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SINGLE-CHAMBER STOP/START
SOLID ROCKET MOTOR (U)
FINAL REPORT
VOLUME II, APPENDIXES
Contract F04611-68-C-0063

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Report AFRPL-TR-69-50

SINGLE-CHAMBER STOP/START SOLID ROCKET MOTOR FINAL REPORT

VOLUME II APPENDIXES

CONTRACT F04611-68-C-0063

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

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

AEROGNET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY
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>
<thead>
<tr>
<th>Part</th>
<th>Drawing Number</th>
<th>Minimum Margin of Safety</th>
<th>Page</th>
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<td>1147001</td>
<td>+.03</td>
<td>3.1.1-1</td>
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<tr>
<td>Throat, Retainer</td>
<td>1147003</td>
<td>+.015</td>
<td>3.1.2-2</td>
</tr>
<tr>
<td>Coupling</td>
<td>1146997</td>
<td>+.17</td>
<td>3.1.3-2</td>
</tr>
<tr>
<td>Piston Retainer</td>
<td>1146999</td>
<td>High</td>
<td>3.1.4-1</td>
</tr>
<tr>
<td>Piston, Pintle</td>
<td>1146998</td>
<td>+.33</td>
<td>3.1.5-3</td>
</tr>
<tr>
<td>Strutted Housing</td>
<td>1146995</td>
<td>+0.0</td>
<td>3.1.6-5</td>
</tr>
<tr>
<td>Entrance Cap, Pintle</td>
<td>1147005</td>
<td>+.05</td>
<td>3.1.7-1</td>
</tr>
<tr>
<td>Exit Cone Pins</td>
<td>1147016</td>
<td>+.51</td>
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</tr>
<tr>
<td>Nozzle Support</td>
<td>1147008</td>
<td>+.31</td>
<td>3.1.9-2</td>
</tr>
<tr>
<td>Nozzle Throat</td>
<td>1147012</td>
<td>.34</td>
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</tr>
<tr>
<td>Outer Nozzle Assembly</td>
<td>1147006</td>
<td>High</td>
<td>3.1.11-1</td>
</tr>
</tbody>
</table>
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 SSFM 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.
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.
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.
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.
PYRO GRAPHITE

THERMAL COEFFICIENT OF EXPANSION OF PYROLYTIC GRAPHITE

ELASTIC MODULUS OF PYROLYTIC GRAPHITE

Figure 2.3
MOLDED ATJ

Figure 2.4
Figure 2.5
THERMAL COEFFICIENT OF EXPANSION OF FM 5064

Figure 2.6
THERMAL COEFFICIENT OF EXPANSION OF MX 5064

Figure 2.7
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3.3.0 PROP. GRAIN STRESS ANALYSIS

**TABLE OF NOTATION**

S = PREDICTED OR CALCULATED STRESS, PSI
F = ALLOWABLE STRESS, PSI
P = TOTAL LOAD, #
P = PRESSURE, PSI
**Sec 3.11** SSRM - Throat Pinle

**Throat, Pinle**

**Fig 3.11**

---

**Shear**

\[ \tau = \frac{F_{\text{Pi}}}{A} \]

- \( F_{\text{Pi}} = 11000 \) N
- \( A = 2\pi (1.75)(1.80) = 630 \) IT

\[ \tau = \frac{3 \times 11000}{2 \times (2.30)} = 2620 \text{ psi} \]

- \( F_3 = 2700 \text{ psi} \)
- \( \text{Room Temp} \)
- \( M.S. = \frac{2700}{20} = 135 \)

**Bending**

\[ \sigma_b = \frac{6M}{I} \frac{1}{r^2} \]

- \( M = 5(4,0)(1.75)11000 = 3540 \) N-m

\[ \sigma_b = \frac{6 \times 3540}{20^2} = 600 \text{ psi} \]

- \( F_T = 100 \times \tan 30^\circ = 500 \text{ psi} \)
- \( M.S. = \frac{7500}{600} = 12.5 \)
Sec 3.11 Sstem - Throat Pintle

THROAT, PINTLE: Dwg 1147001, AG CABE 101

Fig 3.11

\[ C = \frac{6L}{\pi^2} \]

\[ F_s = 2700 \text{ psi} \]

\[ F_t = 1000 \text{ psi} \]

\[ M_s = \frac{7500}{2500} = 3 \]

