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AD 867924

SINGLE-CHAMBER STOP/START  
SOLID ROCKET MOTOR (U)

FINAL REPORT

VOLUME II, APPENDIXES

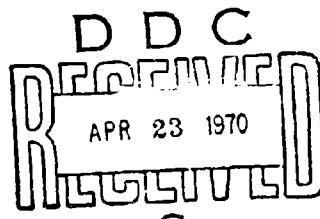
Contract F04611-68-C-0063

Report AFRPL-TR-69-50

March 1970

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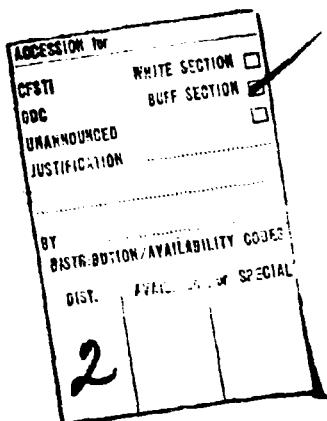


aerojet solid propulsion company

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SINGLE-CHAMBER STOP/START

SOLID ROCKET MOTOR

FINAL REPORT

VOLUME II APPENDIXES

CONTRACT F04611-68-C-0063

Charles T. Levinsky  
Norman P. Mittermaier  
Albert O. Hardrath

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AIR FORCE ROCKET PROPULSION LABORATORY  
UNITED STATES AIR FORCE  
EDWARDS, CALIFORNIA

**AEROJET-GENERAL CORPORATION**  
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

Report AFRPL-TR-69-50, Appendix A

APPENDIX A

STOP/START SOLID ROCKET MOTOR STRESS ANALYSIS

**Best Available Copy**

STOP/START TWENTY-PULSE STRESS ANALYSIS

SECTION I - DISCUSSION

- A. SUMMARY OF RESULTS
- B. METHOD OF ANALYSIS

SECTION II - DESIGN CRITERIA

- A. LOADS
- B. MATERIAL PROPERTIES
- C. GEOMETRY

SECTION III - STRESS ANALYSIS

- A. PRESSURE LOADING
- B. THERMAL PLUS PRESSURE
- C. PROPELLANT GRAIN

I. DISCUSSION

## A. SUMMARY OF RESULTS

The following table provides a summary of the margins of safety of all the significant structural items.

They are based on pressure loads which incorporated a 1.25 factor of safety. The allowables are based on the material properties at the maximum thermal excursion the part will experience, (Ref. Section III-A).

TABLE 1.1

Part	Drawing Number	Minimum Margin of Safety	Page
Throat, Pintle	1147001	+.03	3.1.1-1
Throat, Retainer	1147003	+.015	3.1.2-2
Coupling	1146997	+.17	3.1.3-2
Piston Retainer	1146999	High	3.1.4-1
Piston, Pintle	1146998	+.33	3.1.5-3
Strutted Housing	1146995	+.00	3.1.6-5
Entrance Cap, Pintle	1147005	+.09	3.1.7-1
Exit Cone Pins	1147016	+.51	3.1.8-1
Nozzle Support	1147008	+.31	3.1.9-2
Nozzle Throat	1147012	.34	3.2.5.1
Outer Nozzle Assembly	1147006	High	3.1.11-1

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Section 3.2.0 represents the results of a finite element computer analysis of the pintle and shroud nozzle components.

Figures 3.2.1.0 and 3.2.5.0 are computer output plots of the pintle and shroud. They identify the geometry, materials used in the assembly, nodal point and element locations.

The entire ejection load and piston load is transferred across Section A-A of the SSRM coupling (Ref. Figure 3.2.1.1). Considering thermal excursions at the end of the firing, a high margin of safety is shown. This confirms the analysis performed on Page 3.1.3.1 early in the design.

Sections C-C and B-B (Ref. Figure 3.2.2.1) of the throat retainer must transfer ejection loads on the AG Carb 101 to the piston. Using material allowables at 200°F, the temperature expected at 750 seconds, a high margin of safety is shown.

Tension across the retainer shank is again due primarily to ejection loads on the AG Carb 101. Section A-A, (Ref. Figure 3.2.2.1) at the undercut, has a 0.13 margin of safety at 750 seconds after ignition.

The stresses on the AG Carb 101 are shown in Figures 3.2.4.1 through 3.2.4.6. Sections in shear due to pressure and thermal loads are shown in Figure 3.2.4.1 through 3.2.4.3. The shear allowable is estimated at 2700 psi. This produces a M.S. = 0.24 at 8 seconds.

Hoop stress distribution is shown graphically in Figures 3.2.4.4 through 3.2.4.6 when the thermal gradient is maximum. The compressive stress on the inner surface is maximum and produces a M.S. = 0.0. However, this is conservatively based on tensile allowables. Compression allowables of graphites are appreciably higher than tensile allowables.

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The shroud nozzle geometry is shown in Figure 3.2.5.0. The hoop stress distribution on the pyro insert at 10 seconds is shown in Figures 3.2.5.1 through 3.2.5.3. Again compression on the inner fiber produces a minimum M.S. =0.34. Conservatively, it is based on pyro tensile allowables.

Figure 3.3.2 summarizes the results of the propellant grain analysis. The minimum M.S. =0.19 in the bond.

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B. METHOD OF ANALYSIS

The motor was checked initially using conventional methods and pressure loadings. This analysis (Ref. Section III-A), utilizes a 1.25 factor of safety and material properties expected at the end of the firing.

The initial analysis is two fold in purpose:

- (1) It evaluates geometry and material changes on the design.
- (2) It provides a reasonable geometry for the thermal stress analysis.

The latter analysis, (Ref. Section III-B) incorporates the final thermal map and pressure distribution. It is based on a 1.0 factor of safety.

AGC computer program No. E11405, "Finite Element Analysis of Solids with Nonlinear Material Properties", was used. This analysis is run with thermal distributions expected at the following times in the duty cycle.

1.  $t = 8.0$  seconds

Maximum Gradient in the Pintle Insert.

2.  $t = 10.0$  seconds

Maximum Gradient in the Shroud Insert.

3.  $t = 750$  seconds

Maximum Thermal Excursion in the Pintle.

This analysis, which is time-consuming because of all the details and computer turnaround time, serves two purposes:

1. Verifies the initial analysis.
2. Incorporates the effects of the varying thermal distributions in the structure.

A grain analysis was run utilizing existing parametric design curves.

The grain was checked for the following load conditions:

1. Firing at Ambient Temperatures.
2. Thirty-day Storage at 0°F.

Report AFRPL-TR-69-50, Appendix A

II. DESIGN CRITERIA

A. LOADS

Pressure

MEOP 550 psia

Actuator 3000 psia

F.S. 1.25 yield

Design Loads

$$p_D = 1.25 \times 550 = 690 \text{ psia}$$

$$p = 1.25 \times 3000 = 3750 \text{ psia (Hydraulic System)}$$

B. MATERIAL PROPERTIES

Ref. Page 2.3 through 2.8

C. GEOMETRY

Ref. Figure 2.1 and 2.2

Figure 2.1 is the computer plot of the aft end of the pintle.

Figure 2.2 is the computer plot of the shroud portion of the nozzle.

Report AFPL-TR-69-50, Appendix A

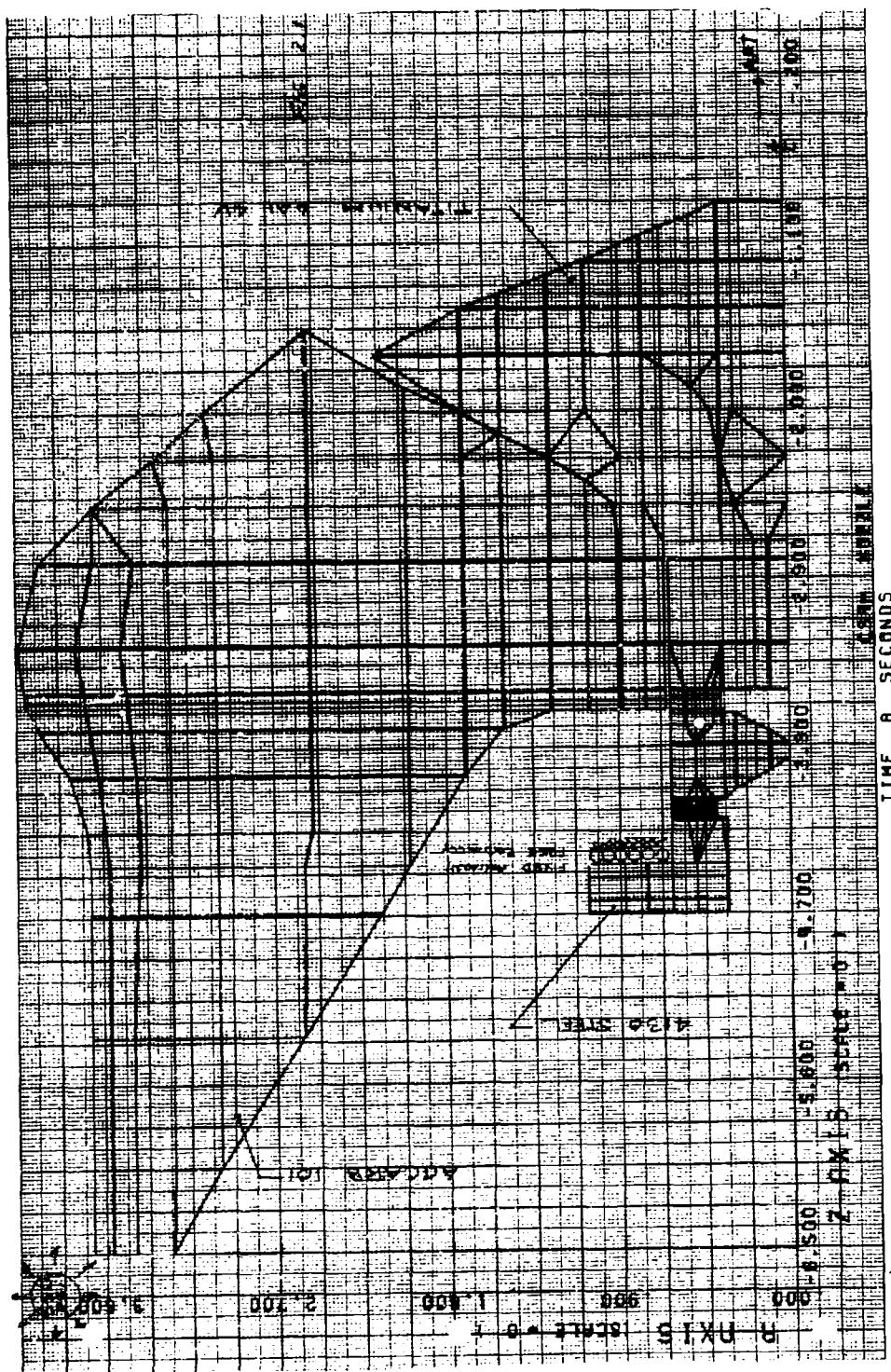


Figure 2.1

Report AFRPL-TR-69-50, Appendix A

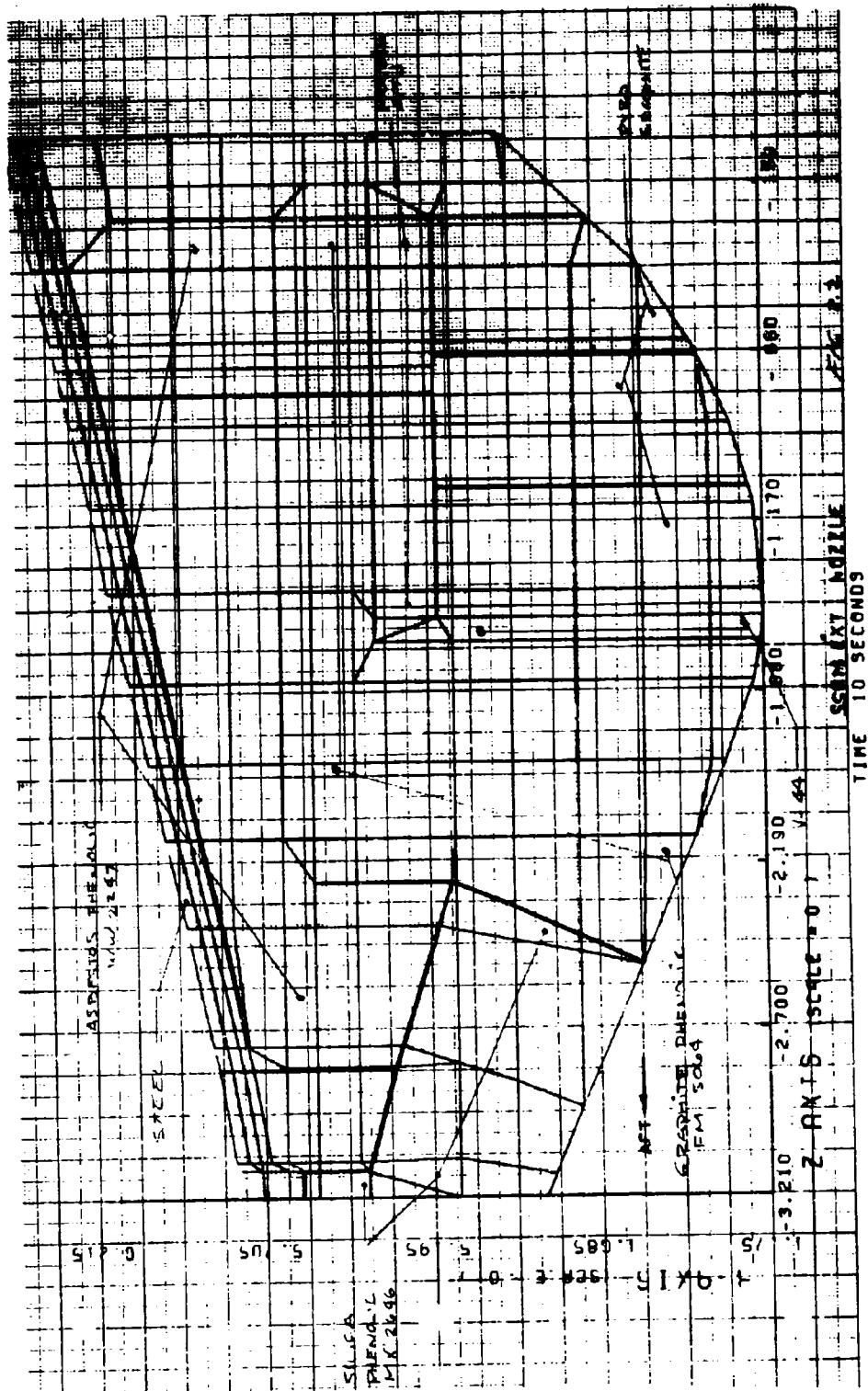


Figure 2.2

PYROGRAPHITE

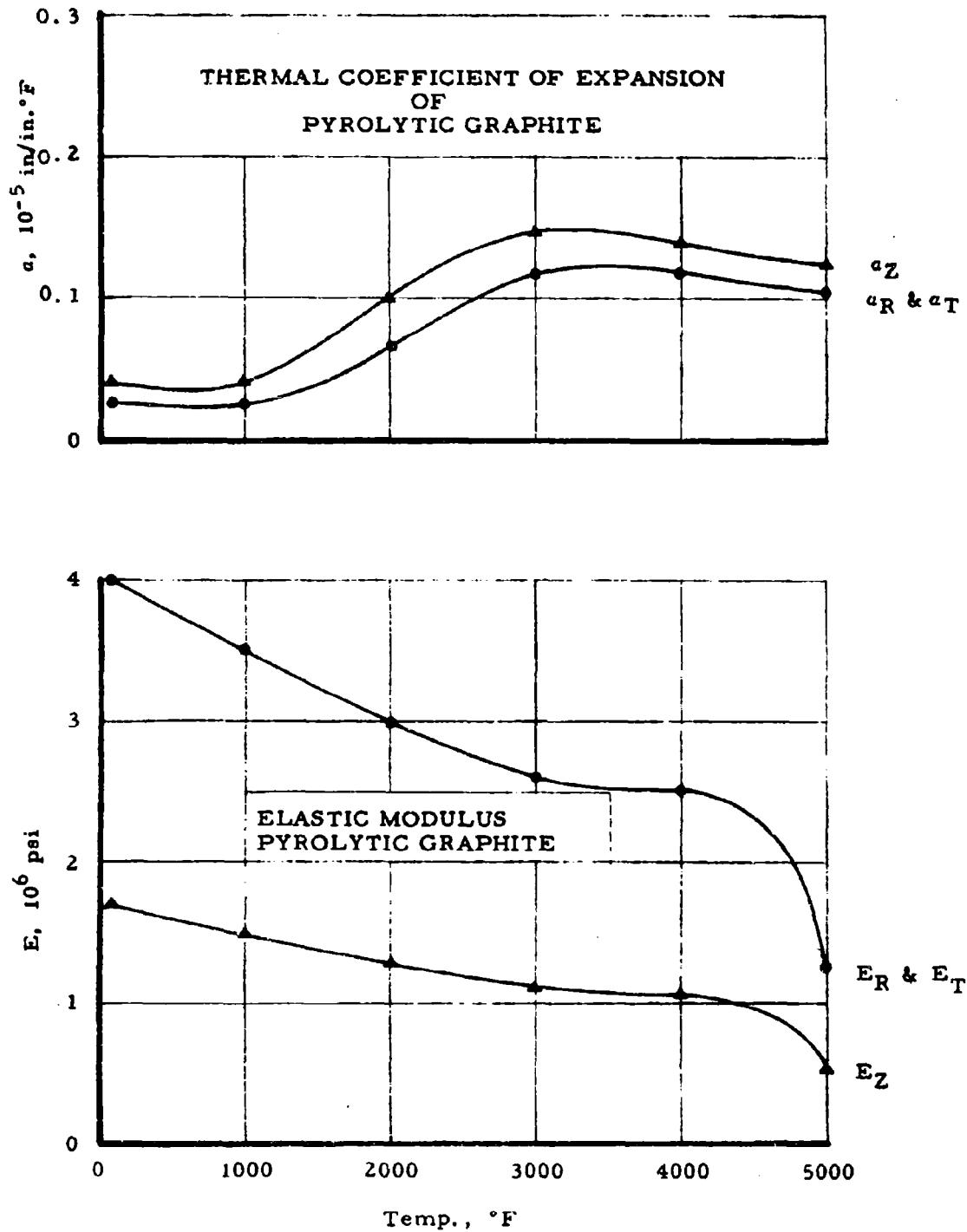


Figure 2.3

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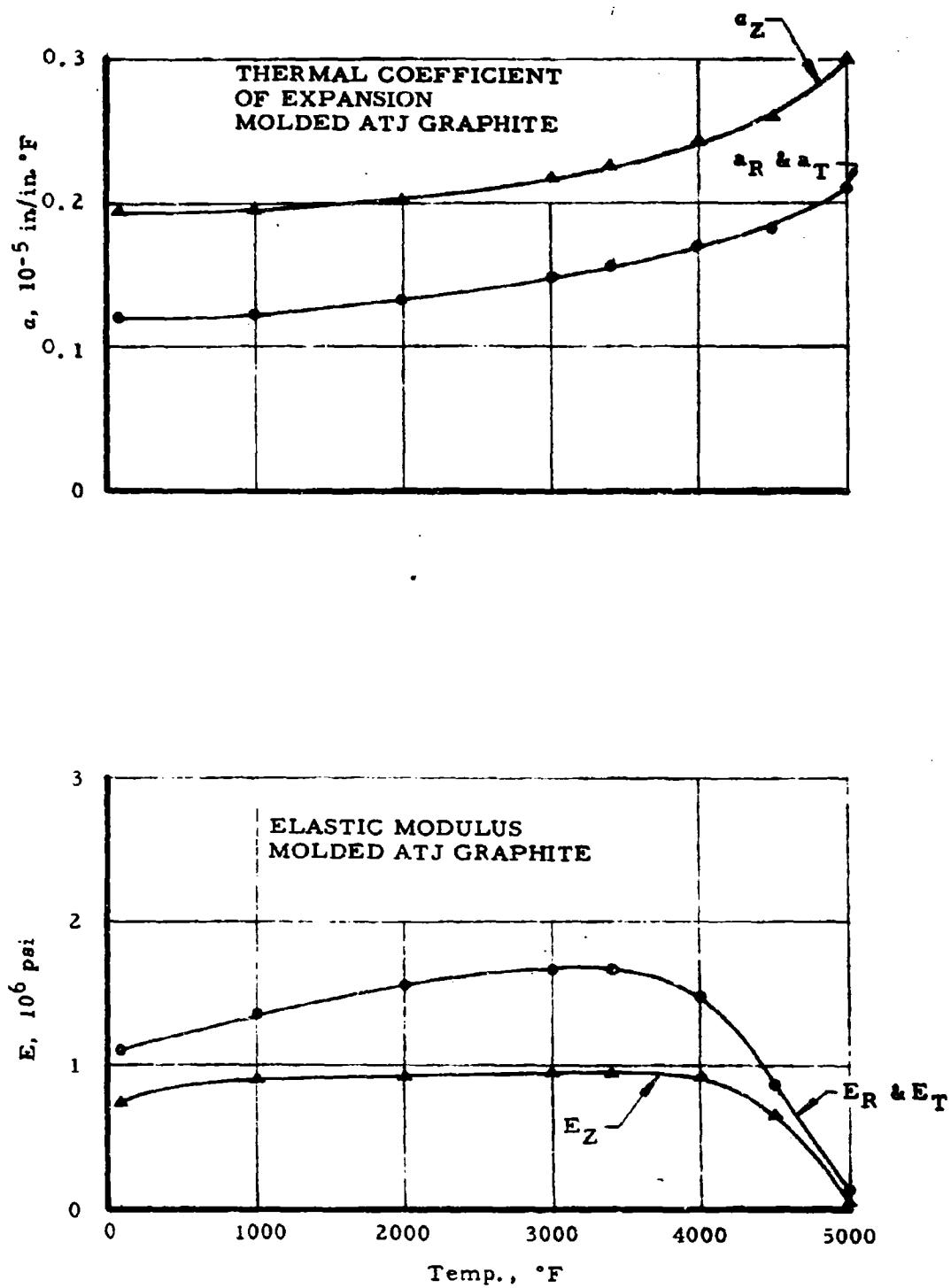


Figure 2.4

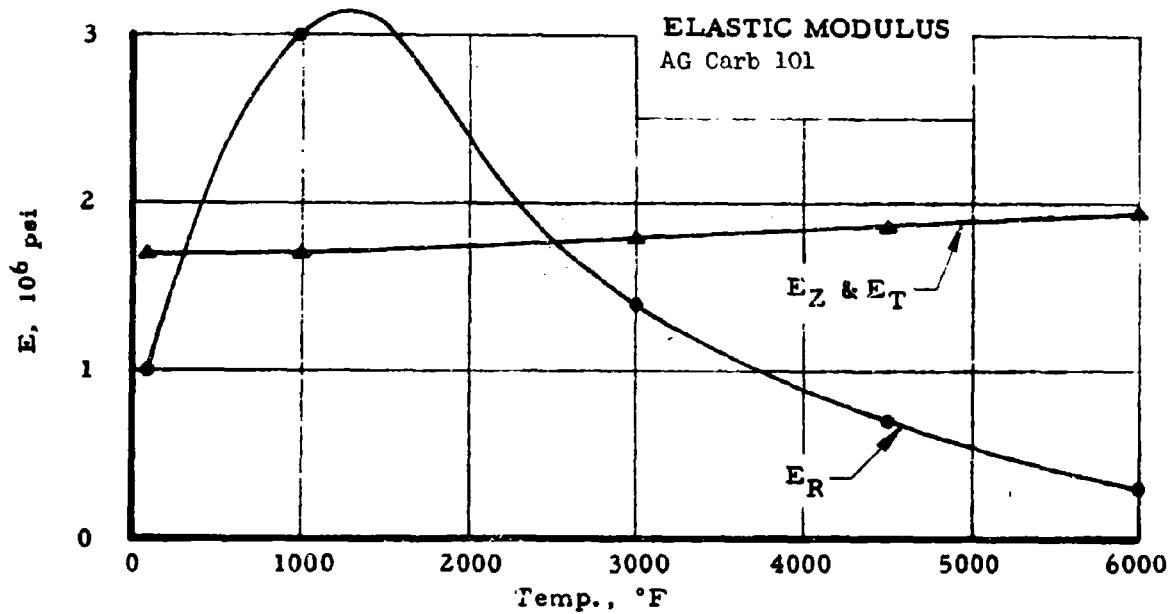
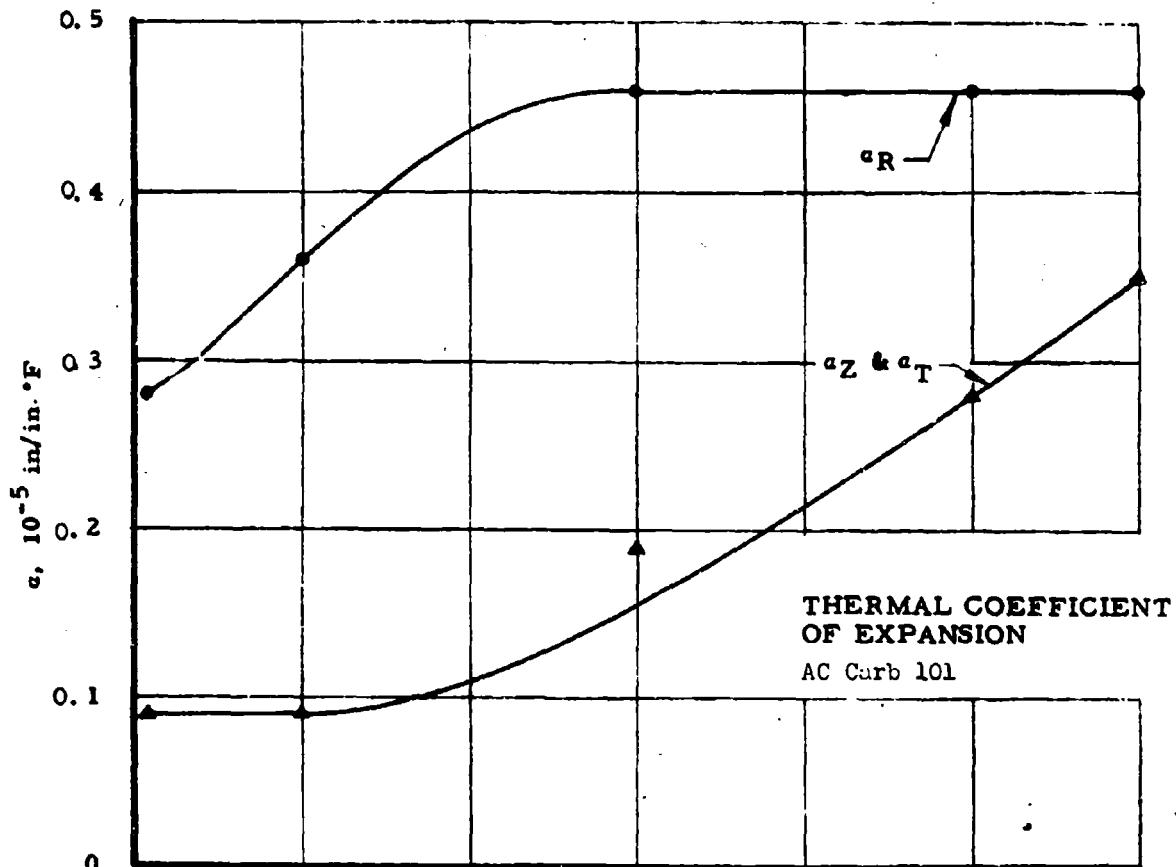


Figure 2.5

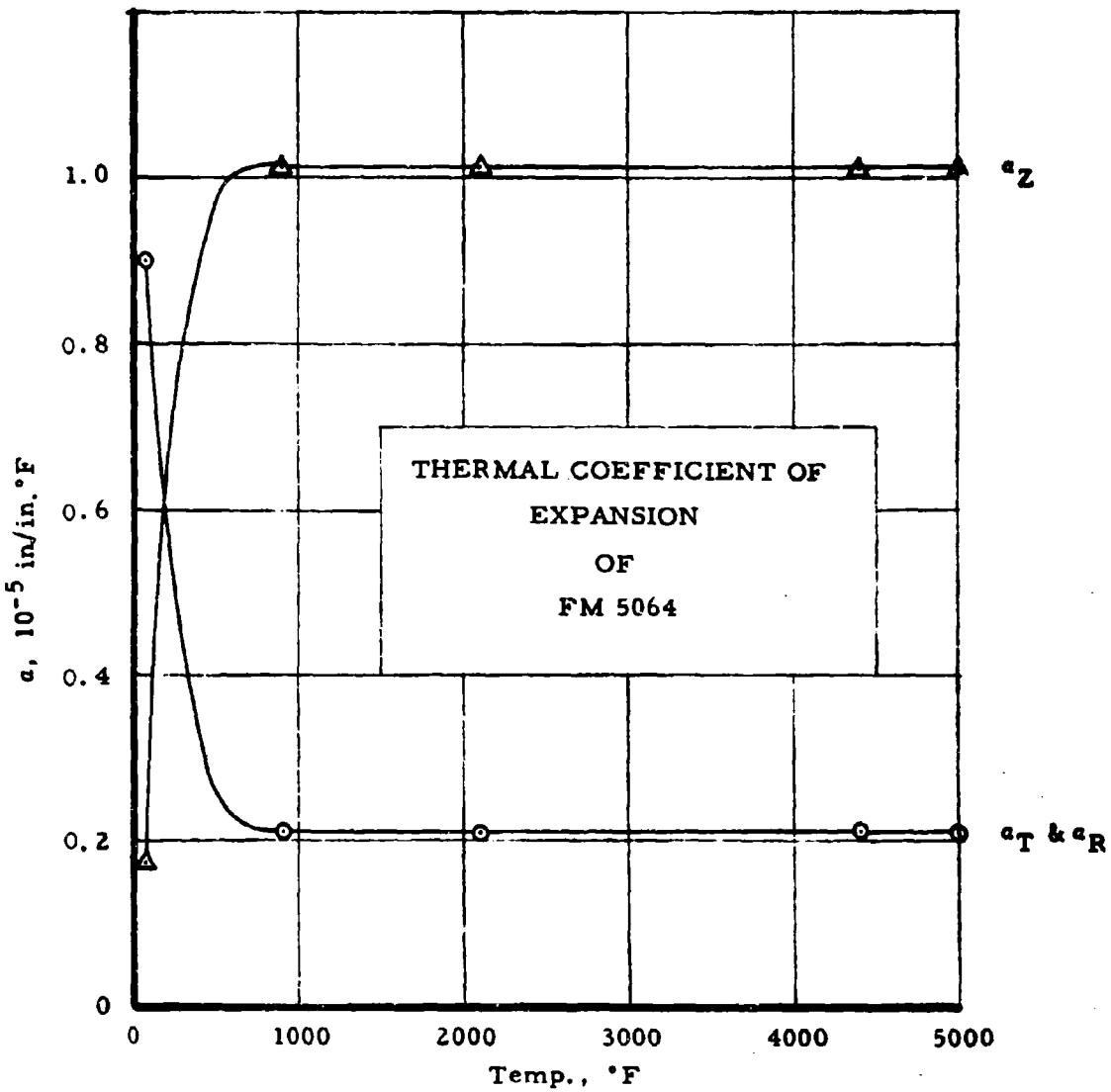


Figure 2.6

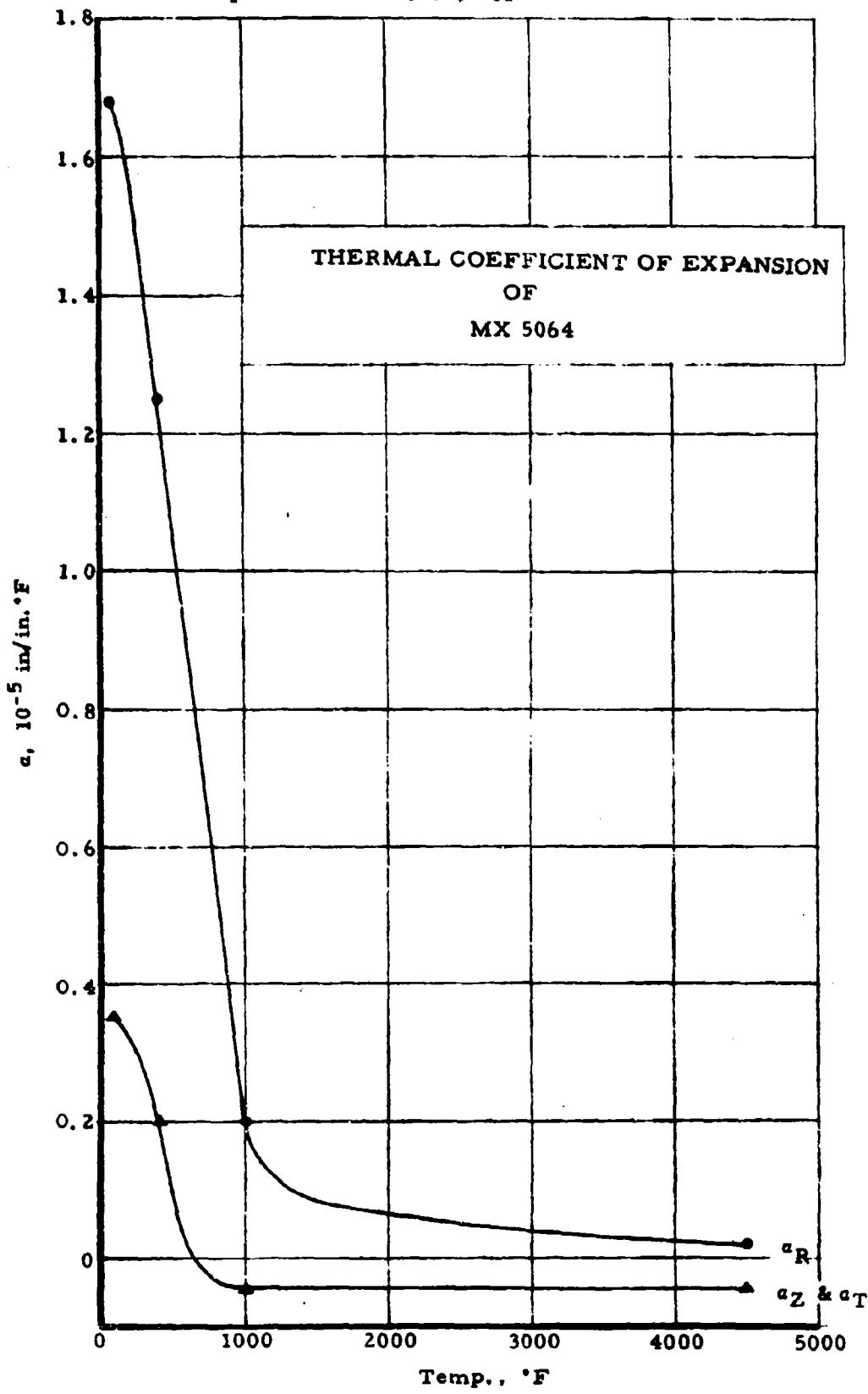


Figure 2.7

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## 20 PULSE

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TABLE OF CONTENTSSEC. 3.0 STRESS ANALYSIS3.1.0 PRESSURE LOADING ONLY, TABLE OF PRELIMINARY  
MIN. MARGINS OF SAFETY

3.1.1	THROAT PINTLE	DWG. NO	1147001
3.1.2	RETAINER THROAT	" "	1147003
3.1.3	COUPLING	" "	1146997
3.1.4	RETAINER, PISTON	" "	1146999
3.1.5	PISTON	" "	1146998
3.1.6	STRUTTED HOUSING	" "	1146995
3.1.7	ENTRANCE CAP (PINTLE)	" "	1147005
3.1.8	PINS (EXIT CONE)	" "	1147016
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3.1.10	NOZZLE THROAT	" "	1147012
3.1.11	OUTER NOZZLE ASSY	" "	1147006
3.1.12	THROAT APPROACH NOZZLE	" "	1147014
	INSULATOR, THROAT	" "	1147009
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	RING, PISTON	" "	1147004
	EXIT CONE	" "	1147015
	SPACER, THROAT NOZZLE	" "	1147011
3.1.12	SLEEVE	" "	1147013

## 3.2.0 THERMAL STRESS ANALYSIS

- 3.2.1 CSR COUPLING - STEEL
- 3.2.2 CSR RETAINER, THROAT - TITANIUM
- 3.2.4 PINTLE THROAT - ALCLAR B 101
- 3.2.5 SHroud THROAT - P-120

## 3.3.0 Prop. GRANt STRESS ANALYSIS

TABLE OF NOTATION

- f: PREDICTED OR CALCULATED STRESS , psi
- F: ALLOWABLE STRESS , psi
- P: TOTAL LOAD , "
- p: PRESSURE, psi

## Report AFRL-TR-69-50, Appendix A



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SEC 3.1.1 SSRM - THROAT PINLE

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DATE

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DATE

BY

H. EFRON

CHK. BY

THROAT, PINLE

Dwg 1147001, AG Case 101

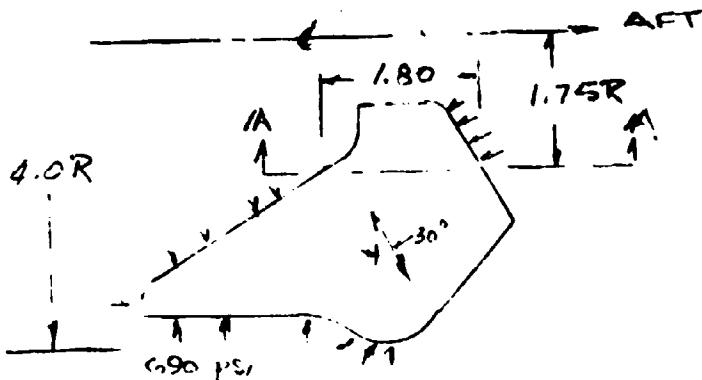


FIG 3.1.1

## @ SEC 1A/1A

STIF A.R.

$$f_s = \frac{3}{2} \frac{P_{FJ}}{A}$$

$$P_{FJ} = 11000 \pi^4$$

$$A = 2\pi(1.75)(1.80) = 630\pi$$

$$= \frac{3(11000)}{2(630)} = 2620 \text{ PSI}$$

$$F_s = 2700 \text{ PSI} \quad \text{e ROOM TEMP}$$

$$\text{M.S.} = \frac{2700}{2620} - 1 = .03$$

BENDING

$$f_b = \frac{6M}{L^2}$$

$$M = .5(4.0 - 1.75) \frac{11000}{2(1.75)} = 3540 \text{ IN-PSI}$$

$$= \frac{6(3540)}{(1.75)^2} = 6550 \text{ PSI}$$

$$F_t = 10,000 \text{ IN-PSI } 30^\circ = 7500 \text{ PSI}$$

$$\text{M.S.} = \frac{7500}{6550} - 1 = .15$$

## Report APRPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

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SEC 3.1.1 SSRM - THROAT PINNLE

BY H. EFRON

CML BY

DATE

THROAT, PINNLE Dwg 1147001 , AG CARE 101

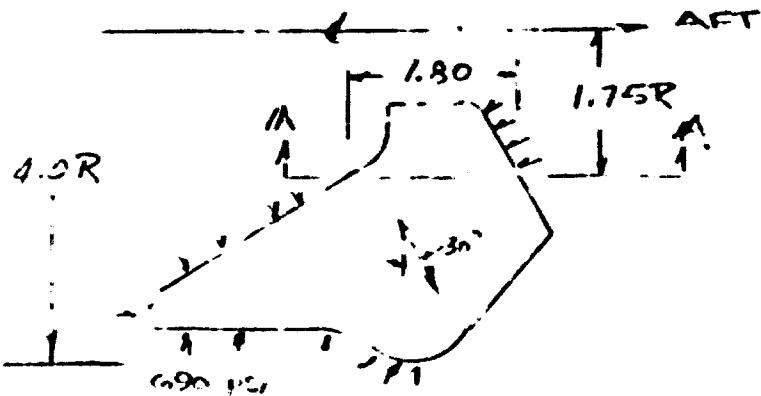


FIG 3.1.1

SEC 1A 1A

STIFF AIR

$$f_s = \frac{F_{p,1}}{A}$$

$$\begin{aligned} F_{p,1} &= 11000 \pi \\ A &= 2\pi(1.75)(1.80) = 630\pi \end{aligned}$$

$$= \frac{3(11000)}{2(630)} = 2620 \text{ PS}$$

$$F_s = 2700 \text{ PS. } e \text{ POOR TEMP}$$

$$\text{M.S. } \frac{2700}{2620} - 1 = .03$$

STIFF AIR

$$f_s = \frac{611}{72}$$

$$11000 \cdot 5(4.0 - 1.75) \frac{11000}{11000} = 3540 \text{ PS}$$

$$= \frac{6(3540)}{(72)^2} = 6570 \text{ PS}$$

$$F_{p,1} = 10.0 \cdot 10^6 \cdot 30^\circ = 300 \text{ PS}$$

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$$\text{M.S. } \frac{7300}{6570} - 1 = .15$$

## Report AFRL-TR-69-50, Appendix A

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SEC 3.1.2 SSRM - RETAINER, THROAT

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BY H. EFRON

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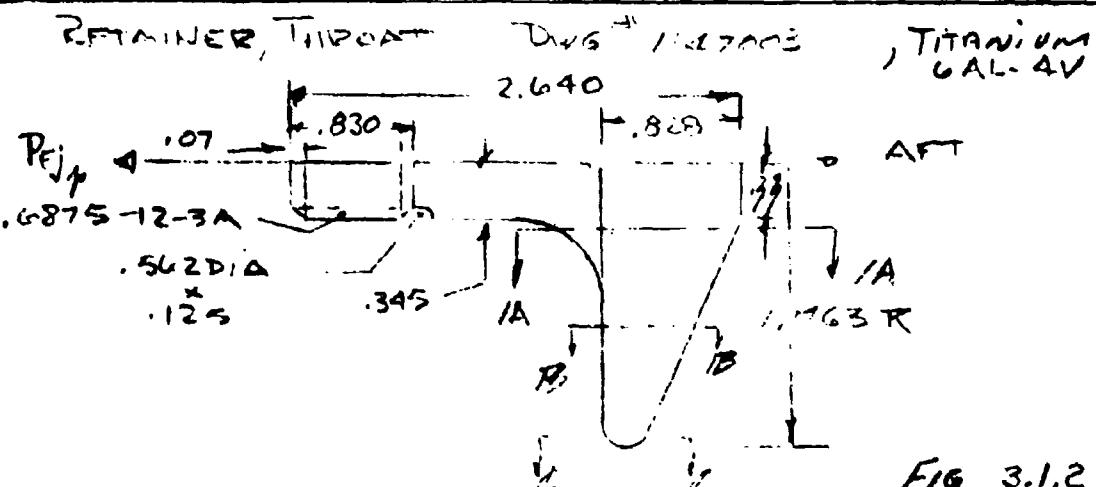


FIG 3.1.2

C SFC A-A  
SHEAR

$$f_{\text{SHR}} = \frac{3}{2} \frac{P_{Ej,p}}{A}$$

$$P_{Ej,p} = 11000 \pi \quad \text{REF. p.31.1.1}$$

$$A = 2\pi \cdot .25 (.328) = .58 \pi \text{ in}^2$$

$$= \frac{11000}{.58} \times 1.5 = 28,500 \text{ psi}$$

$$F_s = 100,000 \text{ psi}$$

$$\text{M.G. } \frac{100.0}{28.5} = 3.5$$

## BENDING

$$f_b = \frac{6 M}{Z^2}$$

IN. S

$$M < P_{Ej,p} (\cdot 763 - .35) / \cdot 77 \pi = \frac{11000 (1.413)}{\cdot 77 \pi} = \frac{22,100}{\cdot 77 \pi} \text{ in}^2$$

$$= \frac{6(22200)}{.92} = \frac{133200}{.81} = 165,000 \text{ psi}$$

$$F_s = 150,000 + 20,000 = 170,000 \text{ psi}$$

$$\text{M.G. } \frac{170}{170} - 1 = \underline{\underline{.03}}$$

## Report AFRL-TR-69-50, Appendix A

ALCOJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

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SSRM RETAINER, THRCAT

BY H. EFKON

CHK BY

DATE

@ THREE D'S 6875-12-3A

TENSION @ U'CUT

$$f_t = \frac{P_{pj}}{A_t}$$

$$P_{pj} = 11000 \pi^{\frac{1}{2}} \text{ REF: p 3.1.1.1}$$

$$A_t = \frac{\pi}{4} (.562)^2 = .08\pi \text{ in}^2$$

$$= \frac{11,000}{.08} = 137,500 \text{ psi}$$

$$F_t = 150,000 \text{ psi}$$

$$\text{M.S.} = \frac{150.0}{137.5} - 1 = .09$$

SHAPE

REF FIG 3.1.2

$$f_s = \frac{P_{pj}}{A_s}$$

$$A_s = \pi (.562)(.5)(.830 - 1.25 - \frac{2}{12} - .14)$$

$$= .398 (.5)(.562) = .112\pi$$

$$= \frac{11000}{.112} = 98,500 \text{ psi}$$

$$F_s = 100,000 \text{ psi}$$

$$\text{M.S.} = \frac{100.0}{98.5} - 1 = .015$$

## Report AFRPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
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Q.S.F. 18.74,  $R = 1.0 \times 2.50"$ , Pre F.  
SHEAR

$$f_s = \frac{3}{2} \frac{P}{A}$$

$$P = \rho \pi (4.0^2 - 1.0^2) = 15\pi 690 \text{ lb/in}^2$$

$$A = 2\pi R t = 1.0 \pi t \\ = 3 \frac{(15350)}{2} = 16,000 \text{ psf}$$

$$F_s = 16,000 \text{ psi}$$

$$M.G. = \frac{100}{100} - 1 = .41$$

BEAMS

$$f_b = \frac{6M}{I}$$

$$M = \frac{F}{2\pi R} (17.3 - 1.0) = \frac{10250(1.73)}{2} \\ = 3940$$

$$\frac{6(3940)}{(.5)^2} = 94,800 \text{ psi}$$

$$f_b = 160,000 + 70,000 = 170,000 \text{ psi}$$

$$M.G. = \frac{170.0}{170.0} - 1 = .00$$

Q.S.F. 6.6,  $R = 1.732 \times 1.25$ 

SHEAR

$$f_s = \frac{3}{2} \frac{P}{A}$$

$$P = \rho \pi (3.0^2 - 1.732^2) = 13\pi 690 \\ = 9000 \text{ lb/in}^2$$

$$A = 2\pi (1.732)(.25) = 830 \text{ in}^2 \\ = 3 \frac{(9000)}{2} = 13,500 \text{ psi}$$

$$F_s = 160,000$$

$$M.G. = \frac{100}{170.0} - 1 = .41$$

## Report AFRL-TR-69-50, Appendix A



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## SEC 3.1.3 SSRM - Coupling

BY H. EFRON CHK BY

Coupling

Dwg 1146997  
4130 STL, cond C3, H.T.  $F_y = 100,000 \text{ psi}$

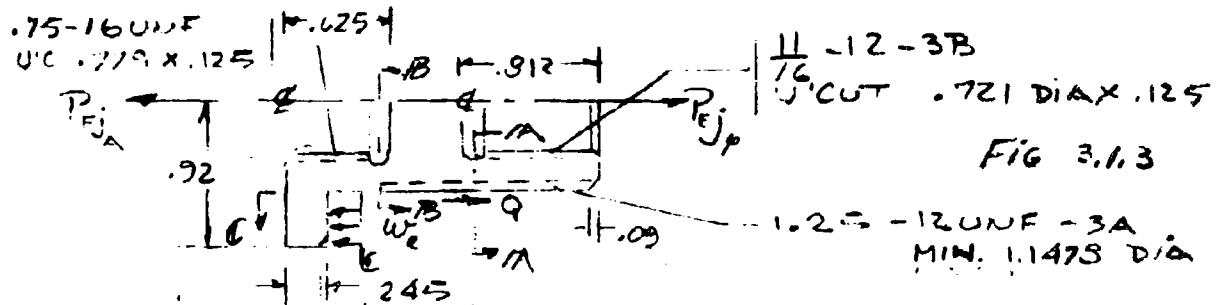


FIG 3.1.3

$1.2 = -12 \text{ UNF} - 3A$   
MIN. 1.1475 DIA

LOADS: 1. DUE TO CHAMBER PRESSURE:  $P_0 = 650 \text{ psi}$   
 $P_{FJA} = P_0 \pi (4.0^2 - .29^2)$  REF 3.2.1 Dwg 1147003  
 $= 650\pi(16.0 - 0.9) = 11,000\pi \text{ psi}$

$$w_e = \frac{P_{FJ}}{A} \quad A = \pi (.92^2 - .579^2) = .52\pi$$

$$= \frac{11,000}{.52} = 21,200 \text{ psi}$$

2. DUE TO ACTUATOR PLATE SURF:  $f_A = 3750 \text{ psi}$

$$P_{FJA} = f_A \pi (1.25^2 - .75^2) = 3750\pi \text{ psi}$$

$$Q = \frac{P_{FJ}}{2\pi R} = \frac{3750\pi}{1.12} = 3230 \text{ psi/in}$$

THREATS  $11/16 - 12 - 3B$

$$f_S = \frac{P}{A}$$

$$P = 11,000\pi \text{ psi}$$

$$A = \frac{11}{16}\pi (.312 - .09 - .125 - \frac{1}{12})(.5)$$

$$= .148\pi$$

$$= \frac{(11,000)}{(.148)} = 74,000 \text{ psi}$$

$$F_S = 100,000 \text{ psi}$$

$$\text{M.S.} = \frac{100}{74} = .35$$

\* REF Dwg \*

\* 1st 1.1475 DIA. 1147003 \*

## Report AFRPL-TR-69-50, Appendix A

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SACRAMENTO CALIFORNIA

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SS 2M - Propulsion

BY H. EFRON	CHK. BY	DATE
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@ SFC 1A-A REF FIG III

TENSION:

$$f_T = \frac{P_{el}}{A}$$

$$\frac{P_{el}}{A} = \frac{11,000 \pi}{\pi (.57^2 \cdot .36)} = .20 \pi \text{ in}^{3,1/2}$$

$$= \frac{11,000}{.20} = 55,000 \text{ psi}$$

$$F_T = 180,000 \text{ psi}$$

$$R_T = \frac{f_T}{F_T} = \frac{55}{180} = .31 \quad \text{STRESS RATIO}$$

BENDING:

$$f_b = \frac{M K}{t^2}$$

$$M = \frac{.5 P_{el} (.57 - .36)}{(.57 + .36) \pi} = \frac{.11 (11,000)}{1.03}$$

$$= 1180 \text{ in}^{-1}/\text{in}$$

$K = 0$  SINCE SAME OF THE MOMENT ( $M$ ) ROTATES THE AFT TUBE

$$t = .5735 - .3605 = .2134$$

$$= \frac{6 \times .5 \times 1180}{(.2134)^2} = 140,000 \text{ psi}$$

$$R_B = \frac{f_B}{F_B} \quad F_B = 180,000 + 80,000 = 260,000$$

$$= \frac{140}{260} = .54$$

COMBINED STRESS:

$$M.S. = \frac{1}{R_T, R_B} - 1 = \frac{1.0}{.85} - 1 = \underline{\underline{.17}}$$

## Report AFRPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

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SSRM - Couplings

04-1  
1/25/68  
FEB 1968

BY H. EFFRON

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DATE

@ SEC 1B-1B

TENSION

$$f_T = \frac{P_{EJ_P} + P_{EJ_A}}{A}$$

$$P_{EJ_P} = 11,000\pi \text{ REF: P7}$$

$$P_{EJ_A} = 3,750\pi$$

$$A = \pi (.57^2 - .389^2) = .173\pi$$

$$= \frac{14,750}{.173} = 86,000 \text{ psi}$$

$$F_T = 180,000 \text{ psi}$$

$$\text{M.S.} = \frac{180}{86} - 1 = \underline{\underline{1.1}}$$

BENDING: DUE ONLY TO ACTUATOR LOAD

$$f_b = \frac{6M}{Z^2}$$

$$M = \frac{.5 P_{EJ_A} (.579 - .379)}{\pi (389 + .579)}$$

$$= \frac{.095(3750)}{.960\pi} = 370 \text{ psi}$$

$$f_b = \frac{6(370)}{(.19)^2} = 64,320 \text{ psi}$$

$$F_B = 180,000 + 86,000 = 260,000$$

COMBINED STRESSES

$$R_T = \frac{f_T}{F_T} = \frac{86}{180} = .48$$

$$R_B = \frac{f_b}{F_B} = \frac{64}{260} = .24$$

$$\text{M.S.} = \frac{1}{R_T} - 1 = \frac{1}{.48} - 1 = \underline{\underline{1.39}}$$

## Report AFRPL-TR-69-50, Appendix A

AGCS-0800-11



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6/25/69

SSRM - COUPLING

WORK ORDER

BY H. EFRON

CHK BY

DATE

$$@ SEC C-C \quad t = 1.25 / 2 = .625$$

BEARING

$$f_0 = \frac{6.4}{\pi^2}$$

$$M = P_{ej} \cdot 5(.92 - .625) / 1.25 \pi \\ = \frac{11000 \pi \cdot 15}{1.25 \pi} = 132000 /$$

$$\ell = .245 \quad \text{REF: FIG 3.1.3}$$

$$f_0 = \frac{6(1320)}{(245)^2} = 132000 \text{ PS.}$$

$$F_0 = 130,000 + 80,000 = 210,000 \text{ PS.}$$

$$M.G. = \frac{100}{152} - 1 = \underline{\underline{.37}}$$

SHEAR

$$f_s = \frac{3}{2} \frac{P}{A}$$

$$P_{ej} = 11000 \pi^2 \quad \text{REF: FIG 3.1.1}$$

$$A = 2\pi r (.245) \\ = 1.25 (.245) \pi = .307 \pi \\ = \frac{3(1100)}{2(.307)} = 54,000 \text{ PS.}$$

$$F_{shear} = 100,000 \text{ PS.}$$

$$M.G. = \frac{100}{54} - 1 = \underline{\underline{.40}}$$



ACCS-600-11

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6/25/68

## SSRM - COUPLING

BY H. EFRON

CHK. BY

THREADS .75 - 16 UNF - 3B

$$f_s = \frac{P_{ejA}}{A}$$

$$P_{ejA} = 3750\pi^*$$

$$A = 5(.75)\pi(.625 - .125 - \frac{3}{16}) \\ = .375\pi (.375) = .375\pi \text{ in}^2$$

$$\therefore \frac{3750}{.375^2} = 26600 \text{ psi}$$

$$F_s = 100,000 \text{ psi}$$

$$M.G. = \frac{100,000}{26,600} - 1 = \underline{\underline{4.1}}$$

\* 1<sup>st</sup> & LAST THREAD INEFFECTIVE



ABCD-0000-11

SUBJECT

SEC 3.1.4

SS.R.M.

RETAINER, PISTON

BY

H. EFRON

CHK. BY

DATE

RETAINER, PISTON Dwg 1146900

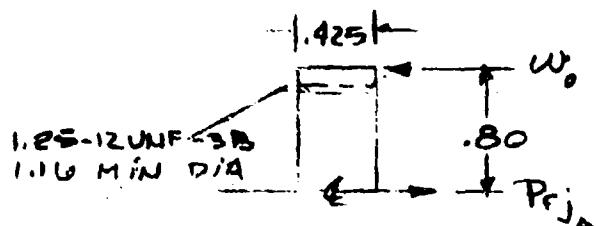


FIG 3.1.4

THREADS :  $D = 1.16 \text{ MIN dia}$ 

$$f_{\text{th}} = \frac{T_{FJA}}{A}$$

$$A = \pi D \left( 1.425 - \frac{D}{12} \right)$$

$$= \frac{1.16}{2} (1.3) \pi = .174 \pi$$

$$P_{FJA} = 3750 \pi^2 \text{ REF } \# 3.1.1$$

$$= \frac{3750}{.174} = 21,600 \text{ psi}$$

Factor 100,000 psi

$$M.S. \frac{100}{22} - 1 = \underline{\underline{4}}$$

## RING ROTATION - BENDING

$$f_o = \frac{McE}{I}$$

$$M = \frac{(.75 - .625)}{\pi (.75 + .625)} [3750 \pi] \\ * \frac{.125 (3750)}{1.375} = 3400 \text{ " " /m}$$

$$I = \frac{bh^3}{12} = \frac{.125 (.425)^3}{12} = \frac{775 \times 10^{-3}}{96} = .81 \times 10^{-3}$$

$$R = .63$$

$$= \frac{3400 (.212) (.63)}{.81} \times 10^3 =$$

$$= 56,500 \text{ psi}$$

## Report AFREL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
SACRAMENTO • CALIFORNIA

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ACCO-0000-11

SUBJECT

SS.RM - Trainer Gun

BY

H. EFFRON

CHNL BY

DATE

$$F_0 = F_0 + 80,000 \\ = 180,000 + 80,000 = 260,000 \text{ psi}$$

$$M.S. = \frac{260.0}{57.0} - 1 = \underline{\underline{M}}$$



AECB-5000-11

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## SEC 3.1.5 SSRM - PISTON, PINTE

BY H. EFRON

CHK. BY

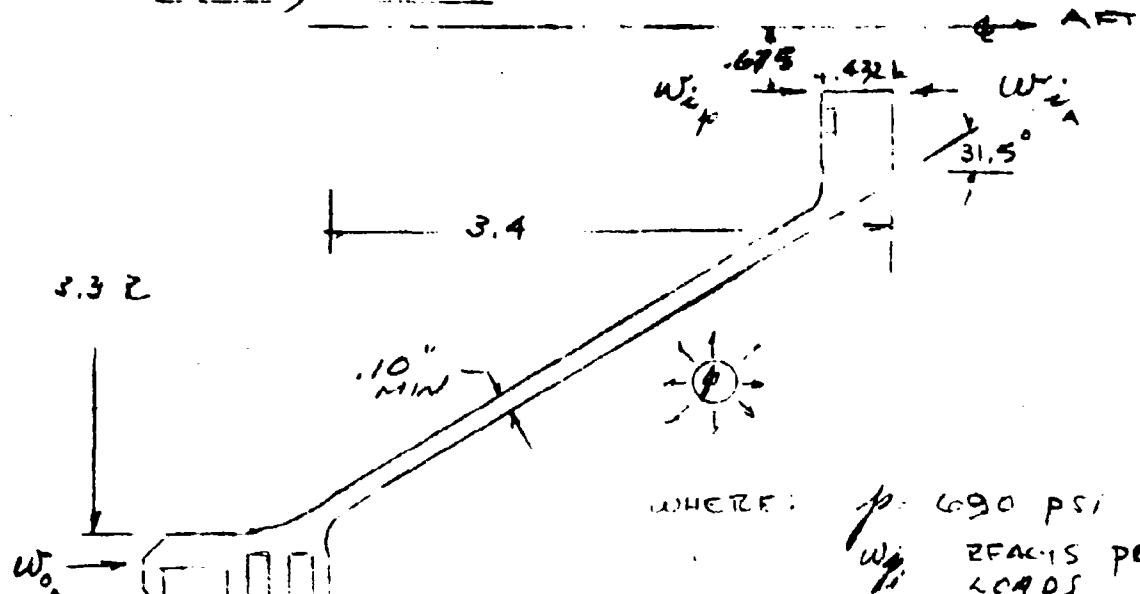
Piston, Pintle Dno 110655.3

FIG 3.1.5.1

CONEHoop Stress:

$$f_u = \frac{pR}{\cos 31.5^\circ} = -\frac{690(3.4)}{.1(.853)} = -27000 \text{ psi}$$

$$F = 150,000 \text{ psi}$$

$$M.S. = \frac{160}{27} - 1 = 4.1$$

ABC-0000-11

SUBJECT

SSRM - PISTON, PINTLE

BY

H. EFFRON

CHK BY

DATE

ELASTIC STABILITY

REF 1) SHELL STRENGTH

W. L. VAUGHAN

DESIGN NEWS 3/29/63

$$\frac{D}{L} = \frac{6.8}{3.4} = 2.0$$

$$\frac{L}{D} = \frac{3.4}{6.8} = .0147$$

$$P_{cr} = EK$$

$$E = 30 \times 10^6$$

$$K = .00009 = 9 \times 10^{-5}$$

$$= 30 \times 9 \times 10^6 = 2700 \text{ psi}$$

$$P = 690 \text{ psi}$$

$$M.S. = \frac{P_{cr}}{P} - 1 = \frac{2700}{690} - 1 = 11$$

RING 1 REF 3.1.5.1

ASSUME

- ① ONLY PRESSURE LOADS ACTING
- ② RING RESISTS THE ENTIRE PRESSURE LOADING IN RING ROTATION.

