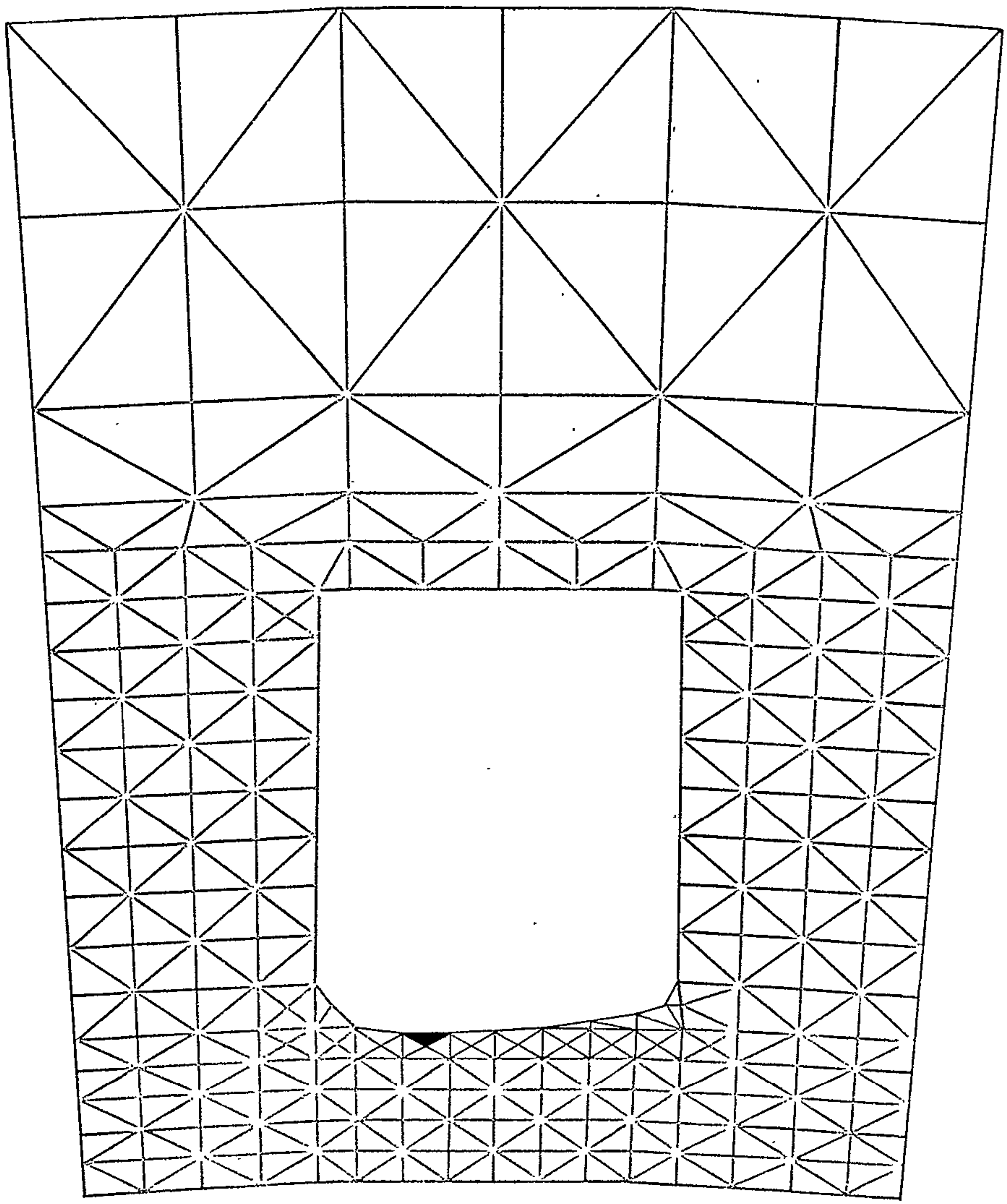


FIGURE 5.2-4: CRITICAL REGION, CHANNEL #35 CONFIGURATION

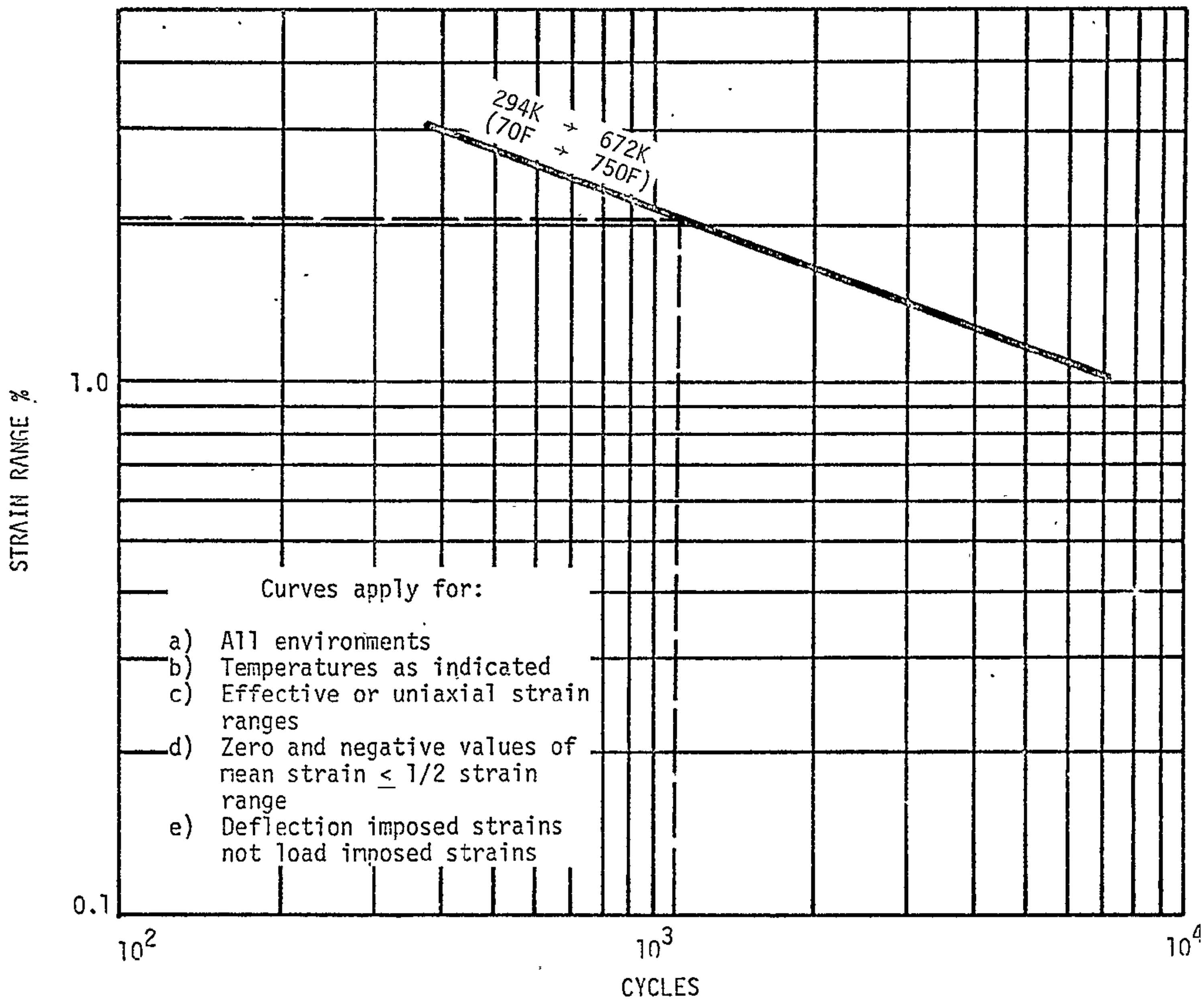


FIGURE 5.2-5: LOW-CYCLE FATIGUE LIFE OF NARloy-Z, ELEMENT #35, 3.3K THRUST CHAMBER

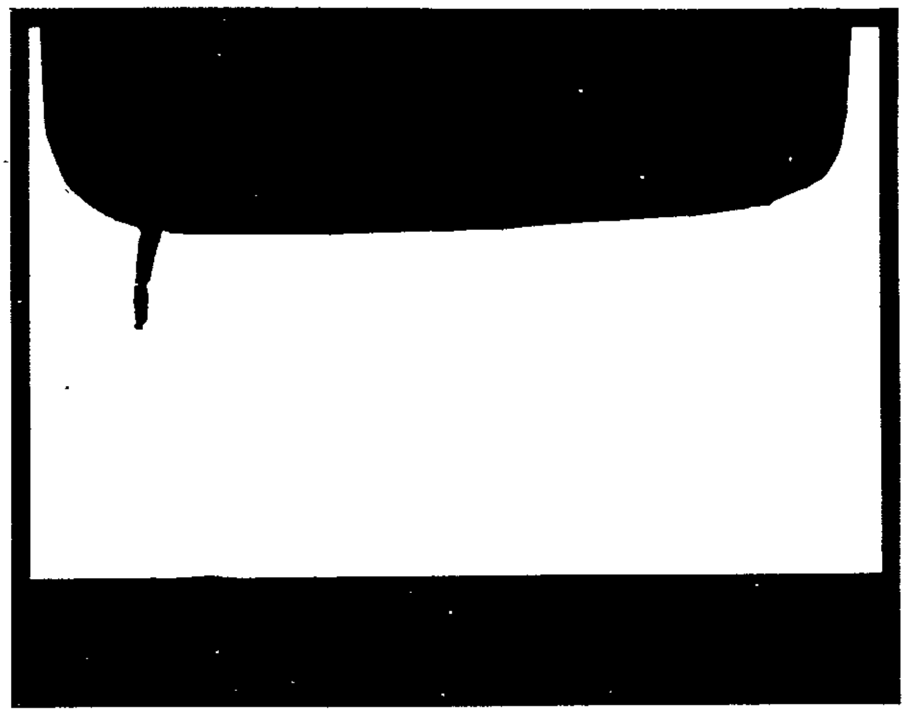


FIGURE 5.2-6: MICROGRAPH OF 3.3K THRUST CHAMBER SHOWING LOW-CYCLE FATIGUE CRACK IN CHANNEL #35 AFTER 1013 OPERATING CYCLES