Preceding Page Blank
Sec 3.1.2 SSRM - Retainer, Throat

Retainer, Throat

Dwg 12.7003 Titanium

Fig 3.1.2

@ Sec M-A Shear

\[ \frac{C_{shear}}{P_{ej}} = \frac{2}{3} \]

\[ P_{ej} = 11,000 + 2,111 \]

\[ N = 2\pi \cdot 2.5 \cdot (1.929) = 584 \text{ in.}^2 \]

\[ F_s = 19,500 \text{ psi} \]

\[ M_s = \frac{100,300}{28.5} \]

Bending

\[ F_b = \frac{6M}{L^2} \]

\[ M < P_{ej} \cdot (170 - 35) \]

\[ = 11,000 \cdot (143) \]

\[ = 1,7100 \text{ in.}^3 \]

\[ = 6(22200) = 133,200 \]

\[ = 165,000 \text{ psi} \]

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

\[ M_s = \frac{170}{17.5} = 9.7 \]
<table>
<thead>
<tr>
<th>TENSION @ U' CUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{F_t}{A_t} )</td>
</tr>
<tr>
<td>( P_{fy} )</td>
</tr>
<tr>
<td>11,000 ( \pi )</td>
</tr>
<tr>
<td>( \frac{A_t}{\pi} = \frac{\pi (0.562)}{2} = 0.08 \pi \text{ in}^2 )</td>
</tr>
<tr>
<td>11,000 ( \frac{0.08 \pi}{\pi} = 137,500 \text{ psi} )</td>
</tr>
<tr>
<td>( F_t = 150,000 \text{ psi} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SHEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{F_s}{A_s} )</td>
</tr>
<tr>
<td>( P_{fy} )</td>
</tr>
<tr>
<td>( A_s = \pi (0.562)(0.5) )</td>
</tr>
<tr>
<td>( = 11,000 \frac{0.393 (0.5)}{\pi} = 98,500 \text{ psi} )</td>
</tr>
<tr>
<td>( F_s = 109,000 \text{ psi} )</td>
</tr>
</tbody>
</table>

\[ M_S = \frac{150,000 - 137,500}{150,000} = 0.08 \]
SSRM - Ps.4.12 - Theor.-

BY H. ERICKSON

\[
\frac{dF}{r} = \frac{3P}{2A}
\]

**Shear**

\[
P = \mu \pi (d^2 - (d - \delta)^2) = 15\pi \delta 
\]

\[
A = 2\pi R^2 + 10\pi 
\]

\[
= 3 \left(\frac{10350}{2}\right) = 16,000 \text{ psi}
\]

\[
F_s = 16,000 \text{ psi}
\]

\[
\frac{M}{L} = \frac{100}{12} = \frac{25}{3}
\]

\[
\frac{6M}{L^2} = \frac{170.0 - 1}{90.5} = \frac{169.9}{90.5} = 1.90
\]

\[
Q \frac{C}{C} = \frac{170.0 - 1}{90.5} = \frac{169.9}{90.5}
\]

\[
\frac{3P}{2A}
\]

\[
P = \mu \pi (d^2 - (d - \delta)^2) = 15\pi \delta 
\]

\[
A = 2\pi (1.35)(2) = 8.25\pi
\]

\[
= 3(9000) = 27,000 \text{ psi}
\]

\[
F_s = 27,000 \text{ psi}
\]

\[
\frac{M_S}{L} = \frac{100}{12} = \frac{25}{3}
\]
**SEC 3.1.3 SS R&M - Coupling**

**BY H. EFRON**

**COUPLING**

**Dwg 1146997**

4130 STL, Cond C3, H.T. $F_y = 180,000$ psi

![Diagram of a connection](image)

**Fig 3.1.3**

**Loads:**

1. **Due to Chamber Pressure:** $P_{c} = 65$ psi, $P_{e1} = \frac{F}{n}(4.5 \times 23^2)$, $\theta = 90^\circ$, $A = 2\pi (16.0 - 0.9) = 11,000$ psi.

   $\therefore \Delta P_{e1} = \frac{\Delta P_c}{\theta} = \frac{11,000}{21,200} = 0.52$ psi.

2. **Due to Actual or T.C.R. Surf:** $P_{e2} = 3750$ psi.

   $\theta = \frac{\pi}{4}(1.25 \times 0.75) = 3750$ psi.

   $Q = \frac{P_{e2}}{2\pi r} = \frac{3750}{7.125} = 520$ psi.