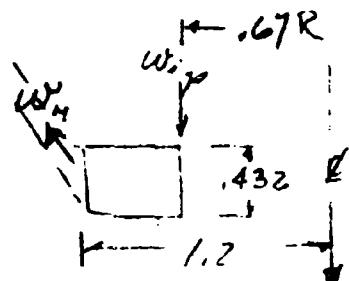


FIG 3.1.5.2

AFT

$$I = \frac{.53 \times .432^3}{12} = 3.5 \times 10^{-3} \text{ in}^4$$

$$A = .432 \times .57 = .25 \text{ in}^2$$

## Report AFRL-TR-69-50, Appendix A

AIRCRAFT-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

AUG-2000-11

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SSLM - PISTON, PINTLE

WORK ORDER

H. EFRON

CHK BY

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## BENDING STRESS

$$f_b = \frac{M_c R}{I}$$

$$I = 3.5 \times 10^{-3} \text{ in}^4 \quad \text{REF FIG 3.1.5.1}$$

$$C = .216 \text{ in}$$

$$R = .93 \text{ in}$$

$$M_c = \frac{.6 P_{ejp}}{2\pi R} = \frac{.3 P_{ejp}}{\pi R}$$

$$= \frac{.3 P_{ejp} (.216)}{\pi 3.5 \times 10^{-3}} = \frac{.016 P_{ejp}}{\pi} \times 10^3$$

$$P_{ejp} = 11000 \pi \quad \text{REF # 3.1.1.1}$$

$$= 160 (11000) = 183,000 \text{ psi}$$

$$F_b = 183,000 + 90,000 = 260,000 \text{ psi}$$

$$R_b = \frac{f_b}{F_b} = \frac{183,000}{260,000} = .705$$

## HOOP TENSION

$$f_h = \frac{W R}{A}$$

$$W = \frac{P_{ejp}}{2\pi R} \tan 31.5^\circ$$

$$= \frac{11000 (.5129)}{2 R} = \frac{3370}{R}$$

$$= \frac{3370}{.25} = 13500 \text{ psi}$$

$$F_t = 180,000 \text{ psi}$$

$$R_t = \frac{13500}{180,000} = .075$$

## COMBINED STRESS

$$\Sigma R = R_b + R_t = .675 + .075 = .75$$

$$M.R. = \frac{1.0}{.746} - 1 = \underline{\underline{.23}}$$

Report AFREL-TR-69-50, Appendix A

AIRBRAKE-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

REPORT NO.

ASCB-0000-11

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SEC 3.1.6

BY H. EFFRON

CHR. BY

Housings, PINTLE

1146995

4130 STL

H.T. 150 KSI, MIN YLD

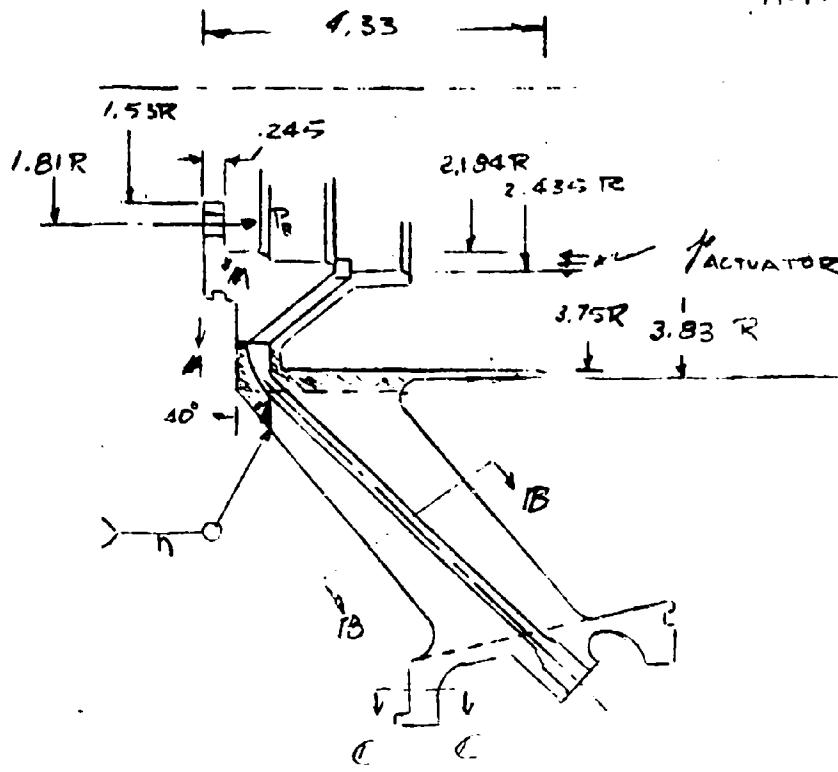


FIG. 3.1.6.1

## Report AFPL-TR-69-50, Appendix A

ACCS-0000-11

SUBJECT



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SSRM - 20 PULSE

BY

H. EFFRON

CMR BY

DATE

@ SEC 1A-1A WHERE "L = .245"

THE BOLTS HOLDING THE PISTON TO THE  
HOUSING ARE LOADED BY THE ACTUATOR  
PRESSURE ACTING OVER 2.194 IN² X 2.435.

$$\begin{aligned} P &= \frac{F_{ACT}}{\text{Area}} \pi (2.435^2 - 2.194^2) \quad \text{REF. FIG 3.1.6.1} \\ &= 3750 \pi (5.985 - 4.955) = 11371 (2750) \\ &= 3250 \pi \text{ lb} \end{aligned}$$

BENDING STRESS

$$f_b = \frac{M}{\frac{D}{2}}$$

$$M = \frac{(2.194 - 1.5)}{2} \cdot \frac{.374 \cdot 42.57}{2.368}$$

$$= 26.5 \text{ in-lb}$$

$$L = .245 \text{ in}$$

$$= \frac{6(36.5)}{(.245)^2} = 36,700 \text{ psi}$$

$$E = 150,000 \text{ psi}$$

$$M.S. = \frac{150,000}{36,700} = 4.1$$

SHEAR STRESS

$$f_s = \frac{3}{2} \frac{P}{A} =$$

$$\begin{aligned} A &= 2\pi R^2 = 2\pi (2.194)(.245) = 1.02\pi \\ &= \frac{4.250}{1.02} \cdot 1.5 = 3900 \cdot 1.5 = 5850 \text{ in}^2 \end{aligned}$$

$$F_s = 90,000 \text{ psi}$$

$$M.S. = \frac{90,000}{5850} = 1.57$$

BOLTS - Piston to Housing  $\frac{1}{4}$ -28 - 10 REF. 12  
SHEET HEAD.

$$P_o = \frac{P}{10} = 4250 \text{ lb} = 137.0 \text{ in}^2/\text{BOLT}$$

$$F_s = 6.700 \text{ in}^2/\text{BOLT}$$

$$M.S. = \frac{6900}{137.0} = 50.41$$



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SSRM 20 PULSE

BY

H. E. EIKON

CHK. BY

DATE

RING - RIVET KICK LOADS $P_R$ 

--- C --- TAN

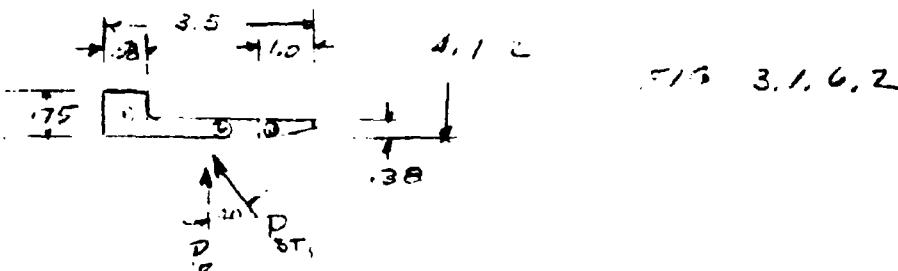


FIG 3.1.6.2

EVALUATING  $P_R$  (NEGLIGEING ALL FACTORS ON PINTLE)

$$P_R = P_{ST} \cos 40^\circ$$

$$= \frac{\pi D^2}{3 \sin 40^\circ} \cos 40^\circ = \frac{\pi D^2}{3} \cot 40^\circ$$

WITH  $D = 690 \text{ F.S.}$   
 $\pi = 3.14159 \text{ F.P.F.}$

$$= \frac{690^2}{3} \cot 40^\circ (1.19) = 18,000 \text{ #/STRUT}$$

EVALUATING GEOMETRY OF THE RING

$T_{FM}$	$AFA$	$Y$	$AY$	$AY^2$	$I$
1	.435	.375	.163	.062	.0206
2	.730	.19	.138	.026	.0089
3	.195	.25	.050	.012	.0020
$\Sigma$	1.360		.351	.100	.0315

$$I_{xy} = \Sigma I_0 + \Sigma A_y^2 - \Sigma A_y^2$$

$$\bar{y} = \frac{\Sigma A_y}{\Sigma A} = \frac{.351}{1.36} = .260$$

$$= .0315 + .100 - (1.36)(.260)^2 = .039 \text{ in}^4$$

$$\Sigma A = 1.36 \text{ in}^2$$

$$C = .75 - .26 = .49$$

$$R_c = 3.97 \text{ "}$$

\* INCLINATION OF RING CENTER LINE = 3.75°

## Report AFRL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

ACCS-8800-11

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55 RM-20 PULSE

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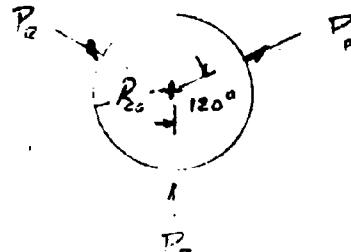
CHK BY

DATE

H. EFRON

EVALUATING BENDING STRESSES.

$$f_b = \frac{M_c}{I} K_b$$



$$R_{co} = 3.97$$

FIG 3.1.6.3

$$M = .5 P_R R_{co} (\frac{1}{3} - 0.75)$$

$$P_R = 18,000 \text{ psi}$$

$$\theta = \pi/3 = 1.05$$

$$\cot \theta = 1.732$$

$$= .5(18,000)(3.97)(.777) = 27,000 \text{ psi}$$

REF: BRAKE  
TABLE VIII  
CAL-F 9  
FORMULAS FOR  
STRESS & STRAIN

K\_b &lt; .50

FACTOR TO ALLOW FOR  
THE STIFFNESS CONTRIBUTED  
TO THE RING BY  
1. CYLINDER AFT OF THE RING  
2. BOSS ON THE SEALING  
PISTON AT THE PIVOT.

$$\frac{f_b}{F_y} = \frac{27,000 (.49) (.50)}{.039} = 173,000 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

$$F_b = 1.25 F_y = 188,000 \quad \text{BENDING MODULUS}$$

$$\text{M.S.} = \frac{188}{173} - 1 = +.09$$

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SSRM

BY

H. FERON

CHK BY

DATE

## EVALUATING COMPRESSIVE STRESS @ X-SECTION

$$f_c = \frac{R}{A} K_t$$

$$\text{WHERE } K_t = 1.5 \cot 60^\circ = .87$$

$$= \frac{18,000 (.87)}{1.36} \quad A = 1.36 \text{ in}^2$$

$$= 11,500 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

$$\text{M.S. } \frac{150}{11.5} - 1 = 11$$

## COMBINED STRESS: Comp. + BENDING

$$R = R_t + R_b \quad \text{STRESS RATIO}$$

$$R_t = \frac{f_t}{F_y} = \frac{11,500}{150,000} = .076$$

$$R_b = \frac{f_b}{F_b} = \frac{173,000}{150,000} = .192$$

$$R = .996$$

$$\text{M.S.} = \frac{1}{R} - 1 = \frac{1}{.996} - 1 = +0.0$$

DEFLECTION, RADIAL  $\Delta K$  - REF: TRAMK: TABLE III  
CASE 5

$$\Delta K = \frac{WR^3}{2EI} \left[ \frac{1}{2\sin^2 \theta} (\theta + \sin \theta \cos \theta) - \frac{1}{6} \right] \quad \text{FORMULA FOR STRESS STREN}$$

$$\theta = \pi/3 = 1.050 \text{ RAD}$$

$$W = 18,000 \text{ lb/in}^2 \quad \text{DESIGN LOAD}$$

$$R = R_c = 3.97 \text{ in}$$

$$EI = 30 \times 6.39 \times 10^6 = 120 \times 10^6$$

$$\Delta R = \frac{18,000 \times 6.2 \times 0.03}{120 \times 10^6} = .016' @ \text{DESIGN LOAD}$$

$$.012' @ \text{LIMIT LOAD}$$

BASED ON E.I. 6.2 FOR DETERMINING LENGTH

$$\Delta R = .012 \times 3.75^2 = .008' @ \text{ACTUAL LOAD}$$

## Report AFPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

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BY	CHK. BY	DATE
H. EFRON		

ELASTIC STABILITY OF THE CYLINDERREF: SHELL STRENGTH - VAUGHN  
DESIGN NEWS 3/20/63

$$\frac{P}{\sigma_e} = K F$$

EVALUATING K

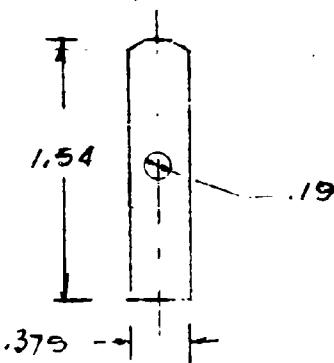
$$\frac{P}{L} = \frac{7.623}{4.33} = 1.78 \quad \text{REF: FIG 3.1.6.1}$$

$$\frac{\epsilon}{D} = \frac{.08}{.76} = .105$$

$$\therefore K = 6 \times 10^{-5}$$

$$= 6 \times 10^{-5} \times 30 \times 10^6 = 1.80 \times 10^3$$

$$M.S. = \frac{1.80 \times 10^3}{220} - 1 = \underline{H_1}$$

@ SEC B-B - STRUT

$$A = .375 \times 1.5 - \pi (.075)^2 = \\ .563 - .03 = .533 \text{ IN}^2$$

$$I \approx \frac{bh^3}{12}$$

$$\approx \frac{.195}{12} (.375)^3 = \frac{1.5}{12} (.054) = \\ \approx .00047 \text{ IN}^4$$

$$P = \sqrt{\frac{I}{A}} \cdot 10' \sqrt{\frac{675}{.533}} = .0112$$

l = 4.5" LENGTH OF COLUMN

COMPRESSION STRESS:

$$f_c = \frac{P_c}{A} = \frac{690 \times (4.6)^2}{33 \sin 40^\circ (.533)} = 44,500 \text{ psi}$$

FULTON ALLOWABLE = PINNED END CONDITIONS

$$F_o = \frac{\pi E}{(\frac{l}{r})^2} = \frac{30 \times 10^6 \times 9.9}{(\frac{4.5}{.19})^2} = 182,000 \text{ psi}$$

$$M.S. = \frac{150,000}{44,500} - 1 = \underline{H_1}$$

ACCS-1000-11  
SUBJECT

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DATA	
DATA	

## SSRM - 20 PULSE

BY	CHEK BY	DATE
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## BEAM COLUMN

ASSUME THAT THE STUTT IS LOADED UNIFORMLY BY A  $\Delta p = 1610$  psi AS SHOWN BELOW

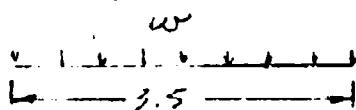


FIG 3.1.6.4

THE LOAD  $w$  IS DETERMINED FROM THE FOLLOWING NET X-SECTIONAL PROJECTED AREA:

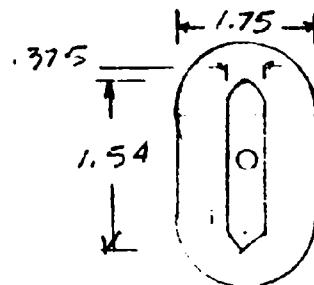


FIG 3.1.6.5

$$w = \frac{1.75}{3.75} \Delta p = \frac{1.75}{3.75} (1610) = 2820 \text{ psi}$$

## BENDING STRESS

$$f_b = \frac{M c}{I}$$

$$M = \frac{w l^2}{8} = 2820 (3.5)^2 = 4320 \text{ in-lb}$$

$$C = .77 \text{ in}$$

$$I = 3.75 \times \frac{1.54}{12} = .115 \text{ in}^4$$

$$= 4320 \left( \frac{.77}{.115} \right) = 29270 \text{ psi}$$

## COMBINED STRESS

$$\sigma = f_c + f_b$$

$$f_c = 44,500 \text{ psi}, \quad \sigma = f_c + f_b = 44,500 + 29,270 = 73,500 \text{ psi}$$

$$F_c = 150,000 \text{ psi}$$

$$M.S. = \frac{150,000}{73,500} - 1 = 1.1$$

Report AFRPL-TR-69-50, Appendix A



AEROJET-GENERAL CORPORATION  
BACAMENTO CALIFORNIA

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SS RM-20 PULSE

PAGE 16, 8 of

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BY H. EFFRON

CHK'D BY

DATE

STRESS DUE TO ACTUATOR FLUID PRESSURE  
IN THE .190" DIAM. HOLE

$$f_H = \frac{P_R}{L}$$

REF: FIG 3.16.4

$$= \frac{3750 (.095)}{.5 (.375 - .19)} = 3850 \text{ psi}$$

$$F_r = 150,000 \text{ psi}$$

$$M.S. = \frac{150,000}{385} = 3.91 \text{ in.}$$

EXTERNAL SHELL:

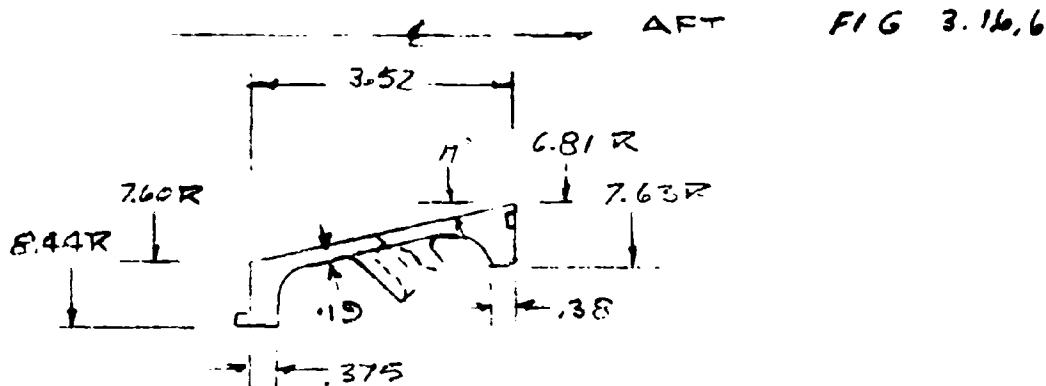


FIG 3.16.6

THE SHELL REQUESTS:

1. INTERNAL PRESSURE
2. STRUT LOADS

$P = 650 \text{ psi}$   
 $P = 18000 \text{ lb}$

Report AFPL-TR-69-50, Appendix A

AUGS-690-11



REPORT NO.

~~REF ID: A620~~

DATE: 9/13/68

SUBJECT

SSRM-20 PULSE

BY

H. EFRON

CHEK BY

DATE

Hoop Stress due to  $f = 690 \text{ psi}$

$$f_h = \frac{P R}{400 S_{17}}$$

$$= \frac{690 (.76)}{.19 (.95)} = 29,000 \text{ psi}$$

$$E_s = 150,000 \text{ psi}$$

$$\mu.s. = \frac{150,000}{29,000} = 1.4$$

STRETCH LOADS:  $P_{st}$

ASSUMPTIONS:

1.  $P_{st}$  L TO SHELL

2. SHELL + FLANGES ACT AS ONE UNIT

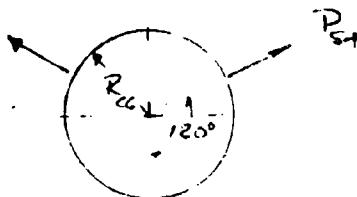


FIG 3.1.6.7

EVALUATING  $P_{st}$  REF FIG 3.1.6.1

$$P_{st} = \frac{P_{st} E}{3 \sin 40^\circ} = \frac{690 \pi 4.6^2}{3 (.642)} = 23,500 \text{ psi}$$



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SSRM- 20 PULSE

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H. EFRON

CHK BY

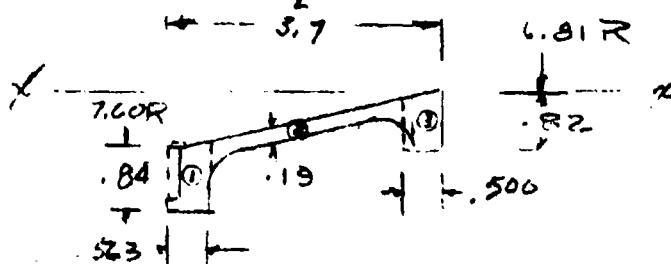
EVALUATING RING GEOMETRY

FIG 3.1.6.8

ITEM	AREA	Y	AY	$AY^2$	$I_o$
1	.473	.41	.194	.080	.0282
2	.38	.50	.190	.035	.0016
3	.41	1.21	.495	.600	.0230
2	1.263		.879	.775	.0528

$$I = \Sigma I_o + \Sigma AY^2 - \Sigma AY^2$$

$$\bar{Y}^2 = \left[ \frac{\Sigma AY^2}{\Sigma A} \right]^2 = \left[ \frac{.775}{1.263} \right]^2 = .7^2 = .49$$

$$= .0528 + .775 - 1.263 (.49) = .157 \text{ IN}^4$$

$$A = 1.263 \text{ IN}^2$$

$$R_{ce} = 6.81 + .70 = 7.51 \text{ IN.}$$

EVALUATING BENDING STRESS:

$$f_b = \frac{Mc}{I}$$

$$M = .5 P R_{ce} (\frac{1}{3} - \cot \theta)$$

REF ROARK, 3<sup>rd</sup> ED.  
TABLE VIII, CASE 3

$$\theta = \pi/3$$

$$\cot \theta = 1.732$$

$$= .5(18000)(7.51)(1.73) = 52,500 \text{ "}$$

$$C = 8.44 - 6.81 - .7 = .93$$

$K = .5$  STIFFNESS ADDED TO RINGS BY  
1. LINERS  
2. BOSSES & ADJACENT SHELL  
STRUCTURES

## Report AFPL-TR-69-50, Appendix A

ASCE-0800-11

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~~100-1000~~

9/13/60

WATER CARRIER

SSRM - 20 PULSE

BY

H. E. FERON

CHK. BY

$$f_{cr} = \frac{M_c K}{I}$$

$$= 52,500 \frac{(.93)}{.197} .5 = 126,000 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

$$M.S. = \frac{150}{126} - 1 = \underline{\underline{.12}}$$

EVALUATING DIRECT STRESS:

$$F_T = \frac{P_{st}}{A} K_t$$

$$\begin{aligned} P_{st} &= 18000 \\ K_t &= .50076 \\ K_s &= .826 \end{aligned}$$

REF. # 8.1.6.3  
REF. ROARK TABLE VIII  
CASE 3

$$= \frac{18000 (.826)}{1.263} = 12,400 \text{ psi}$$

FORMULAS  
FOR  
AND STRESSES

$$F_y = 150,000 \text{ psi}$$

$$M.S. = \frac{150}{12,4} - 1 = \underline{\underline{.11}}$$

COMBINED STRESS:

$$\Sigma f = f_T + f_a$$

$$= 12,400 + 126,000 = 138,400 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

$$M.S. = \frac{150.0}{138,4} - 1 = \underline{\underline{.08}}$$

## Report AFPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
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5/13/68

WORK ORDER

SSRM 20 PULSE

H. EFRON

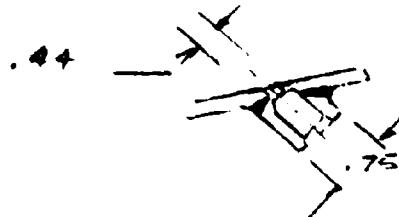
CHK. BY

DATE

WELDS - 100% PENETRATION PROD

--- 4 ---

FIG 3.1.6.9



⑥ PRESSURE TAPS

HOOP STRESS

$$f_s = \frac{P_a R}{t} = \frac{3750(375)}{.15} = 9450 \text{ psi}$$

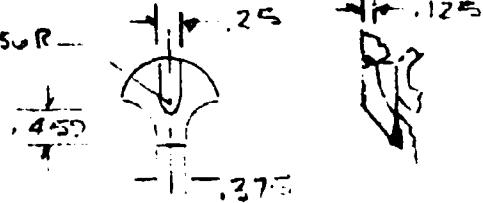
$$F_y = 150,000 \text{ psi}$$

FIG 3.1.6.10

M.F. = H

--- 4 ---

.650R



⑥ TAP TO RING

BLOW-OFF LOAD  $P_b$ 

$$P_b < P_a \cdot \pi t \cdot L C G^2 = 3750(435)1.57 = 2570$$

WELD AREA A (ASSUME 1/8 WELD)

$$A > .125 \pi / 8 = .51 \text{ in}^2$$

WELD STRESS

$$f_s = \frac{P_a}{A} = \frac{3750}{.51} = 7500 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

M.G. =  $\frac{150}{5.5} - 1 - \underline{H}$

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BY

H. FERRON

CHK. BY

DATE

BOLT LOADS - Housing to ChamberBLOW-OFF LOAD / BOLT

$$P_B = \frac{\rho \pi r^2}{60} = \frac{690 \pi (7.6)^2}{60} = 2100 \text{ lb/bolt}$$

KICK LOAD

$$P_K = P_B \times \frac{8.0 - 7.6}{9.3 - 9.0} = \frac{4}{3} P_B = 1.33 P_B$$

TOTAL LOAD / BOLT

$$\approx P = 1.33 P_B = 1.33 (2100) = 4900 \text{ lb}$$

 $\frac{1}{4} - 2.9 \text{ bolts} \rightarrow 6900 \text{ lb ALLEN HEX-HD}$ 

$$M.S. = \frac{6900}{4900} - 1 = .40$$

@ SRC C-C

BENDING:

$$f_b = \frac{6M}{Kt^2}$$

$$f_b = .375$$

$$M = \frac{\rho R}{2} (800 - 7.7)$$

$$= (69)(7.7)(\frac{.3}{2}) = 800 \text{ in-lb/in}$$

$$K = \frac{\pi D - 6.0 (.28)}{\pi D} = \frac{50 - 17}{50} = .68$$

$$= \frac{6(800)}{(141)(.68)} = 50000 \text{ psi}$$

$$F_y = 150,000 \text{ psi}$$

$$M.G. = \frac{150}{50} - 1 = .40$$

## Report AFRPL-TR-69-50, Appendix A

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SACRAMENTO CALIFORNIA

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WOP. ORDER

SSRM ENTRANCE CAP DWG # 1147005

BY W. JORDAN

CHK. BY

DATE

MATERIAL A130 STEEL

$$F_{tu} = 90 \text{ KSI}$$

$$F_{sy} = 70 \text{ KSI}$$

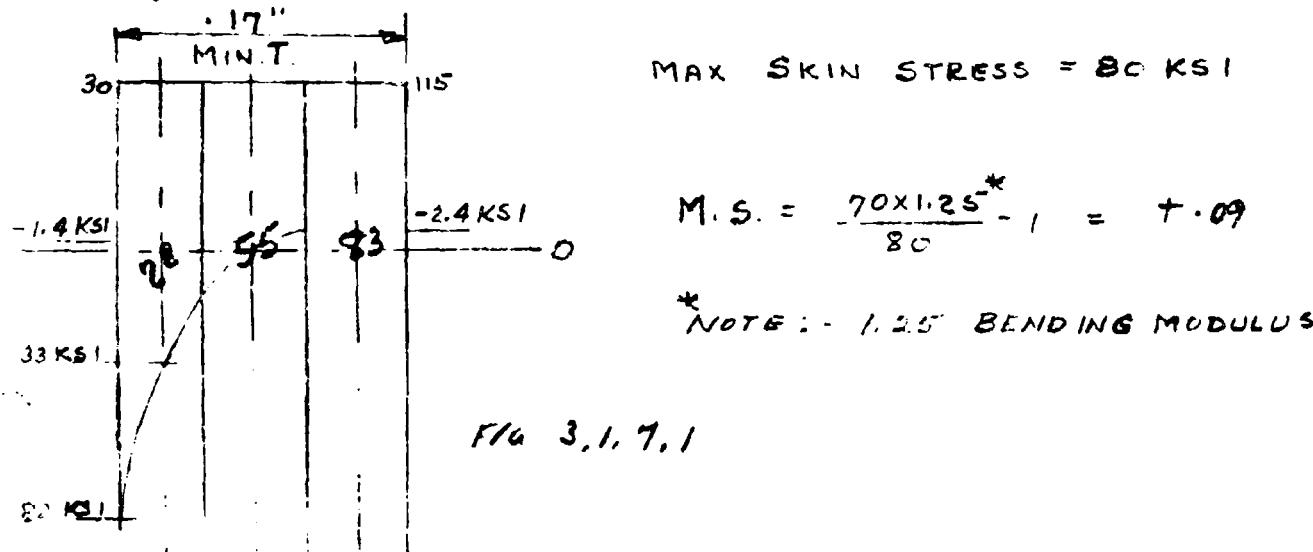
$$\text{PRESSURE } 1.25 \times 550 \text{ PSI} = 690 \text{ PSI}$$

THE CAP WAS ANALYZED MAKING USE OF THE FINITE ELEMENT COMPUTER PROGRAM E 11401 (REF. AGC STRUCTURES MANUAL)

THE FINITE ELEMENT GRID IS SHOWN ON PAGE 3.1.1.2 THE NODAL POINTS 1, 9, 17, 25, 52, 80 & 109 BEING FIXED IN R & Z DIRECTION. NODAL POINTS 171 & 174 BEING PERMITTED TO ROLL OR SLIDE IN RADIAL DIRECTION AND RESTRAINED IN Z DIRECTION.

AS EXPECTED THE HIGHEST STRESSES OCCURRED ACROSS ELEMENTS 28, 55 & 83 NEAR THE CENTER OF THE CAP.

THE FINITE ELEMENT PROGRAM COMPUTES STRESSES AT THE CENTER OF EACH ELEMENT, WHEN BENDING IS PRESENT THESE STRESSES SHOULD BE EXTRAPOLATED TO THE OUTSIDE SURFACE OF THE CAP TO DETERMINE THE MAX. STRESS.



Report AFRPL-TR-69-50, Appendix A

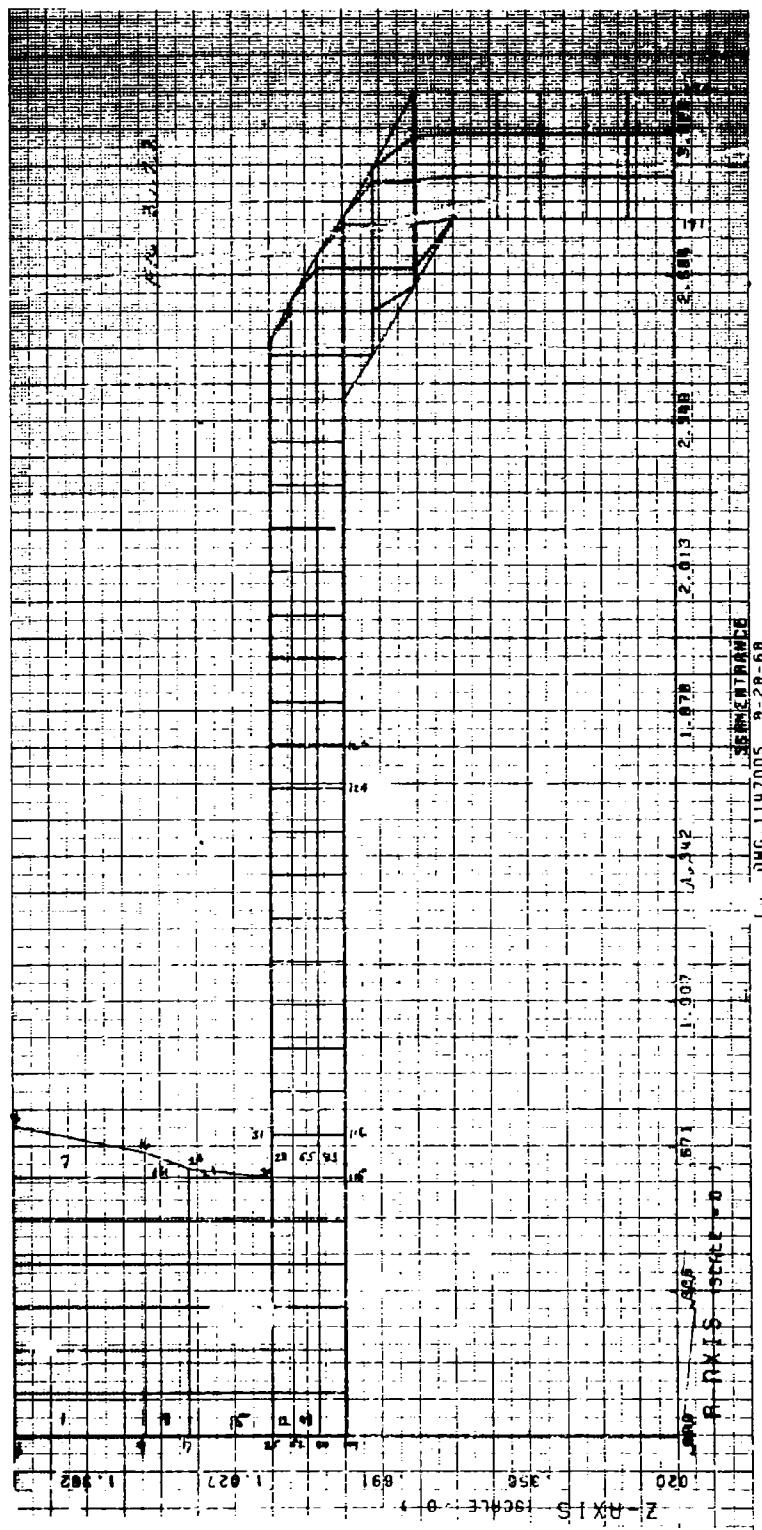
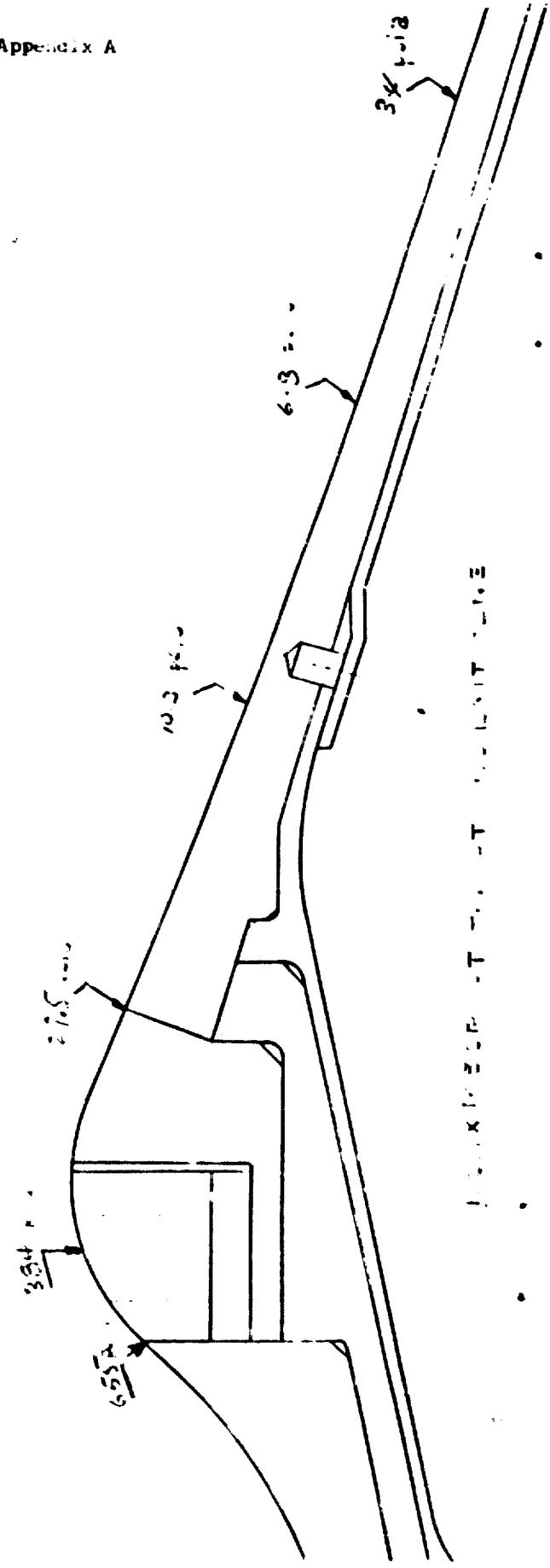


Figure 3.1.7.2

ESTIMATE OF PUFFED SURFACE AREA  
DESIGN SITE - C - UNIT C-11

Report AFPL-TR-10-5C, Appendix A

FIG 3.18.0



10.3 ft dia - T-11 - T-11 - T-11 - T-11 - T-11

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W.D. JORDAN

DATE

## SSRM EXIT CONE PIN DWG # 1147016

BY W. JORDAN CHK BY

MATERIAL SILICA PHENOLIC (MX 2646) AGE 34312-1

$$\left. \begin{array}{l} F_{su} = 5500 \text{ PSI} \\ F_t = 27,000 \text{ PSI} \end{array} \right\} \text{REF FIBERITE HANDBOOK}$$

MARCH 1, 1963 (H. E. FLOW)

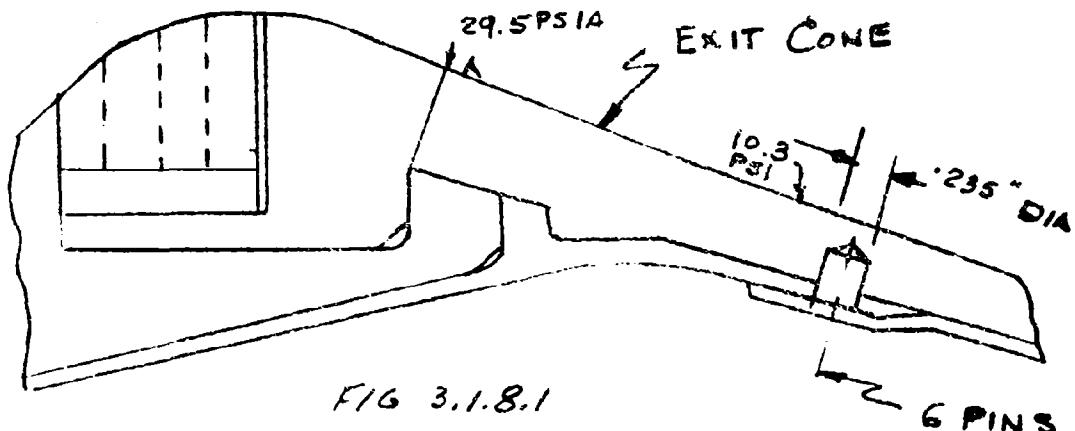


FIG 3.1.8.1

LOAD ON PINS

ASSUME PRESSURE (29.5 PSI) HAS ACCESS BEHIND  
EXIT CONE AT POINT A

THEN POSSIBLE SHEAR LOAD ON PIN

$$= \frac{29.5 \times \pi (5.92^2 - 4.22^2)}{6} - \frac{(29.5 + 10.3)\pi (5.53^2 - 4.22^2)}{2}$$

$$= \frac{1597.6 - 212.4}{6} = 131 \text{ "/PIN}$$

$$\sigma = \frac{P}{A} = \frac{131}{.7854 \times (.225)^2 - (.07)^2} = 3649$$

$$M.S. = \frac{5500}{3649} - 1 = 4.57$$

## Report AFRL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
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SSRM SHELL NOZZLE DWG 1147008

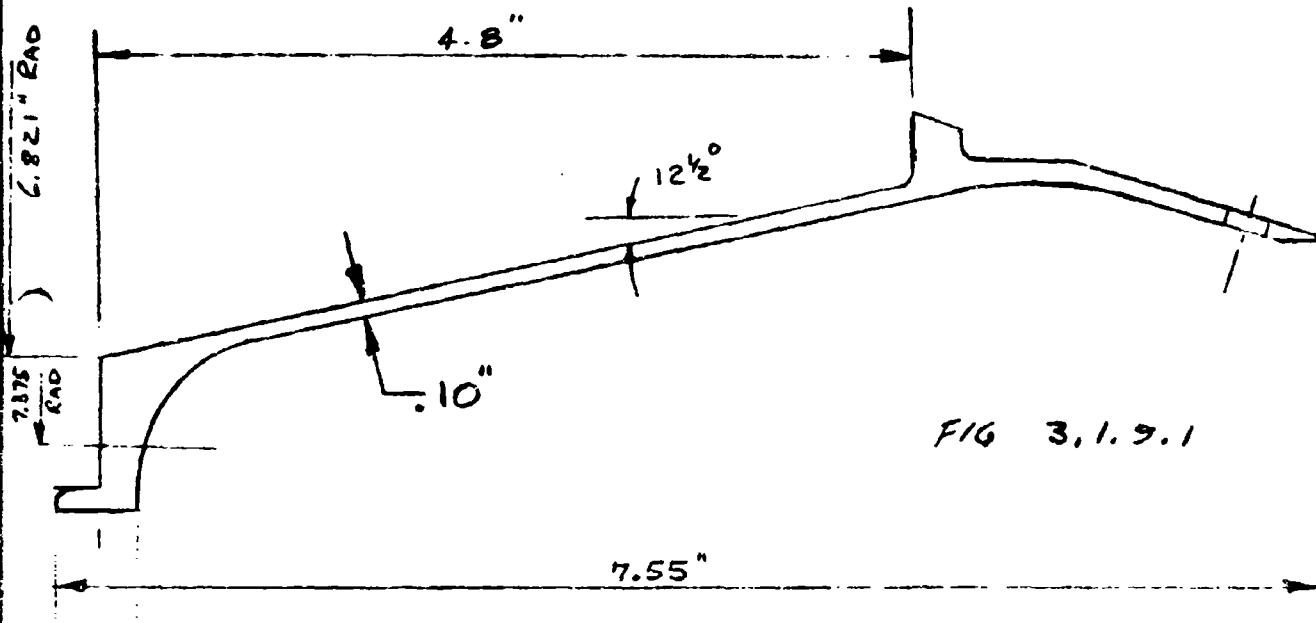
BY W. JORDAN

CHK BY

DATE

MATERIAL STEEL TYPE 4130 MIL-S-675B COND C3.

$$F_y = 150,000 \text{ PSI}$$



.25" MERIDIONAL STRESS @ R = 6.821"

$$\sigma_m = \frac{PR}{E_{GOB}} = \frac{690 \times 6.821}{.09 \times .97630} = 53,564 \text{ PSI}$$

M.S. = HIGH.

$$\epsilon = \frac{53564}{29 \times 10^6} = .0018''$$

## Report AFRPL-TR-69-50, Appendix A

III. 1.9-2

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AEROJET-GENERAL CORPORATION  
SACRAMENTO CALIFORNIA

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NOZZLE SHELL CONT.BOLT LOAD  $74,570 \times 1.30$ 

$$\text{BOLT LOAD / INCH} = \frac{74,570 \times 1.30}{2 \times \pi \times 7.1} = 2174^{\circ}$$

$$\sigma = \frac{6M}{t^2} = \frac{6 \times 2174 \times .55}{(.25)^2} = \underline{114,787 \text{ PSI}}$$

$$\sigma_A = \frac{2174}{.25} = 8,696 \text{ PSI}$$

$$\text{M.S.} = \frac{160,000}{114,787} - 1 = + \underline{.31}$$

## LIP ON NOZZLE SHELL

$$t = .295$$

$$\text{LOAD} = \frac{690 \pi (5.8^2 - 4^2)}{2 \pi \times 5.326} = 1143^{\circ}$$

$$\sigma = \frac{1143}{.295} + \frac{6 \times 1143 \times .295}{(.295)^2}$$

$$= 3875 + 22459 = 26334 \text{ PSI}$$

M.S. HIGH.

## Report AFRPL-TR-69-50, Appendix A

12.1.9-3

AEROSSET-GENERAL CORPORATION  
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NOZZLE SHELL CONT.

$$\text{BOLT LOAD} = P \pi \{a^2 - b^2\}$$

WHERE  $a = \text{SEAL RADIUS} = 7.1"$  $b = 4"$  (THROAT PINTLE SEE PG 3.1.1.1) $P = 690 \text{ PSI}$ 

$$\begin{aligned}\text{BOLT LOAD} &= 690 \times \pi \{(7.1)^2 - 4^2\} \\ &= 74,590^*\end{aligned}$$

30 -  $\frac{1}{4}$ " DIA BOLTS

$$\text{LOAD/BOLT} = \frac{74590}{30} = 2486^* \text{ DIRECT LOAD}$$

ASSUME 30% DIRECT LOAD FOR BENDING

$$\text{LOAD/BOLT} = 1.3 \times 2486 = 3232^*$$

 $\frac{1}{4}$ " BOLT 28 TPI

TORQUE 50-80 IN-LBS.

LOAD IN BOLT @ MIN TORQUE

$$P_b = \frac{T A}{R}$$

$$\begin{aligned}A &= .0326 \text{ IN}^2 \\ R &= .00087 \text{ (LUE)}\end{aligned}$$

$$\frac{8.0 \times .0326}{.00087} = 2998^* \text{ FOR } F_{ut} = 160 \text{ KSI BOLT.}$$

PITCH OF BOLTS =  $1.49"$ USE HIGH STRENGTH BOLTS WITH SUITABLE  
TORQUE

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III.1.10-1



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SSRM SHELL NOZZLE THROAT DWG 1147012

BY W. JOREAN

CHK. BY

DATE

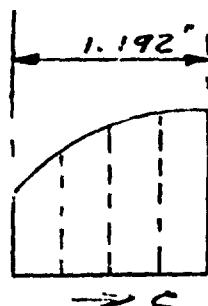
MATERIAL PYROLYTIC GRAPHITE

FIG 3.1.10.1

TEMP. 500°F INSIDE SURFACE

COEF. OF THERMAL EXP.  $\approx +120 \times 10^{-6}$  IN/IN/°F REF AGC  
MATH DATA  
SHEETS

$$\begin{aligned}\Delta &= \alpha \Delta t L \\ &= 120 \times 10^{-6} \times (5000 - 70) \times 1.192 \\ &= .071519 "\end{aligned}$$

NOTE THE NATURAL EXPANSION OF GRAPHITE  
IS AS IF IT CONTAINS THE RUBBER WASHER DWG  
NUMBER 1147011. IZING FIXING IS ABOUT 50% OF  
IT ABOVE. (IE ABOUT .035").

RUBBER WASHER DWG # 1147011-1

MATERIAL V-44) AGC-34161

SHORE HARDNESS 85A

E<sub>comp</sub> = 700 PSI

f = .067

$$\sigma_{comp} = 700 \times \frac{1}{.067} \times (.067 - .035) = 292 \text{ PSI}$$

NOTE- INCOMPLETE;  
M.S. HIGH THERMAL ANALYSIS REQS.

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AEROJET-GENERAL CORPORATION  
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OUTER NOZZLE ASSY. DWG# 1147006

BY W. JORDAN

CHK BY

DATE

MATERIAL GLASS CLOTH STYLE NO 1553 OR EQUIVALENT

$$\left. \begin{array}{l} F_0 = 60,000 \text{ PSI } (\text{WARP}) \\ E = 3 \times 10^6 \text{ PSI } \end{array} \right\} \text{ FROM AGC SOURCE}$$

9-3-68

$$\begin{aligned} t &= 6 \text{ PLIES } = 6 \times .009 = .054 \text{ (COMPOSITE)} \\ \theta &= 16^\circ \end{aligned}$$

$$\sigma_n = \frac{P R}{E G_0 \theta} = \frac{29.5 \times 6.1}{.054 \times .96126} = 3,466 \text{ PSI}$$

M.S = HIGH

$$e = \frac{\sigma}{E} = \frac{3466}{3 \times 10^6} = .001156" / \text{inch}$$

.0011 &lt; .025 OK.

Q P = 3.4

T = 7.2"

$$\sigma_n = \frac{3.4 \times 7.2}{.054 \times .96126} = 472 \text{ PSI}$$

M.S = HIGH.

III. 1.12 - 1

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## MISCELLANEOUS PARTS

PART	DWG. NO	REMARKS
THROAT APPROACH	1147014	THERMAL ANALYSIS OF THIS PART APPEARS IN SEC 3,2 ..
SLEEVE	1147013	SAME
SUPPORT, THROAT	1147010	SAME
INSULATOR, THROAT	1147009	SAME
THROAT, NOZZLE	1147012	SAME
RING, PISTON	1147004	NON- STRUCTURAL
EXIT CONE	1147015	" "
SPACER, THROAT-NOZZLE	1147011	" "

## Report AFRPL-TR-69-50, Appendix A

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## THERMAL STRESS ANALYSIS

RESULTS OF FINITE  
ELEMENT COMPUTER  
PROGRAM E 11405

FIGURES 3.2 AND 3.2.5 SHOW THE  
POSITIONS OF THE PLATE AND SHROUD  
EVALUATED BY THE COMPUTER USING  
ACC COMPUTER PROGRAM E 11405.

THE RESULTS OF THE THERMAL  
STRESS ANALYSIS FOR SPECIFIED CRITICAL  
AREAS ARE REPORTED IN THIS SECTION.

COMPONENT	M.S.	Ref
PIRPLE COUPLING	4.1	3.2.1.1
" THROAT REINFORC.	0.13	3.2.2.2
PIRPLE THROAT	0.00	3.2.4.1 92
SHROUD THROAT	.34	3.2.5.1

This analysis uses a F.S. = 1.0,  
therefore, at limit loads

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Report AFRPL-TR-69-50, Appendix A

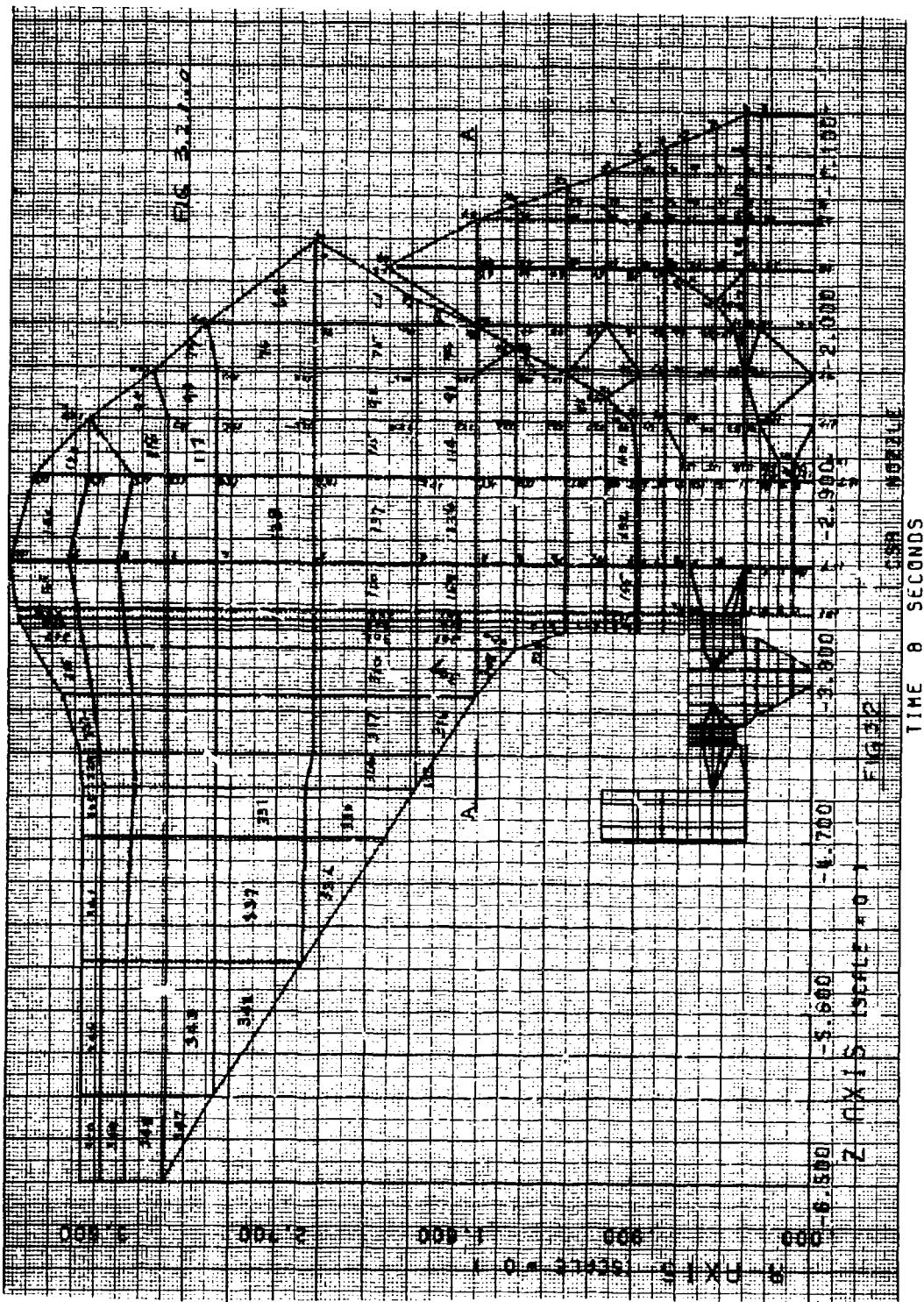


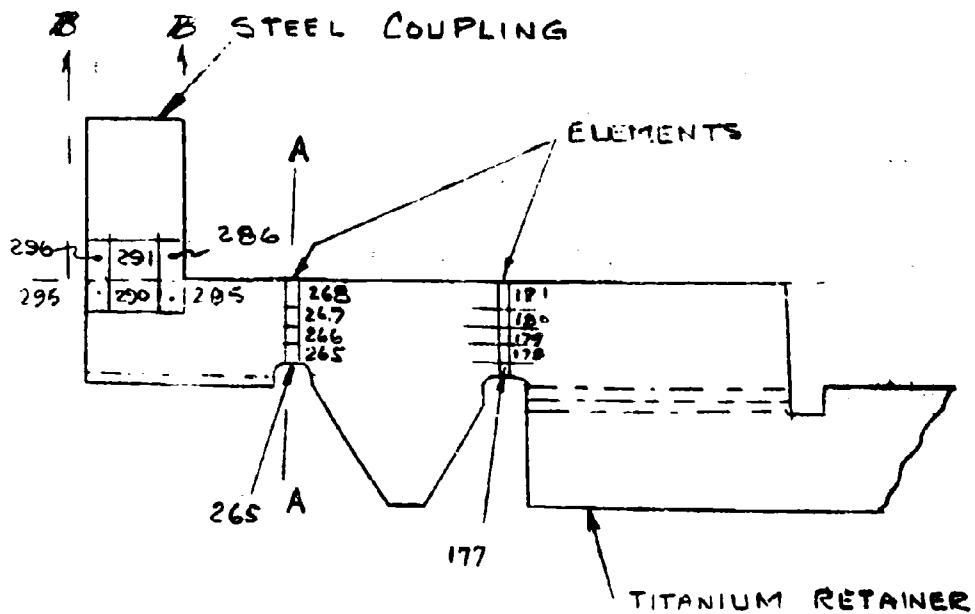
Figure 3.2.1.0

P. 2.1.1

SSRM COUPLING

MATERIAL STEEL 4130

FIG 8.2.1.1



FROM COMPUTER CALCULATIONS, MAX STRESS OCCURS  
AT A-A

$$\begin{aligned} \text{ELEM 265 ; } 37121 \text{ PSI} \times \pi ( .45^2 - .39^2 ) &= 1871 \text{ PI} \\ 266 ; 33,473 &\times \pi (.50^2 - .45^2) = 1591 \text{ PI} \\ 267 ; 36,724 &\times \pi (.58^2 - .5^2) = 1991 \text{ PI} \\ 268 ; 36,961 &\times \pi (.625^2 - .55^2) = \underline{9257 \text{ PI}} \\ &\quad 8610 \text{ PI} \end{aligned}$$

$$\text{KINN-SECTION AREA} = \pi (.625^2 - .39^2) = .2385 \text{ PI}$$

$$\text{AVERAGE STRESS} = \frac{8610}{.2385} = 36,100 \text{ PSI}$$

AT B-B

ELEM 295 ; 15044 PSI SHEAR STRESS

$$\text{M.S.}_{\text{A-A}} = \frac{150,000}{36,100} - 1 = \underline{\underline{4.1}}$$

$$\text{M.S.}_{\text{B-B}} = \frac{80,000}{15,044} - 1 = \underline{\underline{4.1}}$$

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SSRM RETAINER THROAT DWG 1147003

BY

CHK BY

MATERIAL: TITANIUM ALLOY (GAL-4V)

$F_y = 160 \text{ KSI}$  @ ROOM TEMP.

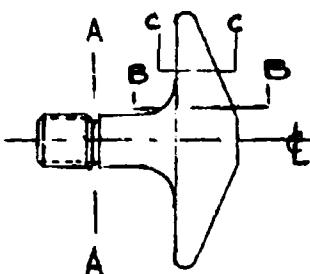


FIG 3.2.2.1

FROM COMPUTER ANALYSIS, THE HIGHEST STRESS IS AT SECTION A-A

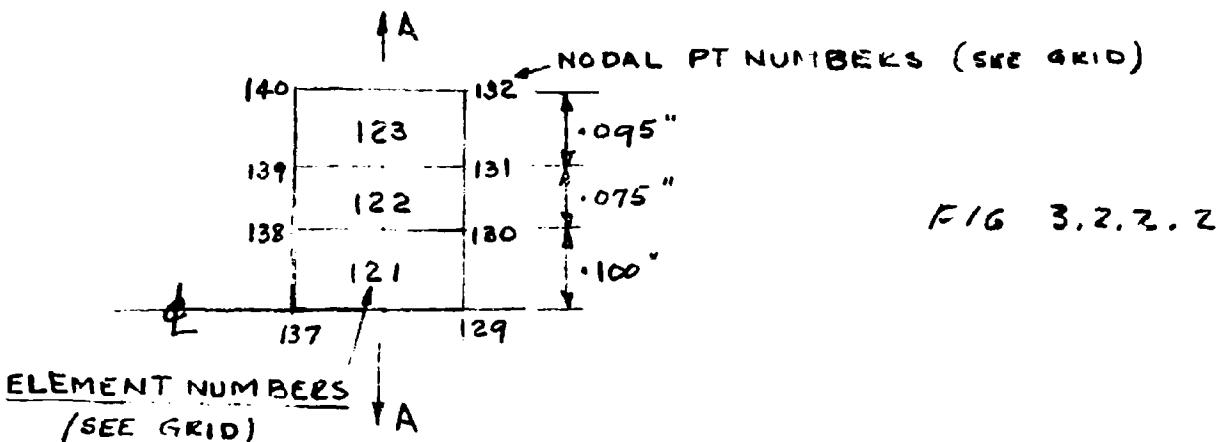


FIG 3.2.2.2

$$\begin{aligned} \text{LOAD ACROSS A-A} &= 151,900 \times \pi \times (2.7^2 - 1.75^2) = 6422 (\text{lb}) \\ 76,495 \times \pi \times (1.75^2 - 1^2) &= 1588 (\text{lb}) \\ 69,961 \times \pi \times 1^2 &= 700 (\text{lb}) \\ &\hline \end{aligned}$$

$$8710 \text{ lb}$$

$$\text{FROM DRAWING DIA. @ UNDERCUT} = .562 - .01 (\text{in}) = .552$$

$$A = .0762 \pi \text{ in}^2$$

$$\text{AVERAGE STRESS ACROSS SECTION} = 114300 \text{ PSI}$$

## Report AFPL-TR-69-50, Appendix A

AEROJET-GENERAL CORPORATION  
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WORN ORDER	
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RETAINER THROAT CONT.

(4) TIME 750 SEC'S TEMP = 200°F

$$\begin{array}{rcl}
 \text{LOAD ACROSS A-A} & = & 151,220 \text{ IN}^2 (27^2 - .17^2) = 6398 \text{ IN} \\
 & = & 77955 \text{ IN} (.17^2 - .1^2) = 16087 \\
 & = & 71030 \text{ IN} (.1^2) = 710 \text{ IN} \\
 & & \hline
 & = & 8711 \text{ IN}
 \end{array}$$

$$A = .0762 \text{ IN}^2$$

AVERAGE STRESS ACROSS SECTION AT A-A

$$= \frac{8711}{.0762} = 114,318 \text{ PSI} @ 200^\circ\text{F}$$

TEMPERATURE DEGRADATION FACTORS @ 200°F REF. MIL-HDBK-5

$$F_{64} = .91 ; F_{87} = .86$$

$$F_{87} = 150,000 \times .86 = 129,000 \text{ PSI}$$

$$M.S. = \frac{129000}{114318} - 1 = \underline{\underline{+.13}}$$

NOTE:- ALL OTHER ELEMENTS IN THE TITANIUM THROAT  
 RETAINER HAD STRESS LEVELS WELL BELOW THAT  
 CALCULATED AT ELEMENTS 121, 122 & 123.

## Report AFPL-TR-69-50, Appendix A

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SACRAMENTO CALIFORNIA

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SSRM RETAINER THROAT DWG 1147003

BY CHK BY DATE

RETAINER THROAT CONT.SECTION B-B (FIG 3.2.2.1)

FROM COMPUTER ANALYSIS THE AVERAGE SHEAR STRESS ALONG B-B

ELEM.	STRESS PSI	WIDTH	LOAD
66	68,900	.25	17225
47	36,000	.30	10800
29	17,300	.25	4325
19	11,500	.075	863
10	8310	.175	1454
3	2090	.31	648
			<u>35,315</u>
			<u>1.36</u> = <u>26,000 PSI</u>

MAX STRESS AT THIS LOCATION IS AT ELEMENT 66  
= 72,700 PSI

$$M.S. = \frac{189,000}{72,700} - 1 = + \underline{\underline{.77}} @ \text{TIME } 750 \text{ SEC}$$

M.S. SHEAR = HIGH

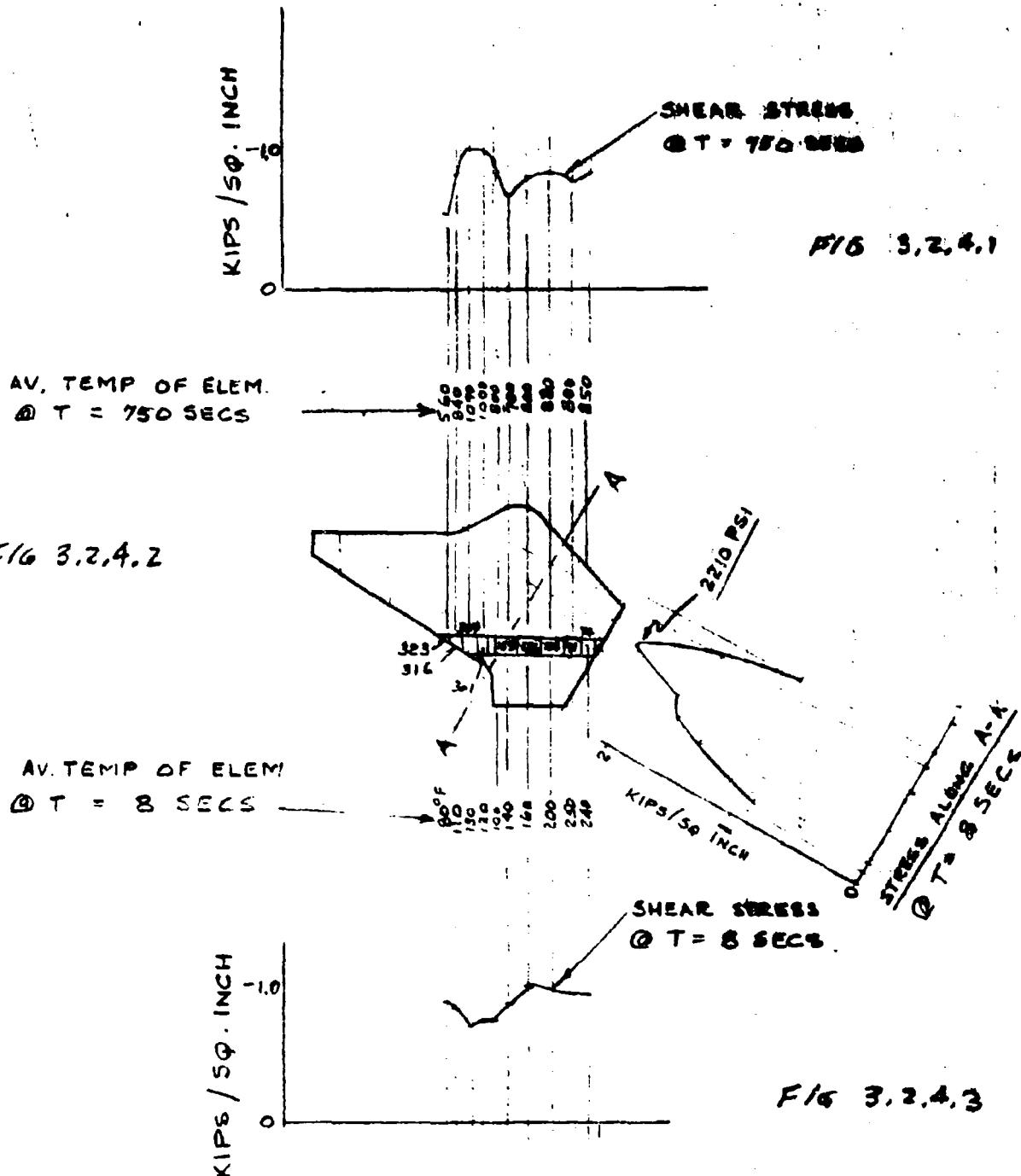
SECTION C-C (FIG 3.2.2.1)

MAX STRESS = 37,500 PSI

M.S. = HIGH

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SSRM THROAT PINTLE

P.E.T. 8.1

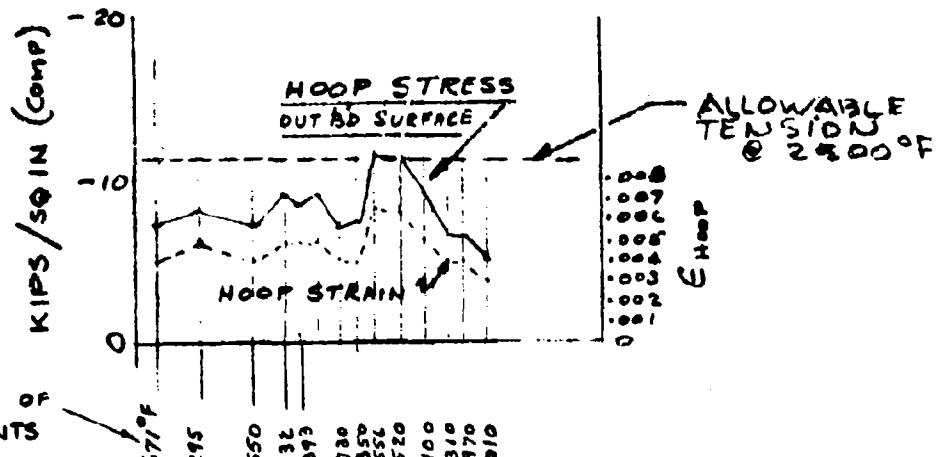


$$T_{S\pi R}^1 = 2700 \text{ PSI} \quad \text{REF } \phi 3.1.1.1$$

$$\text{M.S.} = \frac{2700}{2210} - 1 = .\underline{\underline{24}}$$

SRM THROAT PINTLE TIME 8 SECS

FIG 3.2.4.4



AV. TEMP °F OF OUTBOARD ELEMENTS

FIG 3.2.4.5

AV. TEMP °F OF INBOARD ELEMENTS

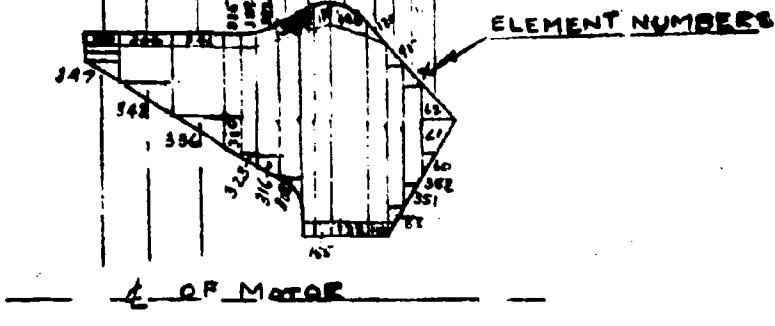
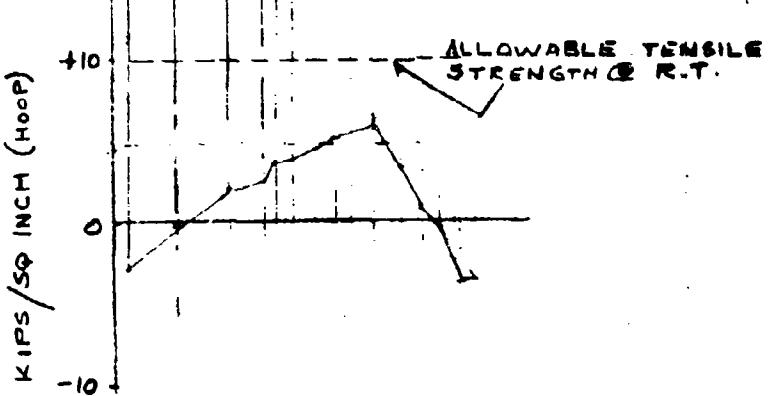


FIG 3.2.4.6

M.S. = O.C.HOOP STRESSES LONG  
INBOARD SURFACE (ASCAIRB 101)

Report AFRPL-TR-69-50, Appendix A

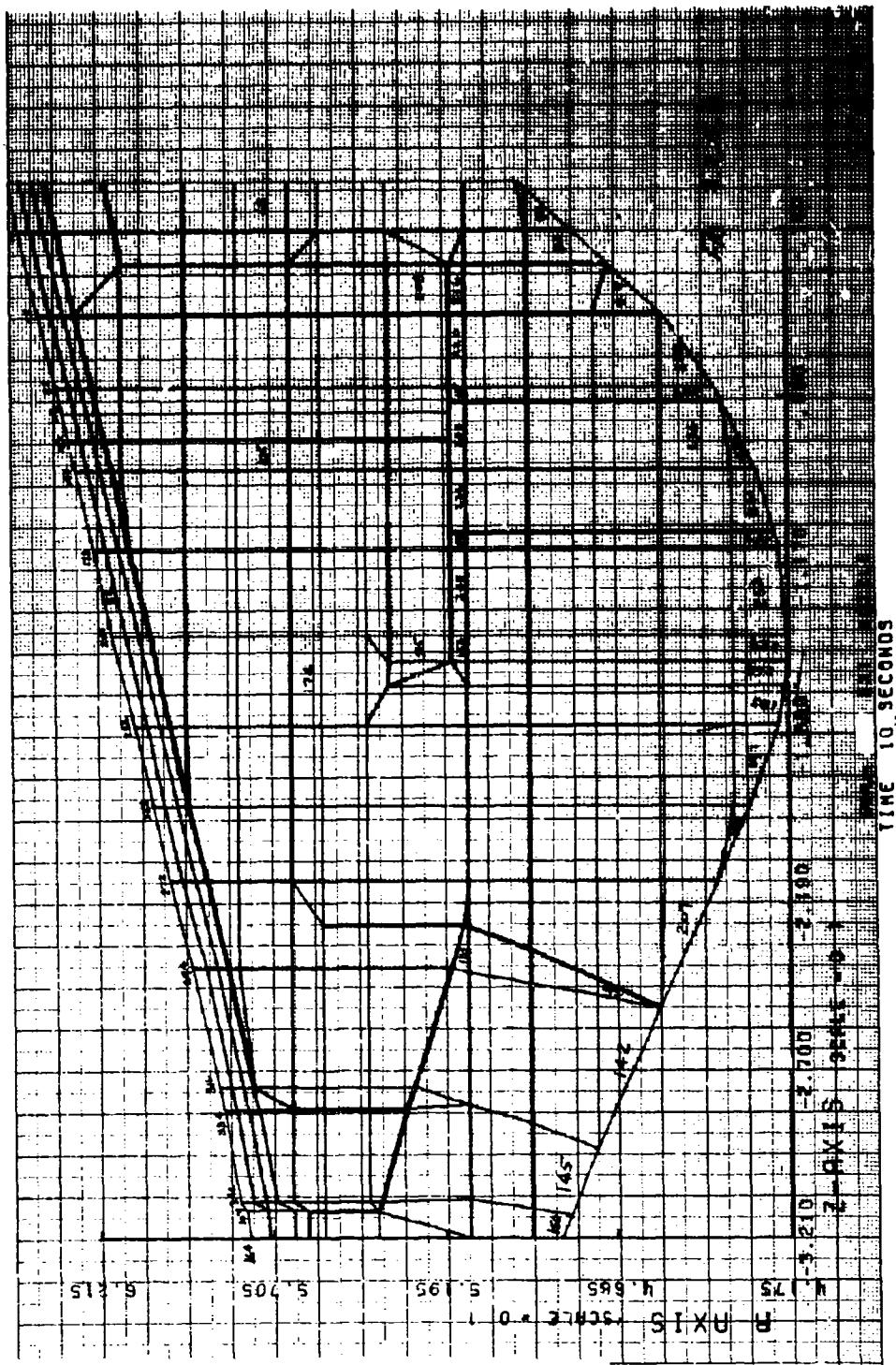


Figure 3.2.5.0

FIG  
3.2.5.1

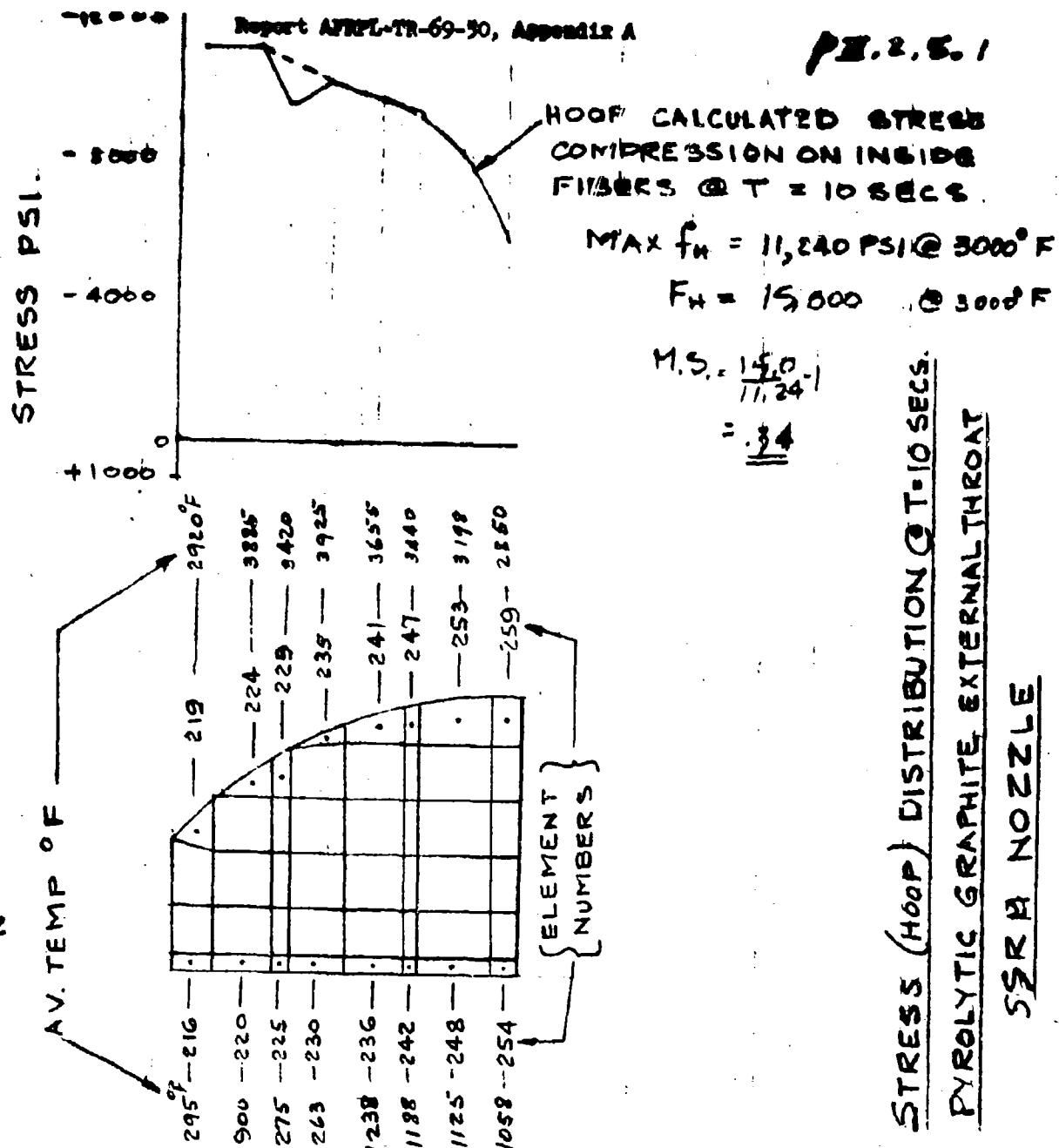
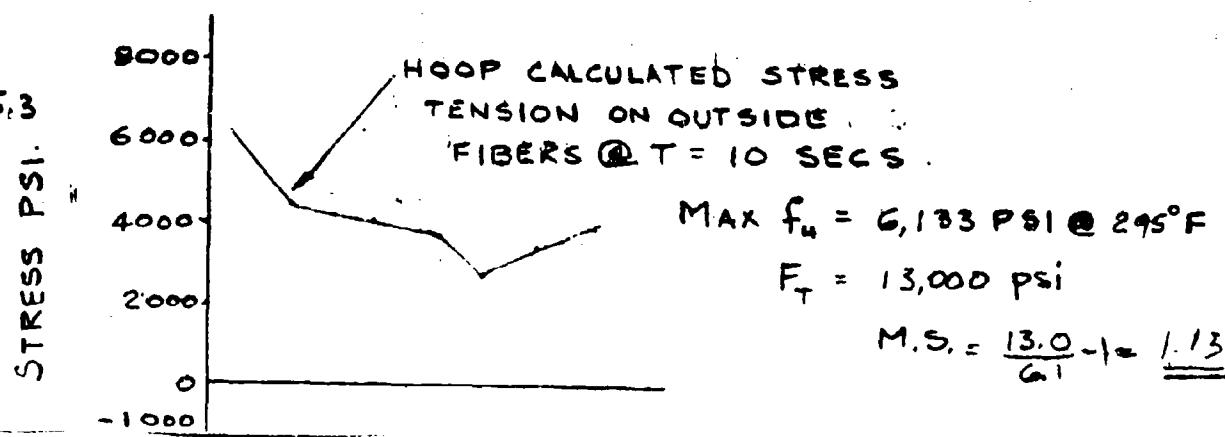


FIG  
3.2.5.3



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SSRM PROPELLANT  
GRAIN STRESS ANALYSIS

AEROJET-GENERAL CORPORATION  
SACRAMENTO

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III.3.1.

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SSRM - PLATINUM THERMISTOR ANALYSIS

BY J.W. THREK

CHK. BY

I. DESIGN

## REFERENCE DRAWINGS

1146991

1146992

II DESIGN CRITERIAA. LIQUIDS

## 1. STORAGE

T = 0°F

t = 30 DAYS

## 2. FIRING

T = 77°F

t<sub>IGNITION</sub> = 155 SEC.P<sub>IGNITION</sub> = 750 PSIA.P<sub>MECH</sub> = 550 PSIG.B. MATERIAL PROPERTIES

## 1. MOTOR CASE

SHELL : AMS 6431 ; t<sub>MARREL</sub> = .070 IN.

INSULATION : GEN-GARD 4010

E<sub>CASE</sub> = 29 x 10<sup>6</sup> PSId<sub>CASE</sub> = 4.3 x 10<sup>-6</sup> IN./IN./°F

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III.3.2

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## 2. PROPELLANT GRAIN (REFERENCE (1))

2. AAP 3318

$$T_{CURE} = 135^{\circ}\text{F}$$

$$\alpha = 6.4 \times 10^{-5} \text{ IN./IN./}^{\circ}\text{F}$$

$$E_{STORAGE} = 315 \text{ PSI} \quad @ T = 0^{\circ}\text{F}$$

$t = 30 \text{ DAYS}$

$$E_{FIRMING} = 500 \text{ PSI} \quad @ T = 77^{\circ}\text{F}$$

$t = 155 \text{ SEC.}$

$$E_{STORAGE} = 220 \text{ PSI} \quad @ T = 77^{\circ}\text{F}$$

$t = 24 \text{ HRS.}$

## C. ALLOWABLES

1. AAP 3318

a. STORAGE ( $0^{\circ}\text{F}$ )

(1) INNER BORE HOOP STRAIN

$$\epsilon_0 = 12\%$$

(2) INTERFACE BOND STRAIN

$$\bar{T}_{R1} = 44 \text{ PSI}$$

$$\bar{T}_{R2} = 28 \text{ PSI}$$



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**b. FIRING (77°F)****a) INNER BORE HOOP STRAIN**

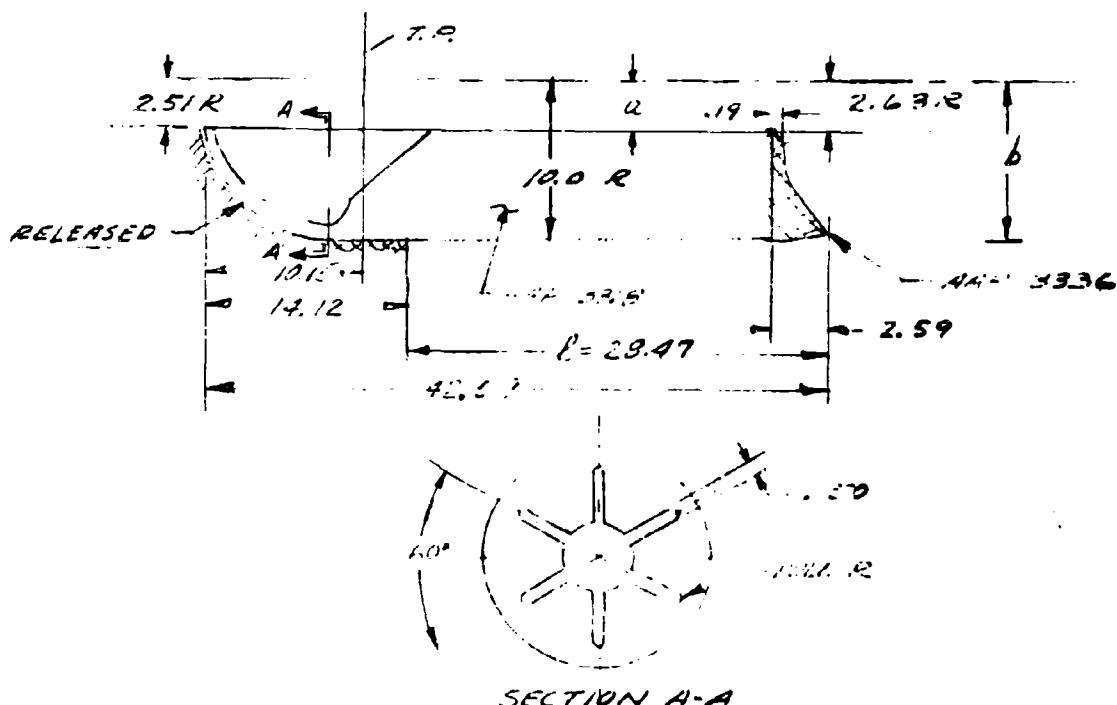
$$\epsilon_0 = 55 \%$$

**2) INTERFACE BOND STRESSES**

$$\tau_{xz} = 188 \text{ psi}$$

**II GEOMETRICAL PARAMETERS****A. GEOMETRY**

FIG. 3.3.1



III.3.4

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B. PARAMETERS

$$\frac{b}{a} = \frac{10.00}{2.63} = 3.80$$

$$\frac{l}{b} = \frac{28.47}{10.13} = 2.85$$

## III ANALYSIS

A PRELIMINARY STRESS AND STRAIN ANALYSIS OF THE GRAIN IS CONDUCTED ON THE BASIS OF THE PARAMETRIC CURVES GIVEN IN REFERENCE (2).

A. ASSUMPTIONS

1. ASSUME CYLINDRICAL GRAIN SHAPE WITH 2.63 IN. BORE AND 28.47 IN. LENGTH.
2. FORWARD SECTION RELEASED PAST TANGENCY PLANE TO LOCATION WHERE FIN SLOTS TERMINATE.
3. AAP 3336 GRAN LOCATED BETWEEN 0- 9 % OF GRAIN LENGTH HAS MATERIAL PROPERTIES AND ALLOWABLES COMPARABLE TO AAP-3318.

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### E. PARAMETRIC STRESSES

#### 1. STORAGE

a. HAP 3318

$$\epsilon_0 = 4.15 \%$$

$$\bar{\tau}_k = 57.9 \text{ psi}$$

$$\bar{\tau}_{\sigma} = 18.5 \text{ psi}$$

b. HAP 3336

$$\epsilon_0 = 2.08 \%$$

$$\bar{\tau}_k = 67.9 \text{ psi}$$

$$\bar{\tau}_{\sigma} = 18.5 \text{ psi}$$

#### 2. FIRING

a. HAP 3318

$$\epsilon_0 = 2.86 \%$$

$$\bar{\tau}_{\sigma} = 10.3 \text{ psi}$$

b. HAP 3336

$$\epsilon_0 = 1.73 \%$$

$$\bar{\tau}_{\sigma} = 10.3 \text{ psi}$$

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## C. BASIC STRESSES

## 1. STORAGE

$$\Delta T = -[135-0] = -135^{\circ}\text{F}$$

## a. AAP 3318

$$\epsilon_0 = 4.15 \times \frac{-135}{-79} = 7.1 \%$$

$$\sqrt{\epsilon_0} = 67.9 \times \frac{315}{1000} \times \frac{-135}{-79} = 37 \text{ psi}$$

$$\tau_{eq} = 18.5 \times \frac{315}{1000} \times \frac{-135}{-79} = 10.0 \text{ psi}$$

## b. AAP 3336

$$\epsilon_0 = 2.08 \times \frac{-135}{-79} = 3.6 \%$$

$$\sqrt{\epsilon_0} = 67.9 \times \frac{315}{1000} \times \frac{-135}{-79} = 37 \text{ psi}$$

$$\tau_{eq} = 18.5 \times \frac{315}{1000} \times \frac{-135}{-79} = 10.0 \text{ psi}$$

## 2. FIRING (77°F)

$$\Delta T = -[135-77] = -58^{\circ}\text{F}$$

## a. AAP 3318

$$\epsilon_0 = 2.9 \%$$

$$\epsilon_{TEMP} = 4.15 \times \frac{-59}{-79} = 3.0 \%$$

$$\epsilon_{TOTAL} = 2.9 + 3.0 = 5.9 \%$$

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$$\sigma_{e2} = 10.3 \times \frac{500}{1000} = 5.2 \text{ PSI}$$

$$\sigma_{R2} = 18.5 \times \frac{220}{1000} \times \frac{-58}{-79} = 3.0 \text{ PSI}$$

$$\sigma_{T2} = \frac{\sigma_{e2}}{\text{TOTAL}} + \frac{\sigma_{R2}}{\text{TOTAL}} = 5.2 + 3.0 = 8.2 \text{ PSI}$$

b. HAP 3336

$$\epsilon_e = 1.7\%$$

$$\epsilon_{e_{\text{TOTAL}}} = 2.08 \times \frac{-58}{-79} = 1.5\%$$

$$\epsilon_{\text{TOTAL}} = 1.7 + 1.5 = 3.2\%$$

$$\sigma_{T2} = \frac{8.2 \text{ PSI}}{\text{TOTAL}}$$

D. MINIMUM MARGINS OF SAFETY

THE MAXIMUM STRESSES AND STRAINS WITH CORRESPONDING MARGINS OF SAFETY ARE GIVEN IN FIGURE 3.3.2. THE MINIMUM MARGIN OF SAFETY WAS DETERMINED TO BE 1.19 FOR THE PROPELLANT-INSULATION BOND TENSILE STRESS DURING STORAGE AT 0°F.

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#### IV. REFERENCES

1. MEMORANDUM TO C.T. LEVINSKY FROM G T SWIG. SUBJECT : "STRUCTURAL INTEGRITY EVALUATION OF 55 CM PROPELLANT/LINER SYSTEM", MEMO. NO. 3044-0740, DATED 17 SEPT. 1968
2. AEROJET STRUCTURES MANUAL

Summary of Propellant Grain  
Stress Analysis

CONDITION	INNER SHEAR TENSILE HOOP STRAIN (%)	BOND STRESS (PSI)	BOND TENSILE STRESS (PSI)	MATERIAL ALLOWABLE M.S.	MAXIMUM ALLOWABLE M.S.
STORAGE * ( $\approx$ 2 DAYS @ 0°F)	7.1	12	+6.9	10	28
FIRING ( $P = 750$ PSIA $\Delta T = 77^{\circ}F$ $t_{100\%} = .155$ SEC)					

\*  $T_{cure} = 135^{\circ}F$

FIGURE 3.3.2

Report AFRPL-TR-69-50, Appendix B

APPENDIX B

STRESS ANALYSIS OF TWENTY-PULSE IGNITER FOR STOP/START ROCKET MOTOR

STRESS ANALYSIS OF THE  
TWENTY-PULSE IGNITER

Section I      INTRODUCTION

- A. Summary of Results
- B. Method of Analysis

Section II      DESIGN CRITERIA

- A. Loads
- B. Material Properties
- C. Geometry

Section III      STRESS ANALYSIS

- A. Forward Boss
- B. Forward Closure and Barrel
- C. Aft Closure
- D. Plastic Components

I. INTRODUCTION

A. SUMMARY OF RESULTS

The table on Page I-2 and I-3 is a summary of the minimum margins of safety. The minimum margin occurs in the threaded portion of the aft closure.

B. METHODS OF ANALYSIS

This report uses two methods of analysis. The basic design was checked using conventional discontinuity pressure vessel analysis (Ref: Kellogg Report - 9th Army-Navy-Air Force Solid Propellant Meeting, Structural Analysis for Design of Lightweight Rocket Shells).

As time permitted later in the design effort, AGC computer program E-11405 was used as a final check. This is a finite element technique which can incorporate arbitrary pressure and geometry of the igniter.

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## TABLE OF MARGINS OF SAFETY

BY	CHK BY	DATE
<u>STRUCTURE</u>	<u>TYPE</u>	<u>MARGIN OF SAFETY</u>
<u>FWL CLOSURE AND BARREL</u>	CROWN SECTION SHEAR LIP	HIGH
	CROWN SECTION BENDING	+1.3
	BOSS HOOP STRESS	+.27
	BOSS MERIDIONAL STRESS	+.29
	BARREL HOOP STRESS	+.03
BARREL MERID. STRESS	+.96	
<u>AFT CLOSURE</u>	<u>THREADED JOINT HOOP STRESS</u>	+ .004
	THREADED JOINT MERID. STRES	+ .51
	THREAD SHEAR	HIGH
	JOINT BENDING & TENSION	+ .17
	MEMBRANE STRESS	+ .28
	FLANGE BOLT STRES	HIGH
	FLANGE BENDING	+ .64
	THROAT SUPPORT STRUCT. STRAIN	HIGH
<u>PLASTIC PARTS</u>	EXIT CONE SHEAR (STEEL)	HIGH
	EXIT CONE BENDING (STEEL)	+ .51
	FASILNER NAS-EGL-2-01 HI	HIGH
SHEAR IN MK 2625 IN EXIT CONE	HIGH	3.D.3
BENDING IN MK 2625 IN EXIT CONE	+ .04	3.D.4
THROAT RETAINER SHEAR	+ .23	3.D.1
" " BENDING	+ .03	3.D.2

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PLASTIC PARTS (CONT'D)	EXIT CONE LINER SHEAR	HIGH	3.D.3
	" " " ENDING	HIGH	3.D.4
	CLOSURE LINER ELONGATION	ADEQUATE	3.D.6
	ENTRANCE CAP	NO LOADS	3.D.6
	THROAT CLEARANCE REQ'D TO PERMIT FREE THERMAL EXPANSION	.036"	3.D.6
	INSULATOR HOOP STRAIN	+ .90	3.D.7



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## 20 PULSE IGNITER

BY

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SECTION II DESIGN CRITERIAA LOADS : 20 CYCLES

MAX. EXPECTED OPERATING PRESS (MEOP) 3000 PSI  
 THRUST 1500"

FACTOR OF SAFETY (SF) = 1.25

DESIGN LOAD  $1.25 \times 3000 \text{ PSI} = 3750 \text{ PSI}$   
 THRUST  $1.25 \times 1500" = 1875"$

B MATERIAL PROPERTIES :-

4130 STEEL

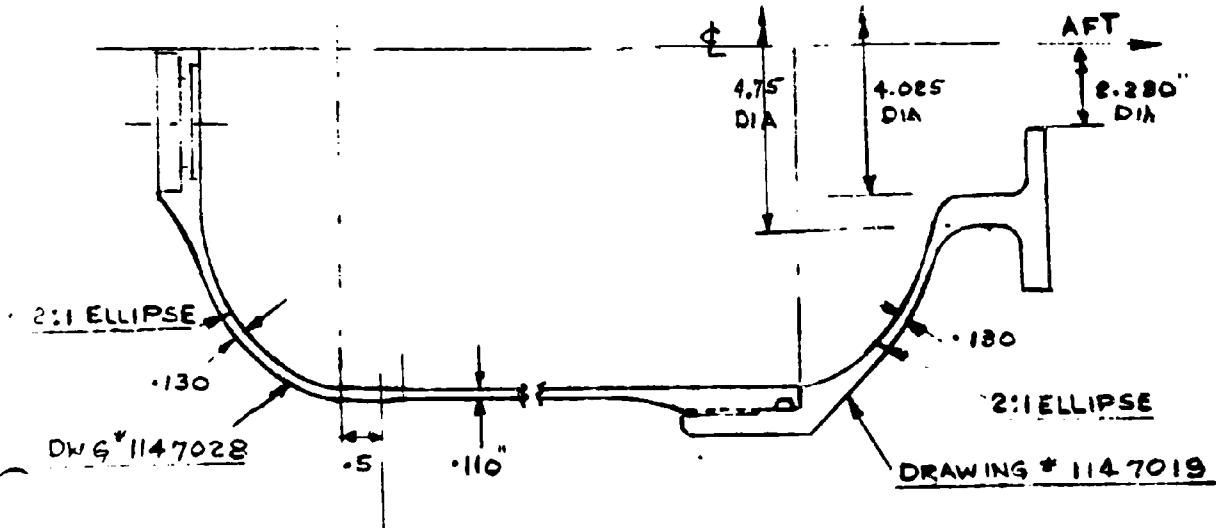
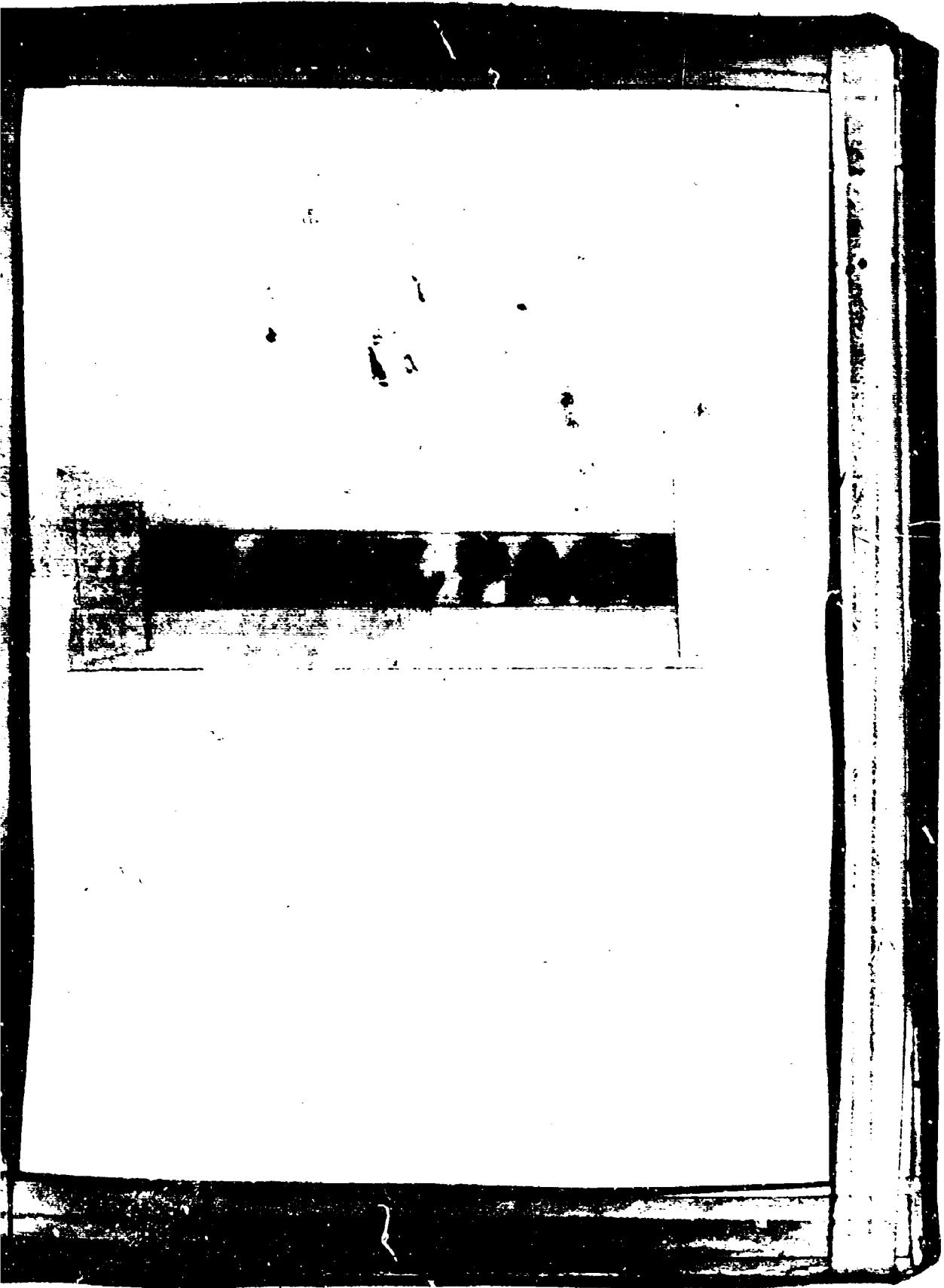
 $F_{tu} = 180,000 \text{ PSI}$  $F_{y} = 163,000 \text{ PSI}$  $F_{su} = 109,000 \text{ PSI}$  $E = 29 \times 10^6 \text{ PSI}$ C. GEOMETRY

FIGURE II - 1



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## SECTION III STRESS ANALYSIS

- A. FWD BOSS AREA
- B FWD CLOSURE & BARREL
- C AFT CLOSURE
- D PLASTIC COMPONENTS

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**SECTION III-A FWD BOSS AREA**

BY J. LOVACS

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REVISED BY W.A. BURNHAM 10-25-68

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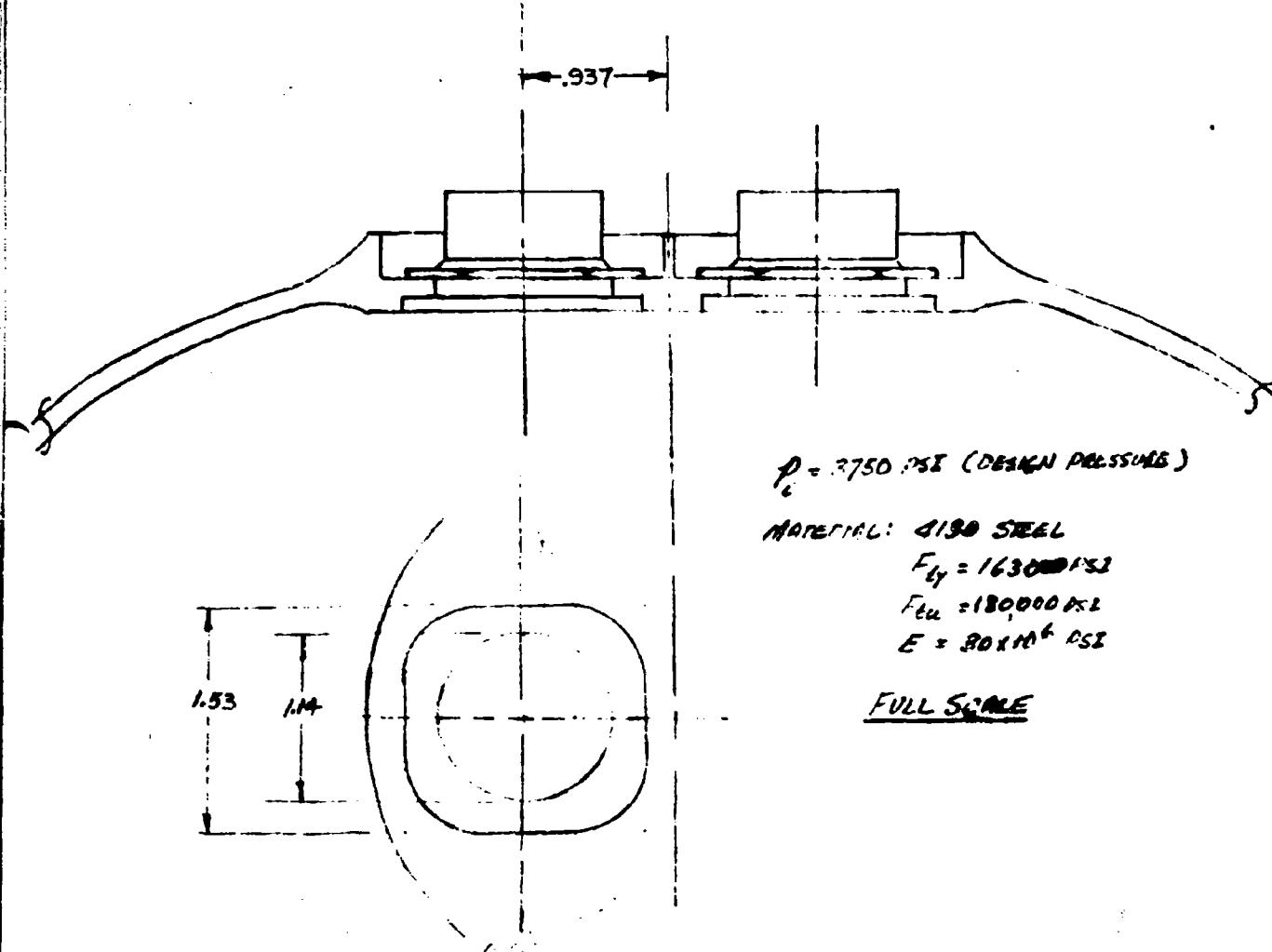
IGNITER PLUGGED CLOSUREBOTTOM VIEW

FIG III-1



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IGNITER PERFORMED CLOSURE - CONT'D

IT IS APPARENT THAT THE CROWN SECTION MID-WAY BETWEEN THE TWO PERFORATIONS IS A CRITICAL AREA. FOR THE PURPOSE OF PRELIMINARY ANALYSIS THE BEST CONSIDERATION OF THE STRUCTURAL RESPONSE IS TO CONSIDER THE MALE STRIP AS A BEAM HAVING THE INDICATED SECTION, LENGTH AND LOADS AS PULLING.

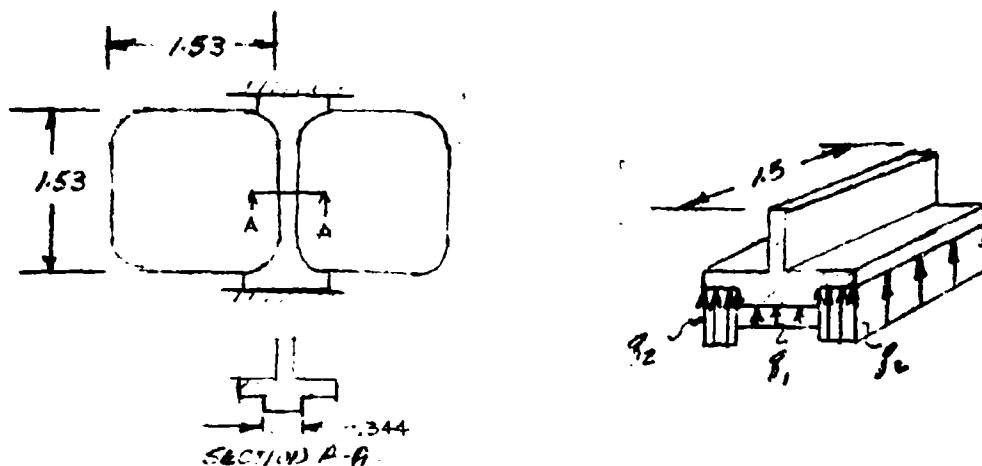


FIG III-2

Total Ejection Load on the Port Face:

$$P = 3750(1.5)(1.5) = 8780 \text{ LBS.}$$

$$\text{PERIPHERY LOAD (SECTION)} + \frac{8780}{6} = 1060 \text{ LBS/IN} = q_2$$

$$q_1 = .344(3750) = 1290 \text{ LBS/IN}$$

$$\text{TOTAL BEAM EQUILIBRIUM LOAD. } q = 2q_2 + q_1 = 2(1060) + (1290) \\ = 4210 \text{ LBS/IN}$$

$$\text{TOTAL BEAM LOAD } P = 4210(7.5) = 6440 \text{ LBS}$$

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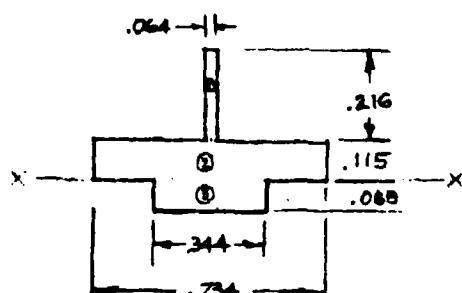
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IGNITER DECORATED CLOSURE - CONT'D

FIG III-3



$$A_1 = .064(.216) = .0139$$

Y = .273 FROM X-X

$$A_2 = .115(.734) = .0845$$

Y<sub>2</sub> = .0575

$$A_3 = .068(.344) = .0237$$

Y<sub>3</sub> = -.0545

$$I_{x1} = \frac{.064(.216)^3}{12} = .0000537$$

$$I_{x2} = \frac{1}{12}(.734)(.115)^3 = .000372 \text{ (ABOUT X-X)}$$

$$I_{x3} = \frac{1}{12}(.344)(.068)^3 = .0000377 \text{ (ABOUT X-X)}$$

A	Y	AY	AY <sup>2</sup>	I <sub>x</sub>	Y - Ȳ	(Y - Ȳ) <sup>2</sup> A	I <sub>x</sub> + A(Y - Ȳ) <sup>2</sup>
.0139	.273	.00380	.00104	.0000537	.2086	.000606	.00066
.0845	.0575	.00486	.000280	.000372	.0067	-	.00372
.0237	-.0545	-.00818	.000928	.00038	.0307	.00023	.00027
$\Sigma$	.1221	.00784					.00465

$$\bar{Y} = \frac{\sum AY}{\sum A} = \frac{.00784}{.1221} = .0642 \text{ IN. UP FROM X-X}$$

NEUTRAL AXIS AT .216 + (.115 - .0642) = .267 FROM TOP

$$I = \sum [I_x + A(Y - Ȳ)^2] = .00465$$

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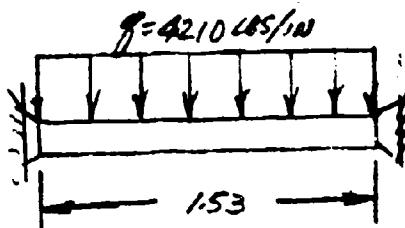
IGNITER PERFORATED CLOSURE - Cont'd

FIG III- 4

SIMPLY SUPPORTED BEAM.

$$M_{MAX} = \frac{qL^2}{8} = \frac{4210(1.53)^2}{8} = 1230 \text{ IN-LB}$$

FIXED END BEAM

$$M_{MAX} = \frac{qL^2}{12} = \frac{4210(1.53)^2}{12} = 820 \text{ IN-LB}$$

THE BEAM WILL APPROXIMATE THE FIXED END CONDITION, BUT ASSUME AV. OF TWO

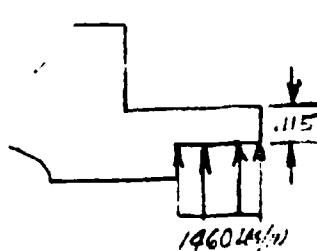
$$M_{MAX} = \frac{1}{2}(1230 + 820) = 1025 \text{ IN-LB}$$

$$\sigma_s = \frac{Mc}{I} = \frac{1025(356)}{0.0465} = \frac{365}{0.0465} = 79,000 \text{ PSI}$$

$$M.S. = \frac{180,000}{77,000} - 1 = + 1.3$$

+ SUBSTANTIAL NUMBER OF STRESS CYCLES IN CYCLES OF THE ANALOGUE MODEL

SMALL LIP:



$$\sigma_s = \frac{1460}{.115} = 12700 \text{ PSI}$$

$$F_{SU} = 109,000$$

M.S. = LARGE

FIG III- 5

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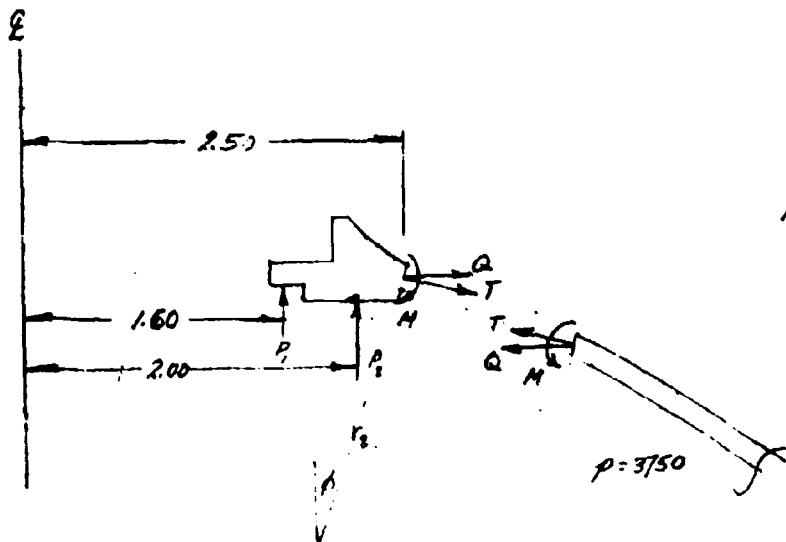
IGNITER ROLL - CLOSURE JOINT

FIG III-C

$$P_1 = \frac{P_3}{2} = \frac{3750(1.60)}{2} = 3000 \text{ LBS/in}$$

$$P_2 = .66(3750) = 2470 \text{ LBS/in}$$

$$\frac{x}{a} = \frac{3.50}{4.6} = .64$$

$$\frac{r_3}{2} = 1.74 \quad r_3 = 1.74(4.6) = 8.00 \text{ IN} \quad \text{RFL 2:1 CURVE}$$

$$\sin \alpha = \frac{2.50}{8.00} = .312 \quad \therefore \alpha = 18^\circ$$

$$T = \frac{P_1 e}{2} = \frac{3750(8.00)}{2} = 15,000 \text{ LBS/in}$$

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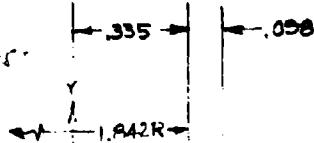


FIG 27-7

$$A_1 = .098(.216) = .0212 \quad Y_1 = .392$$

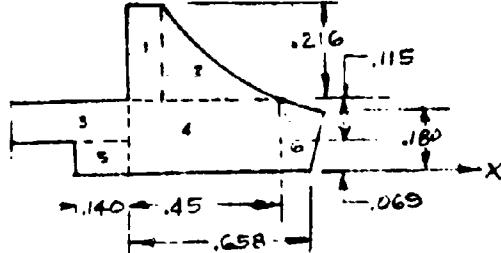
$$I_{01} = \frac{1}{12}(3.52)(.216)^3 = .0000824 \quad I_{02} = .356$$

$$A_2 = .335(.115) = .0385 \quad Y_2 = -.1265$$

$$I_{03} = (.184)(.45) = .00828 \quad Y_3 = .092$$

$$A_3 = .059(.140) = .0097 \quad Y_4 = .0345$$

$$A_4 = .208(.180) = .0374 \quad Y_5 = .090$$



$$I_{01} = \frac{1}{12}(0.098)(.216)^3 = .0000824 \quad I_{02} = \frac{1}{12}(3.52)(.216)^3 = .0000824 \quad I_{06} = \frac{1}{12}(.008)(.18)^3 = .000104$$

$$I_{02} = \frac{1}{36}(3.52)(.216)^3 = .000275 \quad I_{04} = \frac{1}{12}(.45)(.18)^3 = .000233$$

ELEMENT	AREA	Y	FY	AY^2	I <sub>0</sub>	X	AX
1	.0212	.392	.00830	.00325	.0000824	.384	.0119
2	.0380	.356	.01350	.00482	.000975	.550	.0306
3	.0395	.1265	.0649	.00062	.010042	.147	.00643
4	.00828	.092	.0045	.00041	.000233	.560	.0464
5	.0097	.0345	.0003	.00001	—	.265	.00257
6	.0374	.090	.00337	.00030	.000104	1.097	.02415
$\Sigma$	.2276		.0349	.00941			.1290

$$\bar{Y} = \frac{\sum AY}{\sum A} = \frac{.0349}{.2276} = .153 \text{ IN.} \quad \bar{X} = \frac{\sum AX}{\sum A} = \frac{.1290}{.2276} = .573$$

$$I = \sum [I_0 + A(Y - \bar{Y})^2]$$

$$I_1 = .0000824 + .0212(.239)^2 = .000203 \quad I_4 = .000233 + .00828(.061)^2 = .000203 \\ I_2 = .000975 + .0385(.203)^2 = .00255 \quad I_5 = 0 + .0097(.1185)^2 = .00136 \\ I_3 = .010042 + .0385(.0265)^2 = .000312 \quad I_6 = .000104 + .0374(.063)^2 = .000255 \\ I = .003065 + .000930 = .00400 \quad .003065 \quad .000930$$