**Thrusts:**

$F_3 = \frac{P_r}{K}$

$\therefore P_r = 11,000$ psi.

$A = \frac{11,000}{2\pi (1.32 - 0.09 - 1.25 - \frac{3.12}{12})} = 1.48$ psi

$F_3 = \frac{(11,000)}{(1.148)} = 9400$ psi

**M.S.:** 100 - 74 = 26
TENSION:

\[ T = \frac{P}{A} \]

\[ P_{f} = 11,000 \text{ psi} \]

\[ A = \pi \left( 0.51^2 - 0.30^2 \right) = 0.20 \text{ in}^2 \]

\[ T = 11,000 \times 0.20 = 2,200 \text{ psi} \]

\[ R = \frac{T}{F_T} = 35 \times 0.31 \text{ stress ratio} \]

BENDING:

\[ \sigma_b = \frac{6M_k}{I} \]

\[ M_k = 0.5P_e \left( 0.51 - 0.30 \right) = 11 \times 0.59 = 6.53 \text{ in} \cdot \text{lb} \]

\[ I = \pi \left( 0.51^2 - 0.30^2 \right) = 0.20 \text{ in}^4 \]

\[ K = 0.7 \text{ since same of the moment } (M) \text{ rotates the aperture} \]

\[ \sigma_b = \frac{6 \times 1180}{2134} = 149,000 \text{ psi} \]

\[ R_b = \frac{F_b}{F_T} = 180,000 \text{ psi} + 80,000 = 260,000 \]

\[ R_b = \frac{180,000}{260} = 0.54 \]

Combined Stress:

\[ M.S. = \frac{1}{E} + R_b = \frac{10.1}{1.85} = 5.4 \]
SSRM - Couplings

@ Sec 1B-1B

Tension

\[ F_T = \frac{P_{r_{uA}}}{A} \]

\[ P_{r_{uA}} = 11,000 \text{ in}^2 \]

\[ A = \pi \left( \frac{.517}{.389} \right)^2 = .173 \pi \]

\[ = 14.750 = 86,000 \text{ psi} \]

\[ F_T = 180,000 \text{ psi} \]

\[ M.S. = \frac{180}{86} - 1 = 1.1 \]

Bending: Due only to actuator load

\[ f_e = \frac{6M}{I^2} \]

\[ M = \frac{.5 P_{r_{uA}} (399 + 3.27)}{\pi (389 + 5.79)} \]

\[ P_{r_{uA}} = 3,250 \text{ in}^2 \]

\[ = 0.95 (375) \]

\[ = 370 \text{ in}^2 \]

\[ f_e = \frac{6(370)}{(1.9)^2} = 64,000 \text{ psi} \]

\[ F_B = 180,000 + 83,000 = 260,000 \]

Combined Stress

\[ R_T = \frac{F_T}{F_e} = 64 \]

\[ R_B = \frac{F_B}{F_e} = 1.32 \]

\[ M.S. = \frac{1}{T} = \frac{1}{1.1} = 1.32 \]
@ SEC C-C
1: 1.25/20 .025

BEARING

\[ M = P \cdot \frac{d}{2} \cdot R \cdot \frac{1}{2} \cdot \frac{1.25\pi}{12} \]

\[ F_0 = \frac{4(13.20)}{(2.245)^2} = 1.3 \times 1000 \text{ PS} \]

\[ F_0 = 180,000 + 80,000 = 260,000 \text{ PS} \]

\[ N/S = \frac{180}{12} - 1 = 3.7 \]

SHEAR

\[ C = \frac{3P}{2A} \]

\[ P = \frac{11000\pi}{12} \text{ REF: } N/3.1.1 \]

\[ A = 2 + \frac{1}{2} \times (2.245) \]

\[ = \frac{2(11000)}{2(3.7)} = 54,000 \text{ PS} \]

\[ F_{s/n} = 100,000 \text{ PS} \]

\[ N/S = \frac{100}{54} = 1.85 \]
SSRM - COUPLING

BY H. EFRON

THREADS 0.75 - 16 UNF - 3B

\[
f_s = \frac{PejA}{A}
\]

\[
PejA = 37.50 \pi
\]

\[
A = 0.5(0.75)\pi(0.625 - 0.125 - \frac{3}{16})
\]

\[
= 0.375\pi(0.375) = 0.375\pi^2 \text{ in}^2
\]

\[
= \frac{37.50}{0.375^2} = 20000 \text{ psi}
\]

\[
f_s = 100,000 \text{ psi}
\]

\[
M/S = \frac{100,000}{20,000} = 5
\]