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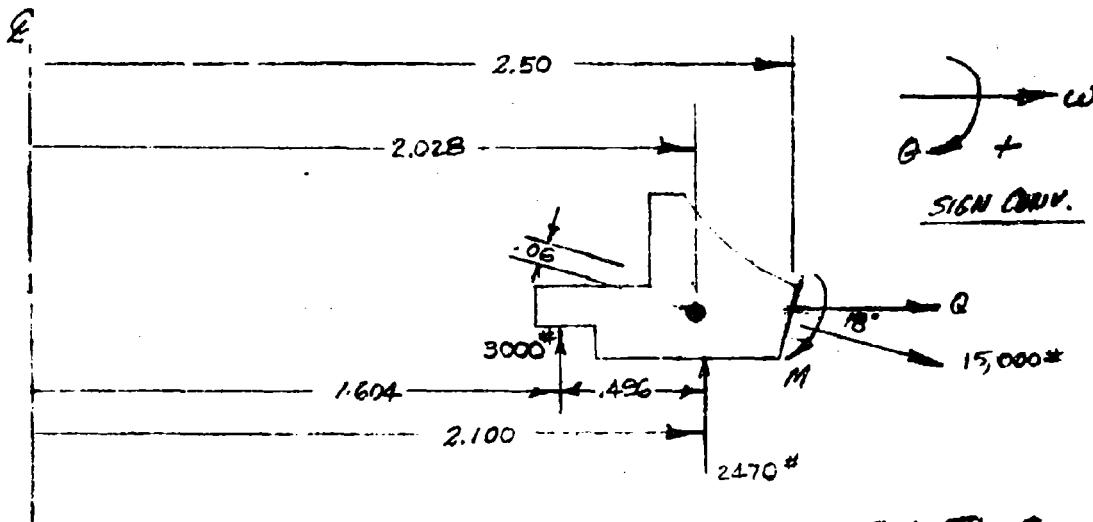
IGNITER PASS - CLOSURE JOINT - CONT'D

FIG III-8

## BENDING DISPLACEMENT EQUATIONS:

$$E\theta_{CG} = \frac{F_{CG}}{I} \sum M_i r_i = \frac{2.028}{.00400} \sum M_i r_i = 507 \sum M_i r_i$$

$$EW_{CG} = \frac{F_{CG}}{A} \sum Q_i r_i = \frac{2.028}{.2276} \sum Q_i r_i = 8.92 \sum Q_i r_i$$

$$\begin{aligned} \sum M_i r_i &= 2.50 M + 3000 (.496)(1.604) + 15,000 (.06)(2.50) \\ &= 2.50 M + 2390 + 2250 = 2.50 M + 4640 \end{aligned}$$

$$E\theta_{CG} = 507. [2.50 M + 4640] = 1270 M + 2,350,000$$

$$\begin{aligned} \sum Q_i r_i &= 2.50 Q + (15,000 \cos 18^\circ)(2.50) \\ &= 2.50 Q + 35,600 \end{aligned}$$

$$\begin{aligned} EW_{CG} &= 8.92 [2.50 Q + 35,600] \\ &= 22.30 Q + 317,000 \end{aligned}$$

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IGNITER BOSS - CLOSURE JOINT - CONT'D

$$\text{AT THE BOSS SHELL JUNCTION: } EW = E\omega_{CG} - X EO$$

$$X = \bar{T} - \frac{180}{\pi} = .153 - .090 \\ = .063$$

$$EW = 22.30 Q + 317,000 - .063 [1270 M + 2,350,000]$$

$$= 22.30 Q + 317,000 - (.80 M + 148,000)$$

$$= - 80 M + 22.30 Q + 169,000$$

## SHELL DISPLACEMENT EQUATIONS:

$$EO = -\frac{M}{2D\beta^2} - \frac{\beta}{2Df^2} + \frac{2.65P_f}{\epsilon}$$

$$EW = -\frac{M}{2D\beta^2} - \frac{\beta}{2Df^2} + \frac{.2P_f}{\epsilon}$$

$$\beta = \frac{1285}{T_1 \epsilon} = \frac{1285}{18.0(.13)} = \frac{1285}{1.02} = 1.26 \quad (\text{FOR } \epsilon = 1.02)$$

$$D = \frac{\epsilon^3}{10.92} = \frac{(.13)^3}{10.92} = .000201$$

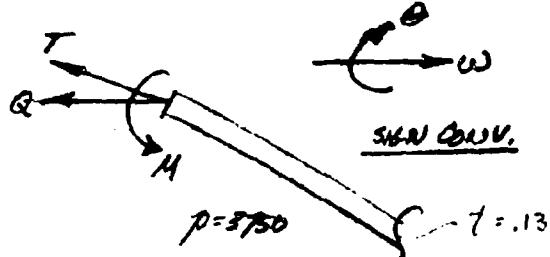


FIG III-9

$$Df = .000201(1.26) = .000253$$

$$D\beta^2 = (.000253)(1.26) = .000319$$

$$D\beta^3 = (.000319)(1.26) = .000402$$

$$2Df^2 = .000638$$

$$2D\beta^2 = .000804$$

$$\frac{1}{Df} = \frac{1}{.000253} = 3950$$

$$\frac{2.65P_f}{\epsilon} = \frac{2.65(3750)(4.6)}{.13} = 352,000$$

$$\frac{1}{D\beta^2} = \frac{1}{.000319} = 1570$$

$$\frac{1}{2D\beta^3} = \frac{1}{.000402} = 1240$$

$$\frac{1}{2Df^2} = \frac{1}{.000638} = 122,000$$

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ANNEALKNOTTED - CLOSURE JOINT - DAWND

$$EB = -3950M - 1570Q + 352,000$$

$$EW = -1570M - 1240Q + 122,000$$

EQUATING ROTATION AND DISPLACEMENT @ JUNCTION:

$$E\theta_{RING} = E\theta_{SHELL}$$

$$1270M + 2,300,000 = -3950M - 1570Q + 352,000$$

$$5220M + 1570Q + 1,000,000 = 0$$

$$M + .301Q + 191 = 0$$

$$EW_{RING} = EW_{SHELL}$$

$$-80M + 22.30Q + 169,000 = -1570M - 1240Q + 122,000$$

$$1490M + 1262Q + 47,000 = 0$$

$$M + .847Q + 31.6 = 0$$

$$\begin{cases} M + .301Q + 191 = 0 \\ M + .847Q + 31.6 = 0 \end{cases}$$

$$-.546Q + 159 = 0$$

$$Q = .291 \text{ LBS/IN}$$

$$M = -.301(291) - 191$$

$$= -278 \text{ IN-LB.}$$

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$$\text{STRESS } \sigma = \frac{\Sigma}{d} = .54$$

$$\frac{\Sigma}{Z} = .10$$

HOOP STRESS:

DIRECT STRESS (BASED ON RADIAL DEFLECTION)

$$WEF = 50M + 22.30Q + 169,000 \quad \text{REF. P. 3.A.8}$$

$$\text{WHERE: } M = 278 \text{ LB}/\text{in}$$

$$Q = 291 \text{ LB/in}$$

$$f_{bd} \leq E = \frac{WE}{R}$$

$$R = 2.50$$

$$f_{bd} = \frac{-50(-278) + 22.30(291) + 169,000}{2.50}$$

$$= \frac{22,750 + 648 + 169,000}{2.50}$$

$$= 76,800 \text{ psi}$$

BENDING STRESS

$$f_{bh} \leq 1.8 \frac{M}{Z}$$

$$\leq \frac{1.8(278)}{619} = \pm 13,900 \text{ psi}$$

$$\sum f_h = 76,800 + 13,900 = 90,700 \text{ psi}$$

$$F_y = 163,000 \text{ psi}$$

$$M.S. = \frac{163,000}{90,700} - 1 = +.80$$

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MERIDIONAL STRESS:

DIRECT STRESS:

$$f_{DM} = \frac{I}{E}$$

$$\begin{aligned} I &= 15,000 \text{ in}^4 \\ E &= .19 \text{ " } \end{aligned} \quad \text{REF f3 3.A.5}$$

$$= \frac{15,000}{.19} = 79,000 \text{ psi}$$

BENDING STRESS:

$$f_{BM} = \frac{M C}{I^2}$$

$$\begin{aligned} M &= 278 \text{ " " } \text{REF f3} \\ C &= \frac{6(278)}{(190)^2} = \frac{6(278)}{361} = 47,500 \text{ psi} \end{aligned}$$

$$\sum f_M = 79,000 + 47,500 = 126,500 \text{ psi}$$

$$F_y = 163,000 \text{ psi}$$

$$M.I. = \left(\frac{163}{126}\right) - 1 = +.29$$

LENGTH OF TRANSITIONS

$$C.F. = \frac{\pi}{2}$$

$$f = \frac{1.57}{3} \quad \text{at } 1.25 \quad \text{REF f3 3.A.8}$$

$$\therefore \frac{1.57}{1.26} = 1.25$$

$$\text{USE } f = 1.35 "$$



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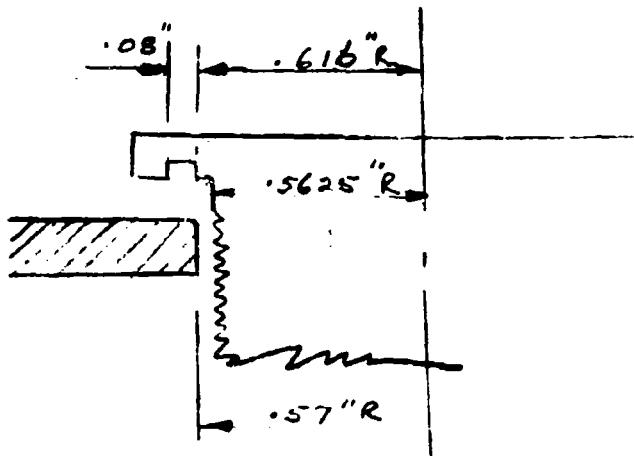
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## RECEPTACLE CONNECTOR

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DESIGN PRESSURE 5000 PSI



## CASE 22. TABLE X

$$W = P \pi (.616 + .04)^2 = 5000 \times \pi \times (.656)^2 = 6760^*$$

$$b = .5625$$

$$a = .57$$

$$S_{tr} = \frac{3W}{2\pi t^2} \left[ \frac{2a^2(m+1) \log \frac{a}{b} + a^2(m-1) - b^2(m-1)}{a^2(m+1) + b^2(m-1)} \right]$$

$$= \frac{3 \times 6760}{2 \times \pi \times t^2} \left[ \frac{2 \times (.5625)^2 (4.3) \log \frac{.5625}{.57} + (.57)^2 (2.3) - (.5625)^2 (2.3)}{(.57)^2 (4.3) + (.5625)^2 (2.3)} \right]$$

$$= \frac{3228}{t^2} \left[ \frac{.075172 + .019587}{1.3707 + .72772} \right]$$

$$S_{tr} = \frac{83}{t^2} \quad \text{for } t = .089 \quad S_{tr} = 10,478 \text{ PSI}$$

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$$\text{TOTAL LOAD} = 6760^*$$

$$\text{LOAD / INCH} = \frac{6760}{27 \times .5625} = 1914^* \text{ / INCH}$$

$$f_s = \frac{3}{2} \times \frac{1914}{t} = \frac{2871}{t}$$

$$t = .094 \pm .005 = .089 \text{ MIN}$$

$$f_s = \frac{2871}{.089} = 32,258 \text{ PSI}$$

$$F_{xy} = 56,000$$

$$F_{xy} = 33,500$$

$$F_{xy} = 35,000 \text{ PSI}$$

$$M.S = \frac{35000}{32258} - 1 = + .08$$

FOR 67000 PSI

PRESSURE

**SECTION III - B** Report AFRL-TR-69-50, Appendix B  
**20 PULSE IGNITER FWD CLOSURE & BARREL** 10-28-68

MATERIAL STL 4130

F<sub>y</sub> = 163,000 PSI (MIN)

THE FORWARD CLOSURE AND PART OF THE CYLINDRICAL SECTION OF THE IGNITER CHAMBER WERE ANALYZED BY MEANS OF A DIGITAL COMPUTER PROGRAM FOR FINITE ELEMENT ANALYSIS AS DESCRIBED IN TECHNICAL MEMORANDUM NO. 23, AEROJET-GENERAL CORPORATION.

MAXIMUM EXPECTED OPERATING PRESSURE = 3000 PSI

FACTOR OF SAFETY = 1.25

DESIGN PRESSURE =  $1.25 \times 3000 = 3750$  PSI

THE HIGHEST CALCULATED STRESS WAS IN ELEMENT 80, WHICH IS ADJACENT TO THE BOSS, HOOP DIRECTION. THIS CALCULATED STRESS WAS 187,200 PSI, WHICH IS GREATER THAN THE YIELD STRESS, HOWEVER, THE AVERAGE HOOP STRESS IN THE CROSS SECTION IS ONLY 120,000 PSI AND LOCAL YIELDING WILL PREVENT EXCESSIVE STRESSES IN ELEMENT 80, THE OUTSIDE ELEMENT.

THE AV. HOOP STRESS IN THE SECTION IS 119,500 PSI.

FOR  $t = .527$ . MIN.  $t = .490$

$$\text{FOR MIN. } t, \sigma_h = 119,500 \left( \frac{.527}{.490} \right) = 127,000 \text{ PSI}$$

$$M.S. = \frac{163000}{127000} - 1 = +.27$$

THE HIGHEST HOOP STRESS AWAY FROM THE BOSS IS IN THE BARREL SECTION WHERE IT IS AS FOLLOWS:

EL. 1	154600	PSI
2	156700	
3	157800	
4	157100	
5	<u>156300</u>	

AV. 156100 BASED ON  $t = .110$

## Report AFRL-TR-69-50, Appendix B

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20 PULSE IGNITER FWD CLOSURE

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FOR MIN.  $t = .100$ 

$$\sigma_H = 158,100 \left( \frac{.110}{.100} \right) = 174,000 = +.51$$

BASED ON NOMINAL THICKNESS  $t = .110$ 

$$M.S. = \frac{163,000}{158,100} - 1 = +.03$$

THE HIGHEST MERIDIONAL STRESS OCCURS IN THE SECTION MADE UP OF ELEMENTS 26-30.

EL. 26	51,400 PSI
27	63,400
28	75,200
29	87,200
30	<u>99,600</u>
AV.	75,360

BASED ON MIN.  $t = .100$ 

$$\sigma_M = 75,360 \left( \frac{.110}{.100} \right) = 83,000 \text{ PSI}$$

$$M.S. = \frac{163,000}{83,000} - 1 = +.96$$

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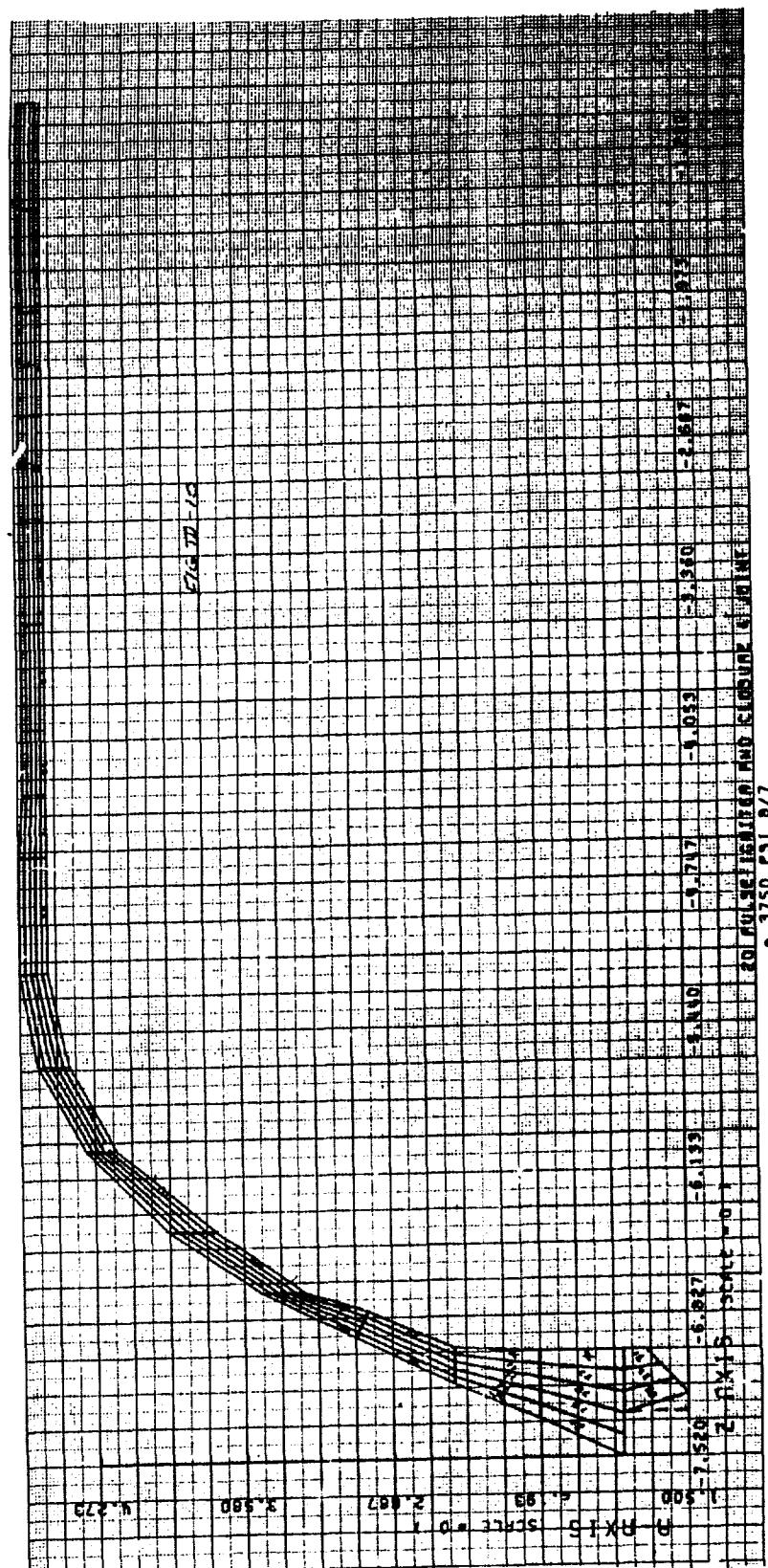


Figure III-10

SEC. III C.

Report AFRL-TR-69-50, Appendix B

3.C.1

20 PULSE IGNITER AFT CLOSURE JOINT

MATERIAL STEEL 4130

$F_{ly} = 163000 \text{ PSI MIN.}$

REF. DRAWINGS 1147019 & 1147028

THE AFT CLOSURE THREADED JOINT WAS ANALYZED BY MEANS OF A DIGITAL COMPUTER PROGRAM FOR THE FINITE ANALYSIS OF SOLIDS WITH NONLINEAR MATERIAL PROPERTIES AS DESCRIBED IN TECHNICAL MEMORANDUM NO 23; AEROJET-GENERAL CORPORATION

MAXIMUM EXPECTED OPERATING PRESSURE = 3000 PSI

FACTOR OF SAFETY = 1.25

DESIGN PRESSURE =  $1.25 \times 3000 \text{ PSI} = 3750 \text{ PSI}$

THE HIGHEST STRESSES OCCURRED IN THE CYLINDRICAL SECTION AT ELEMENTS 181 THRU 186

ELEM. 131  $\sigma_H = 163460 \text{ PSI}$

132  $\sigma_H = 162920 \text{ PSI}$

133  $\sigma_H = 162410 \text{ PSI}$

134  $\sigma_H = 161900 \text{ PSI}$

135  $\sigma_H = 161380 \text{ PSI}$

$812070 \text{ PSI}$  AVG =  $162410 \text{ PSI}$  FOR  $t = .110$

MIN  $t = .110 - .030 = .100"$

$$\sigma_t = \frac{162410 \times .11}{.10} = 178,650 \text{ PSI}$$

BASED ON NOMINAL THICKNESS  $t = .110"$

$$M.S. = \frac{163000}{162410} - 1 = \underline{\underline{+ .004}}$$

MERIDIONAL STRESS IN CLOSURE AT ELEMENTS 1 THRU 6

ELEM 1  $\sigma_{JK} = 110000 \text{ PSI}$

2  $\sigma_{JK} = 109000 \text{ PSI}$

3  $\sigma_{JK} = 108000 \text{ PSI}$

4  $\sigma_{JK} = 107000 \text{ PSI}$

5  $\sigma_{JK} = 107000 \text{ PSI}$

AVERAGE =  $108200 \text{ PSI}$  FOR  $t = .130"$

Report AFRPL-TR-69-50, Appendix B

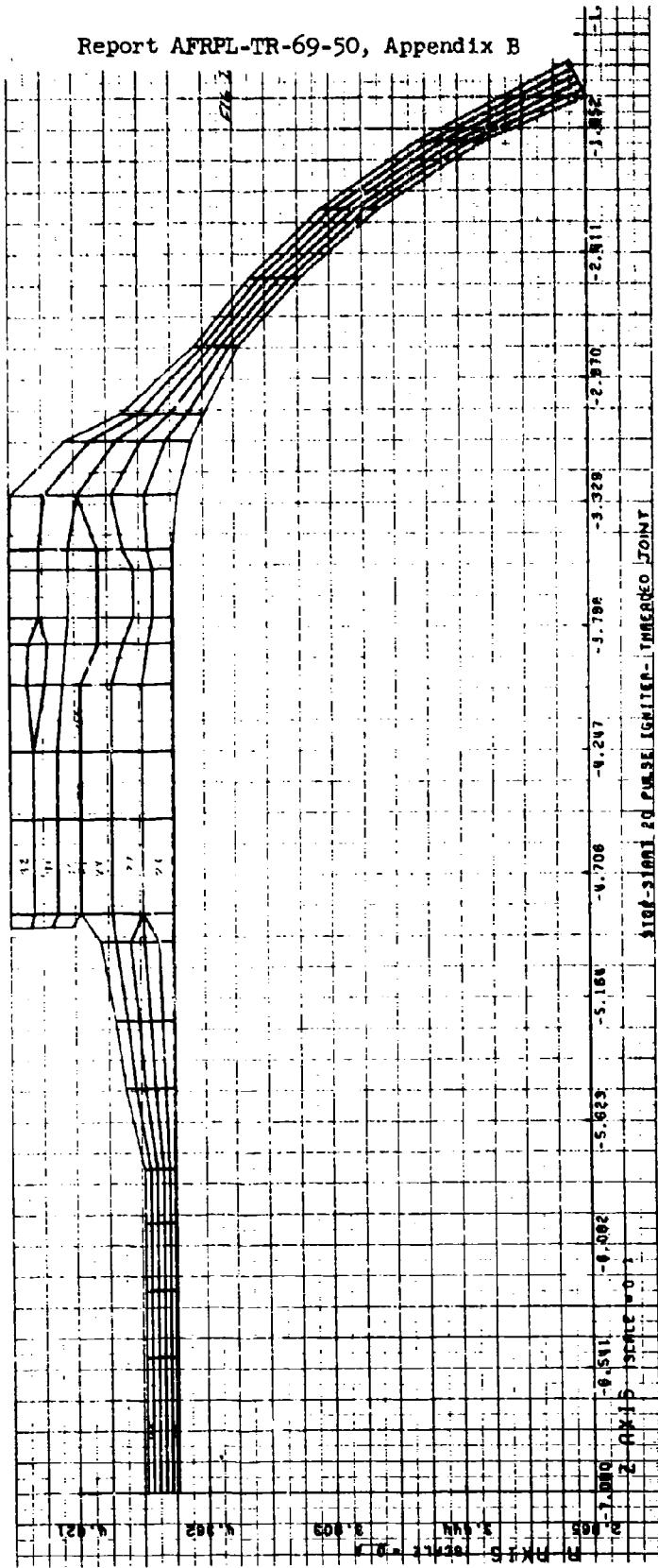


Figure III-11

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20 PULSE IGNITER

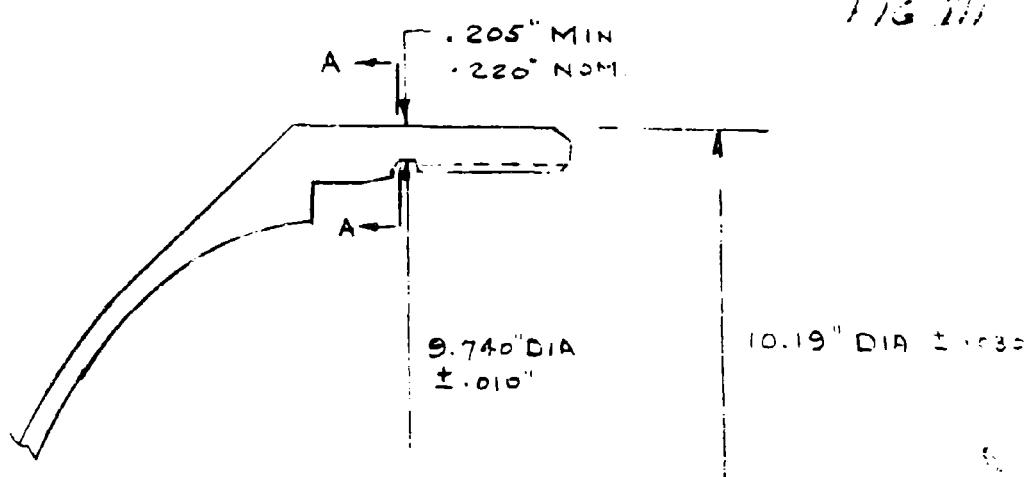
3.C.3

AFT CLOSURE CON'T.

$$\text{AVERAGE STRESS} = 108,200 \text{ P.S.I.} \quad t = .130"$$

$$M.S. = \frac{163,000}{108,200} - 1 = + .502$$

THREADED JOINT



$$F_s = 109,000 \text{ P.S.I.}$$

9.7 - 10 UNS - 2A THREADS

PITCH DIA = 9.63"

L = .864"

ASSUME FIRST & LAST THREAD TO BE INEFFECTIVE  
 THEN LENGTH OF ENGAGEMENT .864 - 2 = .664

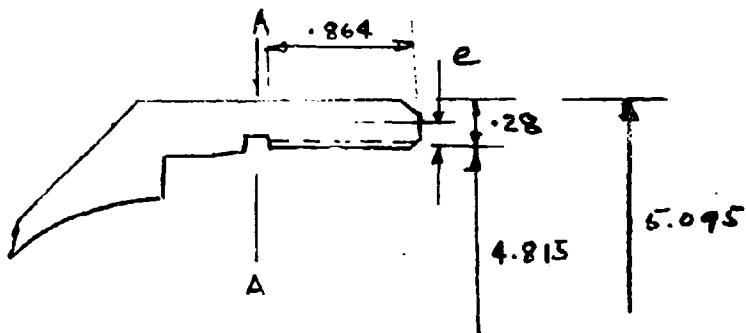
AS AREA IN SHEAR =  $\pi \times .64^2 \times .664$

$$\text{LOAD / INCH} = \frac{F_k}{2} = \frac{37,000 \text{ P.S.I.}}{2} = 18,500 \text{ P.S.I.}$$

$$f_s = \frac{3}{2} \frac{\sigma}{A} = \frac{1.5 \times 18,500}{.56 \times 1} = 24,400 \text{ P.S.I.}$$

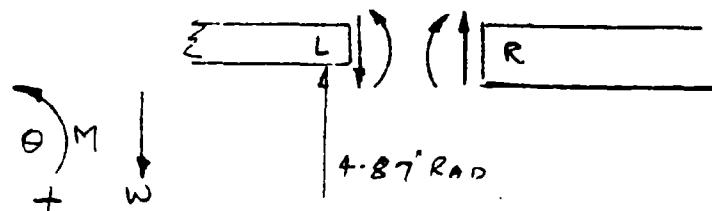
M.S. = HIGH

THREADED JOINT CONT.



MOMENT @ A-A

FIG D1-13



$$\theta_L = \frac{1}{2D\beta^2} Q_L + \frac{1}{D\beta} M_L$$

$$w_L = -\frac{.85 PR^2}{Ec} + \frac{1}{2D\beta^3} Q_L - \frac{1}{2D\beta^2} M_L$$

$$\beta = \frac{1.285}{\sqrt{Rt}} = \frac{1.285}{\sqrt{4.87 \times 2}} = 1.3019$$

$$D = \frac{Ec^3}{10.92} = \frac{29 \times 10^6 \times (.2)^3}{10.92} = .02124 \times 10^6$$

$$\frac{1}{D\beta} = \frac{1}{.02124 \times 1.3019} \times 10^{-6} = 36.16272 (10^{-6})$$

$$\frac{1}{2D\beta^2} = 13.8882 (10^{-6})$$

THREADED JOINT CONT

$$\frac{1}{2DP^3} = 10.66749 (10^{-6})$$

$$\Theta_L = \left[ -13.8882 Q_L + 36.16272 M_L \right] 10^{-6} \quad (1)$$

$$W_L = -\frac{.85 PR^2}{Et} + \frac{1}{2DP^3} Q_L - \frac{1}{2DP^2} M_L$$

$$W_L = \left[ -5897 + 10.667 Q_L - 13.888 M_L \right] 10^{-6} \quad (2)$$

$$\Theta_R = \frac{Mc_g T^2}{EI_{yy}}$$

$$W_R = \left( \Theta_R \times \frac{L}{2} \right) - \frac{Qe^2}{EA}$$

$$I_{yy} = \frac{.864 \times .28^3}{12} = .00158 \text{ N}^4$$

$$e = \frac{9.965 - 9.63}{2} = .1675 \text{ "}$$

$$P = \frac{PR}{2} = \frac{3750 \times 4.815}{2} = 9028 \text{ " / INCH}$$

$$M = 9028 \times .1675 = 1512 \text{ IN-LBS / INCH}$$

$$T = 4.9825$$

$$Mc_g = (-M - Q \frac{e}{2} + 1512)$$

$$\Theta_R = \frac{(-M - .432Q + 1512)(4.9825)^2}{29 \times .00158} 10^{-6}$$

$$= 541.8 \times 10^{-6} (-M - .432Q + 1512)$$

$$\Theta_R = \left[ -541.8M - 234Q + 819202 \right] 10^{-6} \quad (3)$$

3.6.6

Report AFPL-TR-69-XV, Appendix B  
20 PULSE IGNITER

THREADED JOINT CONT.

$$W_R = \Theta_R \times \frac{L}{2} - \frac{QR^2}{EA}$$

$$A = .866 \times .28 = .24248$$

$$\frac{QR^2}{EA} = \frac{Q(4.8925)^2}{29 \times .24248} \cdot 10^{-6} = 3.03Q(10^{-6})$$

$$\frac{L}{2} = .432$$

$$W_R = .432 [-541.8M - 234Q + 819202] 10^{-6} - 3.03Q(10^{-6})$$

$$= [-234M - 104Q_R + 353895 - 3.03Q] 10^{-6}$$

$$W_R = [-234M - 104Q_R + 35389] 10^{-6} \quad (4)$$

$$\Theta_L = \Theta_R$$

FROM (1) & (3)

$$-13.888Q + 36.162M = -541.8M - 234Q + 819202$$

$$577.96M + 220Q - 819202 = 0 \quad (5)$$

$$W_L = W_R$$

FROM (2) & (4)

$$-5897 + 10.667Q - 13.888M = -234M - 104Q + 35389$$

$$220.1M + 114.7Q - 359792 = 0 \quad (6)$$

MULT (6) X 1.918

$$422M + 220Q - 690095 = 0$$

~~(5) 577.96M + 220Q - 819202 = 0~~

~~-155.96M + 129107 = 0~~

$$M = 828 \text{ IN LBS}$$

FROM (5)

$$479551 + 220Q - 819202 = 0$$

$$220Q = 340651$$

$$Q = 1548 \text{ #}$$

THREADED JOINT CONT

$$M = 828 \text{ IN-LBS/INCH}$$

$$Q = 1548^{\circ}$$

$$\sigma_m = \frac{6M}{\pi^2} = \frac{6 \times 828}{(\cdot 205)^2} = 118,215^{\circ} \text{ PSI}$$

$$\sigma_s = \frac{P}{A} = \frac{1548}{\cdot 205^2 \cdot 1} = 7550 \text{ PSI}$$

$$\sigma_t = \frac{PR}{2t} = \frac{3750 \times 4.87}{2 \times .205} = 44,543 \text{ PSI}$$

$$\sigma = \frac{P}{A} \pm \frac{MC}{I}$$

$$= 44543 \pm 118215^{\circ} = 162758 \text{ PSI}$$

$$\begin{aligned} M.S. &= \frac{1}{\frac{44543}{163000} + \frac{118215^{\circ}}{163000 \times 1.25}} - 1 \\ &= + \underline{.17} \end{aligned}$$

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AFT CLOSURE

DWG# 1147019

— E — — AFT —

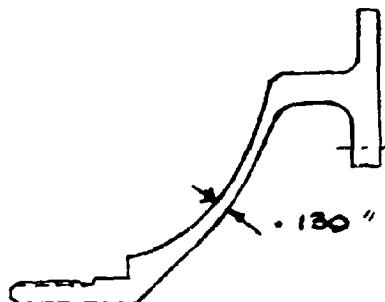


FIG IV-14

BASIC MEMBRANE REF AGC STRUCTURES MANUAL

$$F_{t_y} = 163000 \text{ PSI}$$

$$R = 4.5''$$

$$a = 8.989$$

$$\frac{R}{a} = \frac{4.5}{8.989} \approx .5$$

$$\text{FOR } 2:1 \text{ ELLIPSE } \frac{N\phi}{aP} = .9 ; \quad \frac{N\theta}{aP} = .71$$

FOR  $P = 3750 \text{ PSI}$ 

$$N\phi = .9 \times 3750 \times \frac{8.989}{2} = 15,170^*$$

$$\sigma_\theta = \frac{15170}{(.130 \pm .010)} = 126,420 \text{ PSI (BASED ON MIN. t)}$$

$$M.S = \frac{163000}{126420} - 1 = +.28$$



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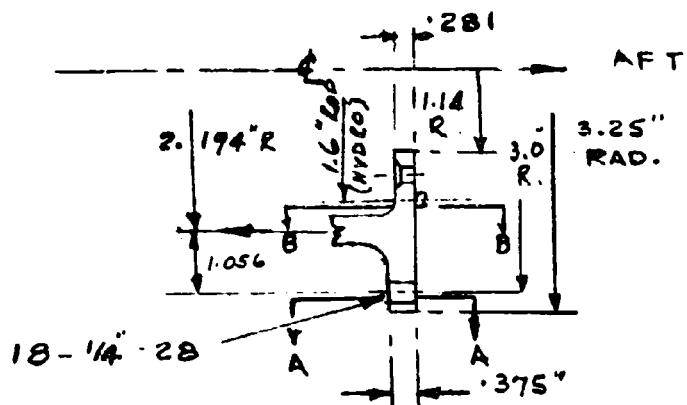
## 20 PULSE IGNITER

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AFT FLANGE DWG # 1147019



MATERIAL STEEL 4130

$$F_{ty} = 163,000 \text{ PSI (MIN.)}$$

$$F_{tu} = 180,000 \text{ PSI}$$

$$F_{su} = 109,000 \text{ PSI}$$

## LOADING CONDITIONS :-

$$(a) FIRING OF IGNITER \quad P_D = P_I \pi (1.14)^2 = 3750 \pi \cdot 1.3$$

$$(b) " " MOTOR \quad P_D = P_M \pi (1.5)^2 = 690 \pi \cdot 2.25$$

$$(c) HYDRO TEST \quad P_D = P_M \pi (1.6)^2 = \underline{3750 \pi \cdot 2.56} \text{ (CRIT.)}$$

$$\text{DIRECT BOLT LOAD} = \frac{3750 \times 2.56 \pi}{18} = 1676 \text{ "}$$

$$\text{ASSUME } P_K = 100\% P_D$$

$$P = 2 P_D = 2 \times 1676 = 3352 \text{ "}$$

$$P_{ALL} = 6190 \text{ "}$$

$$M.S = H_1$$

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AFT FLAP CONT.SECTION A-A

$$\text{TOTAL BOLT LOAD} = 3862^{\text{lb}}$$

$$\text{PITCH OF BOLTS} = \frac{\pi \times 6.0}{18} = 1.047^{\text{"}}$$

$$\text{METAL BETWEEN BOLTS} = 1.047 - .281 \\ = .766^{\text{"}}$$

$$\text{MOMENT PRM} = 3.25 - 3.0 = .25^{\text{"}}$$

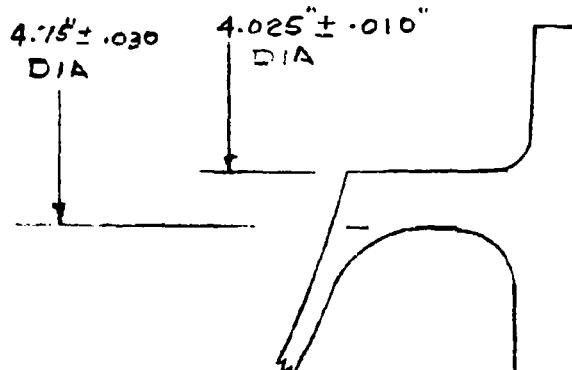
$$\text{MOMENT / INCH} = \frac{3352 \times .25}{.766} = 1094 \text{ IN-LBS/IN}$$

$$\sigma = \frac{6M}{L^2} = \frac{6 \times 1094}{(.375)^2} = 46,677 \text{ PSI}$$

$$\text{M.S.} = \frac{163 \text{ or } 5}{46677} - 1 = H$$

THROAT SUPPORT STRUCTURE

MATL. 4130 STL.



$$\text{MIN T} = \frac{4.75 - 4.025}{2} \\ = .342^{\text{"}}$$

CRITERIA STRAIN  $\leq .0025$ 

$$\epsilon = \frac{PR}{2tE}$$

$$= \frac{3750 \times 2.017}{2 \times .342 \times 29} \times 10^{-6} \\ = 381 \times 10^{-6}$$

$$\text{M.S.} = H$$

FIG III-16

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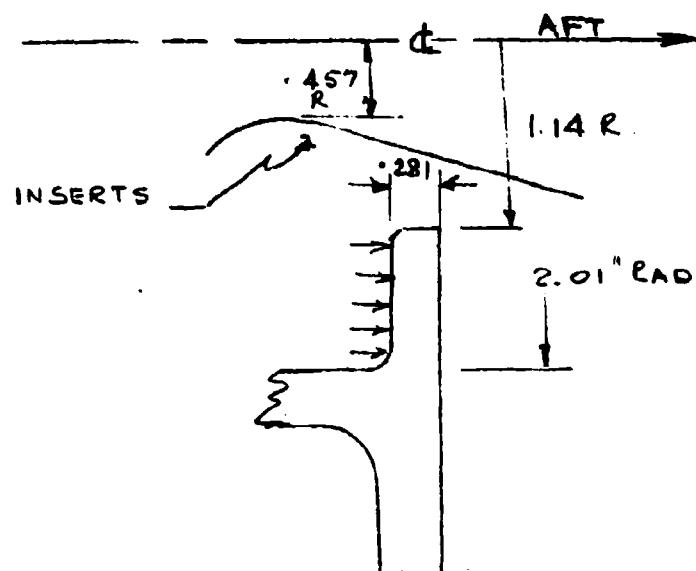
## 20 PULSE IGNITER

BY

CHK'D BY

AFT FLG & CONT.

## SECTION "B-B" IGNITER FIRING

EVALUATING  $\sigma$  TO REFLECT LOAD ON THE INSERTS

$$\sigma = \frac{3750 \pi (2.01^2 - 4.57^2)}{\pi (2.01^2 - 1.14^2)} = 5243 \text{ PSI}$$

STRESS:- REF ROARK TABLE II CASE 17

$$\frac{a}{b} = \frac{2.01}{1.14} = 1.75$$

$$f_b = \frac{\sigma W a^2}{t^2} \quad \beta \text{ FOR } S_y = .370$$

$$W = 5243$$

$$t = .281$$

$$f_b = \frac{.37 \times 5243 \times (2.01)^2}{(.281)^2} = \underline{99,260 \text{ PSI}}$$

$$M.S = \frac{163000}{99260} - 1 = +.64$$



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## SECTION III-D

BY

W. JORDAN

CHK. BY

DATE

RETAINER IGNITER THROAT

DWG 1147021

MATERIAL WB 8217 CARBON PHENOLIC (REF W.B CATALOG.)

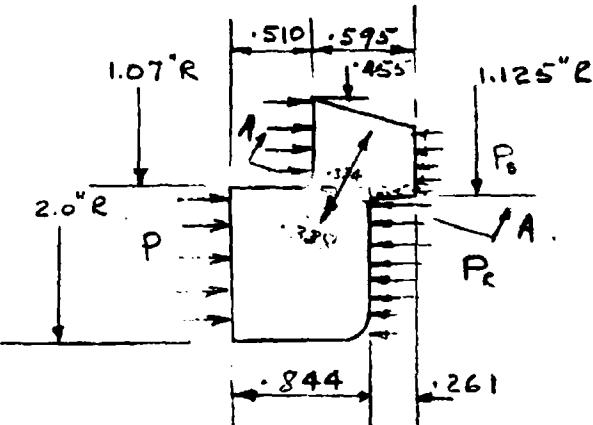


FIG III-18

@ SECTION A-A.

ESTIMATE OF EJECTION LOAD @  $P = 3750 \text{ PSI}$   
 $\& P_s = 450 \text{ PSI}$ 

$$P_{ej} = \pi(1.07^2 - 455^2)(3750 - 450) = 3095 \pi \text{ lb}$$

SHEAR @ SECT A-A

$$f_s = \frac{3}{2} \frac{P_{ej}}{A}$$

$$A = 2\pi R t = 2\pi \times 1.07 \times .338 = .723 \pi$$

$$f_s = \frac{3}{2} \frac{3517}{.723} = 7296 \text{ PSI}$$

$$F_s = .5 F_c = .5(18,000) = 9000 \text{ PSI}$$

$$M.S. = \frac{9000}{7296} - 1 = +.23$$

BENDING @ SECT. A-A

$$f_b = \frac{6M}{Z^2}$$

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## 20 PULSE IGNITER

RETAINER IGNITER THROAT CONT.

$$M = \frac{P_{ex}}{2PL} (1.125 + .03) - (1.070 - .06)$$

$$= \frac{3095 \times .145}{2.14} = 210 \text{ "}/\text{in}$$

$$t = .338$$

$$f_b = \frac{6M}{\epsilon^2} = \frac{6 \times 210}{(.338)^2} = 11,030 \text{ PSI}$$

$$F_b = 18,000 \text{ PSI}$$

$$M.S. = \frac{18,000}{11,030} - 1 = + \underline{\underline{.63}}$$

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EXIT CONE, IGNITER SK 10156B

BY H. FIRON

CHK BY

DATE

Exit Cone Liner - 1<sup>st</sup> Revision MX 2625

Shear-out - 11x2625

$$f_s = \frac{P_{ej}}{A_{sc}}$$

$$P_{ej} = 2630 \text{ ft} \quad \text{REF P 3}$$

$$A_{sc} = \frac{\pi}{2} (2.0 + 4.00) t$$

$$\therefore .400 + .125 = .275 -$$

$$= 6 \pi (.275) = 1.65 \pi \text{ in}^2$$

$$= \frac{2630}{1.65} = 1600 \text{ psi}$$

$$F_{sh} = .5 F_t = .5 (8,500) = 4,250 \text{ psi}$$

$$M.S. = \frac{4250}{1600} = 1.4$$

CHFAZ-OUT - 1020 57L

$$f_s = f_{s_{Mx2625}} \times \frac{t_{Mx2625}}{t_{sc}} \times \frac{D_{Mx2625}}{D_{sc}}$$

$$= 1600 \times \frac{.275}{.125} \times \frac{6.0}{(2.25 + 3.45)}$$

$$= 1600 \times 2.2 \times \frac{6.0}{5.7} = 3750$$

$$F_{sh} = 35,000 \text{ psi}$$

$$M.S. = \frac{35,000}{3750} = 1.1$$

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BENDING: S.I. (APPROXIMATE)

$$f_b = \frac{M I}{E I} \text{ CONSERVATIVE}$$

$$M > f_s I .275 = 3750(1.275) = 10,600 \text{ " " } \\ = \frac{6(10600)}{.275} = \frac{63600}{.275} = 23,200 \text{ psi}$$

$$F_t = 35,000 \text{ psi}$$

$$M.S. = \frac{35000}{23200} - 1 = .51$$

BF. TENS: MX 2625 (APPROXIMATE)

$$f_b = \frac{M I}{E I}$$

$$M > f_s I .275 = 1600 I .275 = 440 I \text{ " " }$$

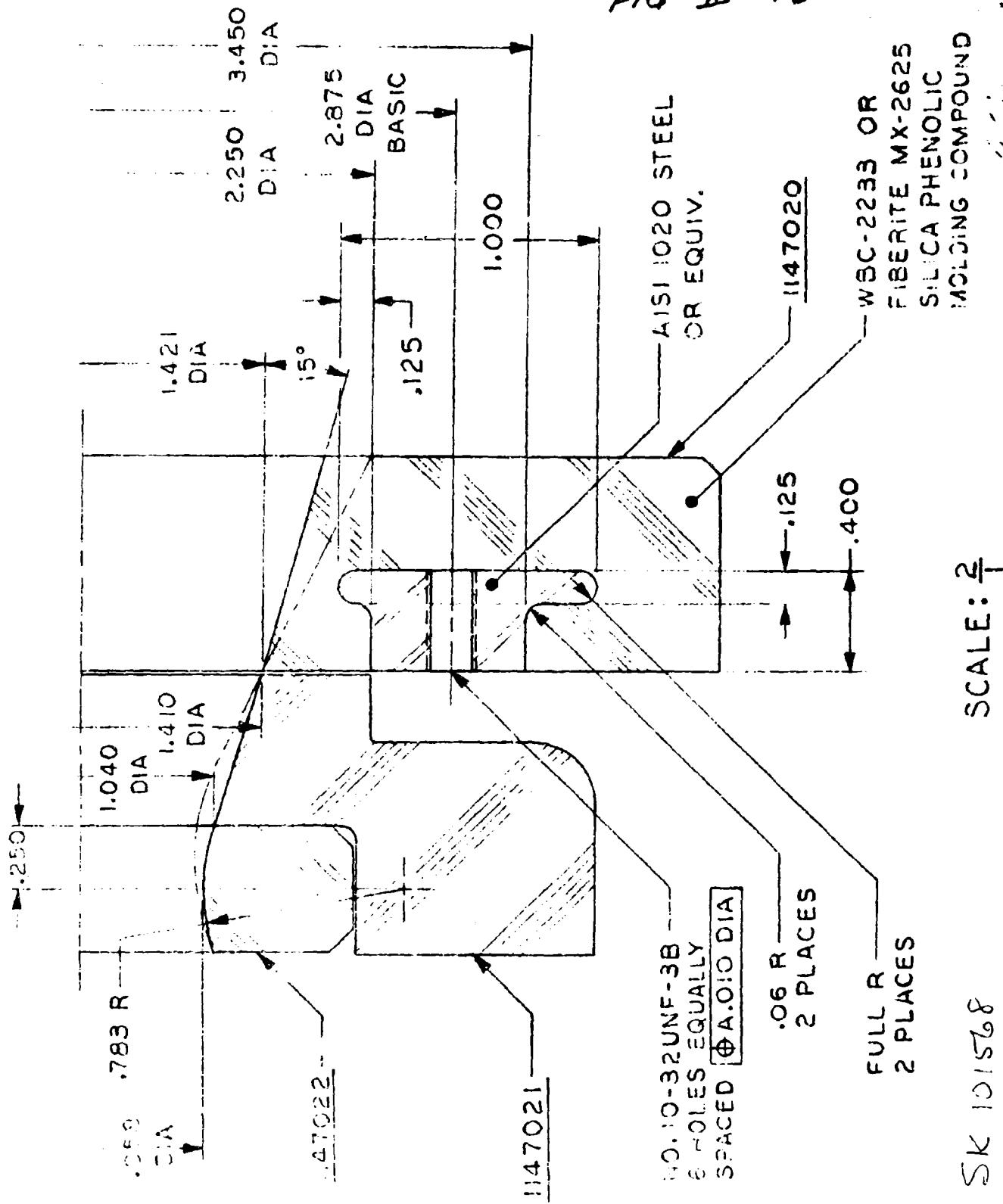
$$= \frac{6(440)}{.275} = 9600 \text{ psi}$$

$$F_t = 10,000 \text{ psi}$$

$$M.S. = \frac{10000}{9600} - 1 = .04$$

S.D. 2

FIG III-19



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BY

H. EFFORD

CHK BY

DATE

LINER, IGNITER CLOSURE # 1147025 NYLON 3<sup>1/2</sup>  
 $E = 700 \times 10^6$  ELONGATION PER SPEC L.P. 10  
 THIS E IS APPROPRIATE

ENTRANCE - AID # 1147022 W.B. B217  
 CARBON DISULFIDE

NO APPARENT PRESSURE LOADS

THROAT IGNITER # 1147022 PYRO,

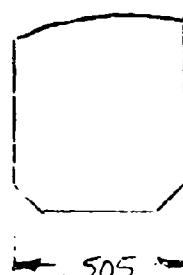


FIG III-20

GAP REQ'D FOR AXIAL THERMAL GROWTH

$$\Delta Z = d \cdot \Delta T$$

d = .505

$\Delta T = 5000^\circ\text{C}$

$d = 14.0 \times 10^{-6} \text{ in.}^\circ\text{C}$

$$= 14 \times .505 \times 5000 \times 10^{-6} = .03535$$

THIS INDICATES THAT 0.036" CLEARANCE IS REQUIRED  
 AT INSTALLATION TO PERMIT FREE THERMAL EXPANSION  
 OF THE PYRO

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20 PULSE JACKET

WORK ORDER

BY

H. EFRON

CHK. BY

DATE

INSULATOR - CLOSURE DING 1147024

WPB 2233

SILICA PHENOLIC

ESTIMATED HOOP STRAIN IN STEEL CLOSURE  
REF TING 1147019

$$\epsilon_{st} = \frac{F_u}{E_{st}} - \frac{P R}{F_t} K$$

$$F_{st} = 30 \times 10^6 \text{ psi}$$

$$K < .76$$

$$= 3000(4.25)(.76) \frac{10^{-6}}{.12 \times 30} = .0025 \% \\ = .25 \%$$

ALLOWABLE STRAIN, ESTIMATE

$$\epsilon_{all} = \frac{F_{all}}{E}$$

$$E = 3.0 \times 10^6 \text{ psi}$$

$$F_{all} = 4.00 \times 10^6 \text{ psi}$$

$$= \frac{1014}{2.0} = .00475$$

$$= .475 \%$$

$$M.G. = \frac{.475 - 1}{.25} = \underline{\underline{.90}}$$

NOT REPRODUCIBLE

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20 PULSE IGNITER

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BY	CHK. BY	DATE
H.FROM		

FASTENER - NAS - 360 - 3 - 00 HK

PULL = 2800<sup>#</sup>  
 P = 1370<sup>#</sup>

M.S. =  $\frac{2800}{1370} = 1.9$

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APPENDIX C

THERMAL ANALYSIS OF TWENTY-PULSE IGNITER FOR STOP/START ROCKET MOTOR

SECTION I

INTRODUCTION

The thermal analysis of the stop/start igniter was performed to determine the maximum possible temperature increase of the SCID located in the igniter membrane for various thicknesses of the membrane. To facilitate the analysis, it was assumed that the SCID temperature corresponds to the backside temperature of the membrane. The computed relationship between the maximum backside temperature increase and the membrane thickness is shown in Figure C-1. For example, this figure gives a temperature increase of 155°F for a 0.1-inch thickness. Figure C-2 shows the backside and frontside temperature responses of the membrane for three different thicknesses.

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SECTION II  
DISCUSSION

To adequately predict the maximum temperature of the igniter membrane, the initial procedure of the analysis was to subdivide the internal surfaces of the igniter chamber into nodal sections. Figure C-3 shows the nodal subdivisions for the case analyzed. Heating of these surfaces was assumed to be caused by convective heat transfer from the combustion products of the propellant.

The temperature responses for each nodal section were obtained from a thermal model which calculates the transient temperature response for a composite material which reacts or decomposes in depth. This is a one-dimensional, transient thermal model capable of including local surface regression, internal decomposition (charring), and transpiration of pyrolysis gases to the exposed surface.

The total heat flux incident on the membrane, assumed to be due to radiation from the chamber internal surface, is the summation of the individual contributions from the different sections. The basic radiation equation used to obtain the heat transfer between the different sections and this membrane is given below.

$$Q_i = \sum_{j=1}^N F_j \sigma (T_{ji}^4 - T_{mi}^4)$$

$Q_i$  = Total incident heat flux on the membrane surface at time (i) (Btu/ft<sup>2</sup>-sec)

$F_j$  = Configuration factor from the membrane to the individual sections (j)

$T_{j,i}$  = Temperature of an individual section at time (i) (°R)

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II, Discussion (cont.)

$T_{m,i}$  = Frontside temperature of the membrane at time  $O_i$  ( $^{\circ}$ R)

$\sigma'$  = Stefan-Boltzmann constant

Using this heat flux data in the previous mentioned thermal model, the temperature responses for the various thicknesses of the membrane were determined as shown in Figure C-2.

This particular configuration (Figure C-3) was selected for analysis because it was estimated that it represented the highest heat flux condition. The basis for this estimation is illustrated by examination of Figure C-4 which shows the maximum temperature response of a typical sidewall for approximately 12 continuous cycles. Also, the heat flux ( $Q_i$ ) in the above equation is estimated to be maximum because of the relative importance of both the configuration factors ( $F_j$ ) for the various axial membrane locations and temperatures of each nodal section.

Some of the important assumptions made in this analysis are listed below:

Igniter Pulse Duration	0.15 second
Motor Pulse Duration	1.5 seconds
Chamber Pressure	2000 psia
Propellant	ANP-3316
Flame Temperature	6048 $^{\circ}$ F

Additional assumptions were: (1) all surface emissivities were unity; (2) combustion products or gas were transparent to thermal radiation during the off-periods; (3) radiation heat fluxes were diffuse.

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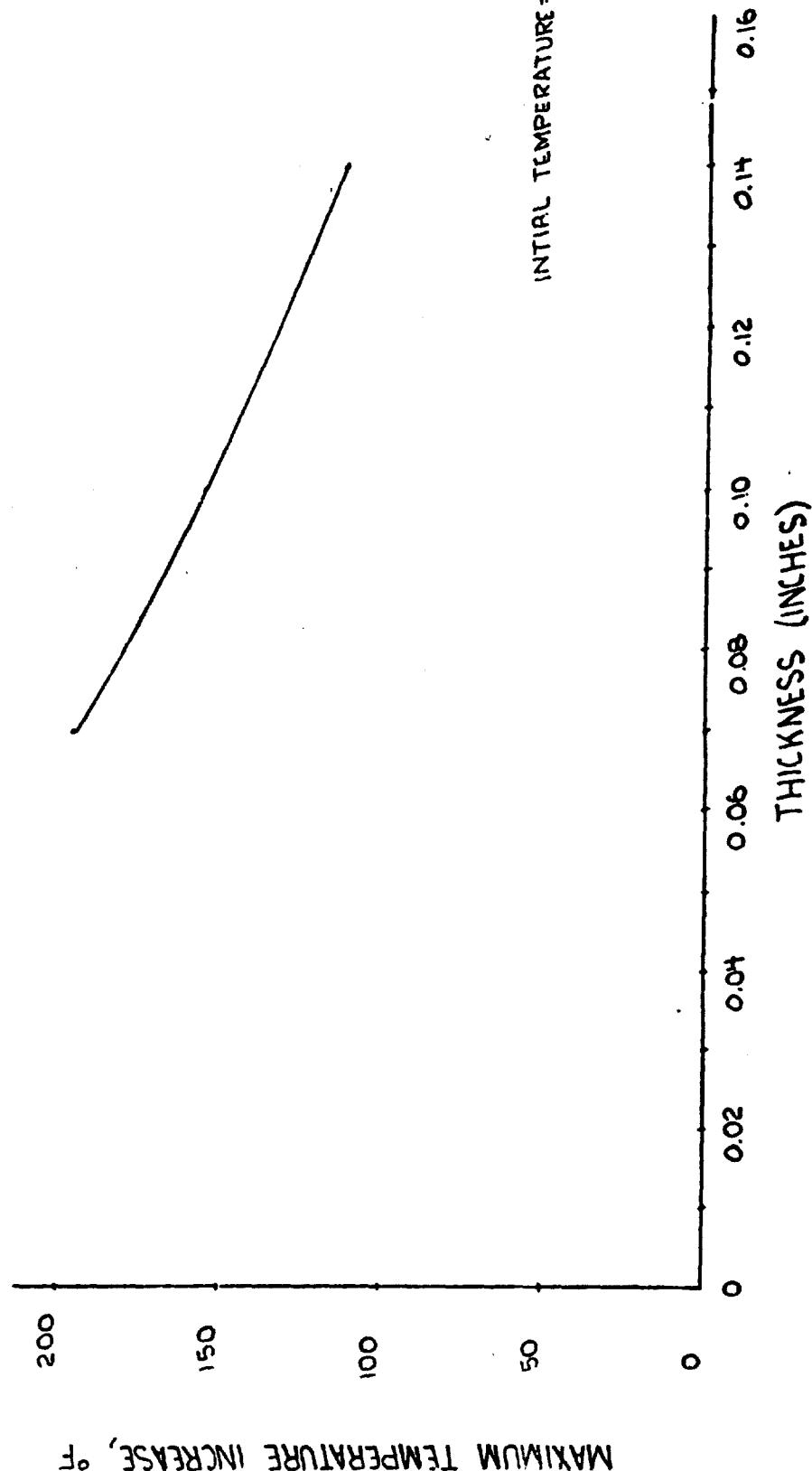
II, Discussion (cont.)

Also, the thermal properties and kinetic constants of three materials and the propellant thermal properties were required for this analysis. The materials were nylon, V-4010, and RTV-60. Adequate data were obtained for V-4010 and nylon. The thermal properties used for the propellant were representative of a typical propellant. However, the only property determined for RTV-60 was the thermal conductivity at a specific temperature. The other required properties were based on the properties of similar materials. For example, the product of specific heat and density is equal to approximately 35 Btu/ $^{\circ}$ F-ft $^3$  in the desirable temperature range. Thus, for a typical value of 90 lb/ft $^3$  for the density, the specific heat can be determined.

The thermal properties and kinetic constants used in this analysis for the different materials are listed below.

	Thermal Properties			Kinetic Constants		
	Thermal Conductivity (Btu/ft-sec- $^{\circ}$ F)	Specific Heat (Btu/lb- $^{\circ}$ F)	Density (lb/ft $^3$ )	Frequency Factor (lb/sec)	E/R ( $^{\circ}$ R)	Order of Reaction
Nylon	0.00004	0.40	71.0	$1.85 \times 10^{13}$	47,100	1.0
V-4010	0.000036	0.45	68.2	$1.252 \times 10^3$	14,660	1.219
RTV-60	0.00005	0.39	90.0	$5.31 \times 10^{10}$	39,400	1.0
Propellant	0.00007	0.3	110.0	-	-	-

MAXIMUM BACKSIDE TEMPERATURE INCREASE OF IGNITER  
MEMBRANE -VS- THICKNESS (SSCSR IGNITER)



MAXIMUM TEMPERATURE INCREASE, °F

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Figure C-1

AEROPHYSICS ---  
JUNE 27, 1968

FRONT AND BACKSIDE TEMPERATURE OF IGNITER MEMBRANE  
VS. EXPOSURE TIME FOR SSSR IGNITER

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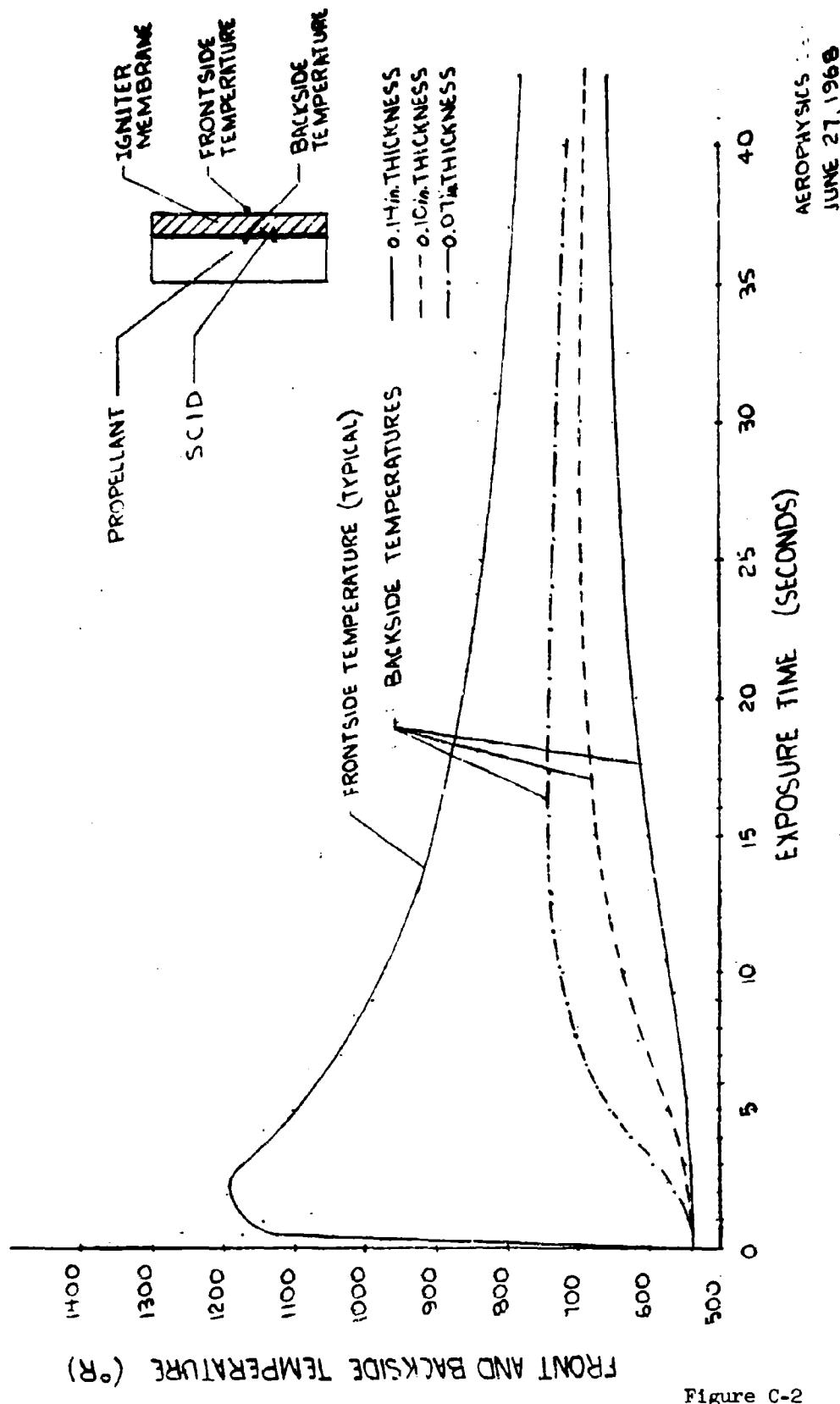
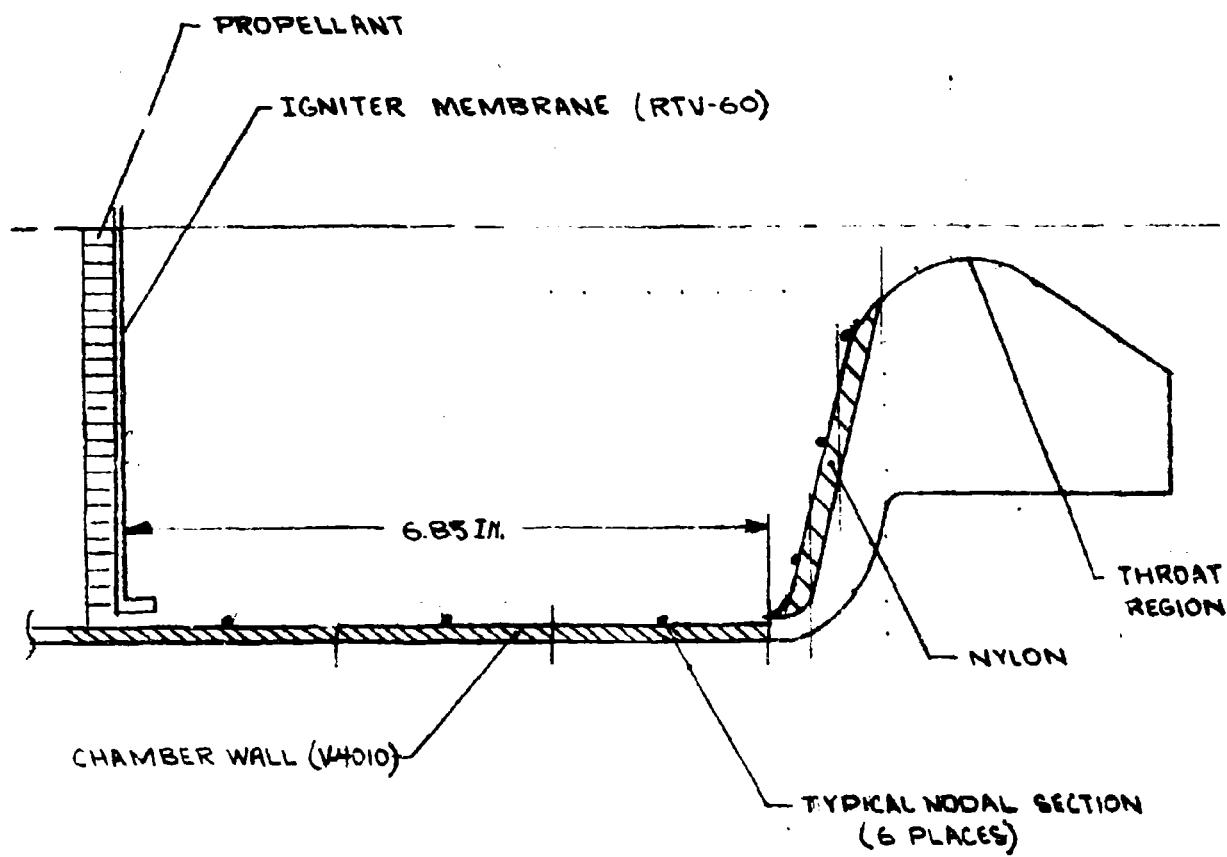


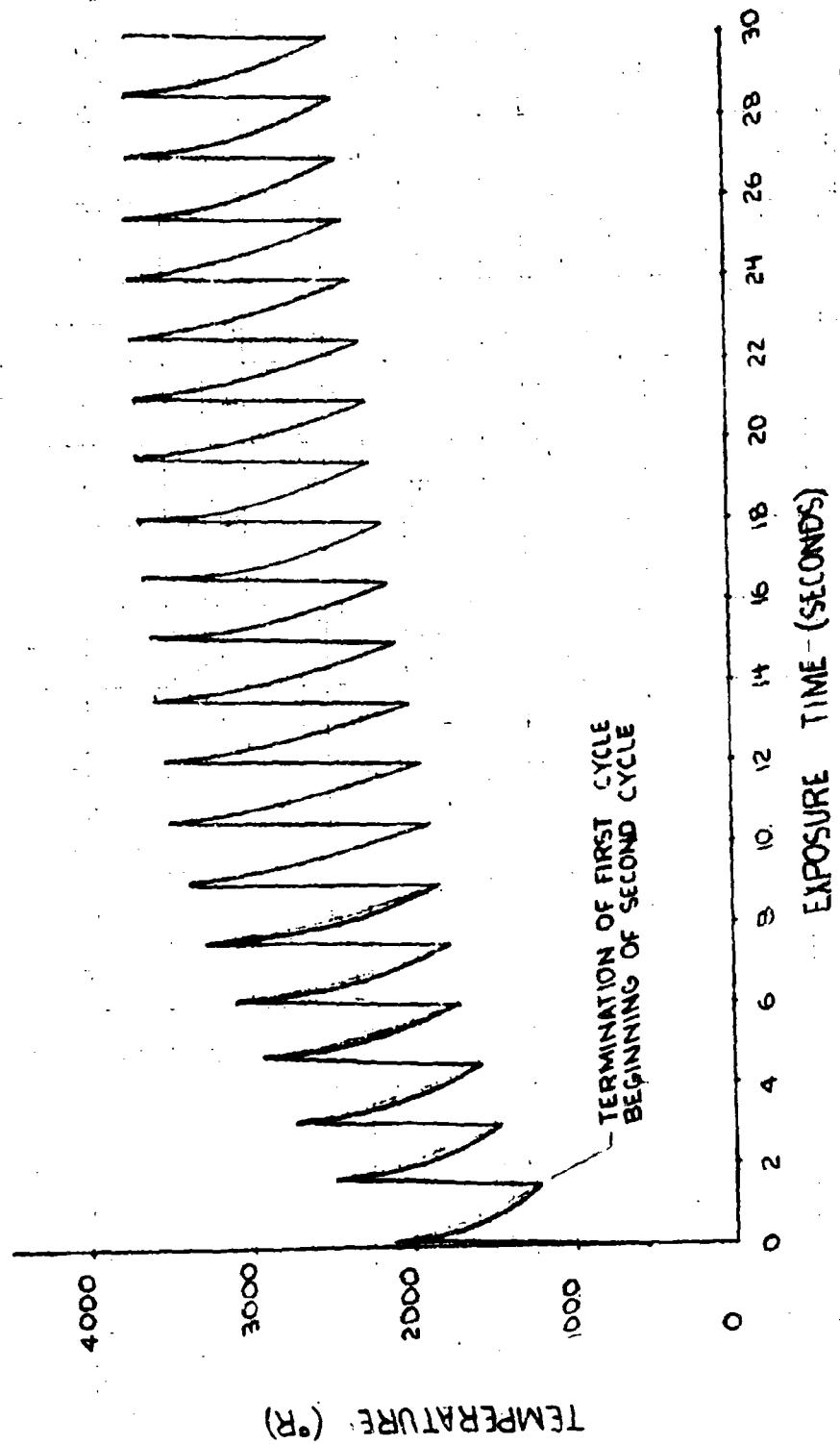
Figure C-2



LOCATIONS OF NODAL SECTIONS FOR  
THE SSCSR IGNITER THERMAL ANALYSIS

Figure C-3

TEMPERATURE OF IGNITER WALL-VS EXPOSURE TIME  
FOR WORSE DUTY CYCLE (SSCSR IGNITER)



MECHANO PHYSICS  
JUNE 27, 1968

Figure C-4

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APPENDIX D

PINTLE THERMAL ANALYSIS FOR SSCR

Report AFRPL-TR-69-50, Appendix D

Thermal analyses were performed on all components of the Stop/Start nozzle. The pintle and pintle housing, because of their severe thermal environment, were thoroughly analyzed to determine the thermal profiles associated with stop/start duty cycle heating.

The particular configuration analyzed is depicted in Figures Appendix D-I and -II. Due to axial variation in local surface heat fluxes and the utilization of dissimilar materials, the heat conduction paths within the pintle was two-dimensional (axial and radial). As a result, all predicted thermal data obtained for the pintle and housing configuration were obtained by use of AGC's "General Thermal Analyzer" computer program. This program considers any given configuration as a series of small elements or nodes. Each node thus becomes part of an analogous electrical network wherein heat capacity and volume define the relative electrical capacity while the thermal conductivity and path length determine electrical resistance. In addition to the conduction network, the program is capable of computing special functions at each time step. For example, variable thermal properties were included by varying resistance and/or capacitance as a function of temperature. Also, resistances which describe heat flow paths between the pintle and pintle housing were varied by a switching technique to duplicate the movement of heated portions of pintle into the cooler regions of the housing. In this manner, a continuous thermal analysis of any particular duty cycle was obtained without repeatedly stopping and starting the analysis after each firing or cooling period.

Thermal analyses results obtained for various duty cycles using the techniques outlined are provided in the following figures. These data are presented in terms of predicted temperature histories for the arbitrarily

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chosen nodes indicated in Figures Appendix D-I and -II. The various duty cycles investigated were:

<u>Figure Number</u>	<u>No. of Pulses</u>	<u>Pulse on Time, Sec</u>	<u>Pulse off Time, Sec</u>	<u>Pintle Material</u>
III-1 thru 5	1	26	474	(Backup) MX 4926
IV-1 thru 6	1	26	474	All AG Carb 101
V-1 thru 5	3	10	30	"
VI-1 thru 5	24	1	30	"
VII-1 thru 6	3	10	1	"
VIII-1 thru 6	24	1	1	"
IX-1 thru 6	27	1	10	"
X - 1 thru 6	3	10	10	"

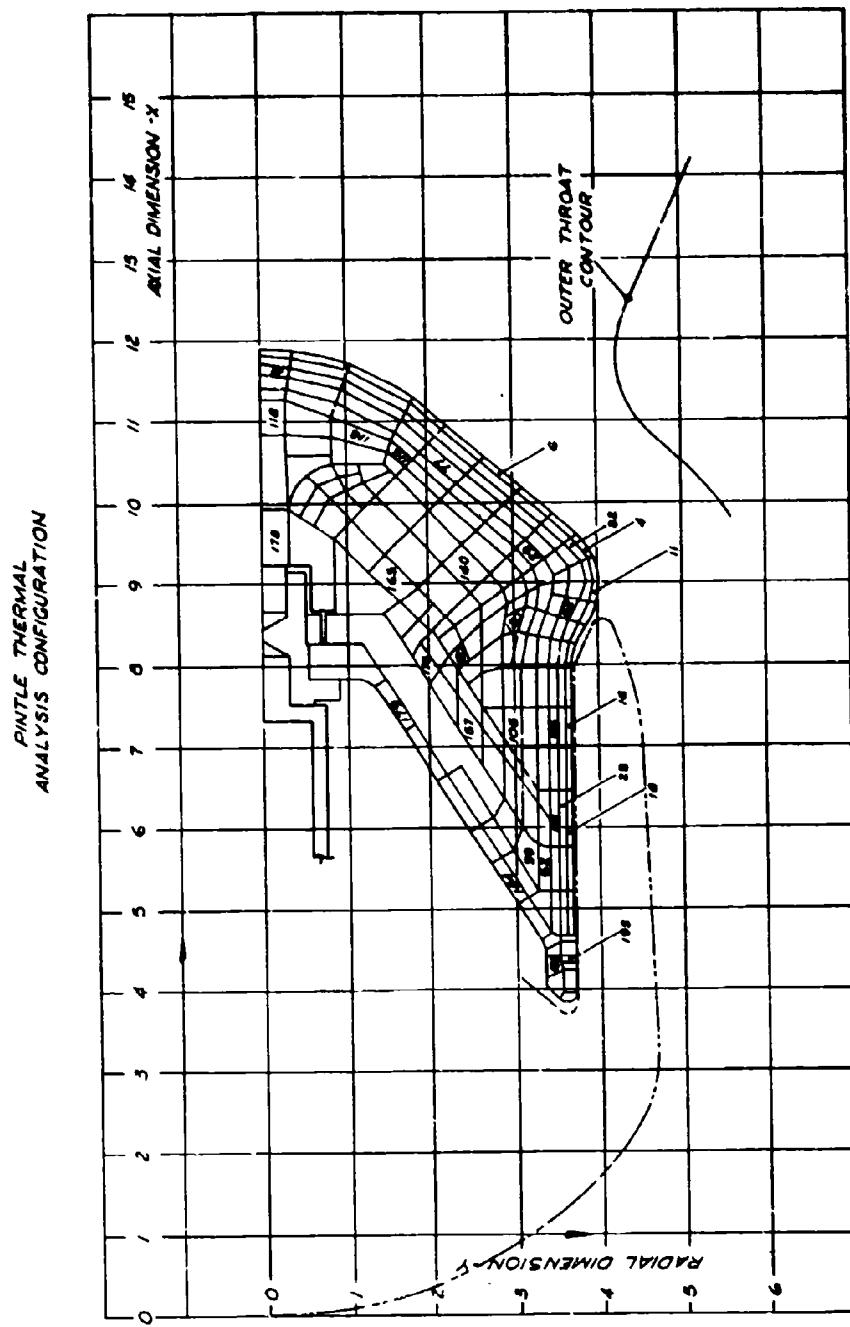


Fig. App. D-1

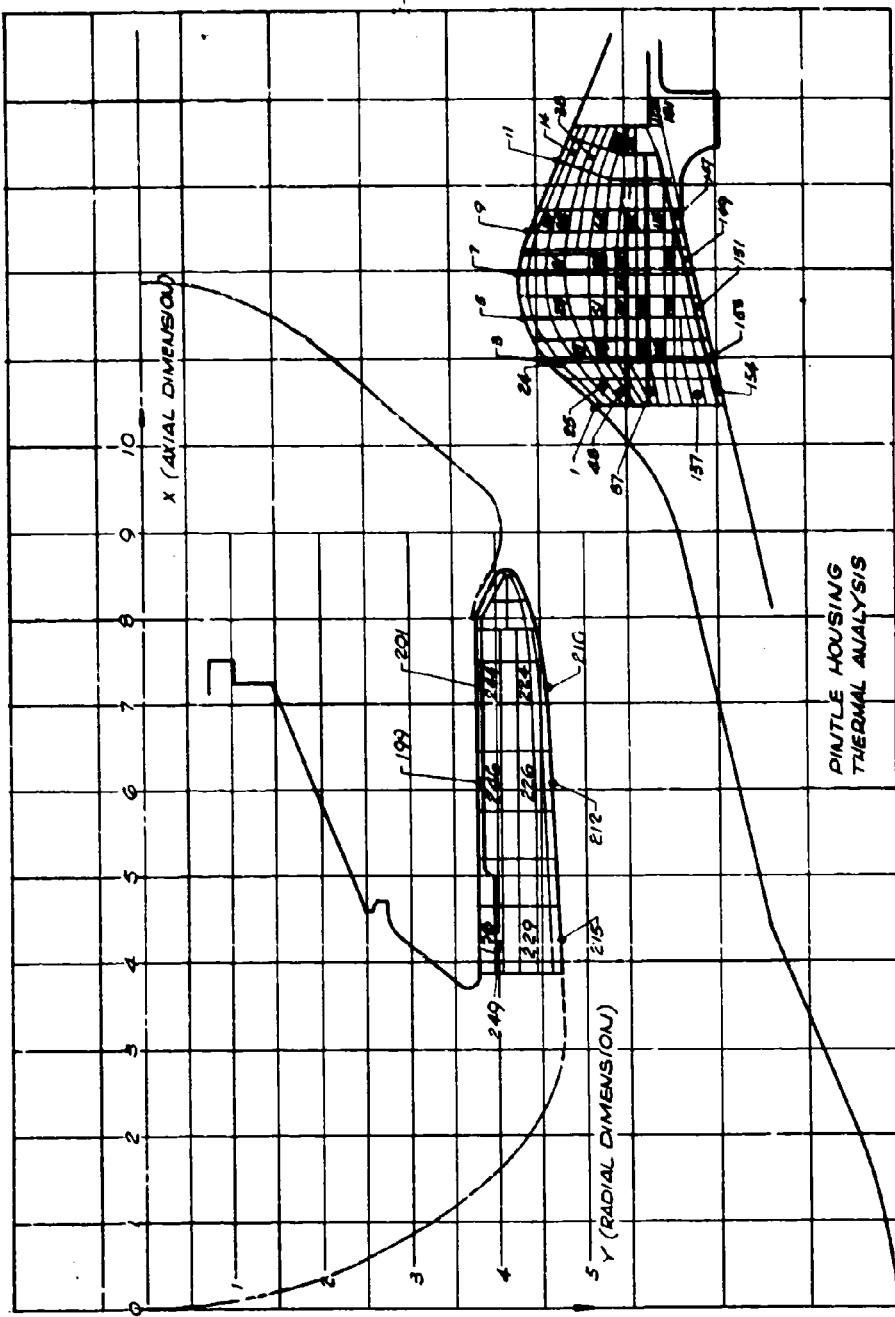


Fig. App. D-2

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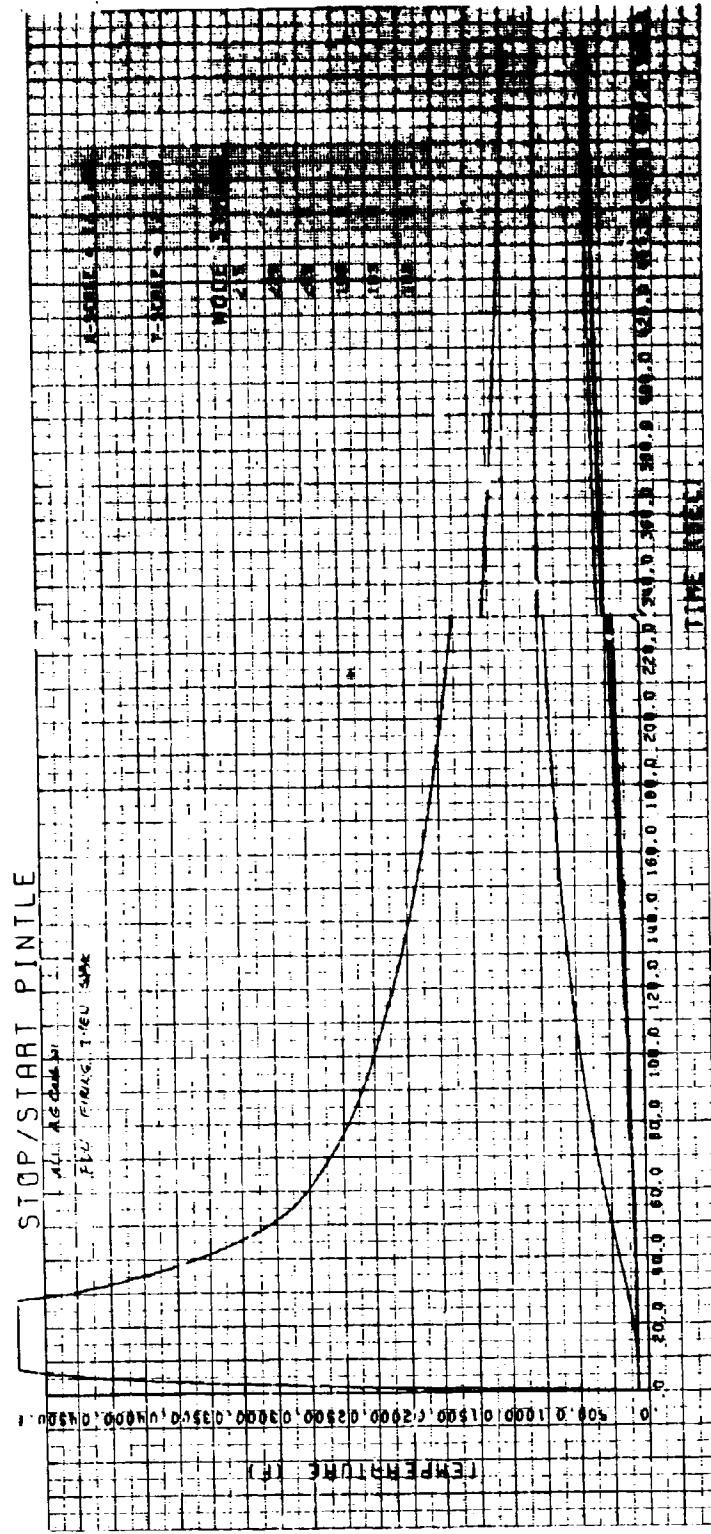


Figure III-1.

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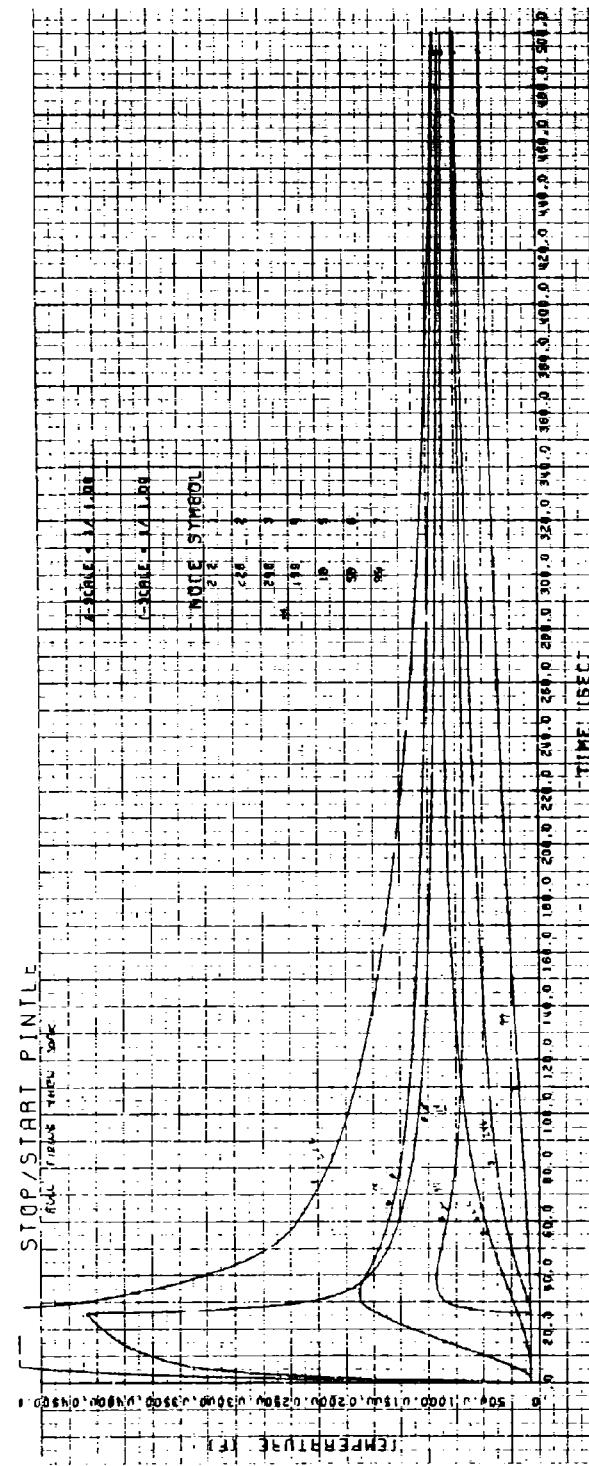


Figure III-2

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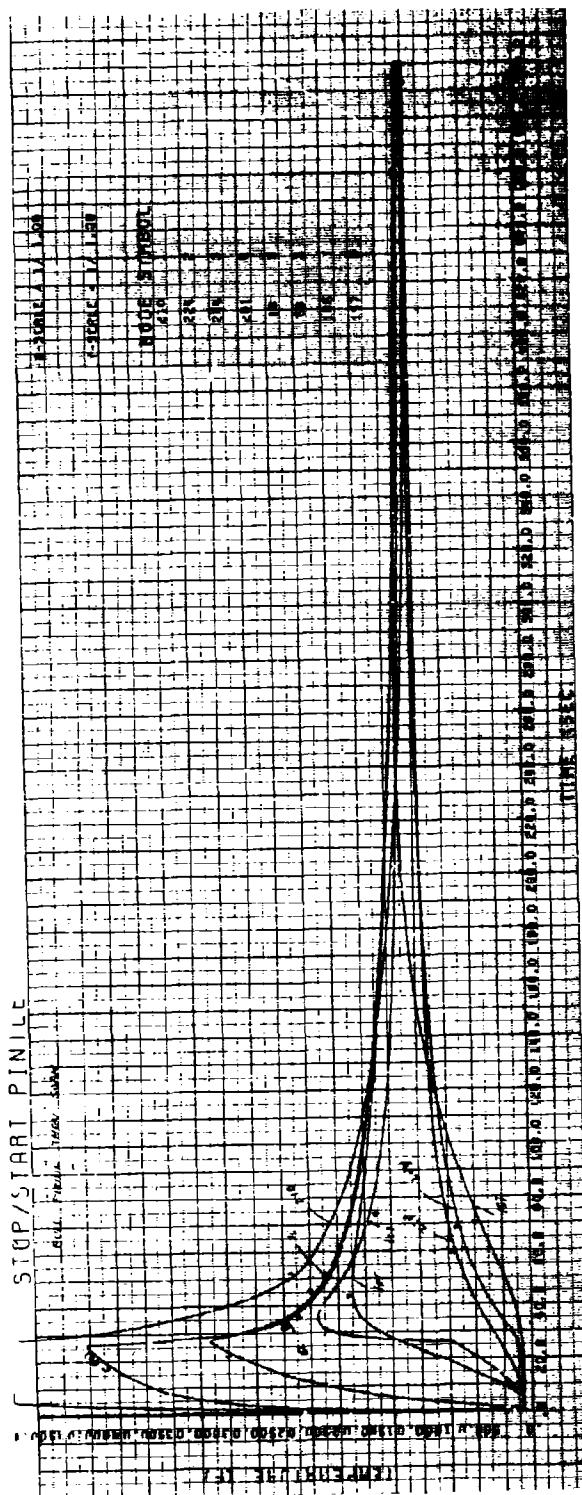


Figure III-3

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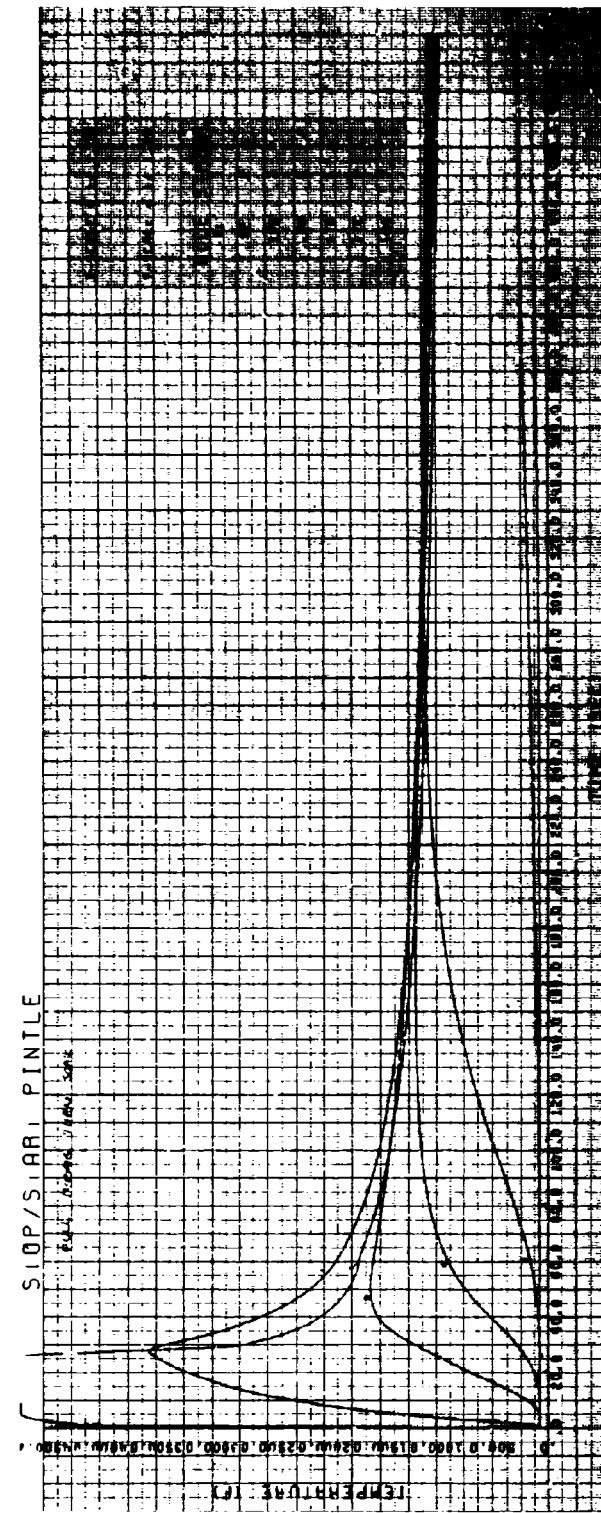


Figure III-4

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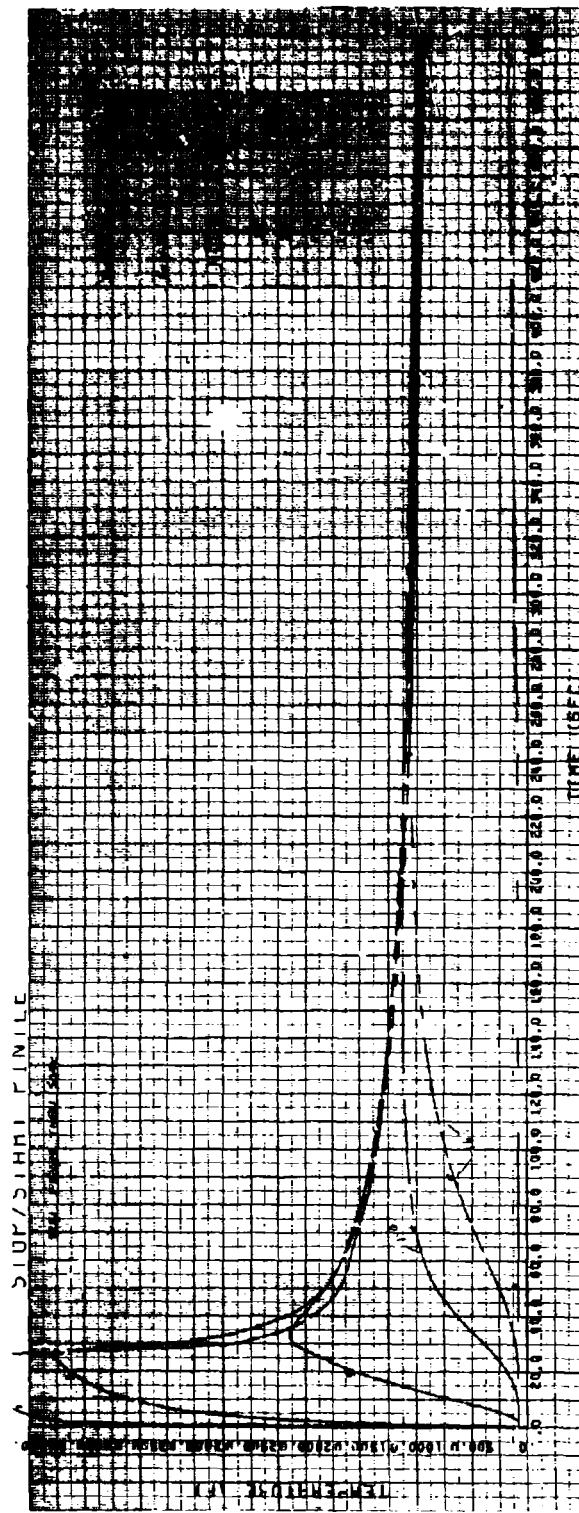


Figure III-5

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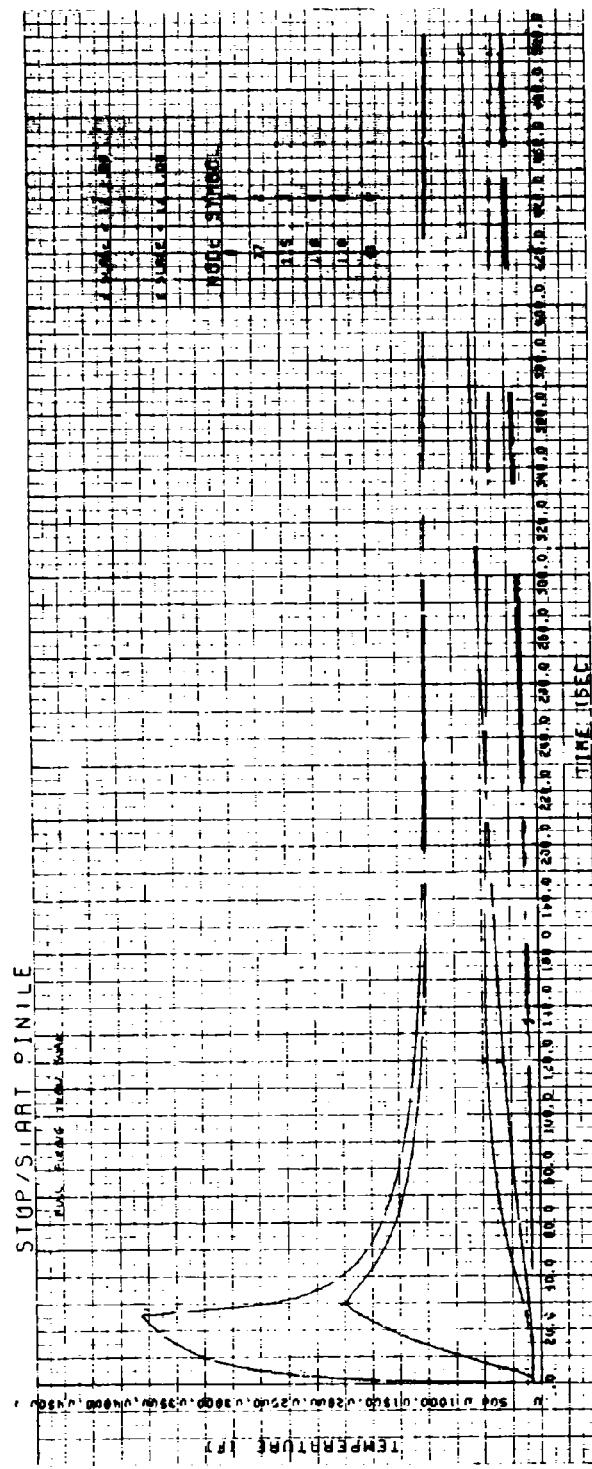


Figure III-9

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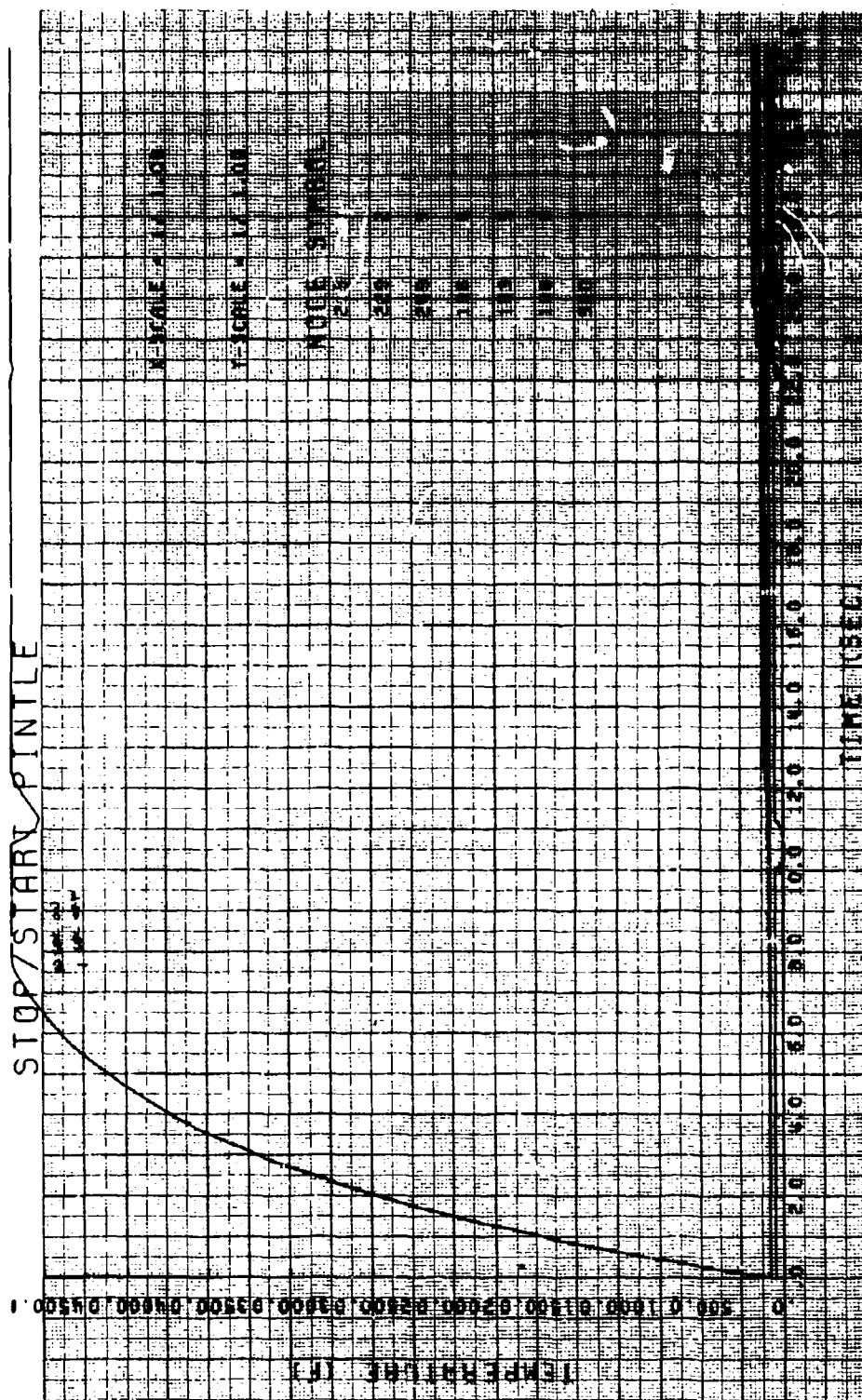


Figure IV-1

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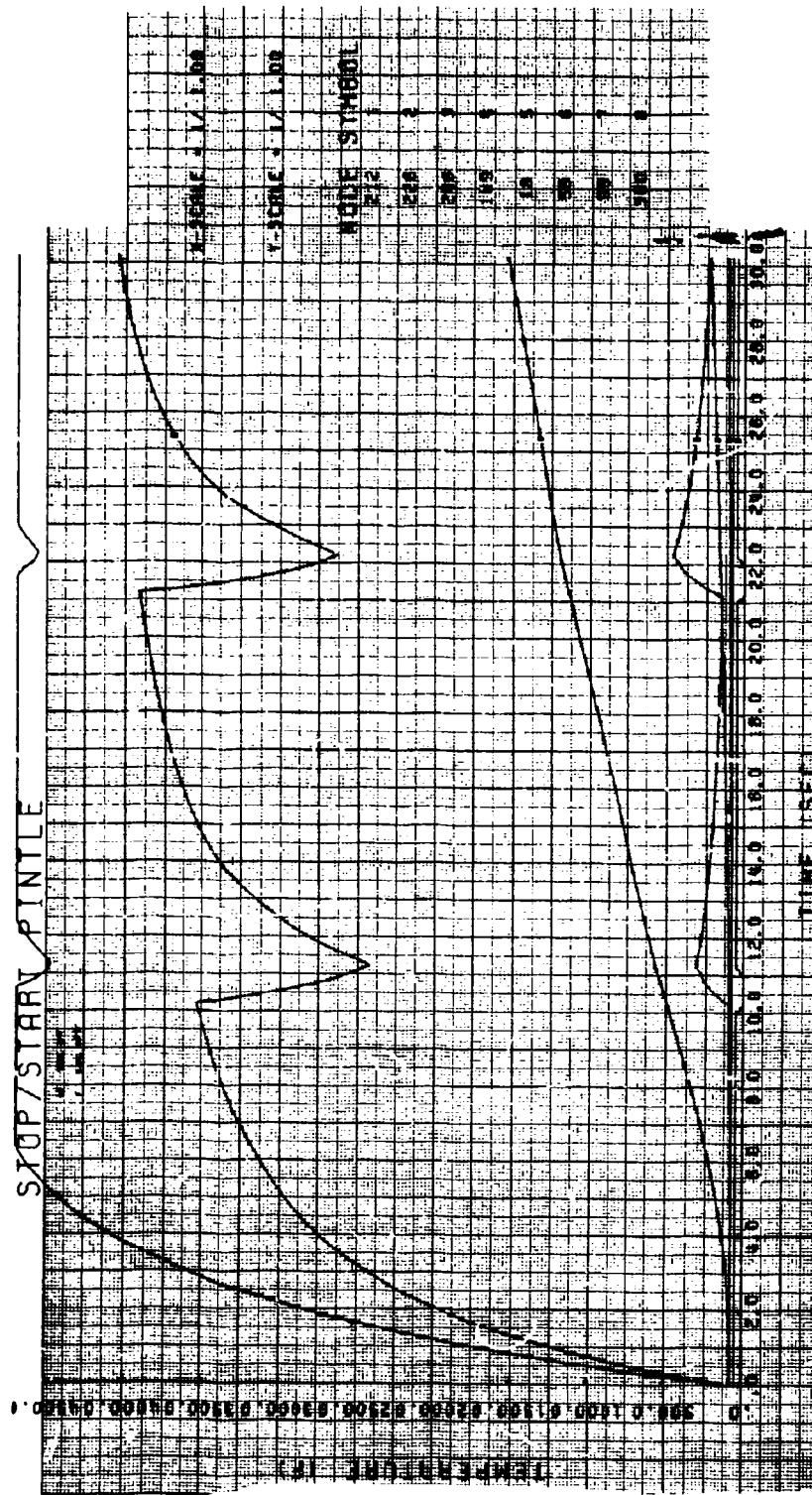


Figure IV-2

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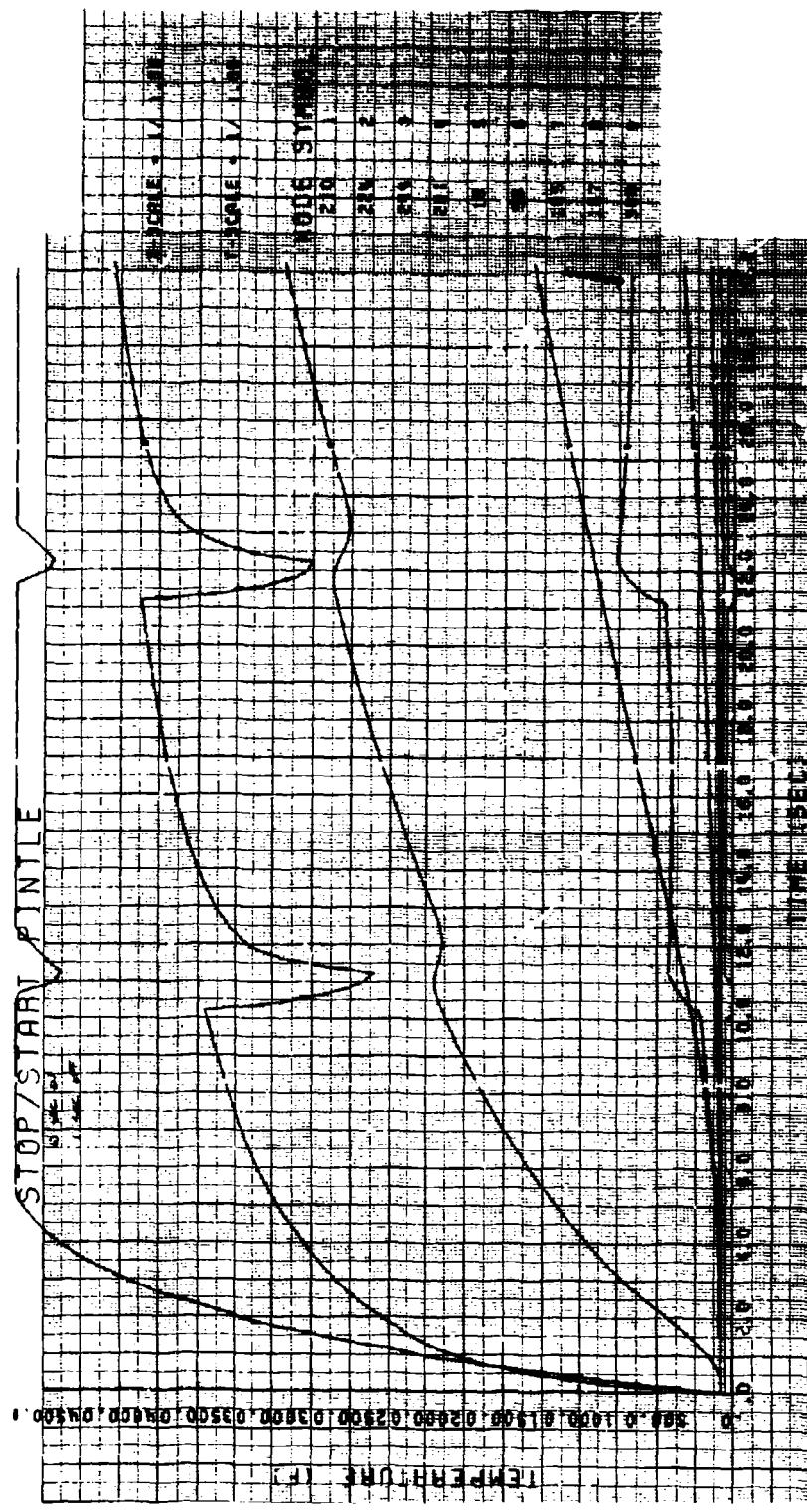


Figure IV-3

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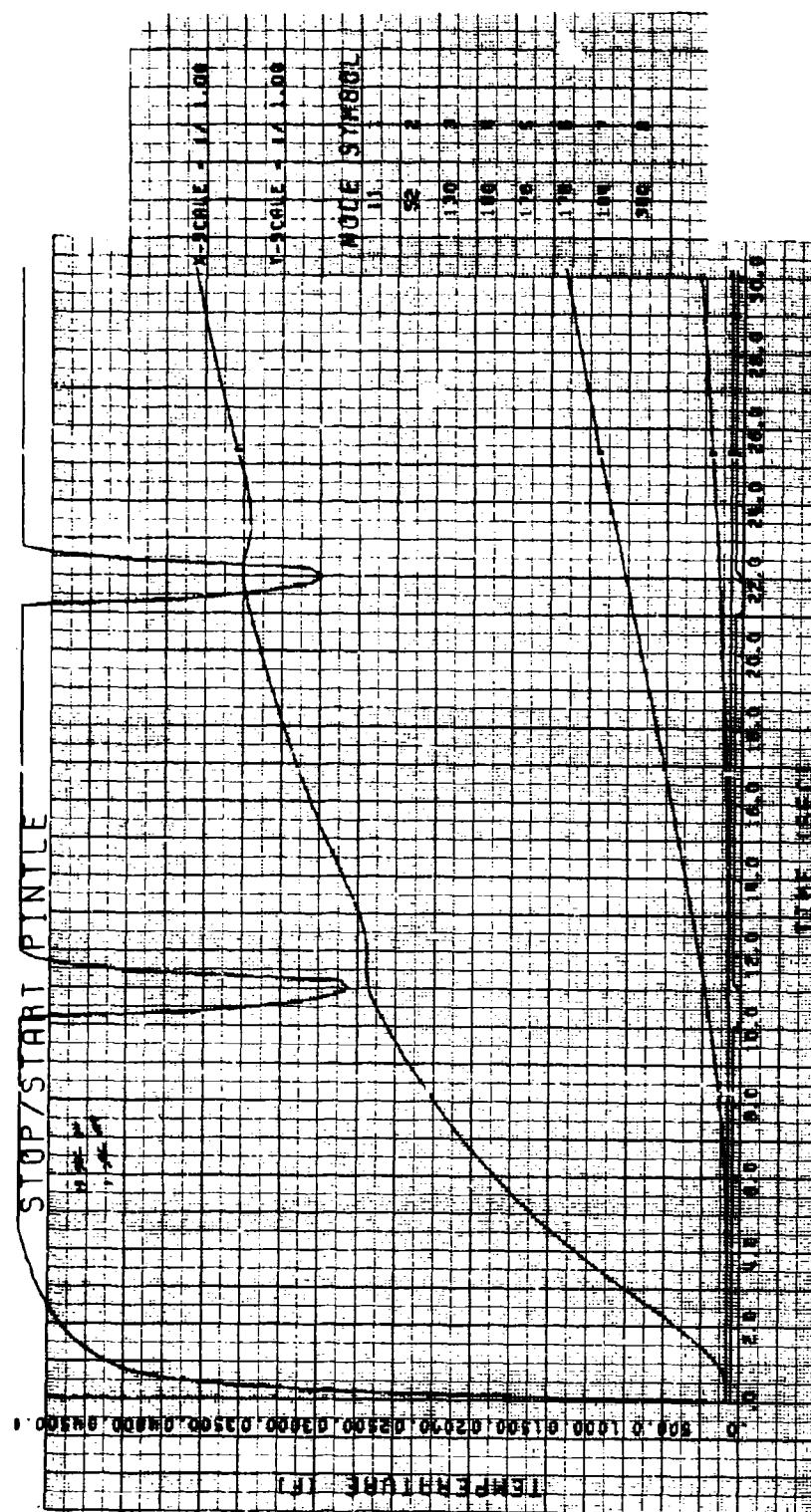


Figure IV-4

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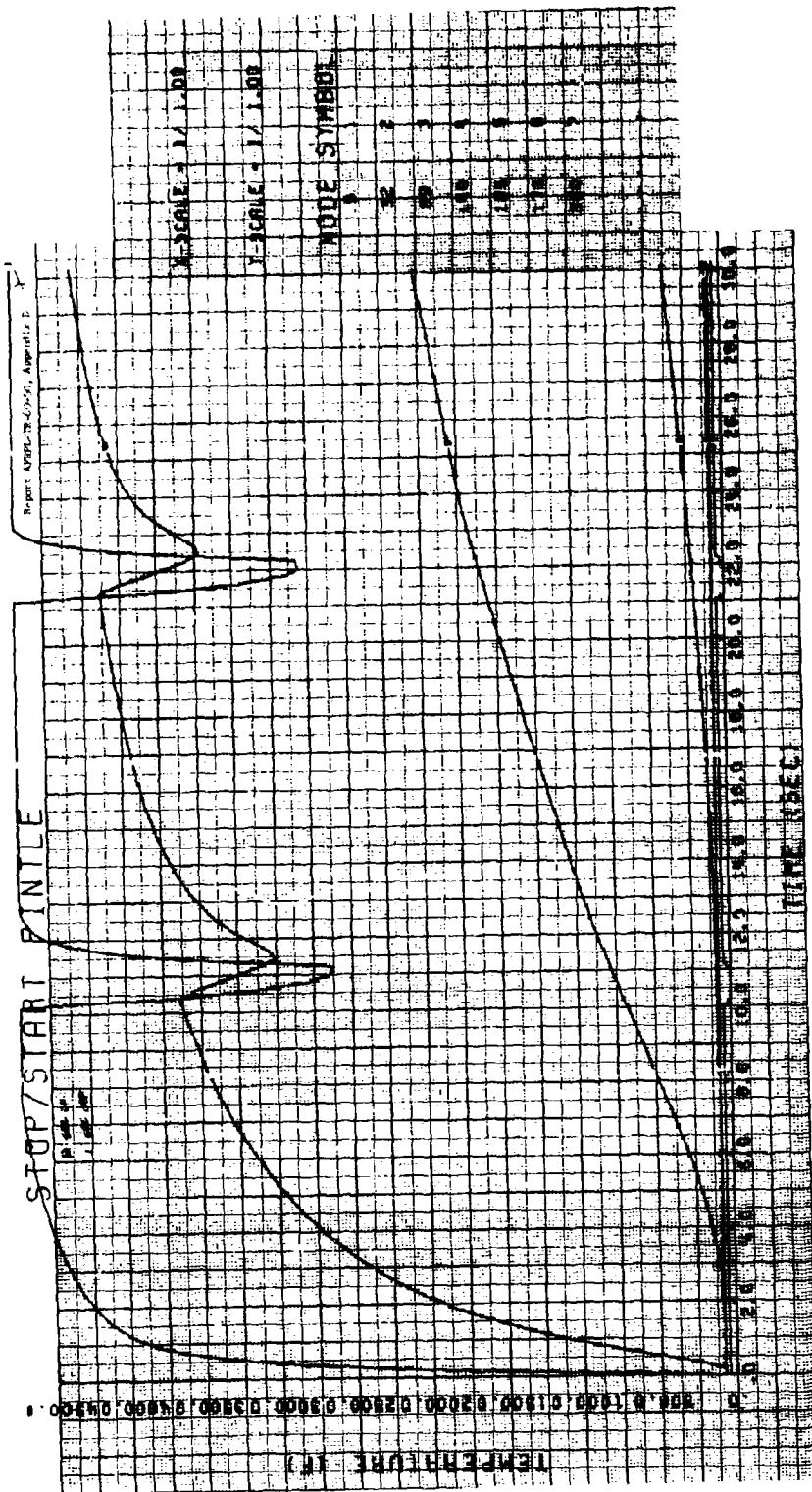