4th LAST TEMPO EFFECTIVE
**Sec 3.14**

**SS, R.M.**

**Retainer, Piston**

**BY H. EFRON**

---

**Retainer, Piston**

**Dwg 114699**

**Fig 3.1.4**

**Threads**

\[ D = 1.16 \text{ min dia} \]

\[ t = \frac{T_{\text{fj}}}{A} \]

\[ A = \pi D (4.25 - \frac{2}{12}) \]

\[ = \frac{1.16 (1.3)}{2} = 1.74 \pi \]

\[ P_{\text{fj}} = 3750 \pi \text{ Ref p 3.11} \]

\[ = 2850 + 21,000 \text{ psi} \]

\[ F_{\text{min}} = 100,000 \text{ psi} \]

\[ M.S. = \frac{100}{22} = 4.5 \]

**Ring Rotation - Bending**

\[ C = \frac{M.E}{I} \]

\[ M = \frac{(1.75 - 1.625) [3750 \pi]}{(1.75 + 1.625)} \]

\[ = \frac{125 (3750)}{3.375} = 3409 \text{ in} \cdot \text{lb} \]

\[ C = \frac{21}{12} \]

\[ I = \frac{bh^3}{12} = \frac{125 (425)}{12} = \frac{775}{96} \]

\[ R = 0.63 \]

\[ = 340 (2.12) (0.63) \times 10^3 \]

\[ = 56,500 \text{ psi} \]
\[ F_0 = F_v + 80000 \]
\[ = 180,000 + 80,000 = 260,000 \text{ psi} \]
\[ M.S. = \frac{260,000}{570} - 1 = M_1 \]
SEC 3.1.5  SSVM - PISTON, PINPLE

PISTON, PINPLE  Dwg  [Dwg number]

WHERE:

$W_x$: REACTS PRESSURE LOADS

$W_A$: REACT ACUATOR LOADS

FIG 3.1.5.1

CONE

$$\sigma_h = \frac{PR}{2 \cos 31.5^\circ} = \frac{0.90(3.4)}{2 \cos 31.5^\circ} \approx -27000 \text{ psi}$$

$$F = 160,000 \text{ psi}$$

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

Ref: Shell Strength
W. L. Vaughan
Design News 3/29/63

\[ \frac{D}{L} = \frac{6.8}{3.4} = 2.0 \]

\[ \frac{t}{D} = \frac{1}{6.8} = 0.147 \]

\[ P_c = \frac{E K}{L} \]

\[ E = 30 \times 10^6 \]

\[ K = 0.0009 \times 9 \times 10^5 \]

\[ = 30 \times 9 \times 10^5 = 2700 \text{ psi} \]

\[ P = 690 \text{ psi} \]

\[ N_s = \frac{P}{\frac{P_c}{P}} \cdot \frac{3000}{690} - 1 = 4.0 \]

Ring

Assume

1. Only pressure loads acting
2. Ring exists the entire pressure loading in ring position.

\[ \frac{K}{R} = 1.67 \]

\[ I = \frac{0.53 \times 0.432^3 - 0.35 \times 10^3}{12} \text{ in}^4 \]

\[ A = 0.432 \times 0.57 = 0.25 \text{ in}^2 \]
BENDING STRESS

\[ S_b = \frac{M_b R}{I} \]

\[ I = 3.5 \times 10^{-3} \text{ in}^4 \quad \text{REF Fig. 3.1.5.1} \]
\[ c = 0.216 \text{ in} \]
\[ R = 0.93 \text{ in} \]
\[ M = 0.6 P_{ejR} = \frac{3 P_{ejR}}{2\pi R} \]
\[ \frac{2\pi R}{3.5 \times 10^{-3}} = \frac{0.06 P_{ejR}}{10^3} \]
\[ P_{ejR} = 11000 \quad \text{REF Eq. 3.1.1.1} \]

\[ F_b = 180,000 + 50,000 = 230,000 \text{ psi} \]

\[ R_b = \frac{\rho}{F_b} = \frac{183,000}{750,000} = 0.24 \]

HOOP TENSION

\[ S_h = \frac{W R}{A} \]
\[ W = \frac{P_{ejR} \tan 31.5^\circ}{2\pi R} \]
\[ = \frac{11000 \cdot 0.129}{2 \times 0.93} = \frac{3370}{1.86} \]
\[ = 1850 \text{ psi} \]
\[ F_h = 180,000 \text{ psi} \]
\[ R_h = \frac{13500}{180,000} = 0.075 \]