Figure IV-5

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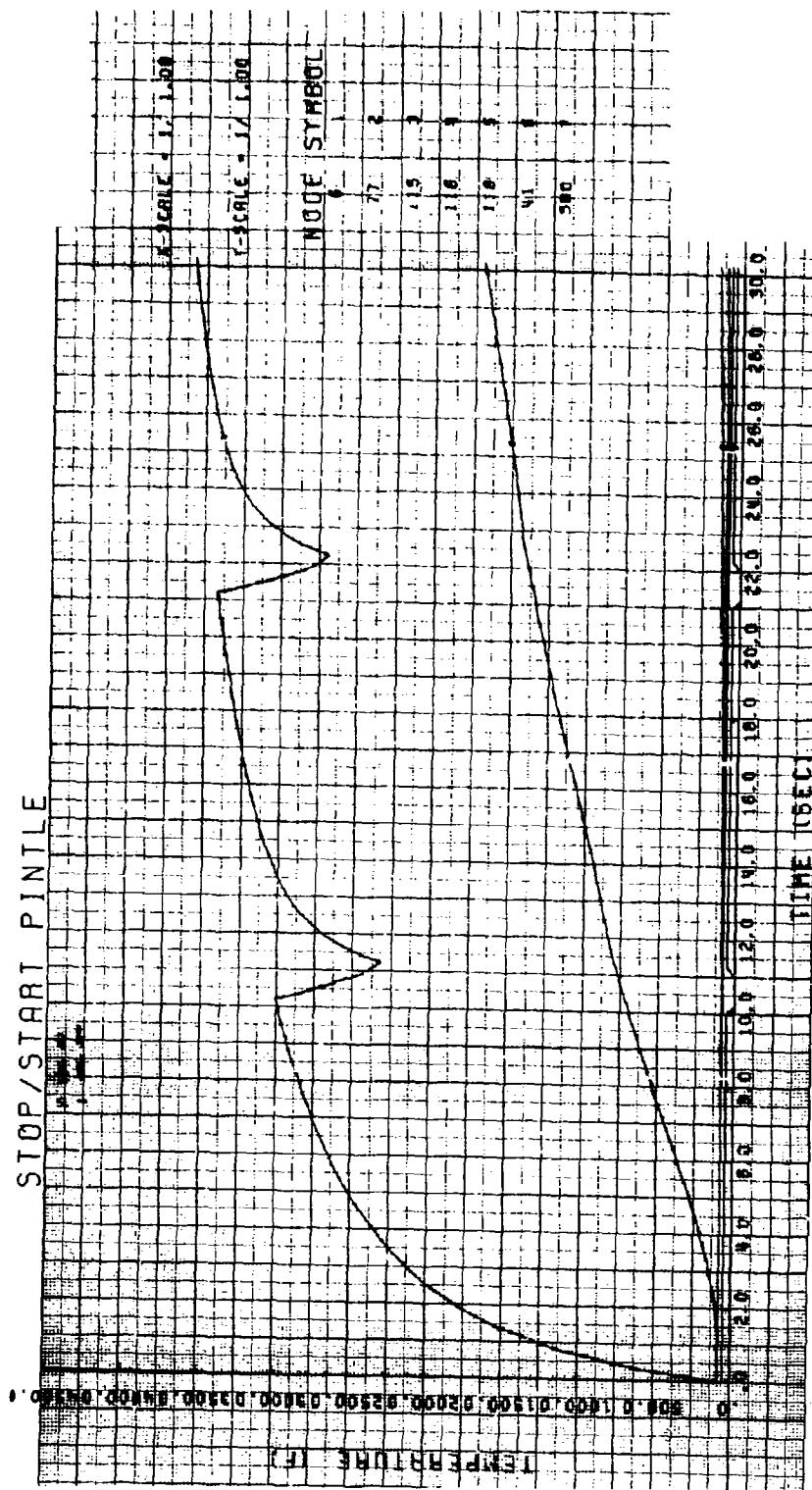


Figure IV-6

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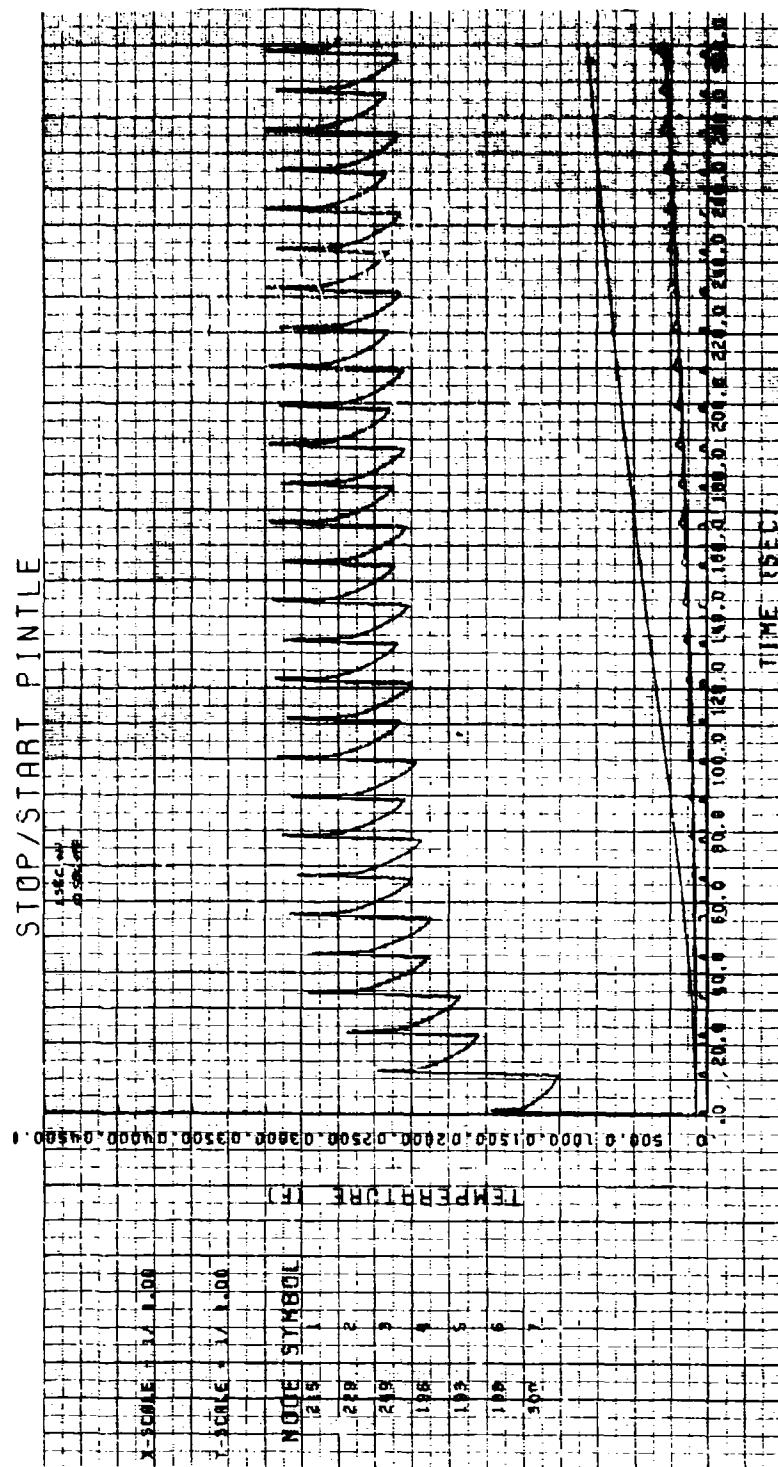


Figure V-1

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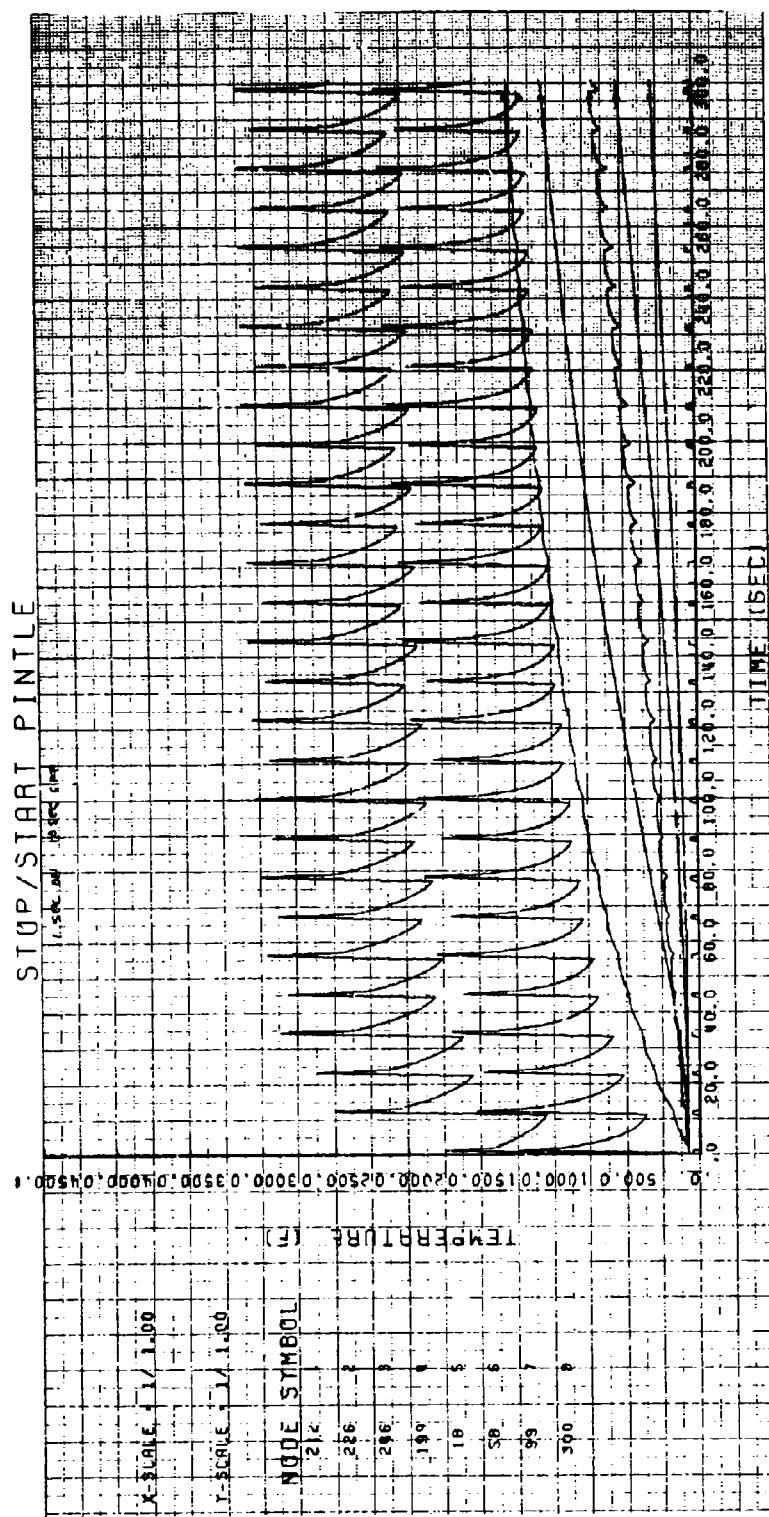


Figure V-2

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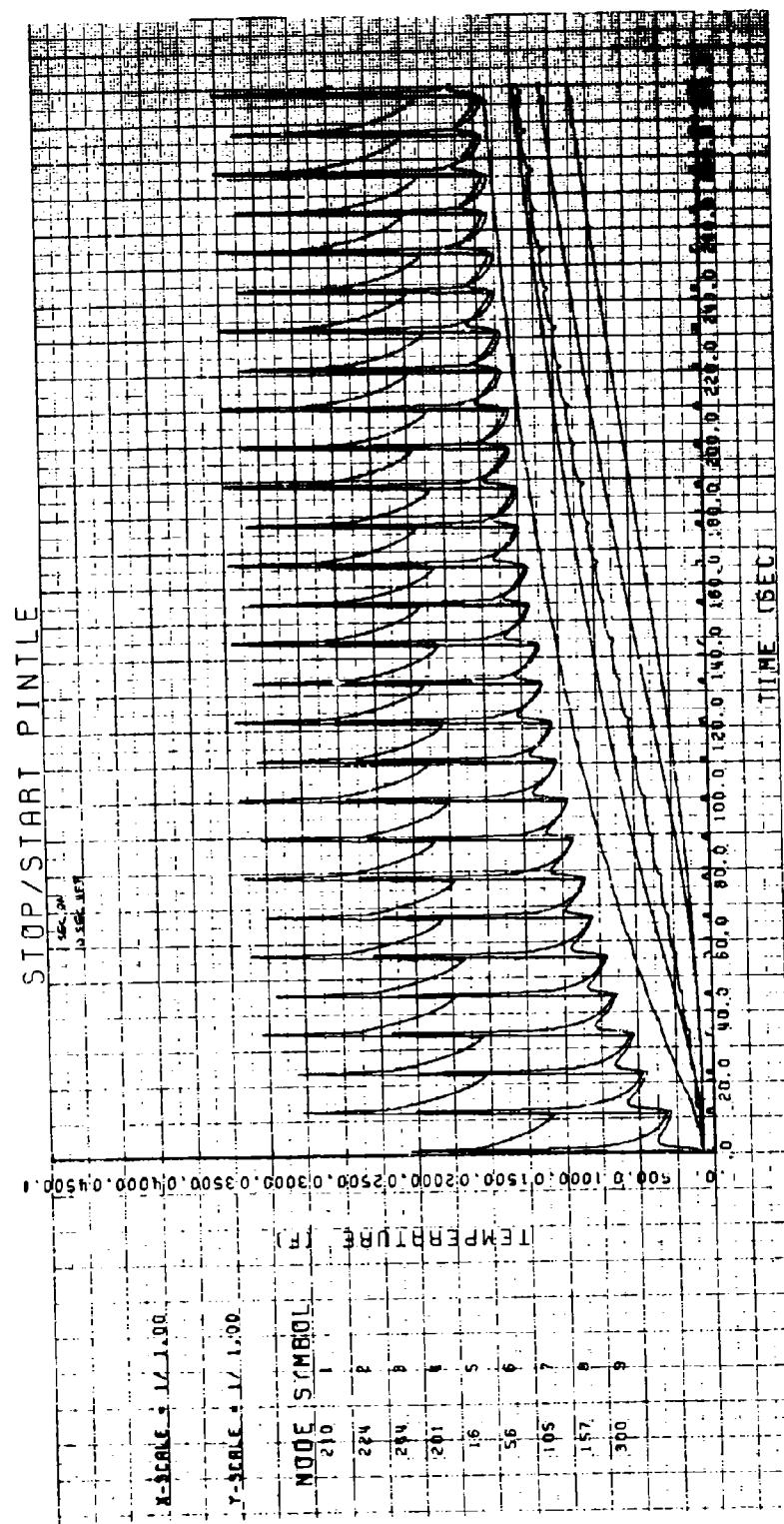


Figure V-3

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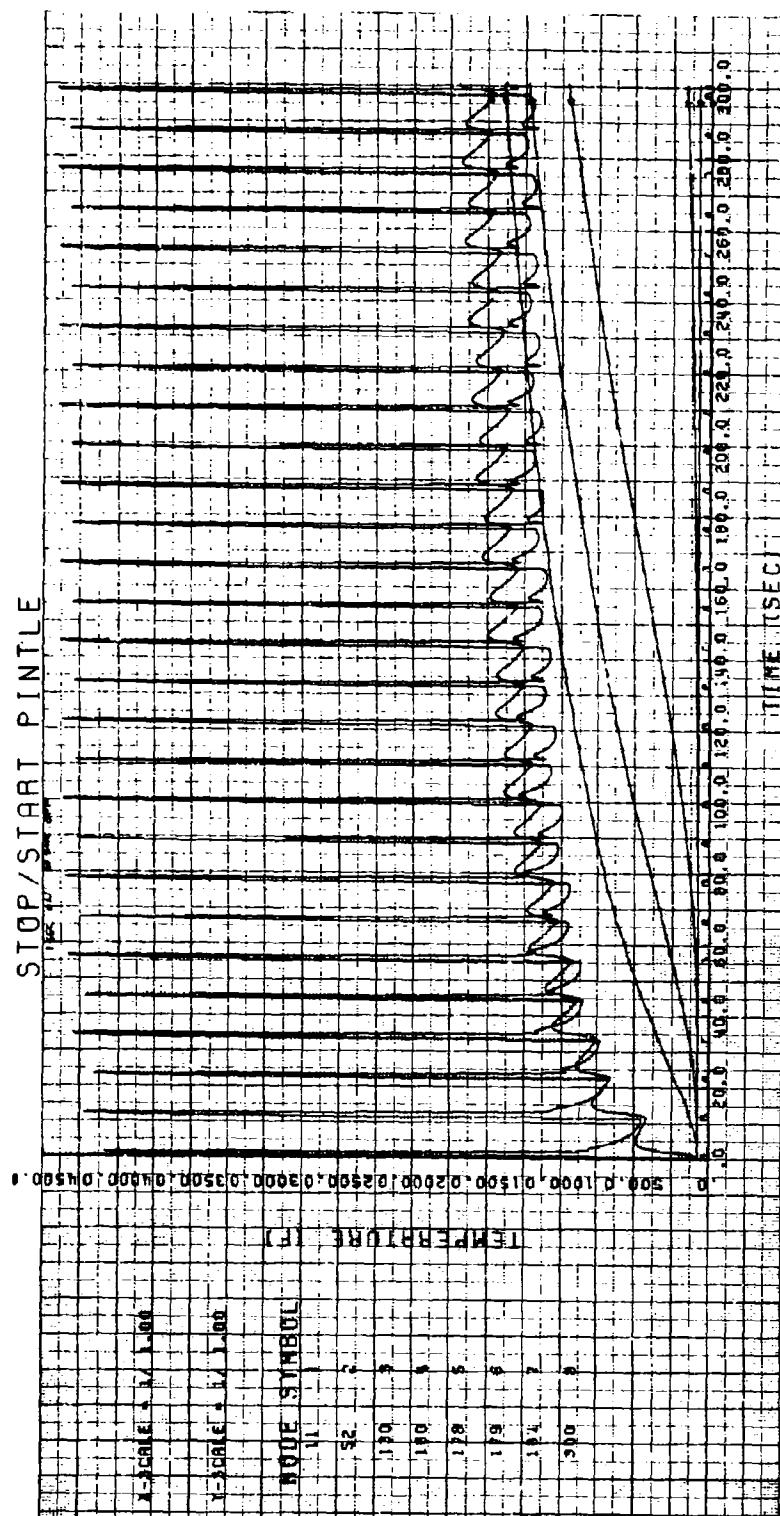


Figure V-4

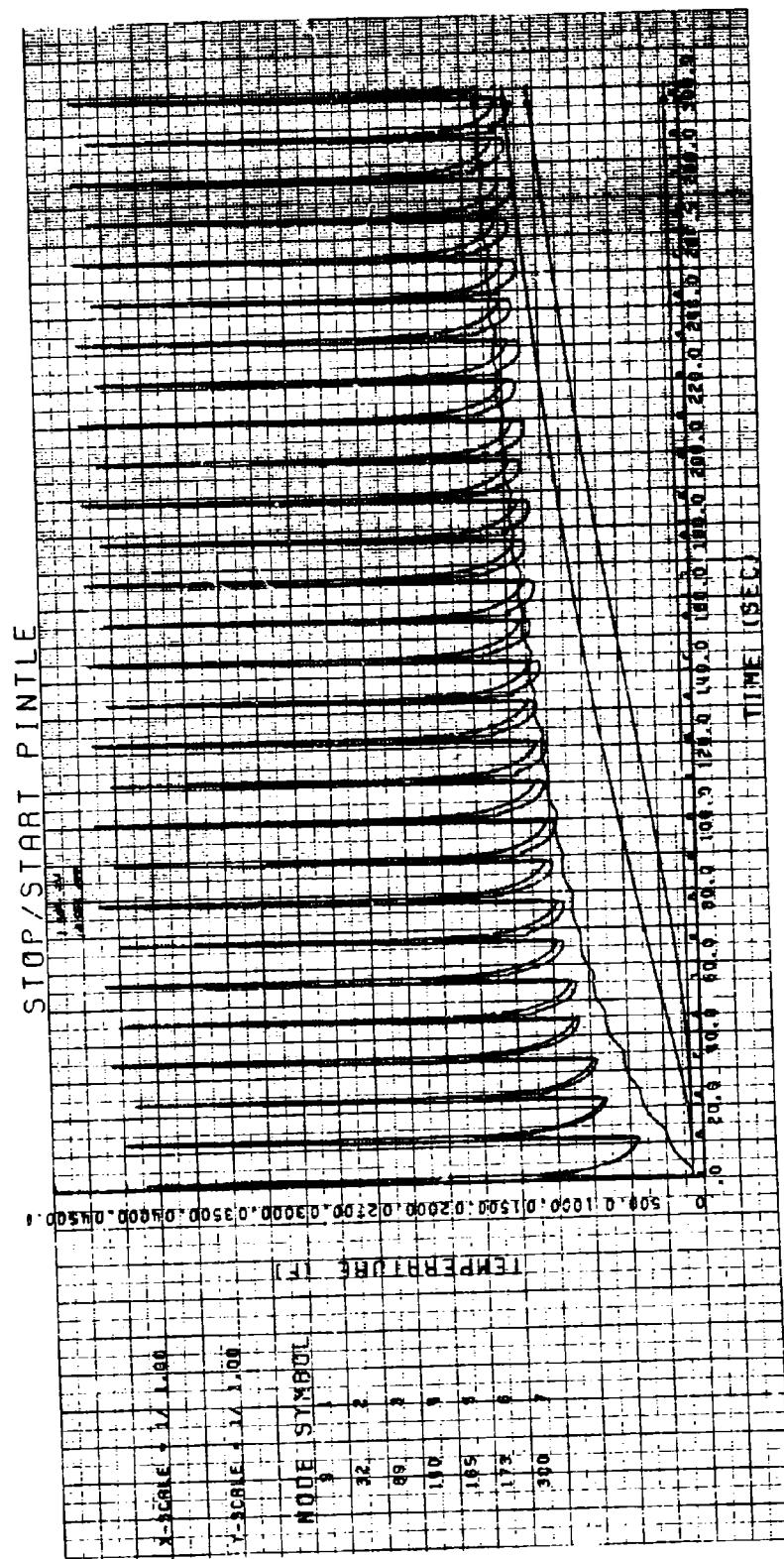


Figure V-5

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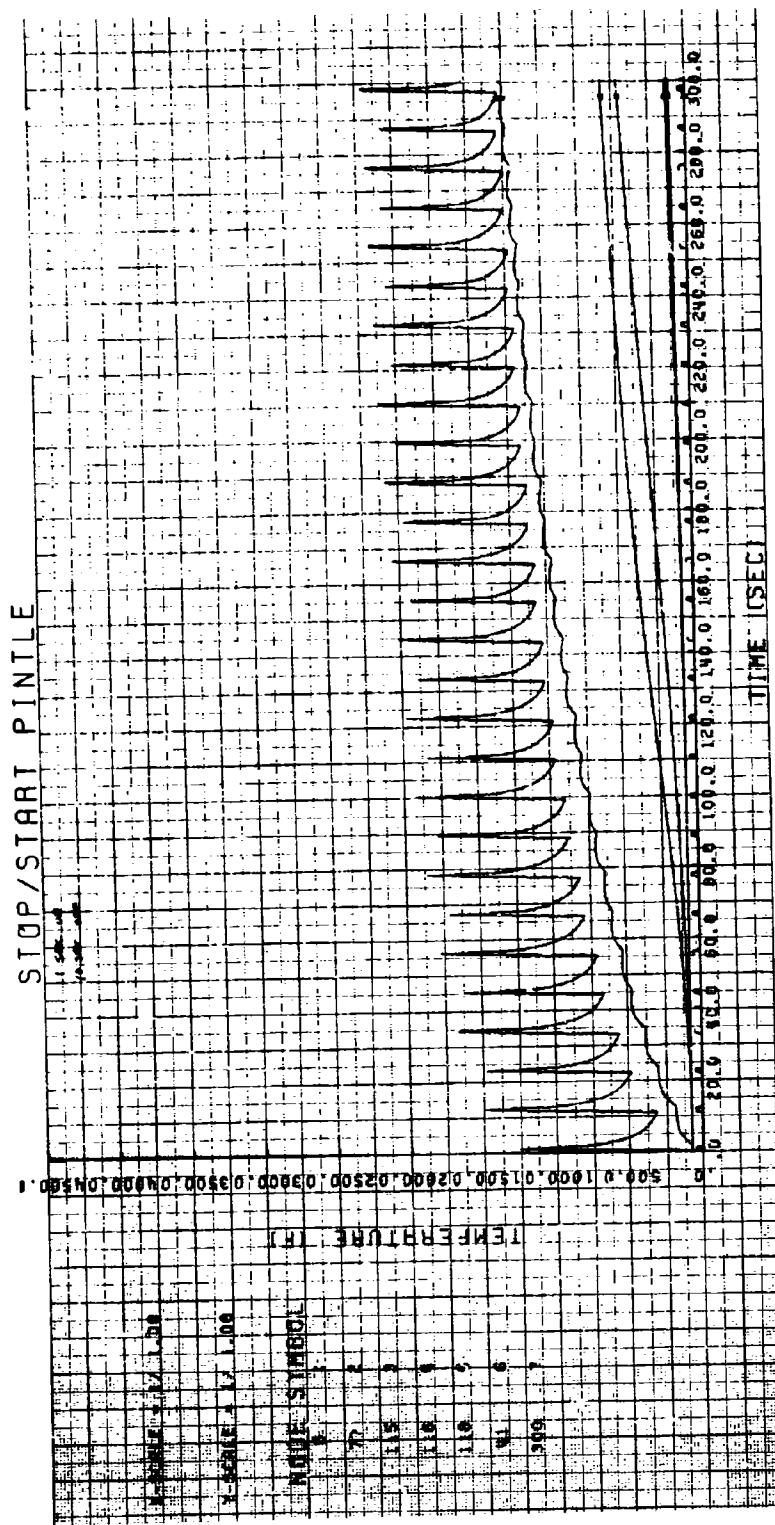


Figure V-6

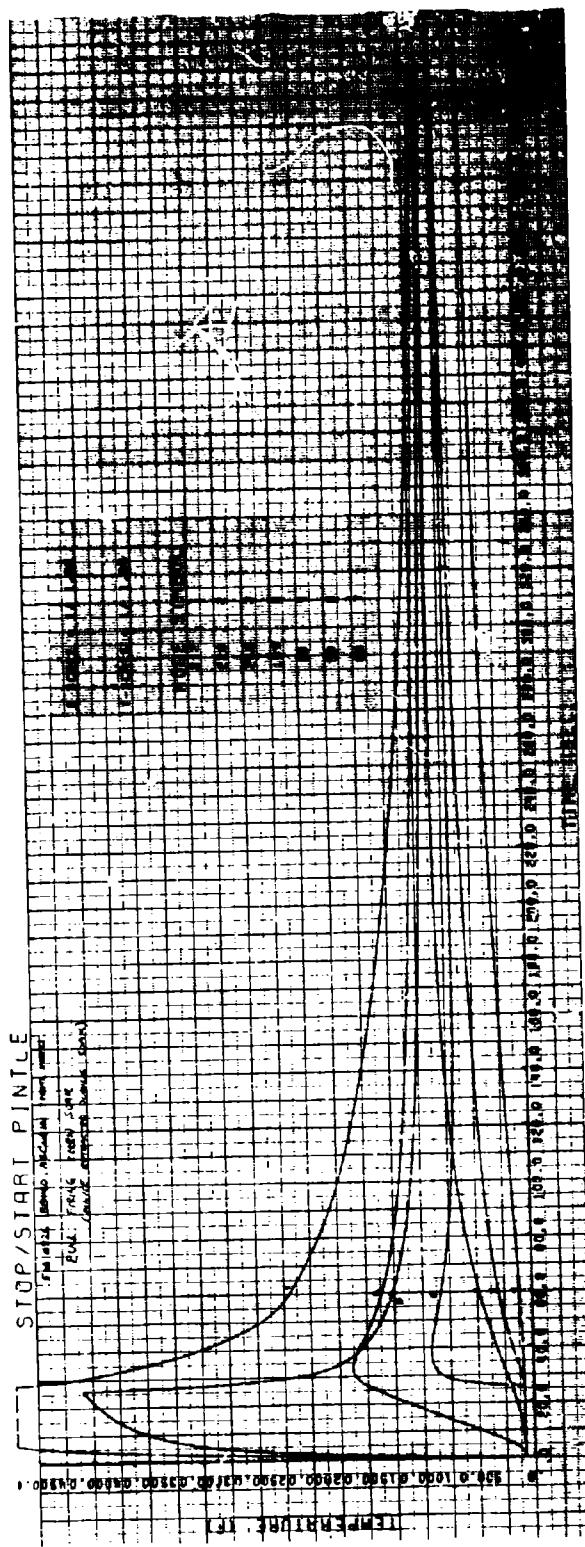


Figure VI-1

Report AFRPL-TR-69-50, Appendix D

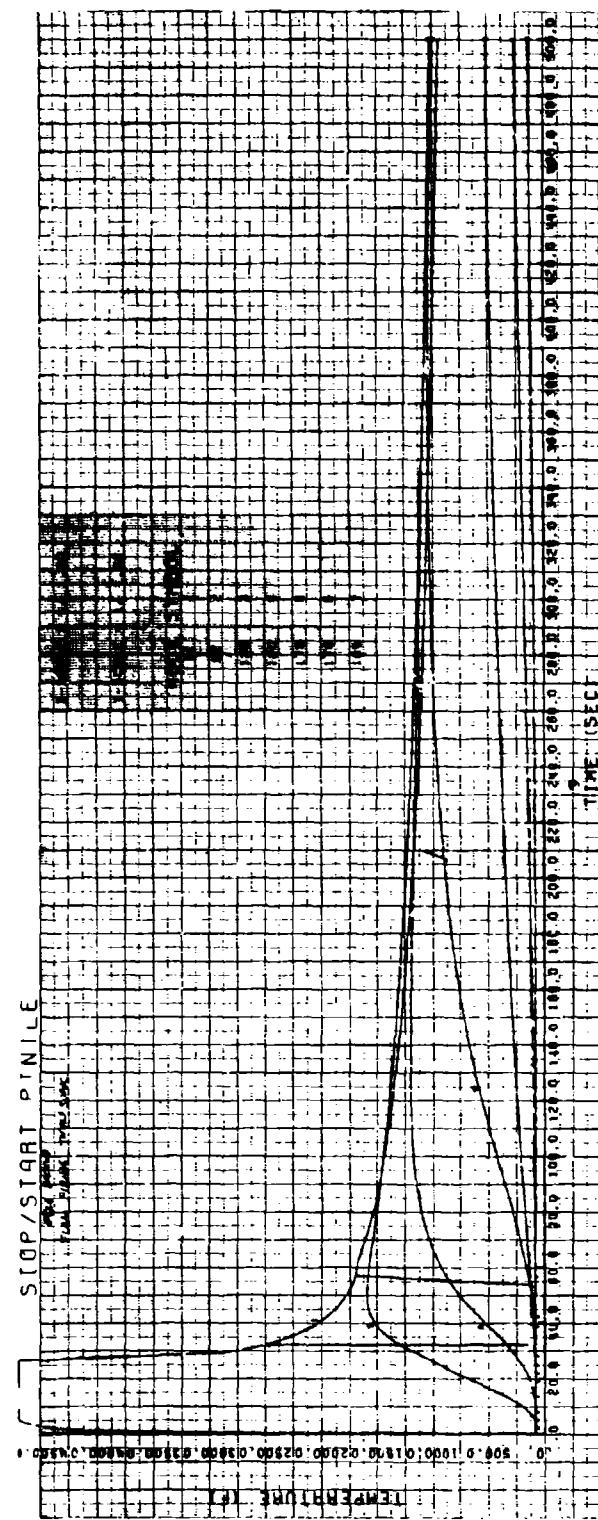


Figure VI-2

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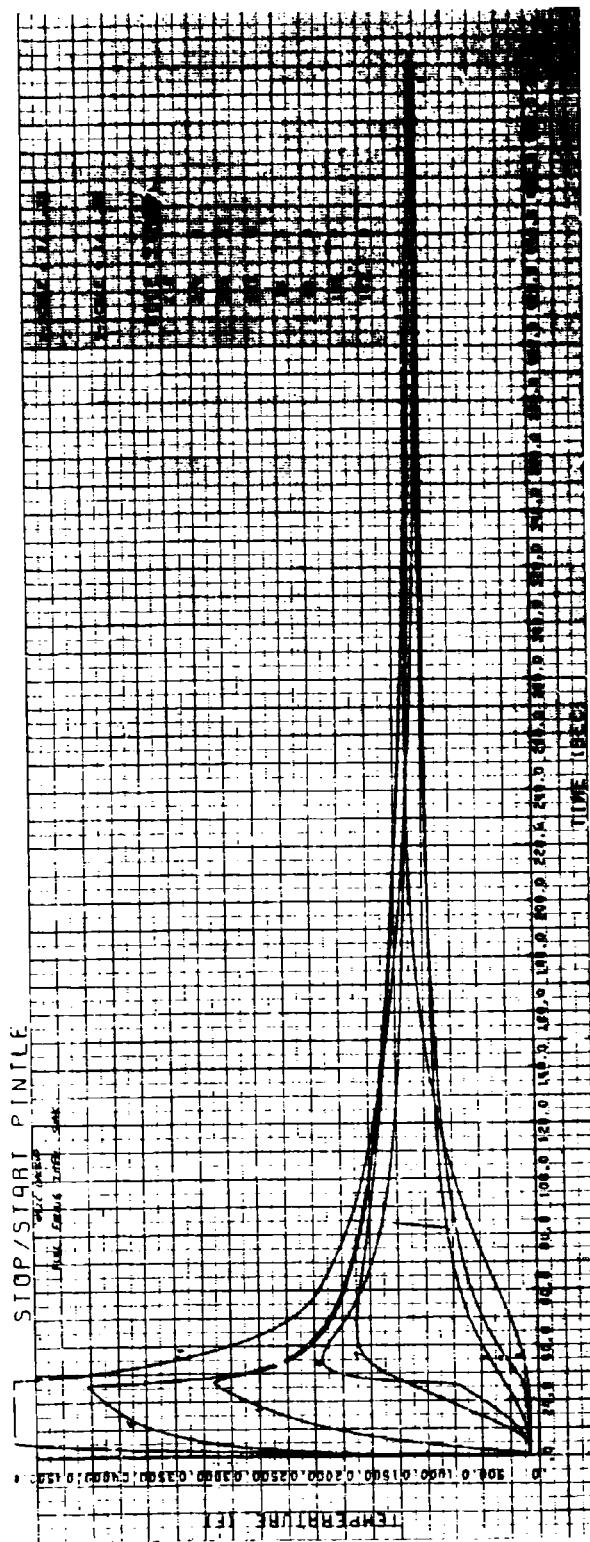


Figure VI-3

Report AFRPL-TR-69-50, Appendix D

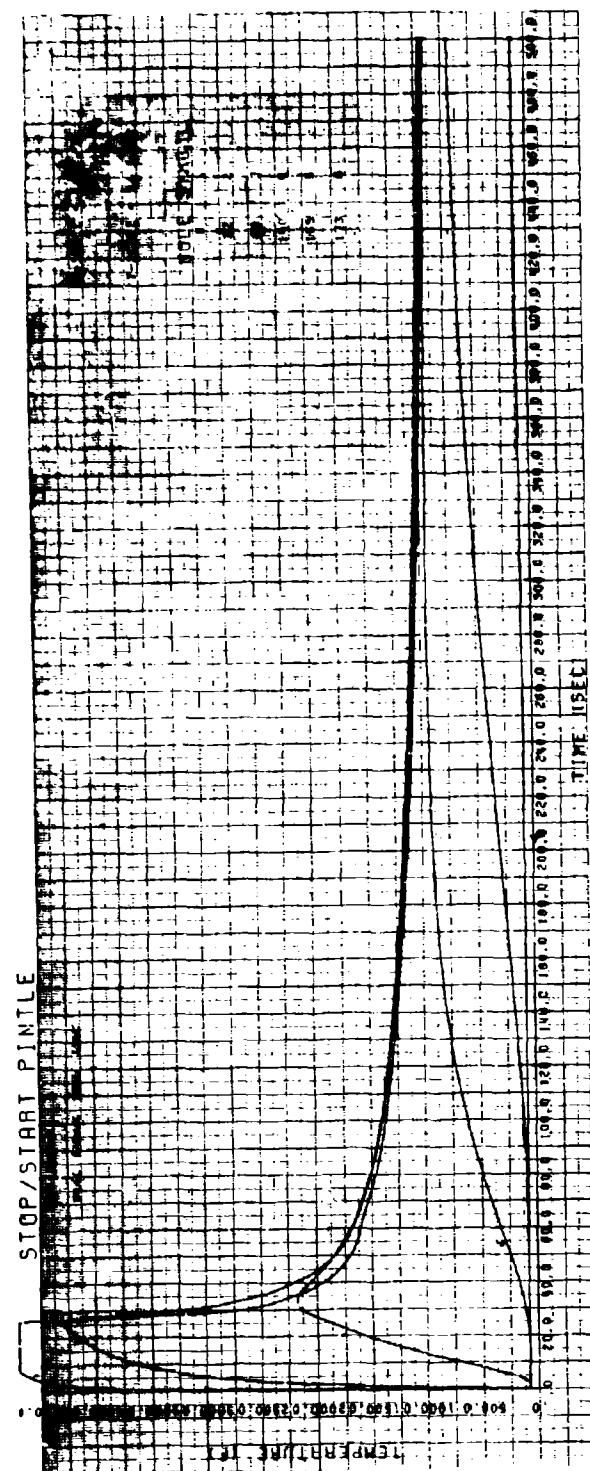


Figure VI-4

Report AFRPL-TR-69-50, Appendix D

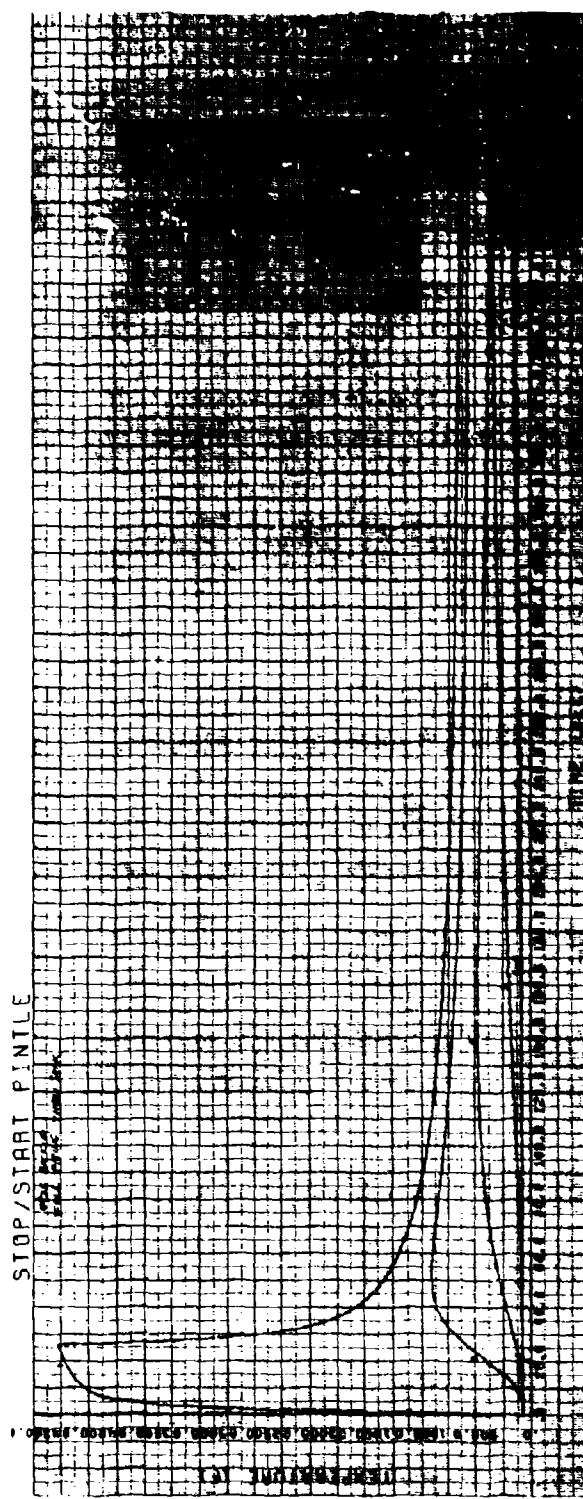


Figure VI-5

Report AFRPL-TR-69-50, Appendix D

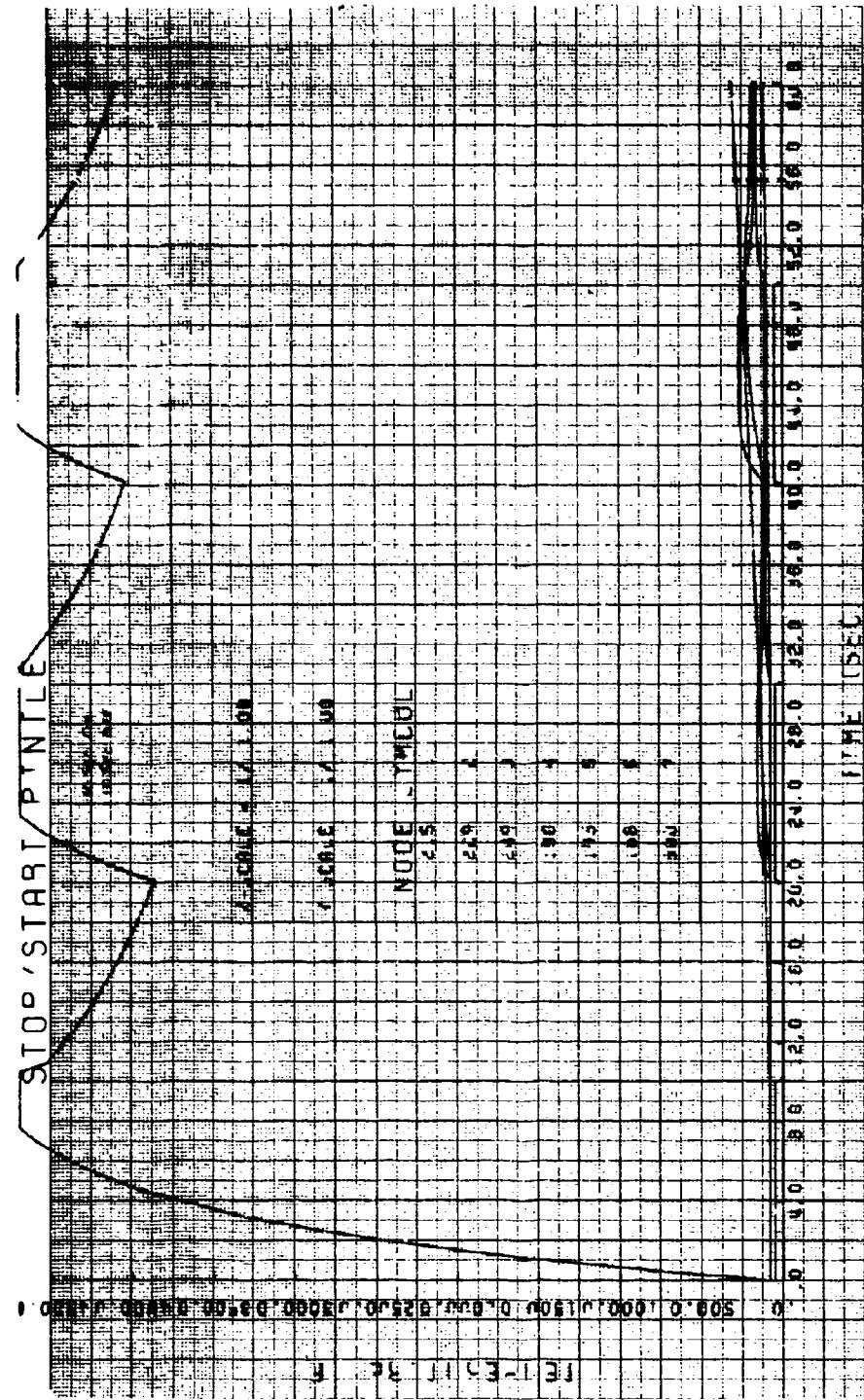


Figure VII-1

Report AFRPL-TR-69-50, Appendix D

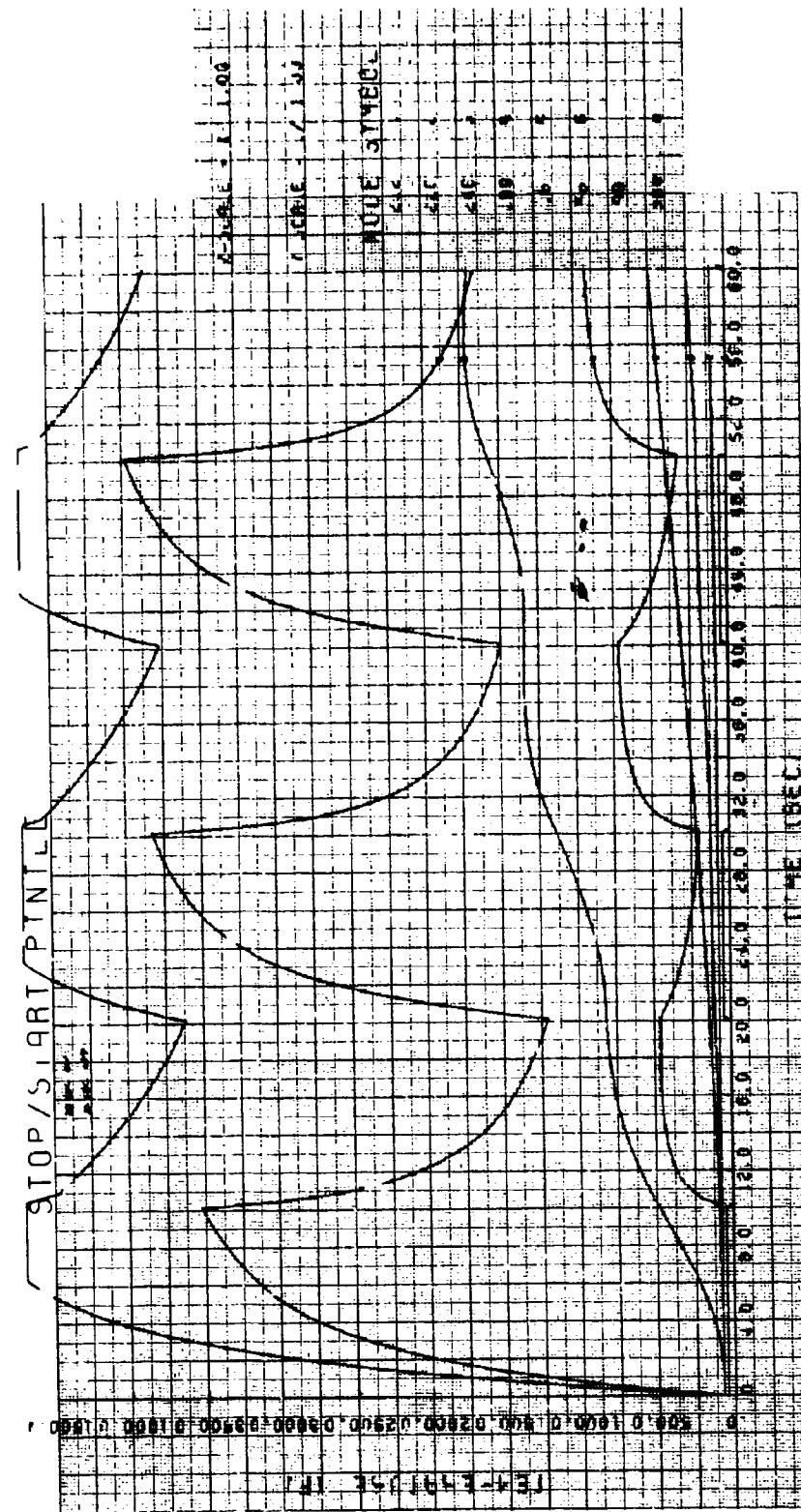


Figure VII-2

Report AFRPL-TR-69-50, Appendix D

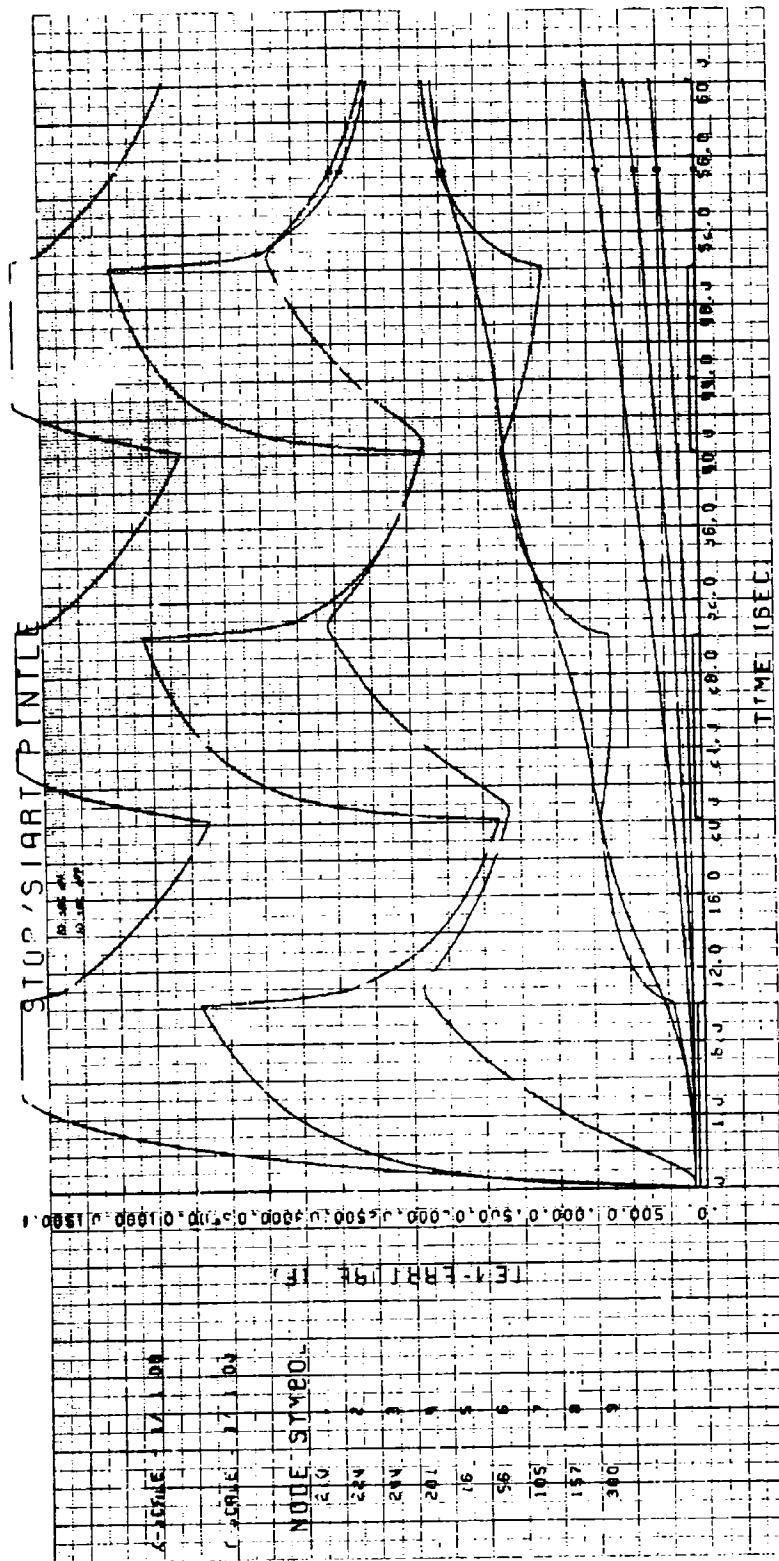


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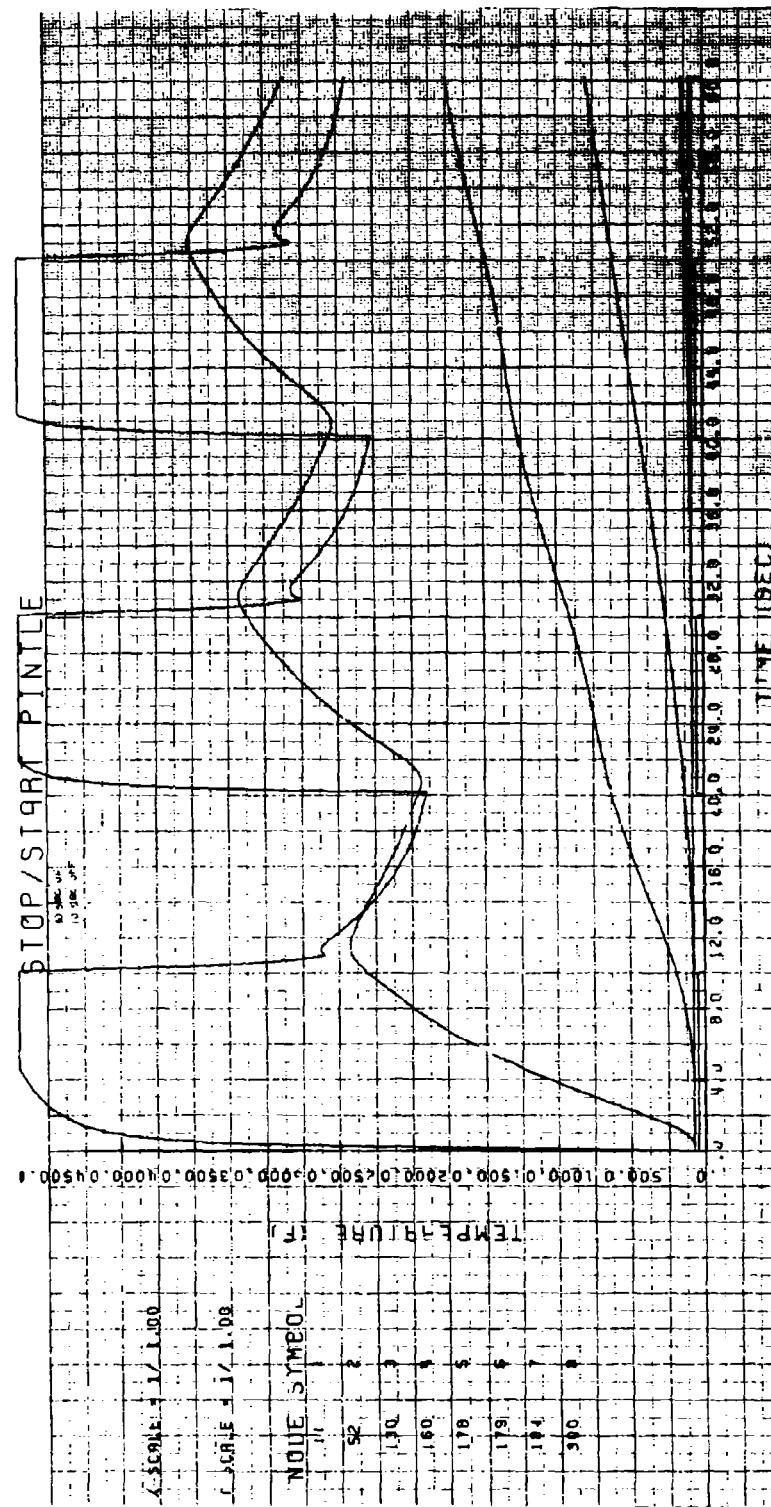


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Report AFRPL-TR-69-50, Appendix D

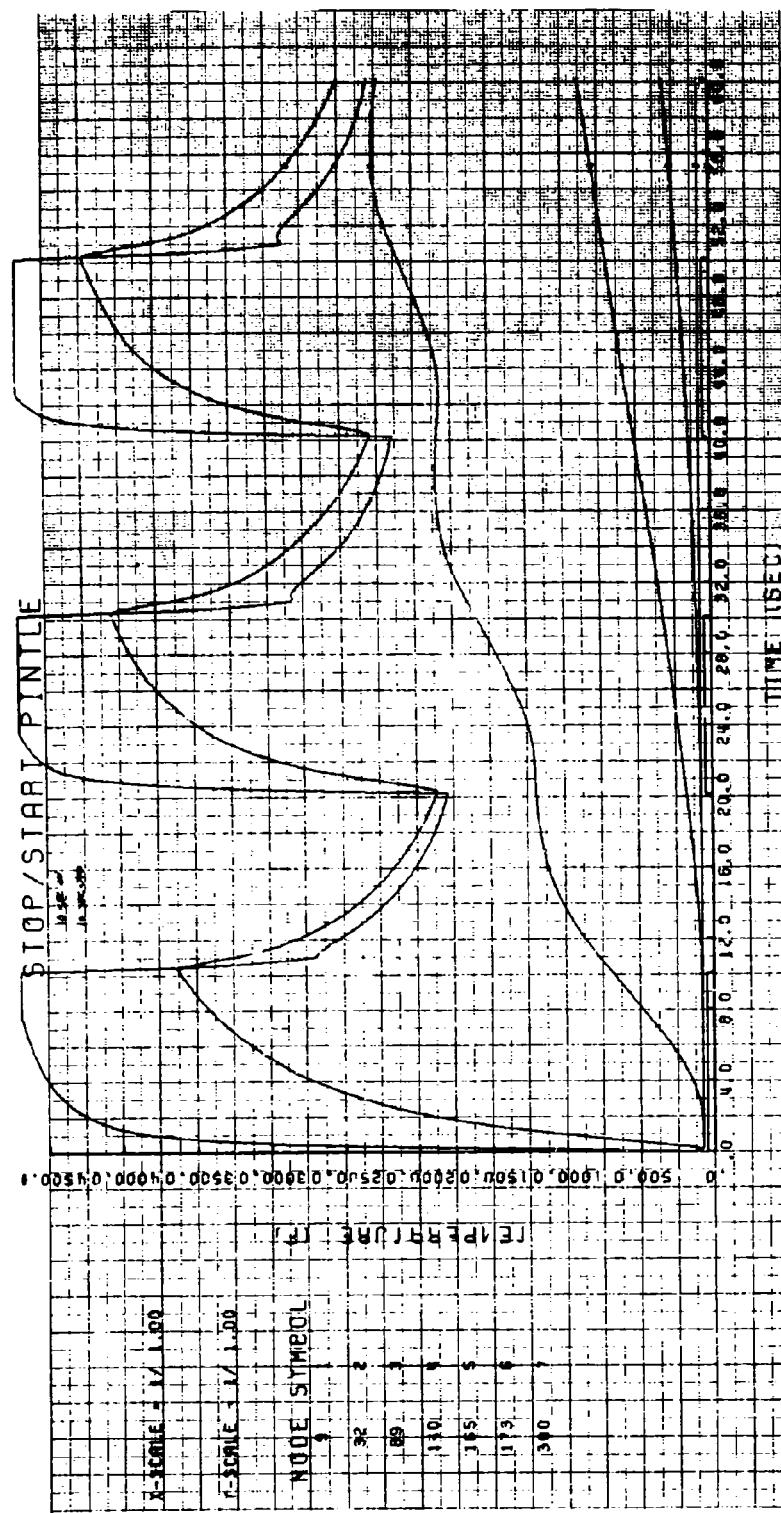


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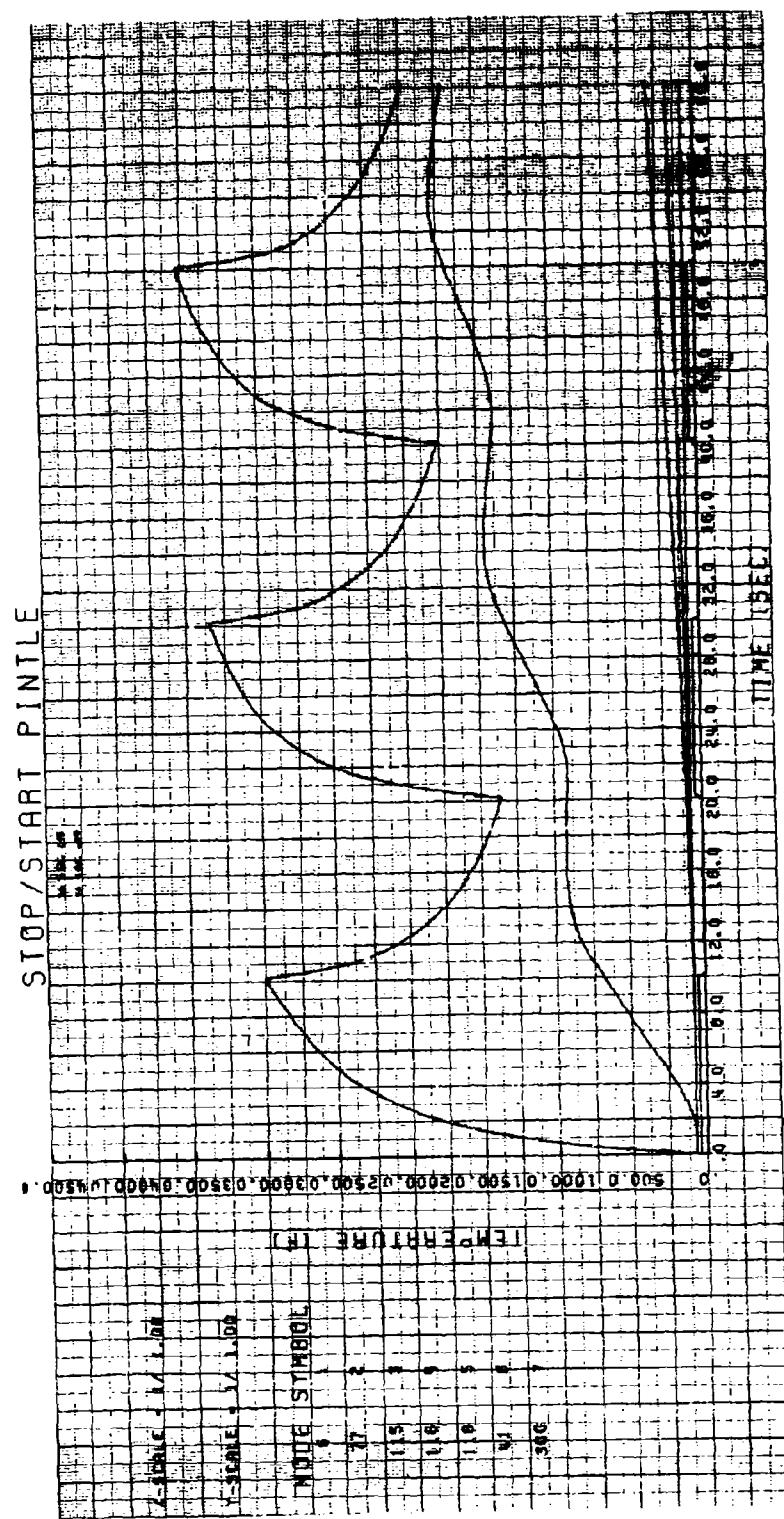


Figure VII-6

Report AFRPL-TR-69-50, Appendix D

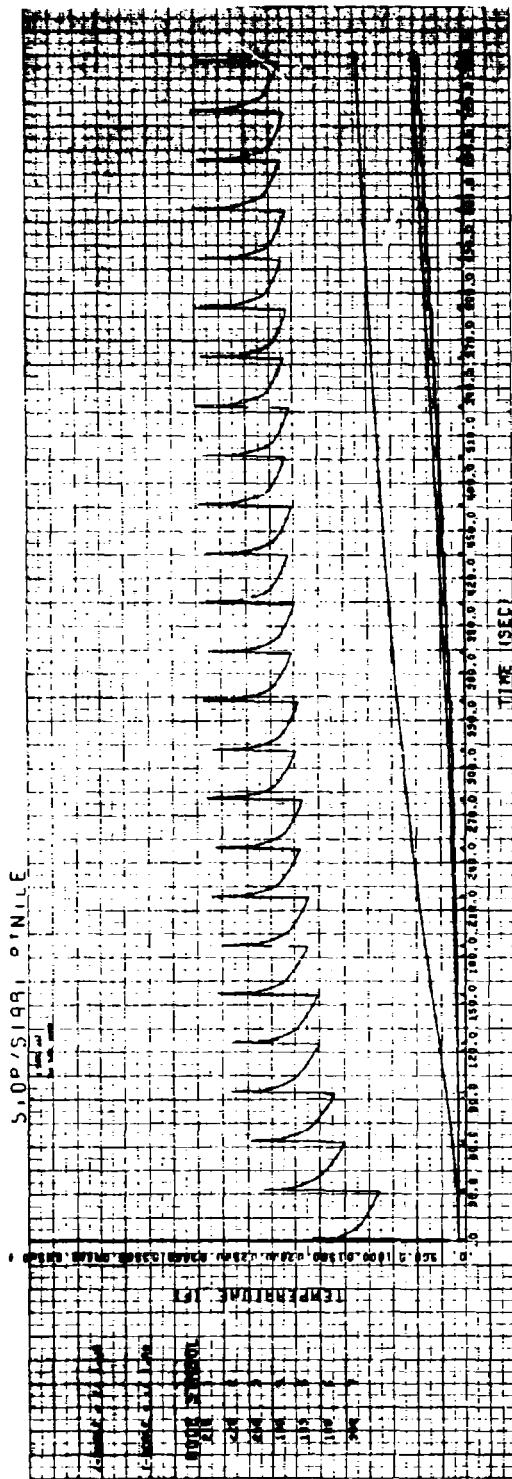


Figure VIII-1

Report AFRPL-TR-69-50, Appendix D

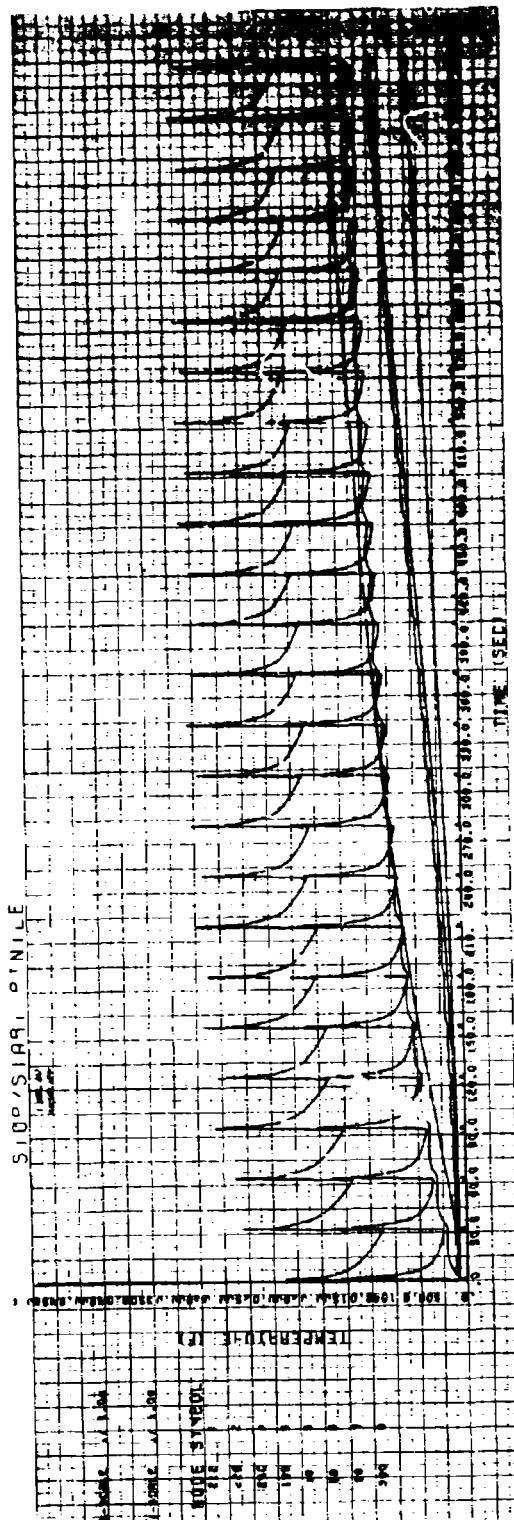


Figure VIII-2

Report AFRPL-TR-69-50, Appendix D

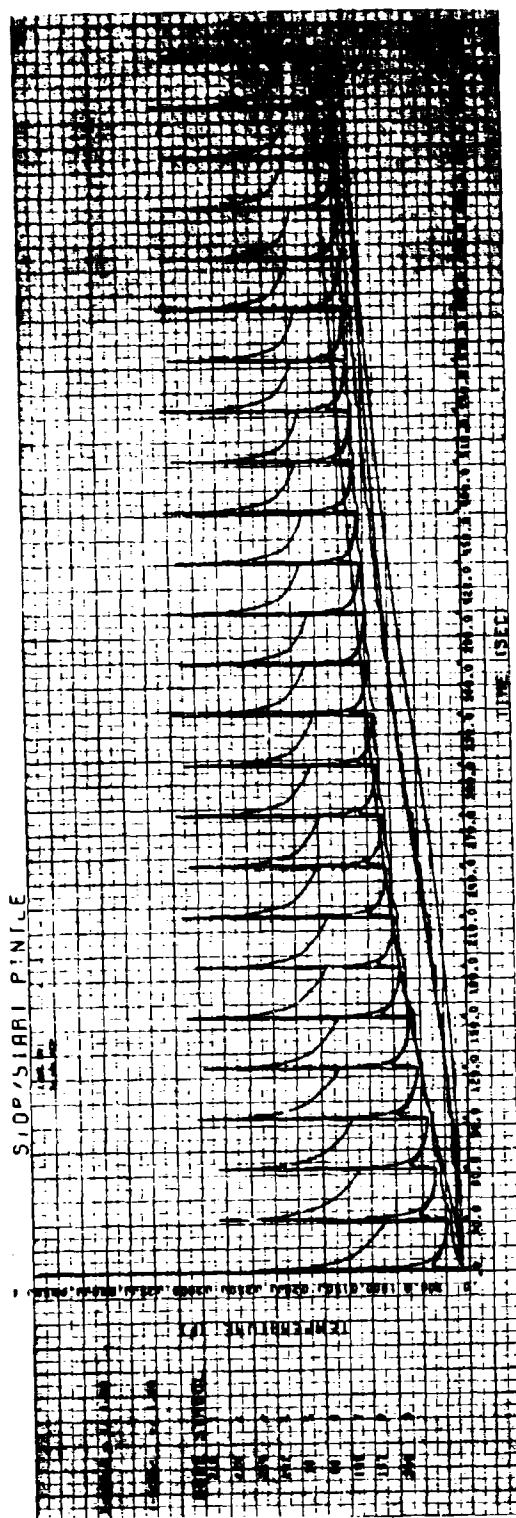


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Report AFRPL-TR-69-50, Appendix D

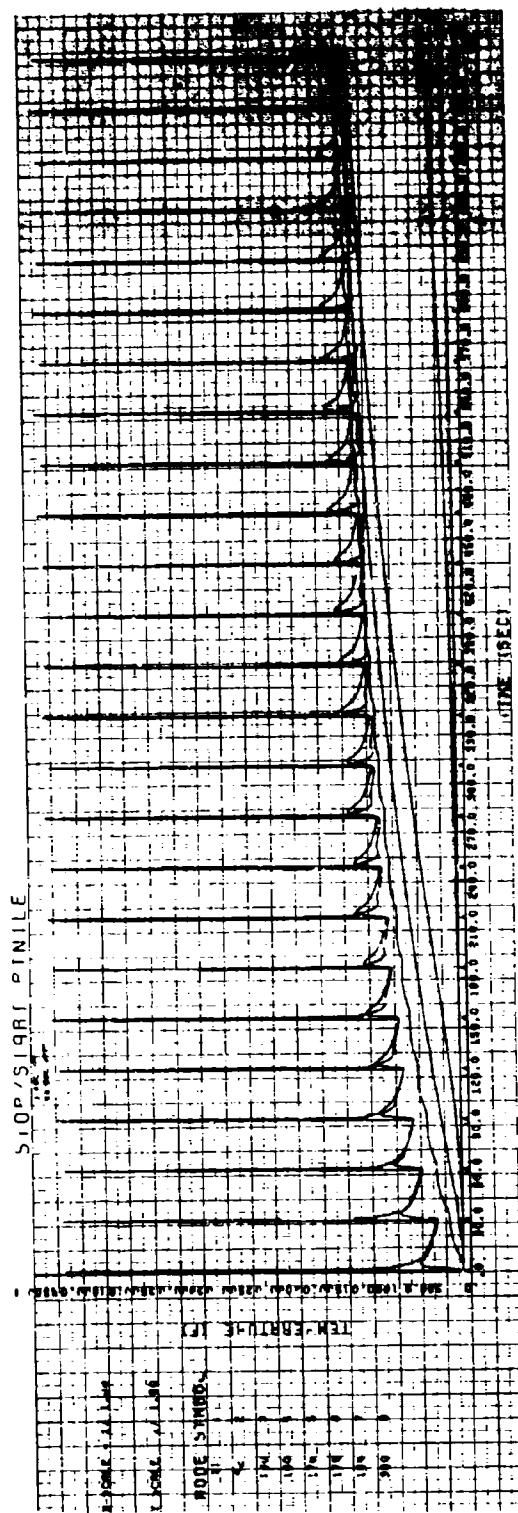


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Report AFRL-TR-69-50, Appendix D

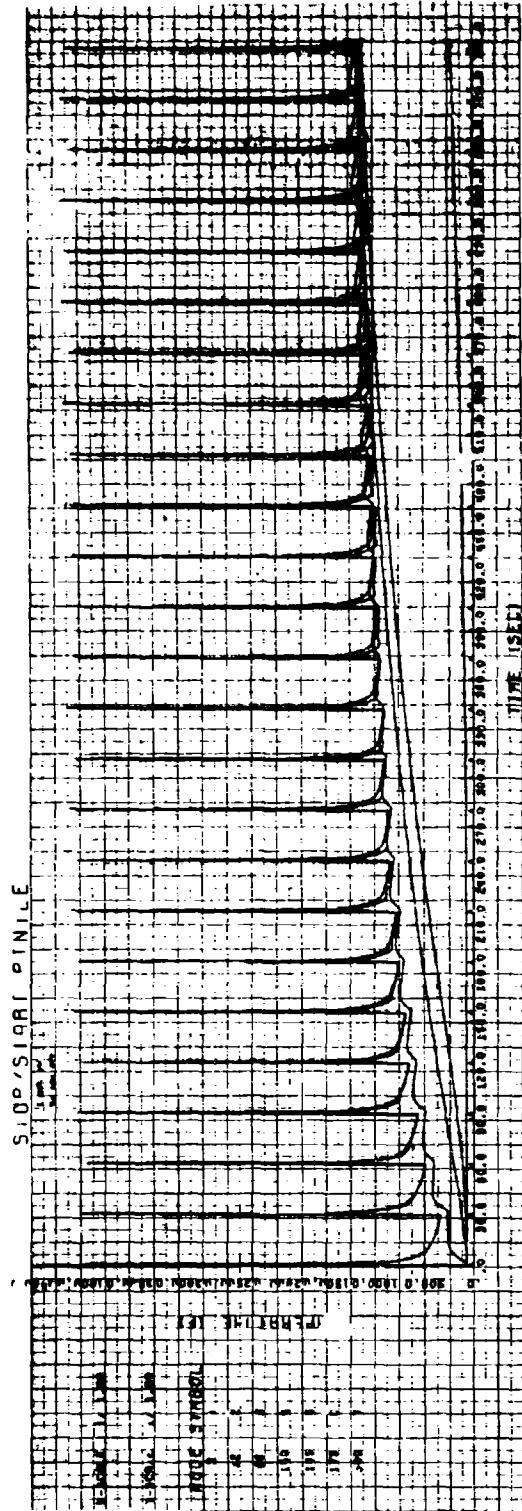


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Report AFRPL-TR-69-50, Appendix D

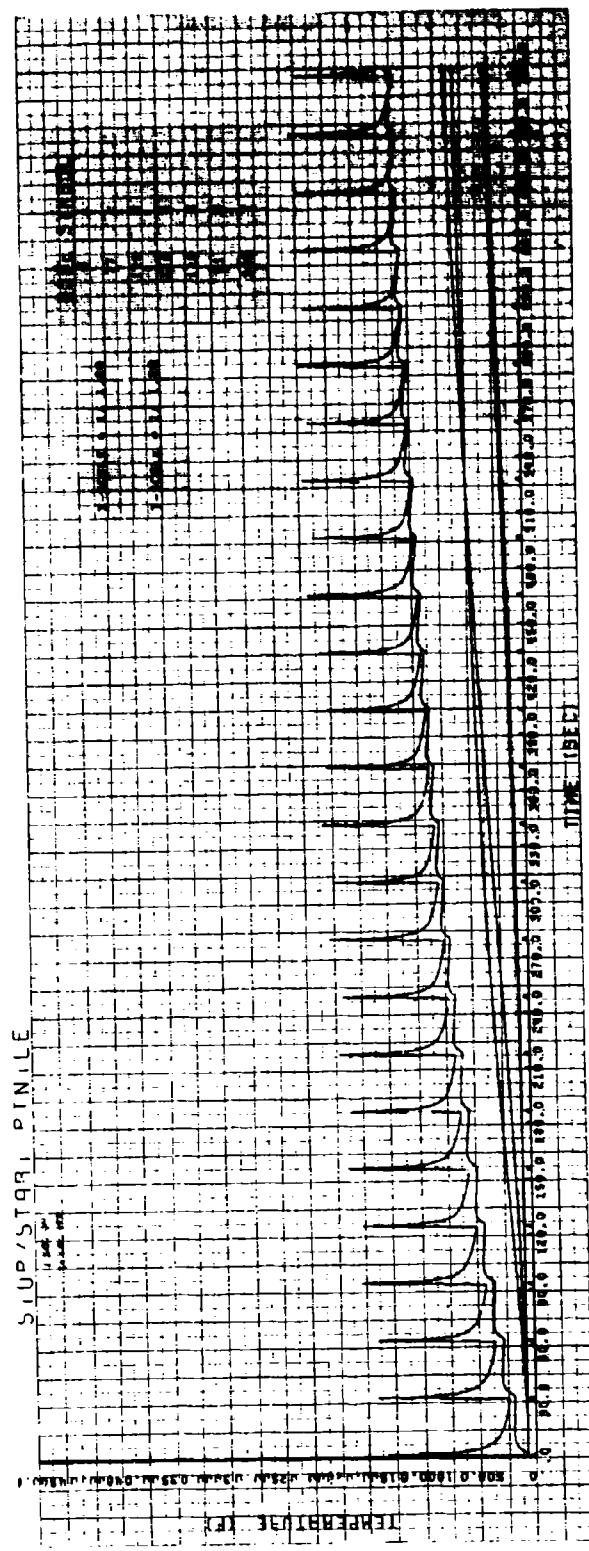


Figure VIII-6

Report AFRPL-TR-69-50, Appendix D

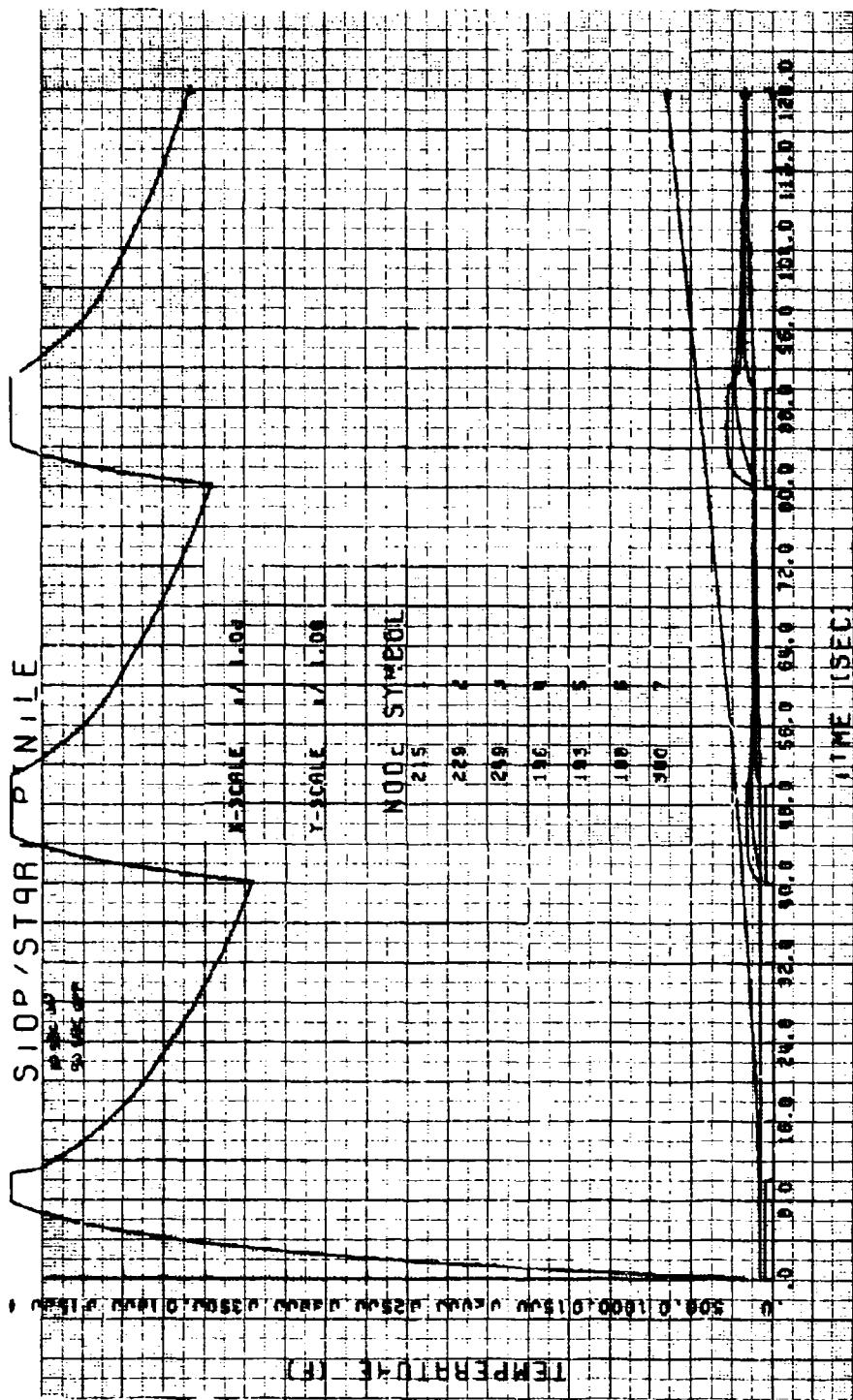


Figure IX-1

Report AFRPL-TR-69-50, Appendix D

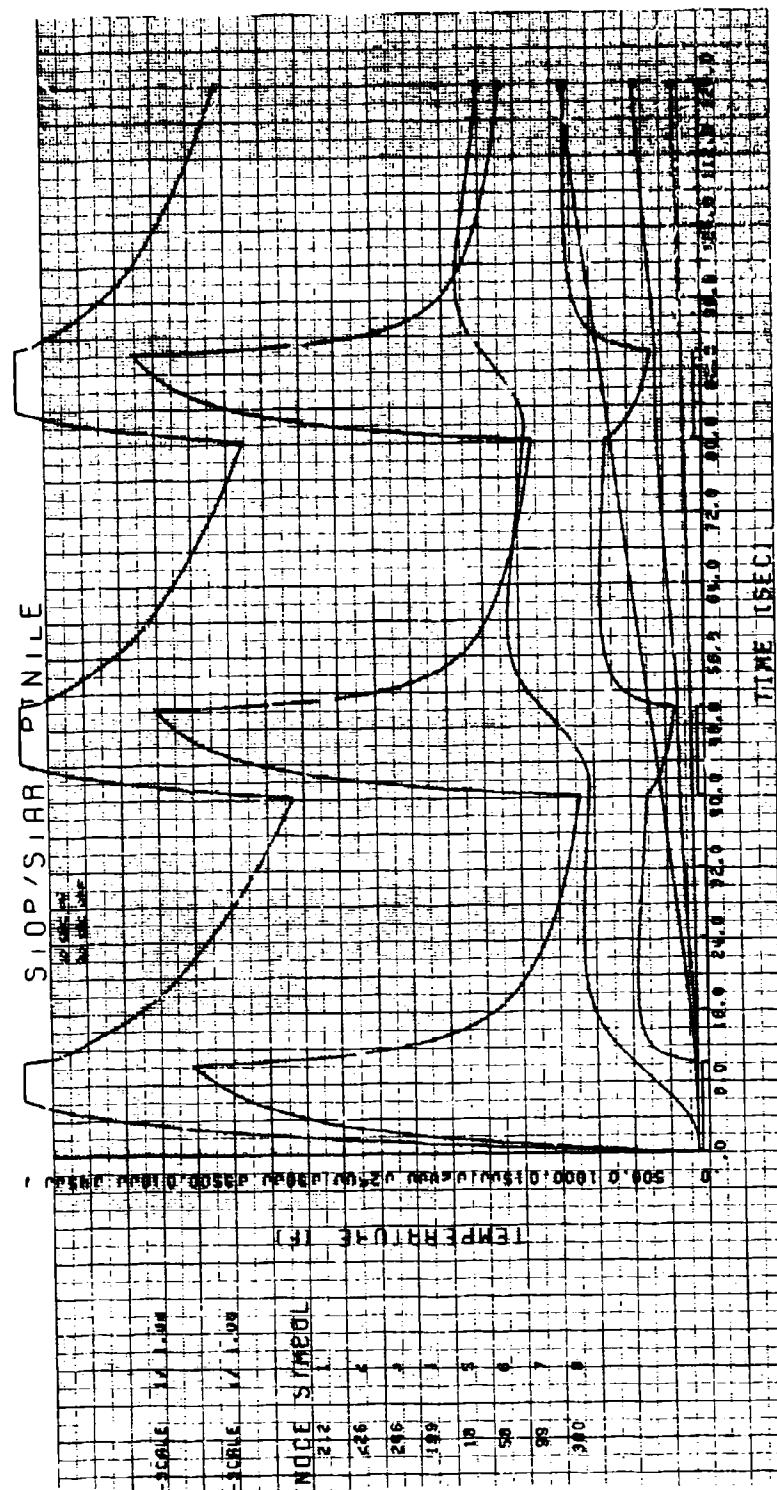


Figure IX-2

Report AFRPL-TR-69-50, Appendix D

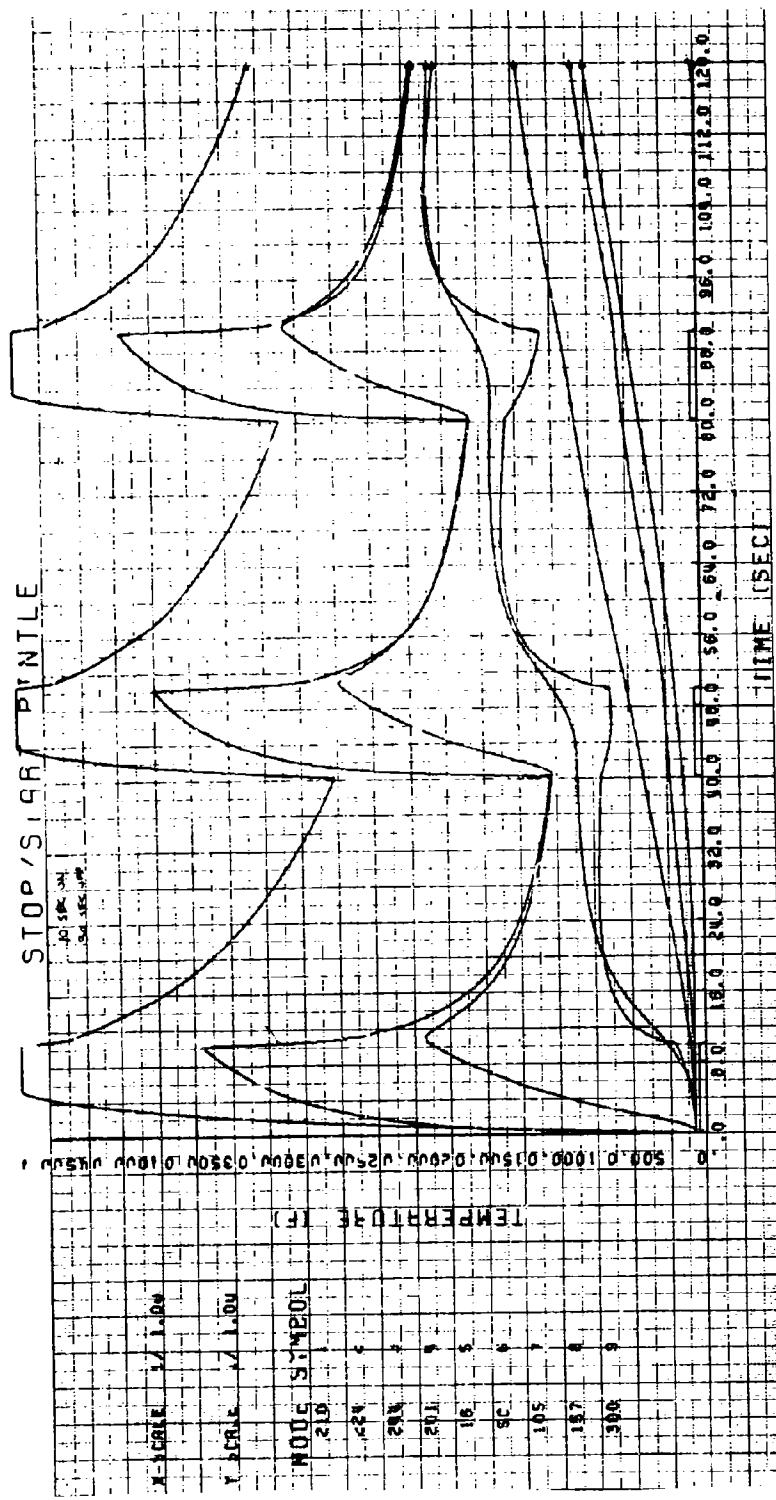


Figure IX-3

Report AFRPL-TR-69-50, Appendix D

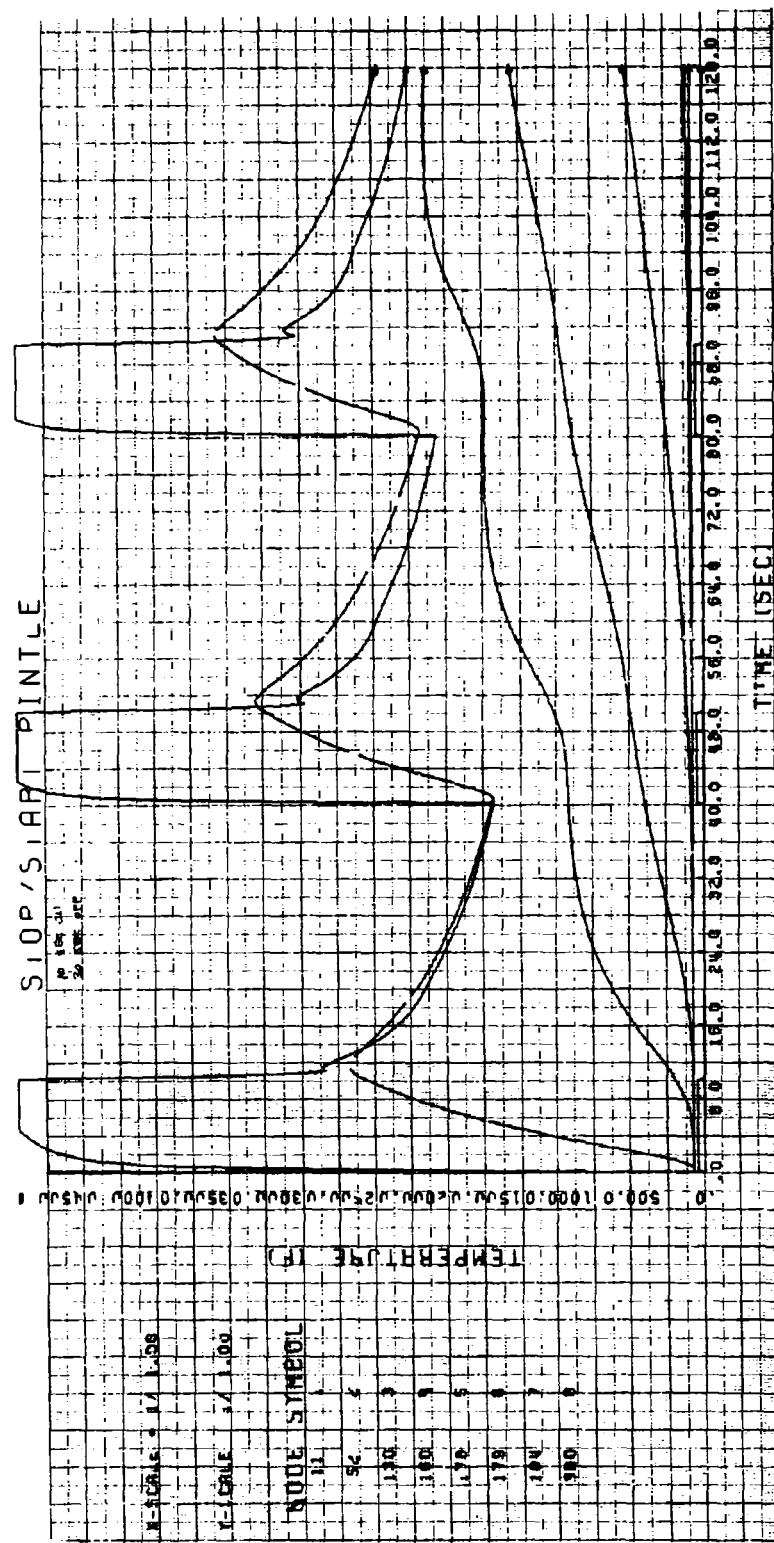


Figure IX-4

Report AFRPL-TR-69-50, Appendix D

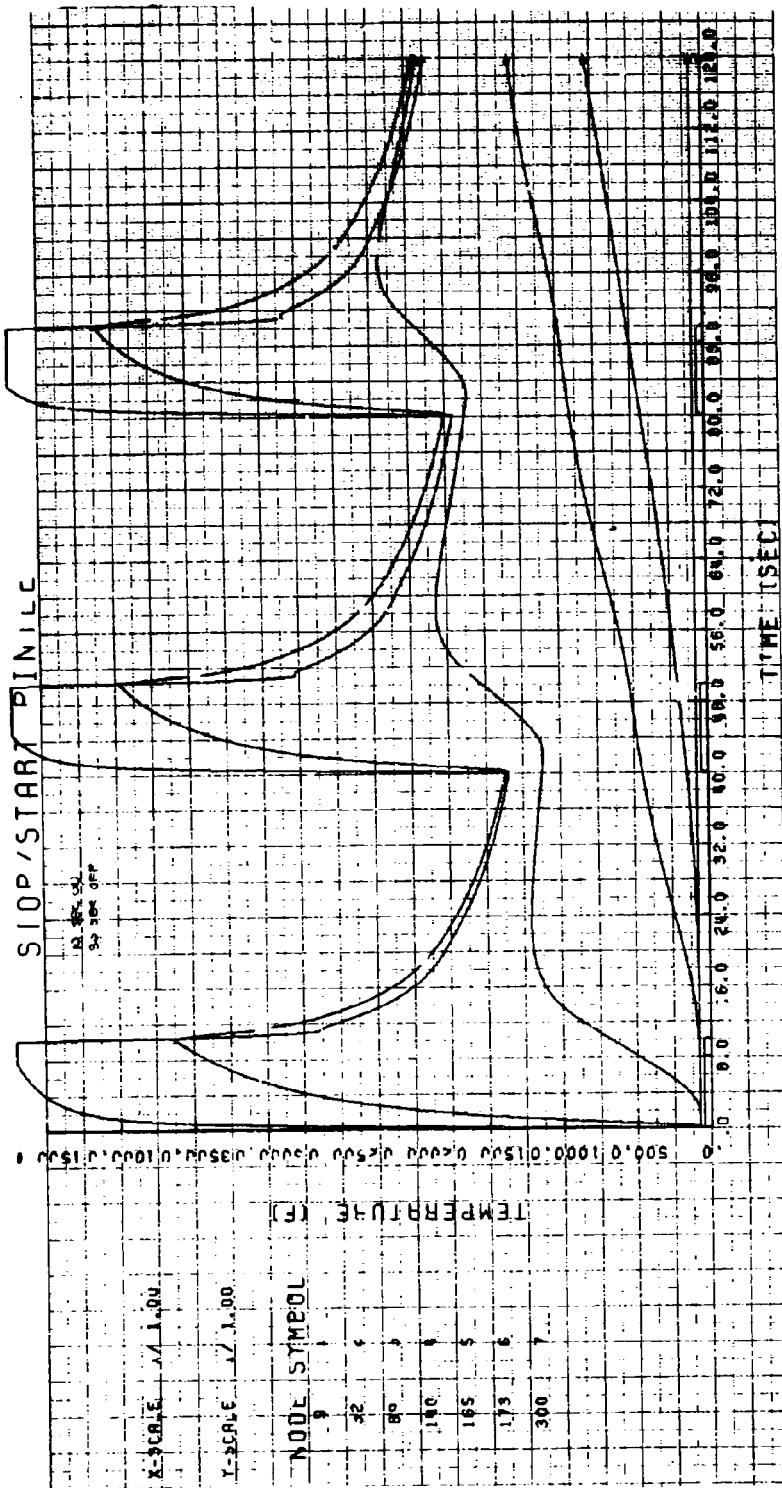


Figure IX-5

Report AFRL-TR-69-50, Appendix D

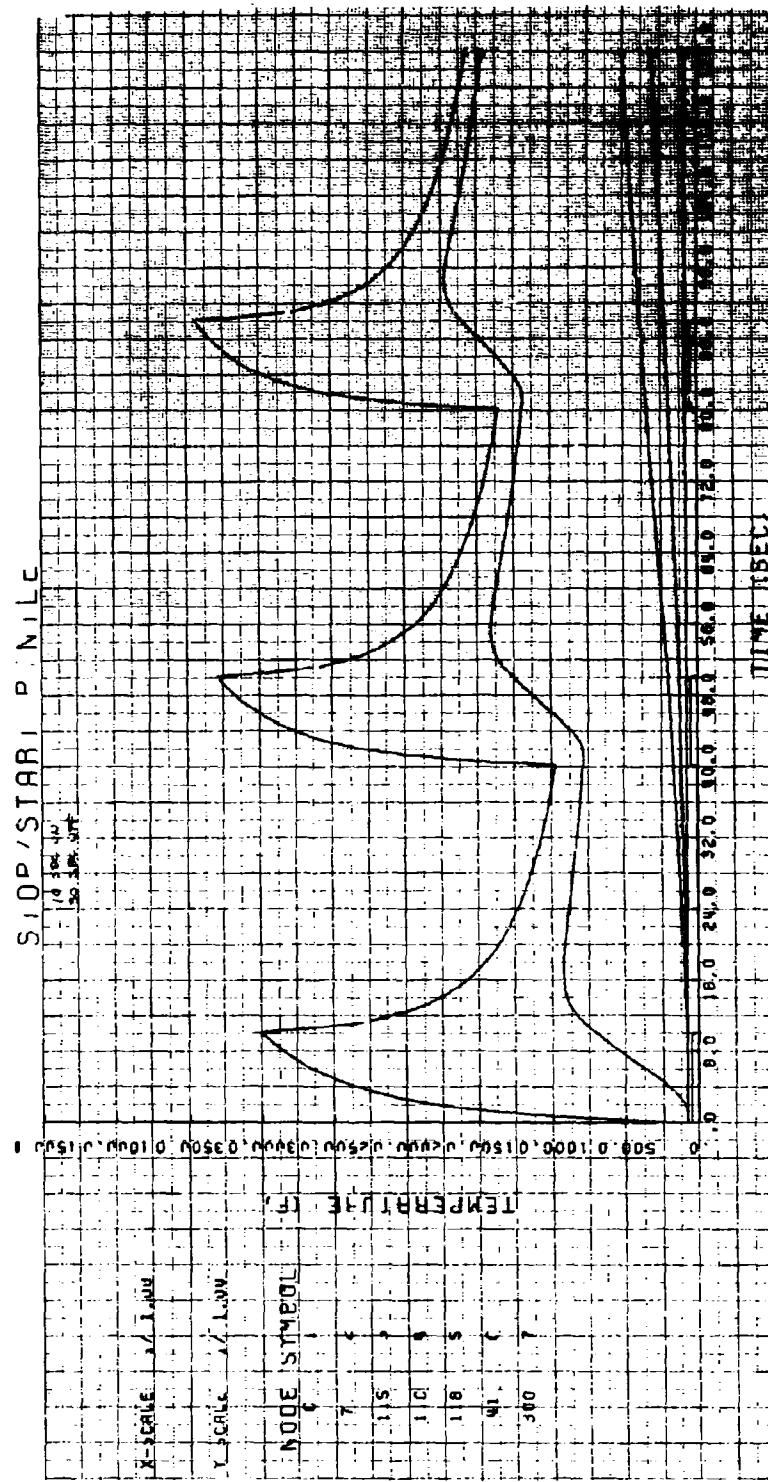


Figure IX-6

Report AFRPL-TR-69-50, Appendix D

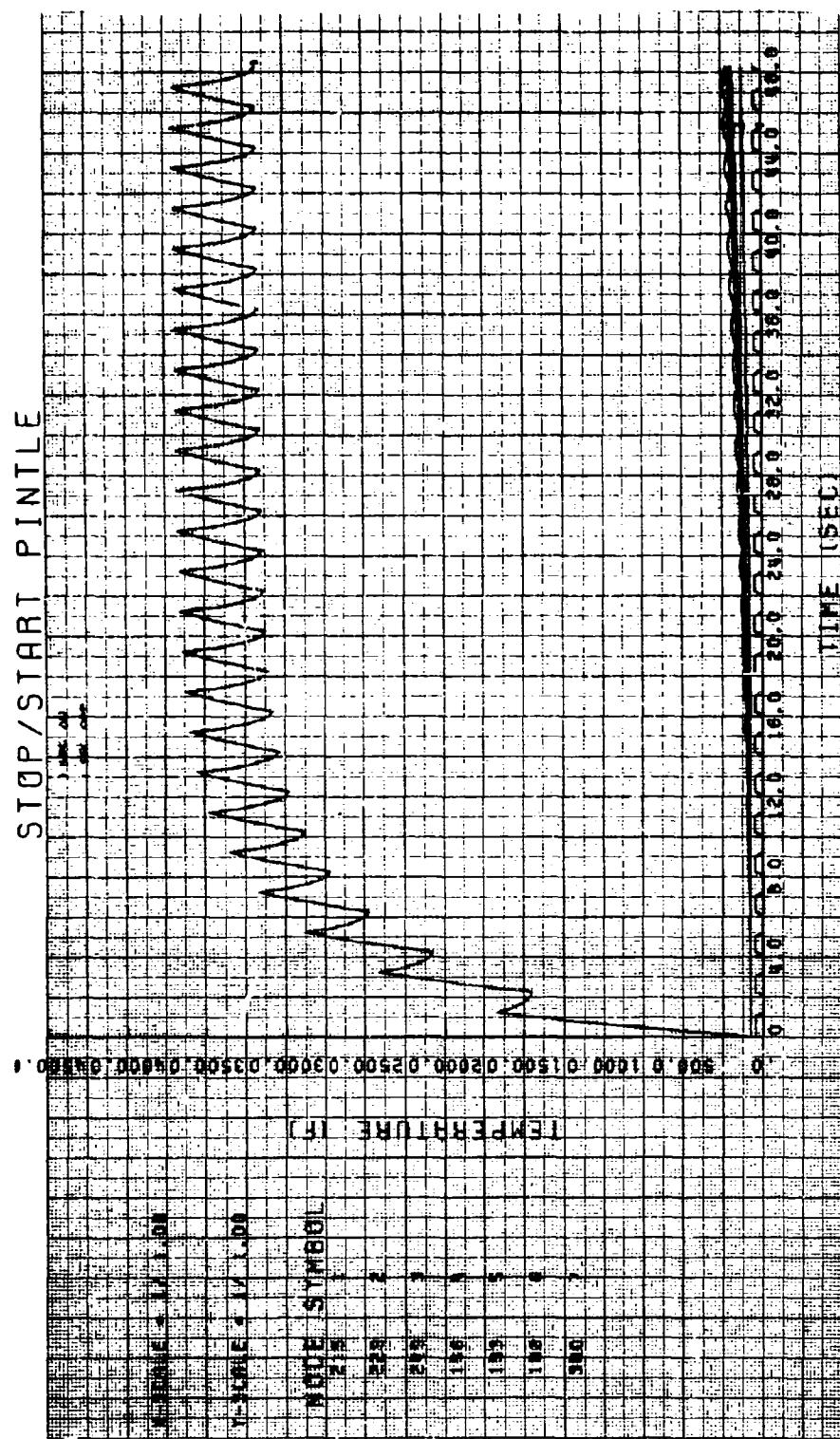


Figure X-1

Report AFRPL-TR-69-50, Appendix D

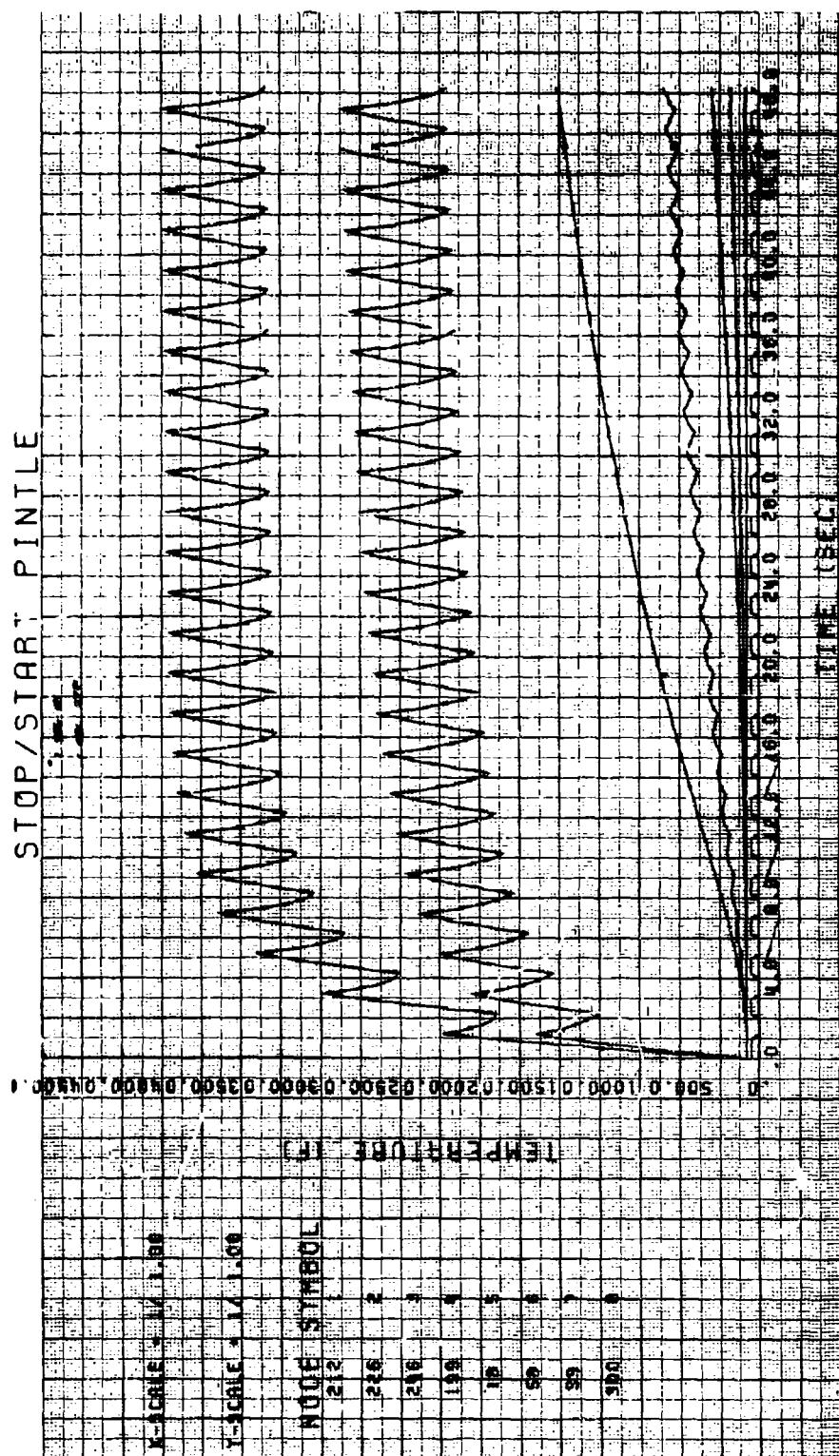


Figure X-2

Report AFRPL-TR-69-50, Appendix D

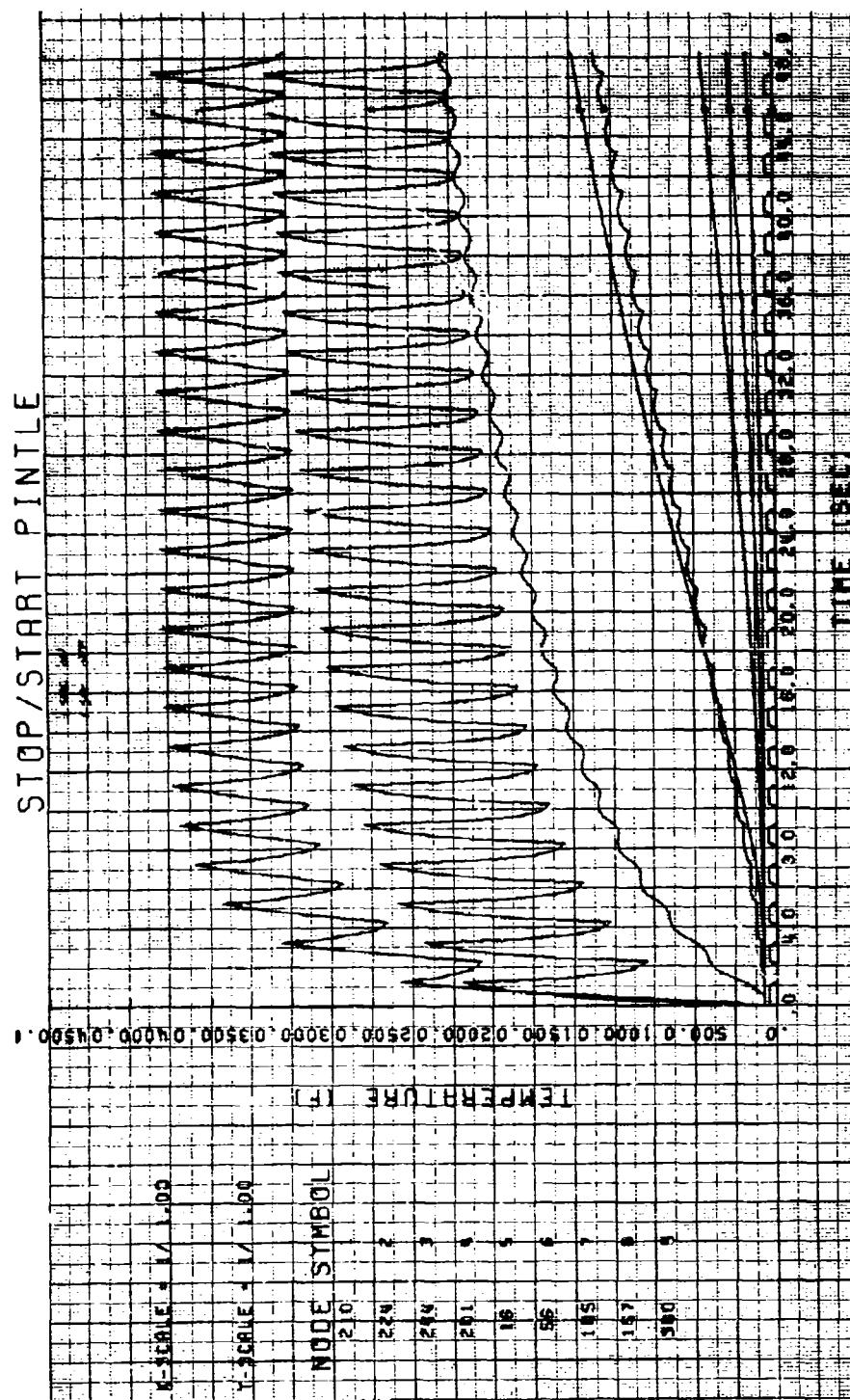


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Report AFRPL-TR-69-50, Appendix D

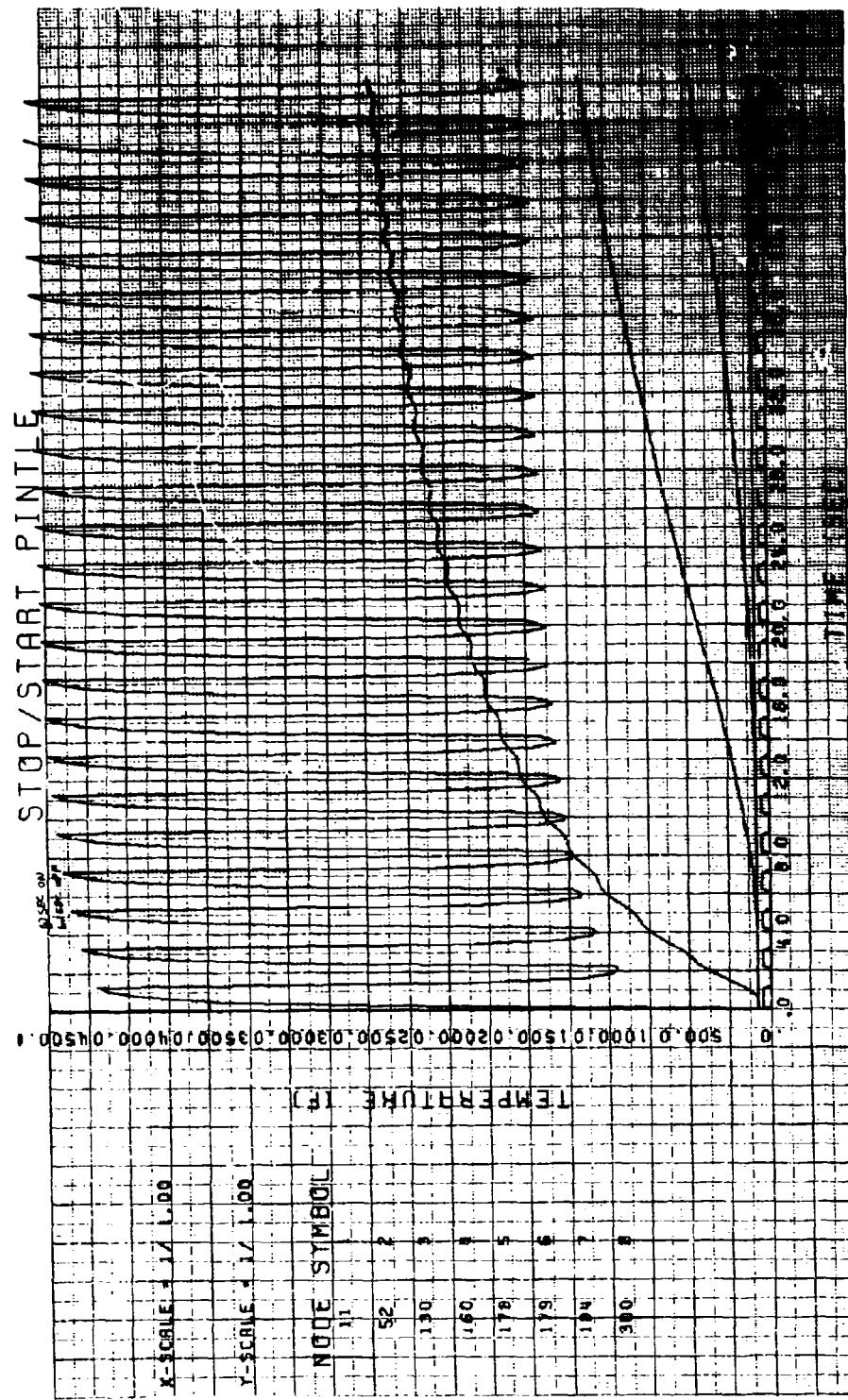


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Report AFRPL-TR-69-50, Appendix D