COMBINED STRESS

\[ ER = P_b + 2 = 1.075 + 0.075 = 1.15 \]
\[ \alpha_{l/2} = 1.746 - 1 = 0.746 \]
SEC 3.1.6

Housing, Pintle #1146995

4130 STL
H.T. 150 KSI, Min YLD

Actuator

Fig 3.1.6.1
14. CHM By

BENDING STRESS

\[ M = \frac{(2.194 - 0.01)}{2} = \frac{2.194}{2} \]

\[ = \frac{2.194}{2} = 1.147 \]

\[ F = \frac{6(36.5)}{2(245)^2} \]

\[ E = 100,000 \text{ psi} \]

\[ M = \frac{150.5}{1.147} \]

\[ H = \frac{150.5}{1.147} \]

SHEAR STRESS

\[ A = 2\pi \times 2.194(245) = 1.007 \]

\[ F_s = 90,000 \text{ psi} \]

\[ M_s = \frac{90.0}{0.85} - 1 \]

BOLTS: PISTON TO HOUSING

\[ \frac{P}{10} = \frac{4750}{10} = 1370 \text{ ft/lb} \]

\[ F_{bolts} = 6700 \text{ lb/bolt} \]

\[ M_s = \frac{6700}{1370} - 1 = 41 \]
Ring - Pivine Kick Loads

\[ P_R = \frac{F}{\cos \theta} \]

Evaluating \( P_R \) (resulting after acting)

\[ P_R = \frac{F}{\cos 40^\circ} \]

\[ = \frac{110}{\cos 40^\circ} \]

\[ \approx 166.7 \text{ ft-lbs} \]

\[ \frac{P_R}{F} = \frac{166.7}{60} \approx 2.8 \]

Evaluating geometry of the ring

\[ T_{xy} = 2T_0 + 2A_y^2 - 2A_y^2 \]

\[ \gamma = \frac{E A_y}{L_y} = \frac{351}{136} = 2.6 \]

\[ T_{xy} = 0.015 + 0.1 + (0.039)^2 = 0.39 \text{ in}^4 \]

\[ A = 1.36 \text{ in}^2 \]

\[ P = 128 - 26 = 49 \]

\[ P = 3.97 \]
Evaluating Bending Stress, $S$

\[ S = \frac{Mc}{I} \]

\[ \begin{align*}
M &= 0.5 P \cdot R \left( \frac{1}{2} - 0.4 \right) \\
P &= 18,000 \text{ lb} \\
R &= 7.777 \\
cot \theta &= 1.732 \\
\theta &= \frac{\pi}{6} = 1.05 \\
&= 5 \left( 18,000 \right) \left( 3.97 \right) \left( 377 \right) = 27,000 \text{ in} \\
K < 0.50 & \text{ Factor to allow for the stiffness contributed to the ring by a cylinder aft of the boss and a boss on the sealing piston of the ring.}
\end{align*} \]

\[ \begin{align*}
\frac{c}{2} &= \frac{27,000 \left( 49 \right) \left( 50 \right)}{0.5} = 173,000 \text{ psi} \\
F_y &= 150,000 \text{ psi} \\
P_0 &= 1.25 F_y = 188,000 \text{ psi} \\
E &= 1.25 \rho = 188,000 \\
\frac{133}{125} &\approx 1.09
\end{align*} \]
EVALUATING COMpressive STRESS IN X SECTION

\[ C = \frac{R}{K} \]

WHERE

\[ K_t = 1.5 \cot 60^\circ = 0.87 \]
\[ P = 18,000 \text{ lb} \]
\[ A = 1.36 \text{ in}^2 \]

\[ R = \frac{18,000 \cdot 0.87}{1.36} = 11,500 \text{ psi} \]
\[ F = 150,000 \text{ psi} \]

\[ M.S. = \frac{150,000 \cdot 1}{11.5} \]

COMBINED STRESS: COMP. + BENDING

\[ R = \frac{R_t + R_b}{R_t} \]
\[ R_t = \frac{C}{F} = \frac{11,500}{150,000} = 0.076 \]
\[ R_b = \frac{C}{F} = \frac{173,000}{125,000} = 0.92 \]

\[ R = 0.906 \]