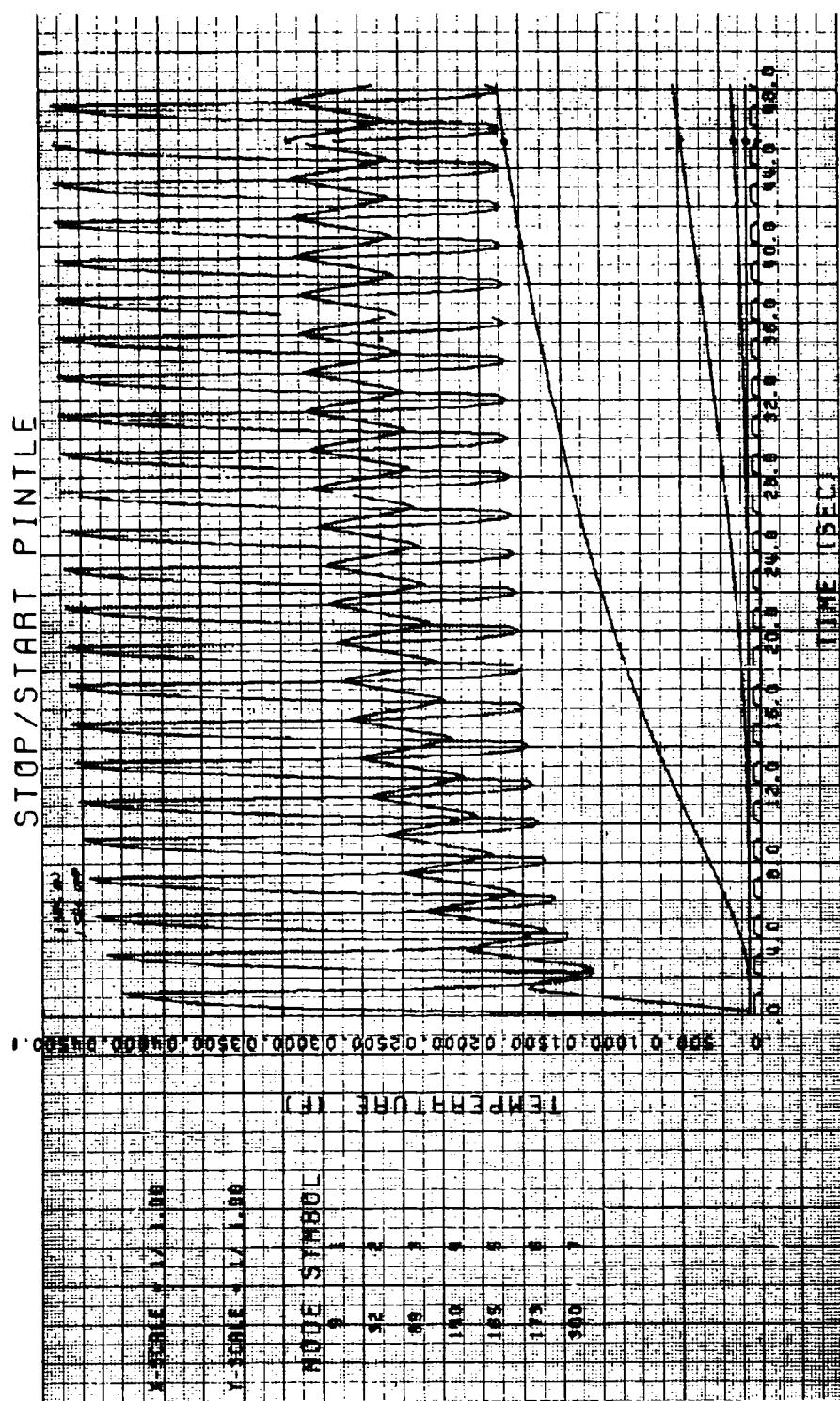


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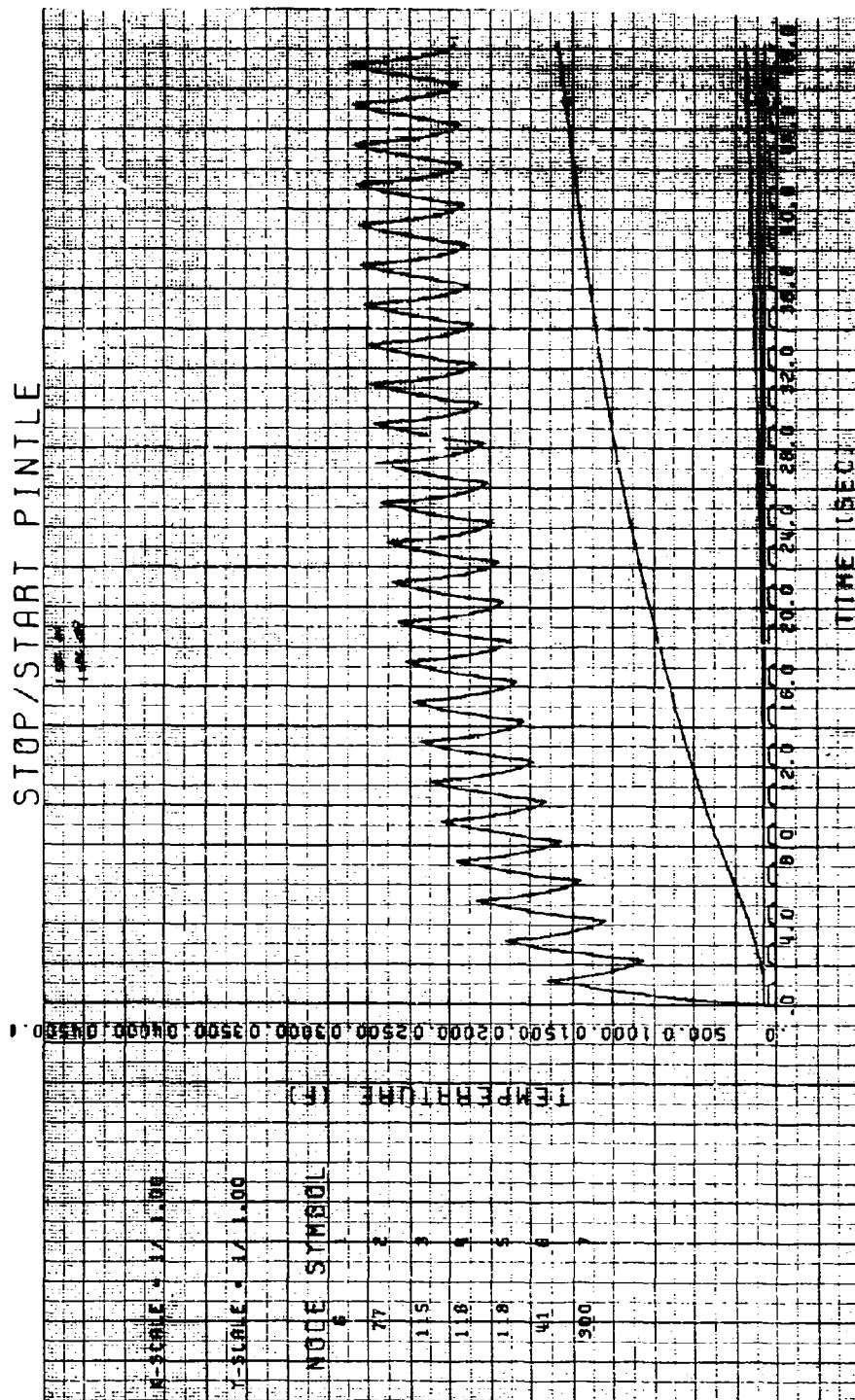


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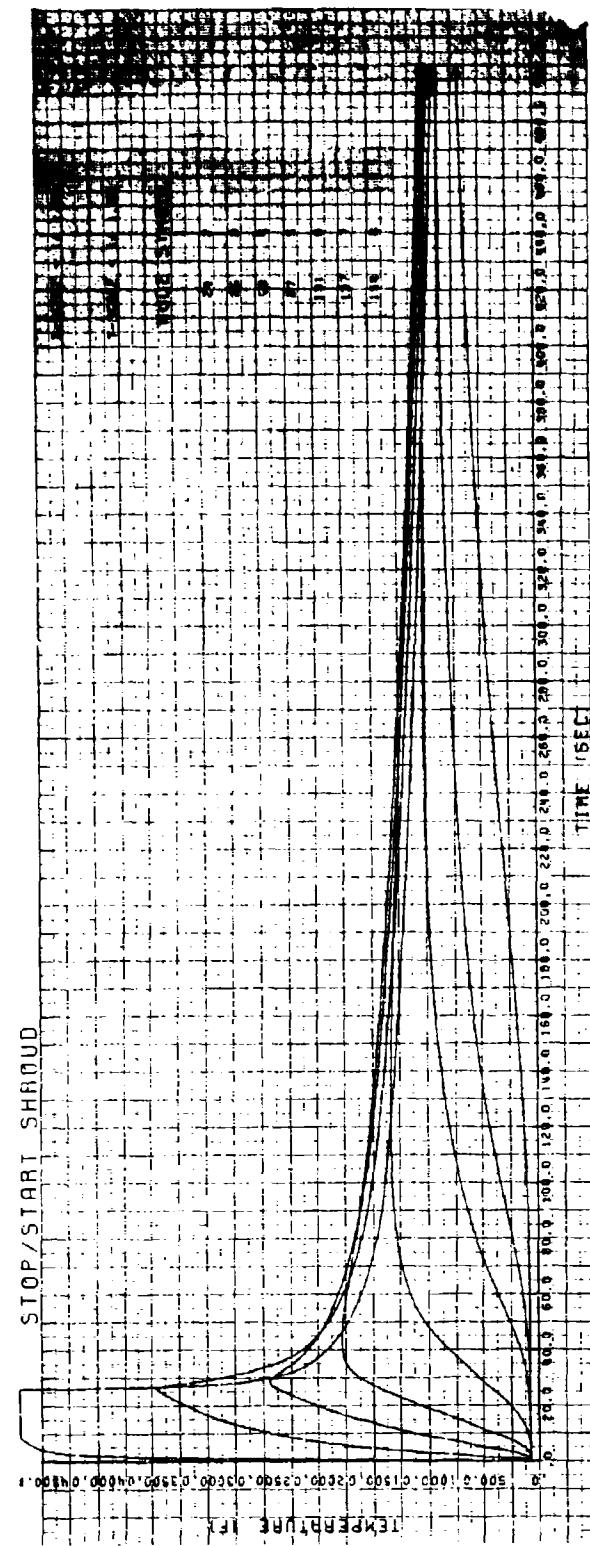


Figure XI-1

Report AFRPL-TR-69-50, Appendix D

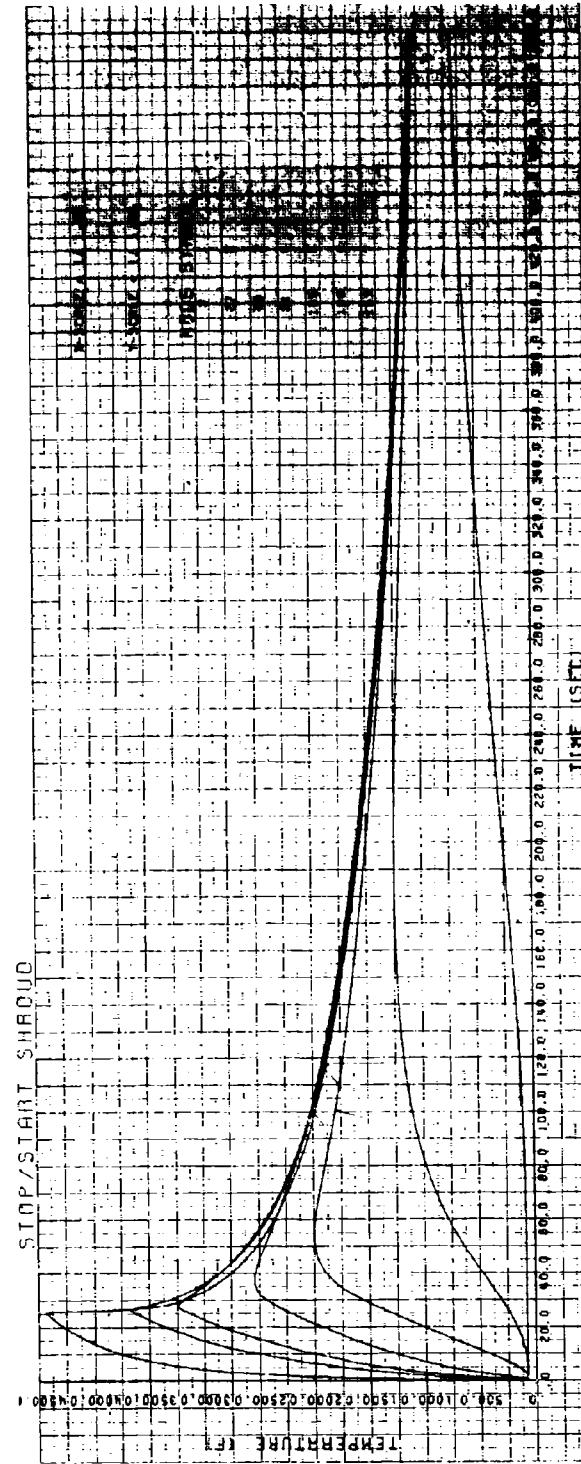


Figure XI-2

Report AFRPL-TR-69-50, Appendix D

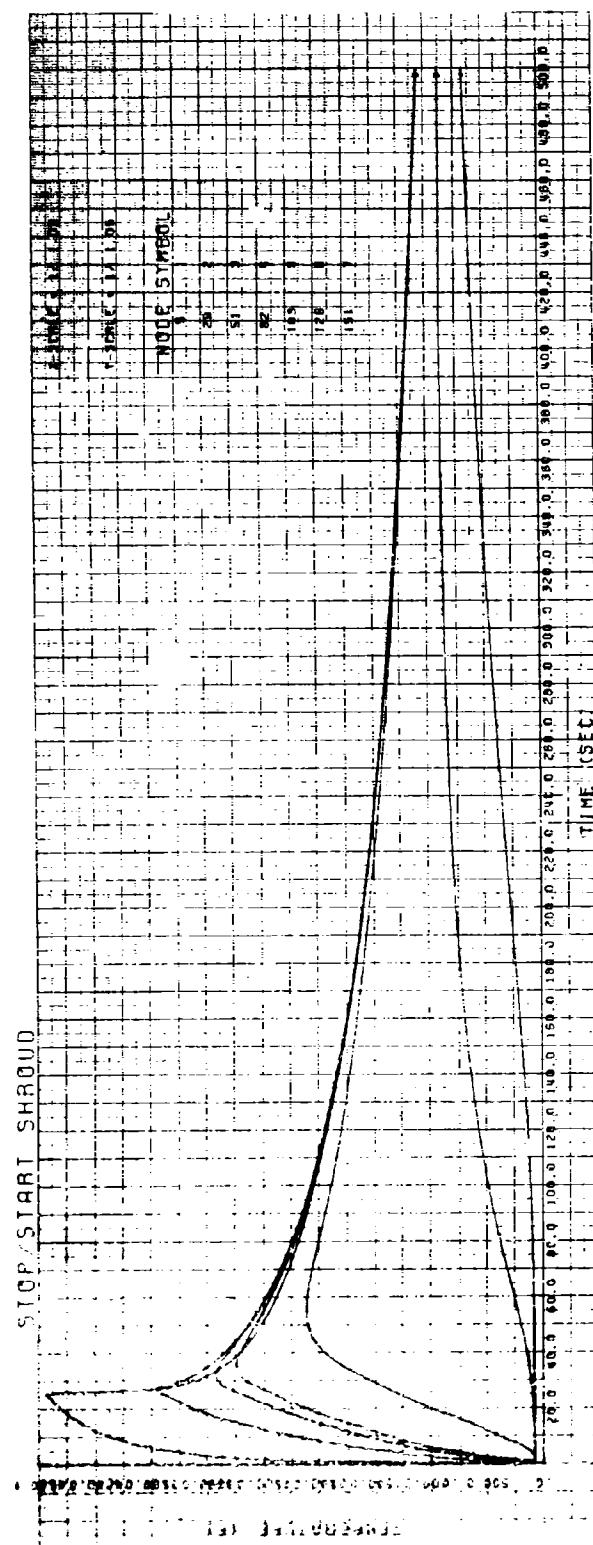


Figure XI-3

Report AFRPL-TR-69-50, Appendix D

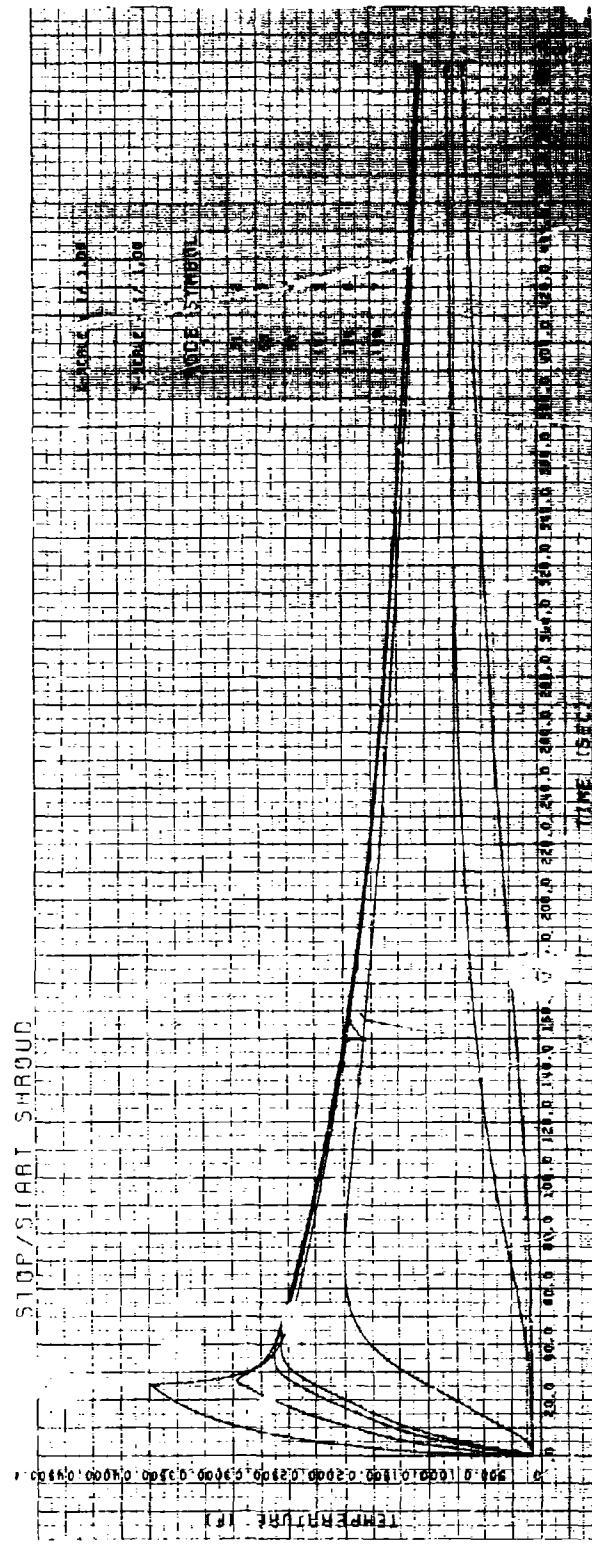


Figure XI-4

Report AFRPL-TR-69-50, Appendix D

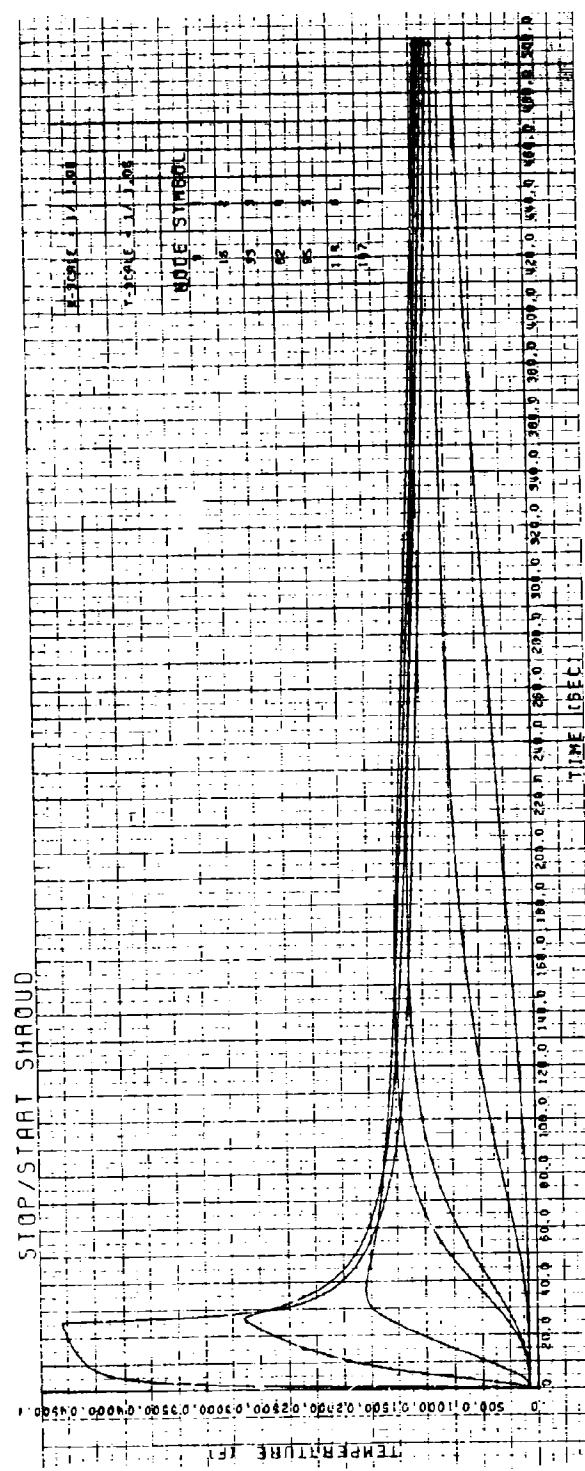


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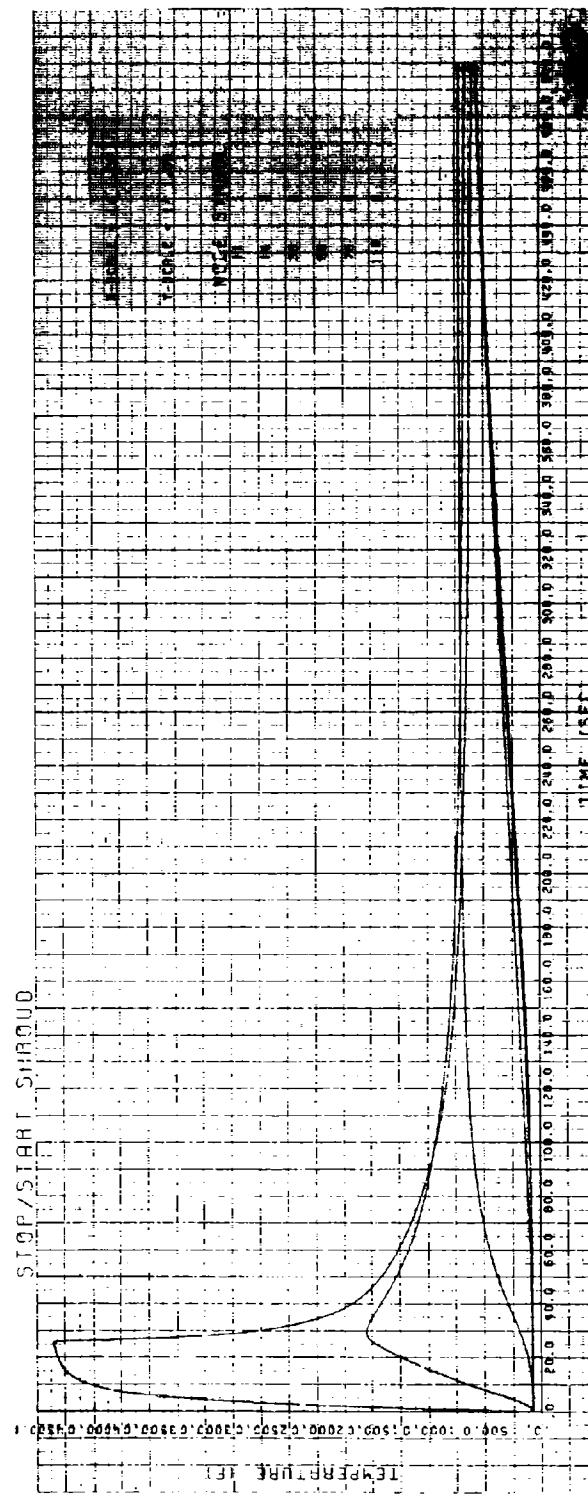


Figure XI-6

Report AFRPL-TR-69-50, Appendix E

APPENDIX E

THERMAL STUDY OF THE SINGLE CHAMBER STOP/START PROPELLANT ENVIRONMENT

Report AFRPL-TR-69-50, Appendix E

SECTION I

INTRODUCTION

The purposes of the thermal analyses of the stop/start motor propellant environment were to predict: (1) the incident radiation flux to the propellant and (2) the pyrolysis gas evolution rate during the "soak" period following pulse action of the motor. These predictions are then to be used in propellant reignition studies. The methods used in performing this study are outlined.

SECTION II

DISCUSSION

The significant parameters which determine the reignition of propellants in stop/start motor environment include the incident radiation flux distribution to the propellant and the pyrolysis gas evolution rates from the motor insulation system. Since both the insulation surface temperature and the energy stored in the insulation increase with pulse duration, the radiation flux to the propellant during "soak" periods will also increase with pulse action time. In the present study the pulse duration considered was 8.3 sec which corresponds to approximately one-third of the total motor action time. Further, the exposed area of the insulation surface and the radiation view factors vary with total motor action time. For this reason the propellant environment was predicted for propellant burn-back conditions corresponding to each of three 8.3 second pulses.

The procedure followed in defining the environment of the propellant was first to predict the response of the internal insulation at representative locations in the motor. For this phase of the study, the chamber wall was divided into regions according to exposure time and magnitude of the local convective heat transfer coefficients. The response of the insulation at each of these regions was then calculated using a computer program. This program utilized the thermal response of elastomeric insulation materials which decompose in depth when exposed to the environment associated with solid rocket chamber environment.

II, Discussion (cont.)

The incident radiation to the propellant grain was then obtained by summing the individual contributions of the various regions of the chamber insulation.

A summary of the results of this study is presented in Figures E-1 through E-5. Figure E-1 shows the calculated incident heat flux at a typical forward propellant station for the soak periods following each of the assumed pulse durations. It will be seen from this figure that the initial rate at which the incident heat flux decreases is large compared to that for later times. This characteristic is due to the fourth-power temperature dependence of radiation and the rapid decay in source (insulation) surface temperature. The insulation material, V-4010, and other elastomeric insulation materials have (1) low conductivity, (2) low char density, and (3) a high yield of pyrolysis gas from the virgin material. These properties are desirable in applications where the attainment of low heat flux to the propellant grain is necessary because they result in a rapid decay in insulation surface temperature. The calculated response of V-4010 at a typical location, as shown in Figure E-6, illustrates this characteristic.

The incident heat flux to typical propellant locations in the aft motor section are shown in Figure E-2. These results exhibit characteristics similar to those shown in Figure E-1 for the forward stations. The magnitudes of incident heat flux in the aft region are somewhat greater, however, due to the more severe environment of the insulation during action time and a small radiation contribution by the components in the throat region.

Figure E-3 shows the calculated propellant surface temperature variation at typical forward propellant stations for the heat fluxes shown in

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II, Discussion (cont.)

Figure E-1. It will be noted in this figure that the propellant surface temperature decreases continuously.

Figure E-4 shows the propellant surface temperature response for the typical aft propellant stations. These results exhibit characteristics similar to those for the forward stations. As noted above, the environment is slightly more severe and the propellant surface temperatures are correspondingly higher.

Figure E-5 shows the total mass evolution rates of the insulation pyrolysis gas for the three "soak" periods considered. It will be noted from this figure that the pyrolysis gas evolution rate decreases with time for each of the "soak" periods, and that the magnitude of the evolution rate for equal "soak" periods increases with total action time. The latter characteristic is due to the increase in exposed insulation area with action time.

EUGENE DIETZGEN CO.  
MADE IN U. S. A.

40.3 SENSITIVITY - DIETZGEN GRAPH PAPER  
10 VOLTS PER HALF INCH

INCIDENT HEAT FLUX  
AT TYPICAL FORWARD PROPELLANT STATIONS

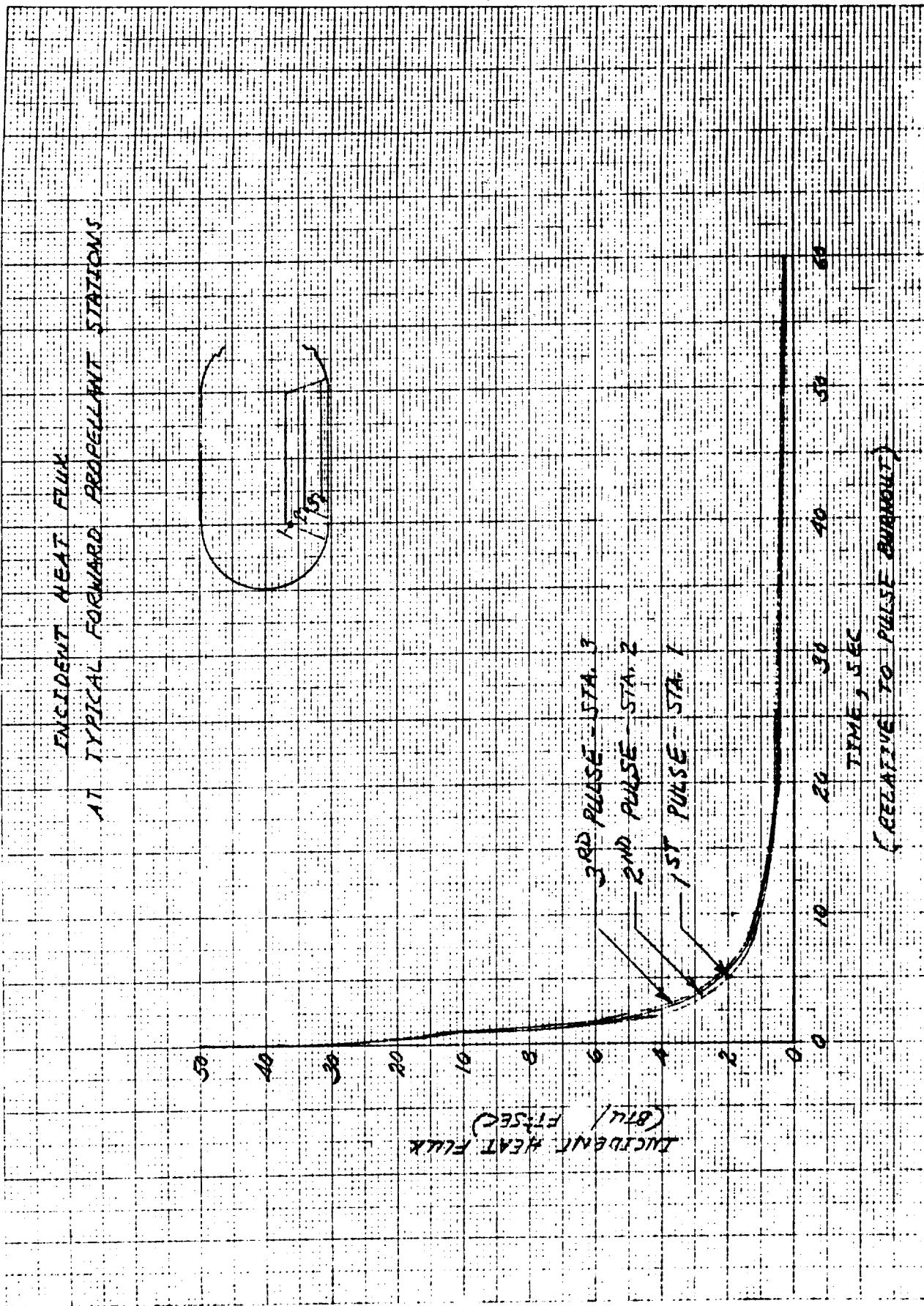


Figure E-1

Report AFRPL-TR-69-50, Appendix E

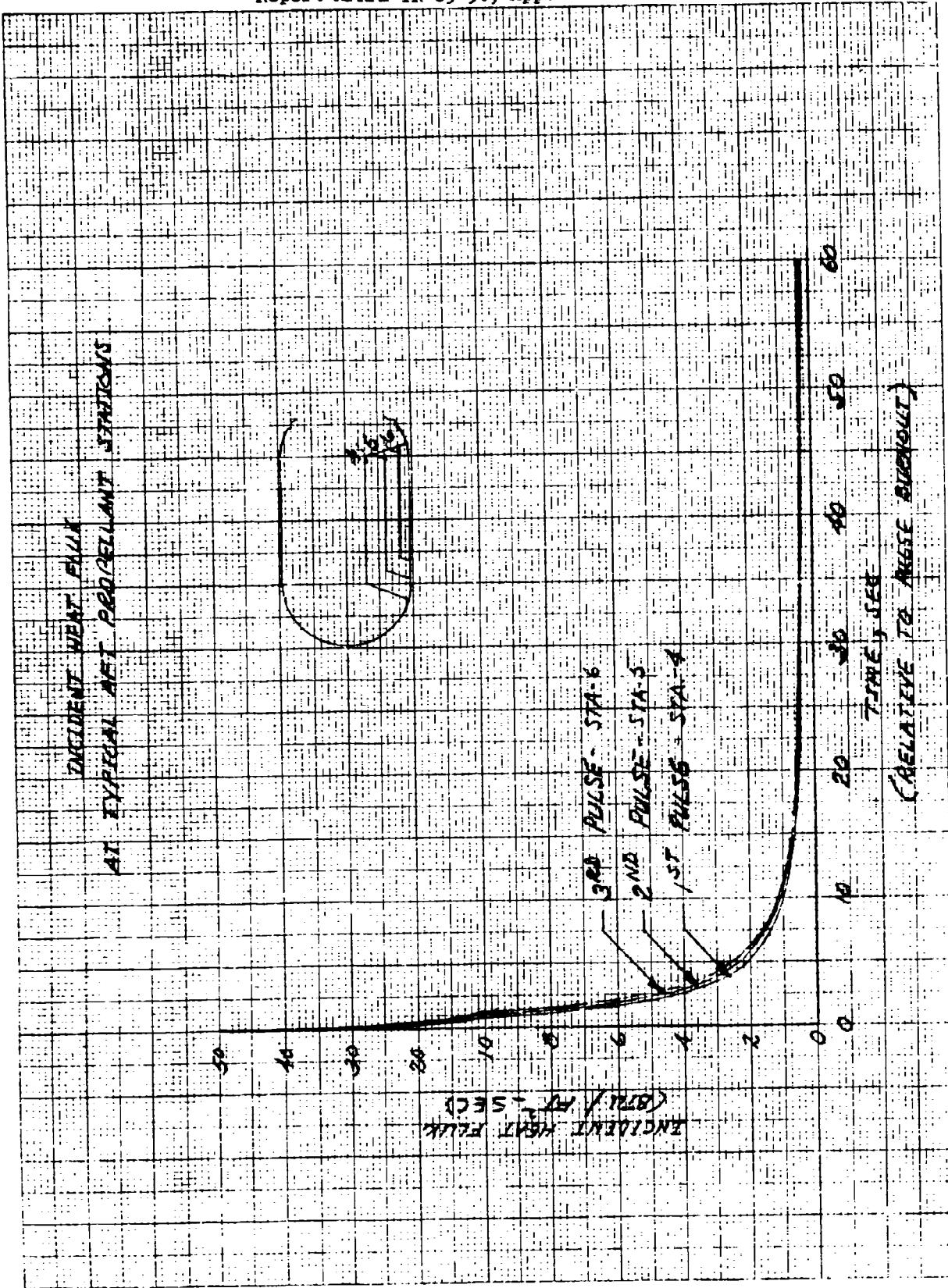


Figure E-2

EUGENE DIETZGEN CO.  
MADE IN U.S.A.

N.D. 500' 1/2" DIETZGEN GRAPH PAPER  
50 X 100 FT. 1/2" GRID

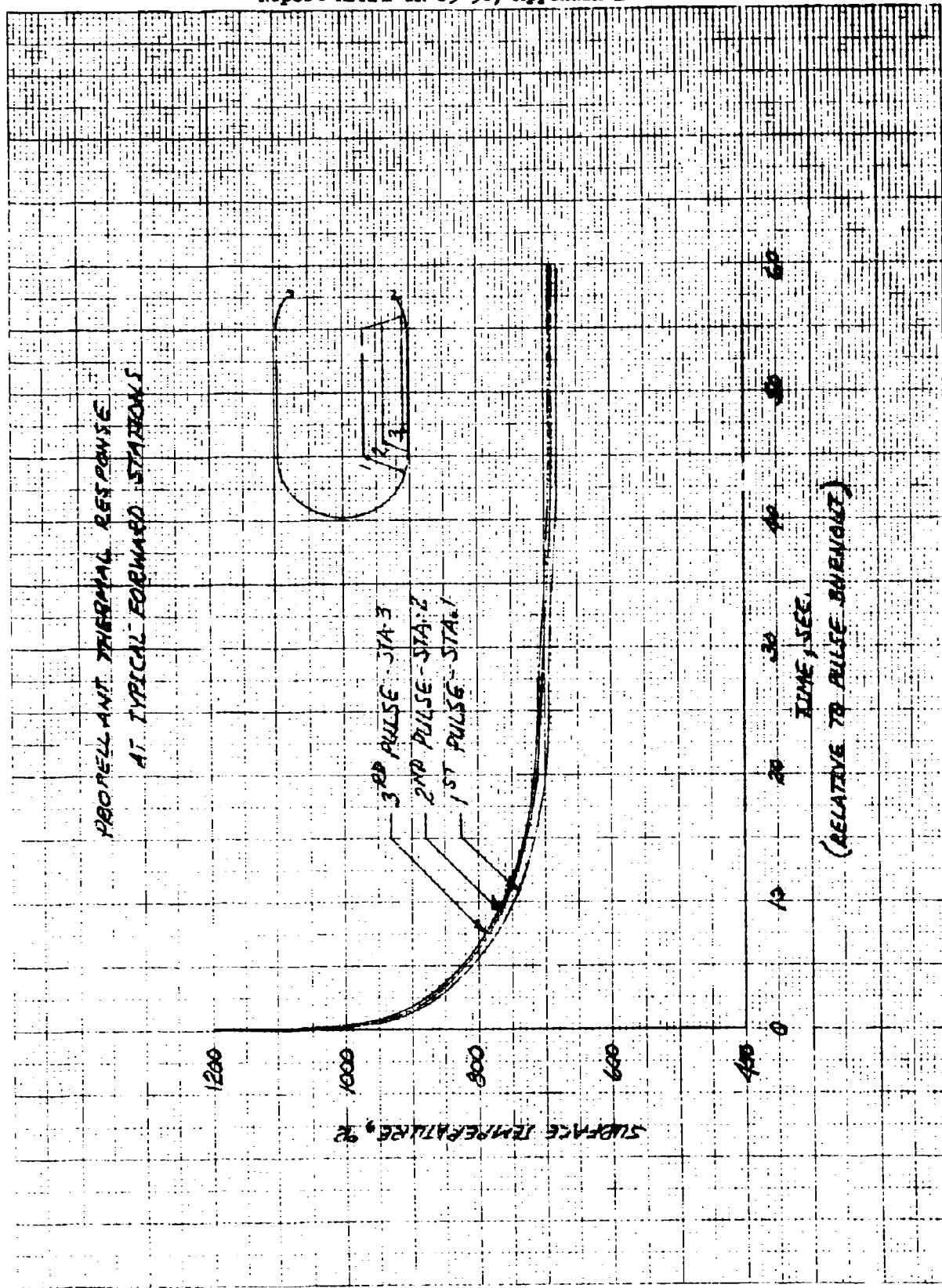


Figure E-3

Report AFRPL-TR-69-50, Appendix E

CURVED DIAZOGEN GRID  
MADE IN U. S. A.

NW 310102 DIAZOGEN GRAPH PAPER  
10 C. 16 PPI HALF INCH

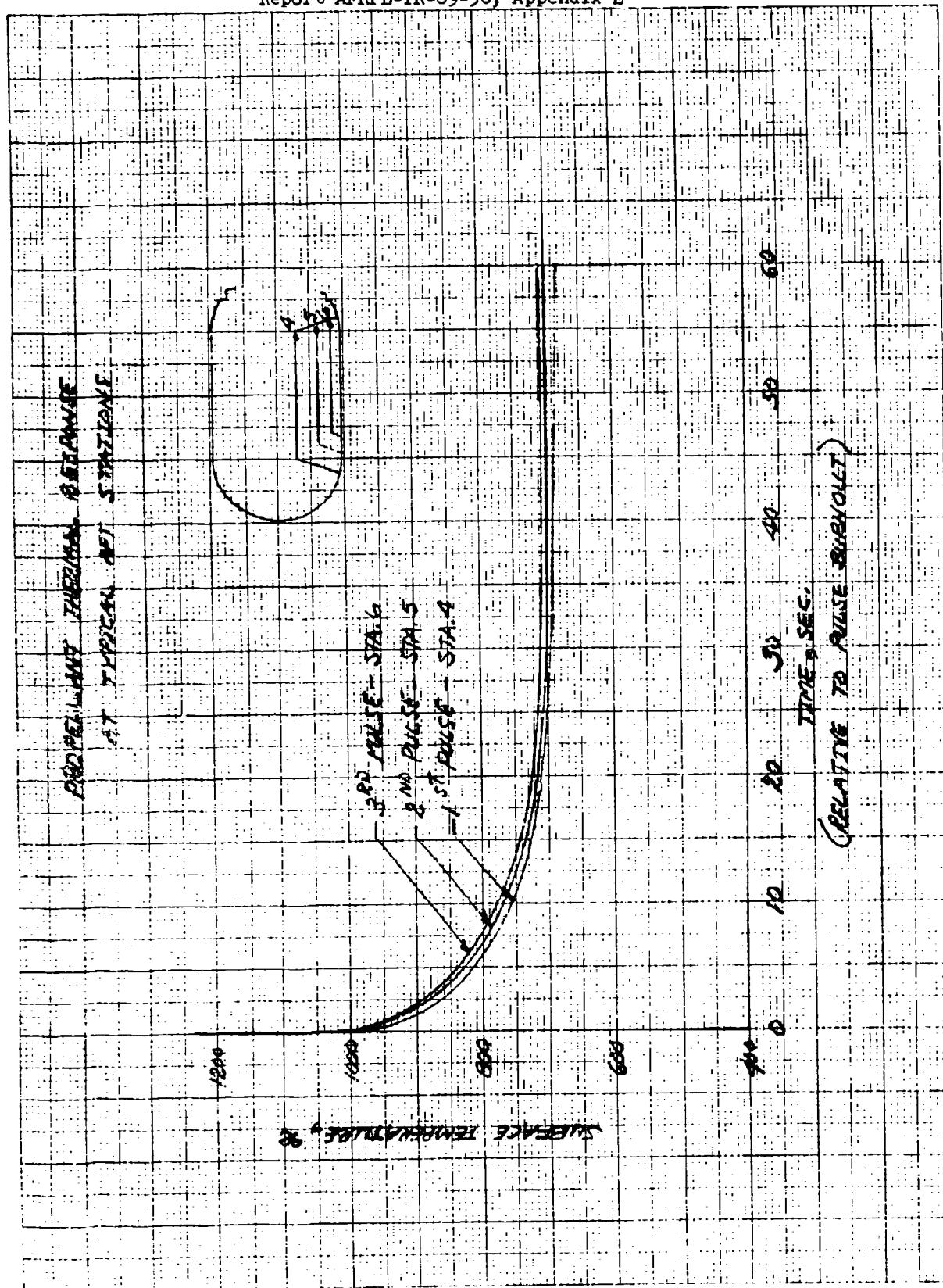


Figure E-4

Report AFRPL-TR-69-50, Appendix E

EUGENE DIETZGEN CO.  
MADE IN U.S.A.

DIETZGEN STROBAPH PAPER  
1000' ROLL, 100' LENGTH, 1/4" INCH

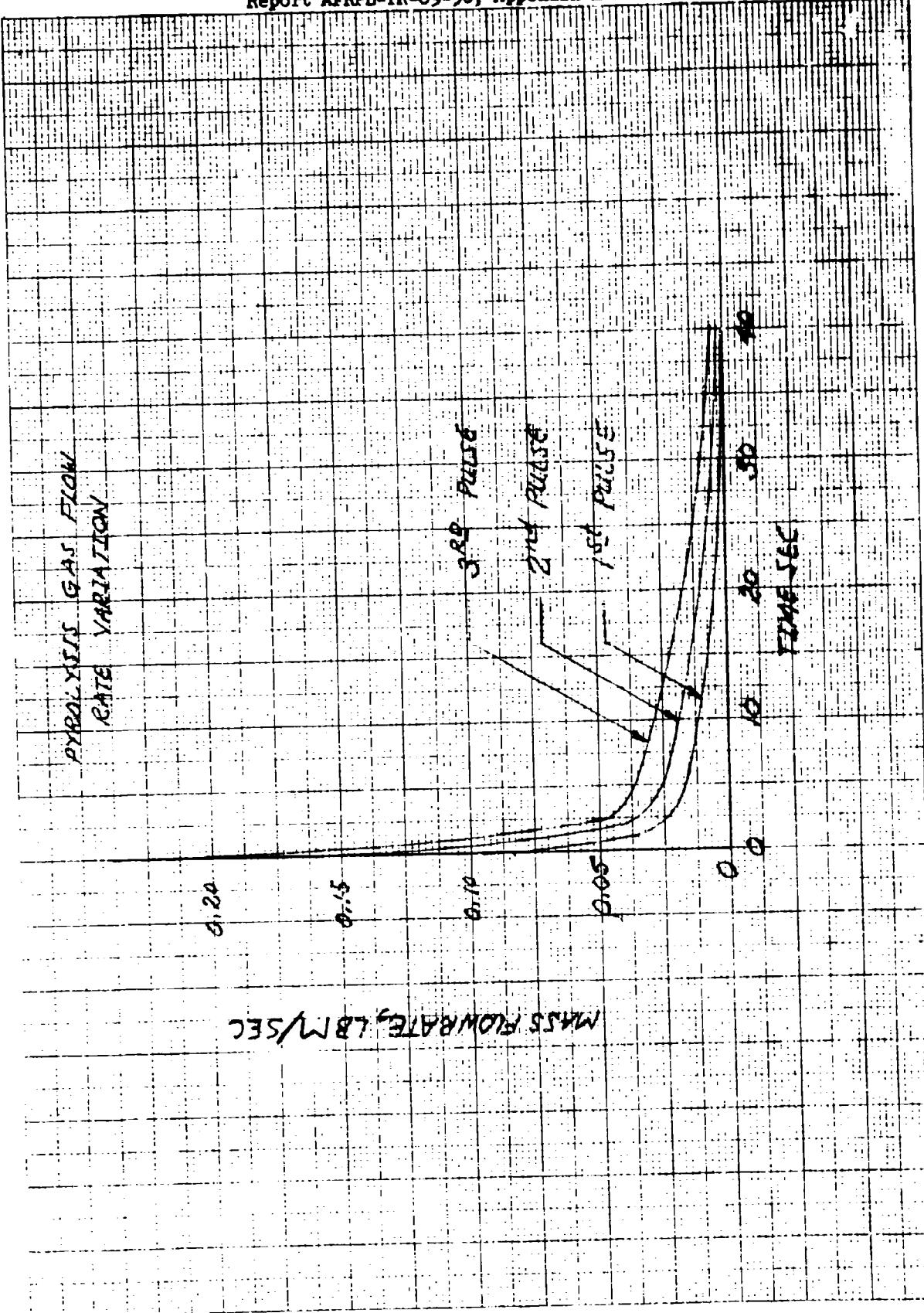


Figure E-5

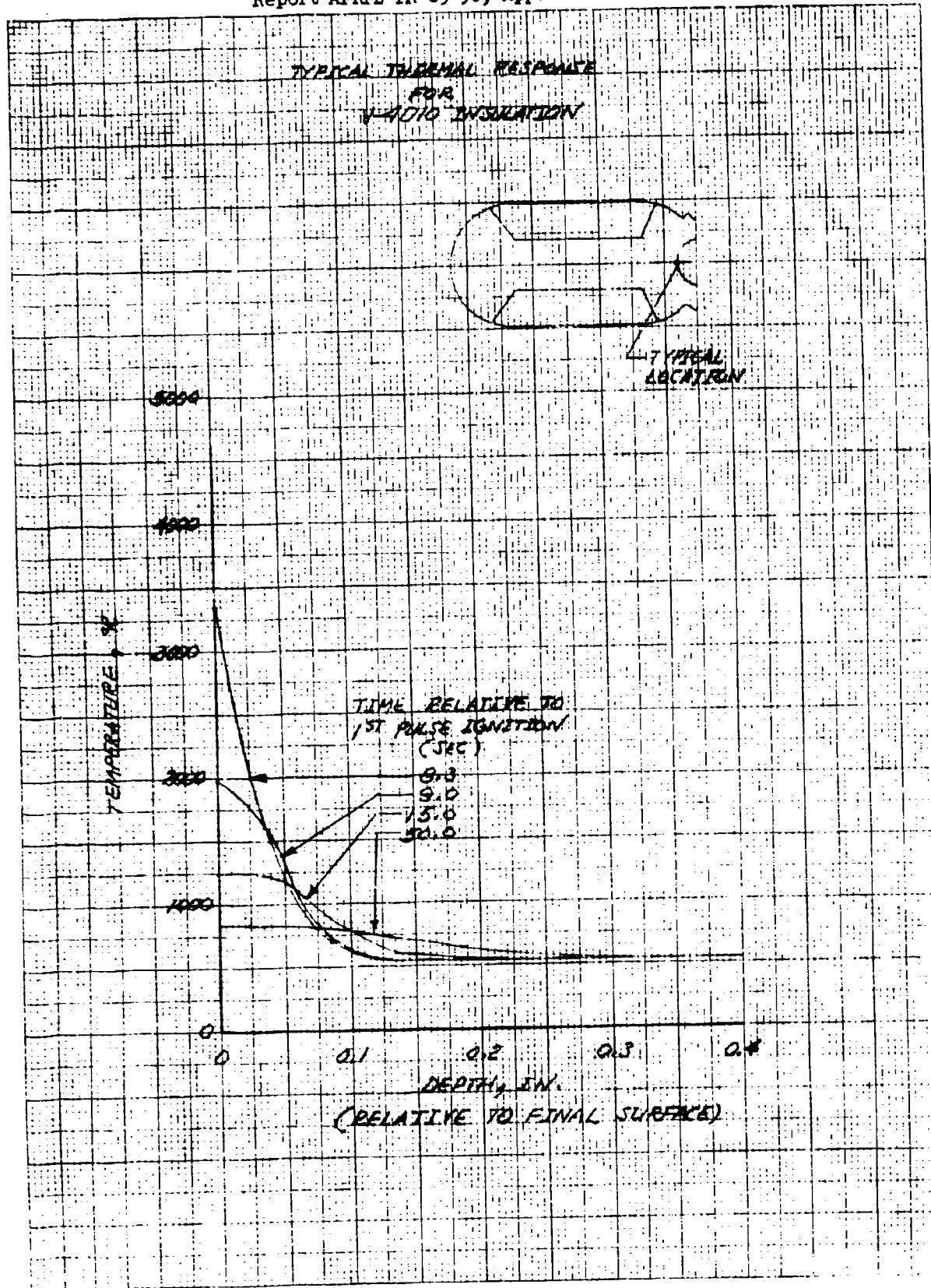


Figure E-6

Report AFRPL-TR-69-50, Appendix F

APPENDIX F

RE-IGNITION ANALYSIS OF THE SINGLE-CHAMBER STOP/START  
CONTROLLABLE SOLID ROCKET MOTOR

Report AFRPL-TR-69-50, Appendix F

SECTION I

INTRODUCTION

A re-ignition analysis has been conducted of the stop/start motor to determine if motor re-ignition could occur after a pulse termination. The analysis was based on the results of Appendix E.

SECTION II

DISCUSSION

Rocket motor ignition phenomena are analyzed through the use of ignitability data derived from tests conducted in the arc-image furnace under controlled environmental conditions. From these tests, time to ignition for a particular propellant is defined in terms of induced heat flux and pressure. In addition, propellant critical ignition pressure is determined through the use of the furnace where critical pressure is defined as the highest pressure at which the time-to-ignition is considered infinite. After the test data is obtained, it is placed through a smoothing process and scaling laws developed for extrapolation to other flux levels.

Internal motor pressure is derived from insulation pyrolysis and propellant ablation due to the thermal and pressure environment. These data are shown in Appendix E.

SECTION III

THEORY

The general ignition theory considers the induced heat flux and the temperature profile in the solid propellant grain. Heat is transferred to the propellant grain by convection and radiation modes. For this motor, the means of heat transmission is principally by radiation. Time to propellant ignition,  $t_{\text{ff}}$ , is defined as the summation of the thermal induction interval,  $t_o$ , and the chemical induction interval,  $t_c$ . The thermal induction period is defined in terms of heat flux, propellant diffusivity, conductivity, auto-ignition, bulk temperature, and a critical propellant depth. The critical depth is a characteristic depth to which the propellant must be raised to auto-ignition temperature for sustained ignition to occur. The chemical induction period is defined in terms of the critical pressure, local pressure, and an empirical constant determined from arc-image data.

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SECTION IV

DISCUSSION

A curve fit of the propellant ignitability data was made after a smoothing process. Particular emphasis was placed on assuring a good fit on the lowest heat flux curve since Appendix E shows a low flux environment in the motor. Time to ignition for any heat flux may be found from,

$$t_{\text{ig}} = t_0 + t_c$$

$$t_{\text{ig}} = \frac{\ln q - \ln (q - 0.21977 (490 - T_{\text{amb}}))}{40.568} + \frac{1}{0.65 (P - 45)}$$

where:  $t_{\text{ig}}$  = seconds

$q$  = Btu/ $\text{ft}^2\text{-sec}$

$T_{\text{auto}}$  =  $490^{\circ}\text{F}$

$P^*$  = 45 psia

By inspection, it is seen that there are two quantities which tend to make  $t_{\text{ig}}$  approach infinity:

$$(1) q - 0.21977 (490 - T_{\text{amb}}) = 0; \ln 0 = -\infty$$

$$(2) P - 45 = 0; \lim_{P \rightarrow 45} \frac{1}{P-45} = \infty$$

The critical depth has been found to be approximately 0.004 inch. Figure D-1 shows that for any pulse time there is a steep temperature gradient in the solid propellant and that at a depth of 0.004 inch the local temperature is below the autoignition temperature.

Figures E-1 and E-2 of Appendix E show that incident heat flux is at a maximum when  $t = 0$  and decreases extremely fast with increasing time. The mean heat flux for the first 0.500 second is approximately  $25 \text{ Btu}/\text{ft}^2\text{-sec}$ . Using this information and propellant ignitability data, with an assumed

## IV, Discussion (cont.)

chamber pressure of 2.0 psia due to insulation and propellant pyrolysis, the propellant ablation rate is found to be approximately  $40 \times 10^{-4}$  in./sec. Normally, the incident heat flux would be determined for all locations on the propellant grain and the effects on ablation rate integrated over the total mass flow. Since the motor configuration is relatively complex, this approach was not deemed feasible. Thus, for a first approximation, the maximum flux was considered to exist in all locations over the complete propellant surface. This approximation will yield a conservative answer with respect to re-ignition. Induced pressure is found by summing the mass flow from all sources and assigning an overall mass flow coefficient to the gases. For any pulse, the maximum pyrolysis occurs near  $t = 0$ , where  $t$  is the time after normal burning termination. Also, from Appendix E, the induced heat flux is independent of pulse, therefore the maximum mass flow occurs after the last pulse where maximum surface area occurs. The induced pressure is found as follows:

$$P = \frac{\sum \dot{W}}{A_t C_w} = \frac{1}{A_t C_w} (\rho r_a A_b + \dot{W}_{\text{pyrolysis}})$$

$A_t$  = throat area, 39 in.<sup>2</sup>

$\rho$  = density, lbm/in.<sup>3</sup>

$r_a$  = ablation rate, in./sec

$A_b$  = total propellant surface area, in.<sup>2</sup>

$C_w$  = assumed flow coefficient, lbm/lbf-sec

$$P = \frac{1}{39(0.012)} (0.063 (0.004) (1400) + 0.175) = 1.13 \text{ psia}$$

P < 2.0 (assumed)

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SECTION V

CONCLUSIONS

Based on results of Appendix E and this study, it may be concluded that re-ignition will not occur for the motor configuration as designed. In the predicted thermal environment within the motor, none of the requirements for ignition are satisfied, as shown below.

<u>Quantity</u>	<u>Maximum Predicted Value</u>	<u>Critical Value</u>
$P_{induced}$ , psia	1 - 2	45
$\dot{q}_{induced}$ , Btu/ $ft^2$ -sec	35	91

Although there have been several simplifying assumptions made in this analysis, it should be noted that each would tend to provide more favorable ignition conditions than actually exist. Thus, all estimates are conservative assuring that re-ignition will not occur.

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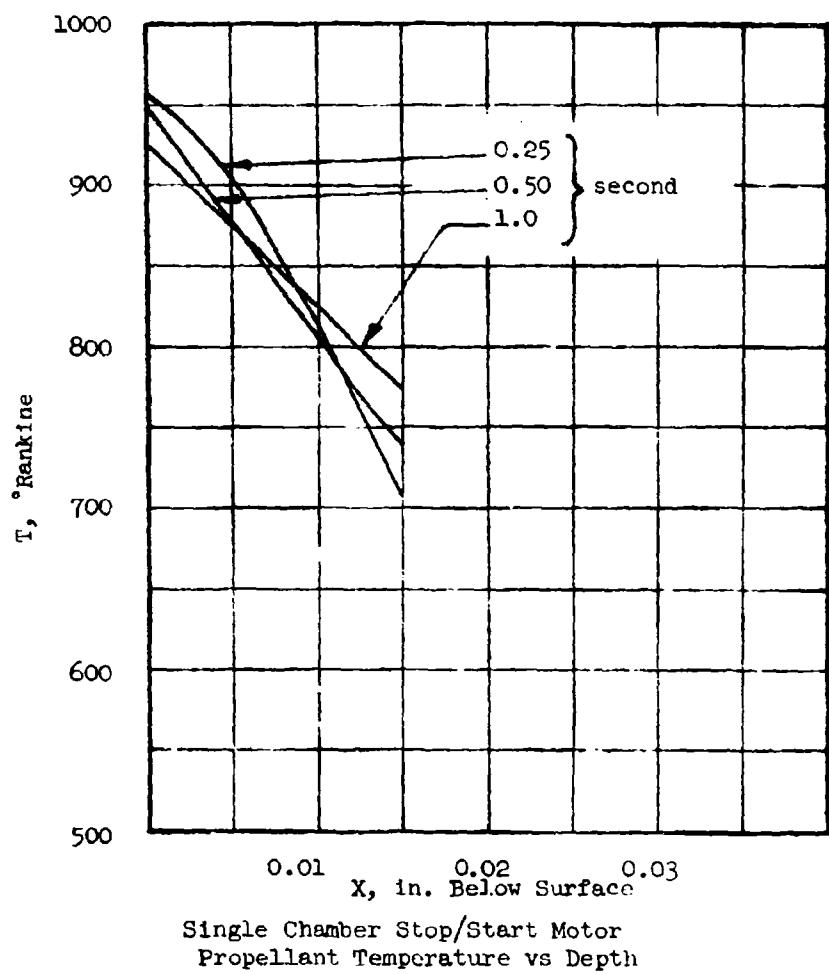


Figure F-1

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3. REPORT TITLE (Unclassified Title) Single-Chamber Stop/Start Solid Rocket Motor
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Charles T. Levinsky  
Norman P. Mittermaier  
Albert O. Hardrath

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Edwards, California 93523
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13. ABSTRACT This report deals with the technical effort conducted during the fulfillment of Contract F04611-68-C-0063, "Single-Chamber Stop/Start Solid Rocket Motor." The program comprised five phases made up of preliminary design, propellant tailoring, component testing, lightweight motor design, and lightweight motor fabrication and testing.
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Although some problems were encountered in pintle nozzle and igniter function, the program yielded some very significant results. The basic design concepts of the motor were demonstrated to be sound and practical. The functional problems encountered are identified and solutions are presented to eliminate them.

The program clearly demonstrated that a lightweight solid rocket motor can be repeatedly stopped and started at a simulated altitude of 60,000 ft and that a wide diversity of duty cycles can be attained to meet the spectrum of potential mission requirements.

DD FORM 1 NOV 65 1473

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Stop/Start Single-Chamber Movable Pintle Nozzle Pulse Igniter Cold Flow Static Test Firing Burning Rate Burning Rate Exponent						

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