M.S. = \[\frac{1}{R} - 1 = \frac{1}{0.906} - 1 = 0.04 \]

DEFLECTION, Torsional \[ AK = \text{REF: REA 634, TABLE 7 IN CASE 9} \]

\[ NR = \frac{W^2}{2EI} \left[ 2 \sin^2 \left( \frac{\theta}{2} \right) - \frac{\theta}{2} \right] \]
\[ \theta = \pi = 1.05 \text{ rad} \]
\[ W = 18,000 \text{ lb} \]
\[ E = 3,000,000 \text{ psi} \]
\[ I = \frac{30 \times 0.5^4}{12} = 120 \times 10^4 \]

\[ \Delta R = 18,000 \times 0.05 \times 0.016 = 0.012 \text{ at design load} \]
\[ 0.12 \times 0.008 = 0.008 \text{ at limit load} \]

BASED ON K = 0.01 FOR DEFLECTION LIMITS

\[ \Delta R = 0.12 \times 0.008 = 0.008 \text{ at actual load} \]
ELASTIC STABILITY OF THE CYLINDER

REF: SHELL STRENGTH - VAUGHN
DESIGN NEWS 3/20/63

\[
T_D = KE
\]

EVALUATING K

\[
\begin{align*}
D &= 2.623 \\
L &= 4.33 \\
I &= 0.08 \\
\frac{t}{D} &= 0.0105 \\
\rho &= 6 \times 10^{-6}
\end{align*}
\]

\[
K = 6 \times 10^{-6}
\]

\[
= 6 \times 10^{-6} \times 30 \times 10^4 = 180 \times 10^3
\]

\[
M.S. = \frac{18 \times 10^3}{0.5} = 36\%
\]

SEC II.B. B - STRUT

\[
A = \frac{3.75 \times 3.0 - \pi \times (0.05)^2}{3.03 - 0.03} = 0.493 \text{ in}^2
\]

\[
I = \frac{bh^3}{12}
\]

\[
= \frac{1.5 \times 4 \times (3.75)^3}{12} = 4.5 (\text{in}^4);
\]

\[
\sigma = 0.00976 = 1 \text{in}^4
\]

\[
\rho = \sqrt{\frac{4}{A}} = 10 \sqrt{\frac{0.493}{5}} = 0.12
\]

\[
L = 4.5'' \text{ length of column}
\]

COMPRESSION STRESSES:

\[
F_c = \frac{Bt}{A} = \frac{190\pi (4.6)^2}{3.5 \times 10^{-4} \times (3.3)} = 44,500 \text{ psi}
\]

FLEXURE ALLOWABLE - Pinned End (0.05)

\[
F_c = \frac{\pi E}{(L)^2} = \frac{20 \times 10^6 \times 3.9}{(0.5)^2} = 182,000 \text{ psi}
\]

\[
M.S. = \frac{150,000}{44 \times 0.05 - 1} = 44\%
\]
ASSUMING THAT THE STRUT IS LOADED UNIFORMLY BY A $w = 1410$ psi AS SHOWN BELOW.

\[ w \]
\[ F = 3.5 \]

FIG. 8.1.6.4

THE LOAD $w$ IS DETERMINED FROM THE FOLLOWING NET SECTION PROJECTED AREA.

\[ W = 1.75 \]
\[ A = 1.75 \times 1616 = 2820 \text{ psi} \]

BEARING STRESS

\[ \sigma_b = \frac{F}{I} \]

\[ M = \frac{W^2}{8} = 2820(2.5)^2 = 4320 \text{ in-lb} \]
\[ c = 0.77 \text{ in} \]
\[ I = 375 \times \frac{1.54}{12} = 115 \text{ in}^4 \]
\[ = 115(0.77) = 89200 \text{ psi} \]

COMBINED STRESS

\[ \sigma = \sigma_c + \sigma_b \]
\[ \sigma_c = 44,500 \text{ psi}, \sigma_b = 89200 \text{ psi} \]
\[ = 44,500 + 89200 = 73,500 \text{ psi} \]
\[ F_c = 120,000 \text{ psi} \]

MS. $\frac{150.0}{73.5} - 1 H_1$
Stress due to actuator fluid pressure in the 0.150" dia. hole:

\[
\sigma = \frac{3750 \times 0.095}{5 \times (375 - 1.9)} = 3850 \text{ psi}
\]

\[P = 150,000 \text{ psi}\]

Design:
\[
\frac{150,000}{385} = 3.91
\]

**External shell**:

---

**AFT**

**Fig 3.16.6**

Shell thickness:

\[
\begin{align*}
3.52 & \quad 7.44 \quad 6.81 \quad 2.60 \\
1.9 & \quad 1.38 & \quad 0.375
\end{align*}
\]

The shell design:

1. **Internal pressure**
2. **Structural loads**

*P* = 650 psi

*P* = 18000*
Report AFRL-TR-69-50, Appendix A

SSRM-20 PULVE

BY H. EPRON

Harsh Shells due to $P = 6000$ psi

\[ P = \frac{6000}{600/7} \]

\[ \frac{600 - 3.6}{19(1.34)} = 29000 \text{ psi} \]

\[ F_0 = 150,000 \text{ psi} \]

\[ M.S. = \frac{150000}{250} = 600 \text{ psi} \]

Stress Loads: $P_{st}$

Assumptions:
1. $P_{st}$ to Shell
2. Shell + Flanges act as one unit

Evaluating $P_{st}$ Refer to Fig. 3.1.6.7

\[ P_{st} = \frac{690 \pi (4.6)^2}{3 \times 160} = 23,500 \text{ psi} \]
EVALUATING RING GEOMETRY

\[ I = \pi I_0 + \frac{3A_y^2}{2} - \frac{3A_y}{2} \]

\[ \Delta = \left[ \frac{E A_y}{2A_y} \right] \left[ \frac{-0.275}{1.263} \right]^2 \]

\[ = 0.0528 + 0.775 - 1.263 (0.49) = 0.157 \text{ in}^4 \]

\[ A = 1.263 \text{ in}^2 \]

\[ R = 6.81 + 1.70 = 7.51 \text{ in.} \]

EVALUATING BENDING STIFFNESS:

\[ C = \frac{M^2}{E I_z} \]

\[ M = 0.07 \times 5 \times 7.8 \times 0.3 \times 3 \]

\[ = 1.77 \text{ in.} \]

\[ \theta = 1.732 \]

\[ \cot \theta = 1.732 \]

\[ = 0.5(1800)(7.51)(1.72) = 52.500'' \]

\[ L = 8.44 - 6.81 - 7 = 4.93 \]

\[ K = 0.5 \text{ stiffness added to bins by 1. liners} \]

\[ 2. bosses + adjacent shell structures \]
SSRM - 20 pulse

\[ C_0 = \frac{M_E}{K} \]

\[ = \frac{52,500 (0.93)}{197} = 126,000 \text{ psi} \]

\[ F_y = 150,000 \text{ psi} \]

\[ M_S = \frac{150}{126} = 1.19 \]

EVALUATING DIRECT STRESS:

\[ T_1 = \frac{P_r}{A} \]

\[ P_r = 18000 \]

\[ K_1 = 0.50 \text{ ksi} \]

\[ = \frac{18000 (0.50)}{126} = 12,400 \text{ psi} \]

\[ F_y = 150,000 \text{ psi} \]

\[ M_S = \frac{150}{126} = 1.19 \]

COMBINED STRESS:

\[ \sigma = \sigma_1 + \sigma_3 \]

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

\[ F_y = 150,000 \text{ psi} \]

\[ M_S = \frac{150}{135.4} - 1 = 0.88 \]
SSRM 80 PULSE

WELDS - 100% Penetration RPD

FIG 3.1.6.9

@ Pressure Taps

HCOP C-REFS

\[
\frac{A}{\pi \frac{R}{2}} = \frac{3750(3.75)}{0.15} = 94.50 \text{ psi}
\]

\[ F_y = 150,000 \text{ psi} \]

FIG 3.1.6.10

\[ M.S. = \frac{150}{5.5} = \frac{M}{} \]

BLOW-OFF LOAD \( P \)

\[ P < \frac{P_a 1.5 \pi L L^2}{2} = \frac{3750(1.5)}{2} = 2426 \text{ psi} \]

WELD AREA \( A \) (ASSUME 1/8 WELD)

\[ A < \frac{125 \pi 1.3}{2} = 0.15 \text{ in}^2 \]

WELD STRESSES

\[ \sigma = \frac{P_a}{A} = \frac{2750}{0.15} = 18333 \text{ psi} \]

\[ F_y = 150,000 \text{ psi} \]

\[ M.S. = \frac{150}{5.5} = \frac{M}{} \]
BOLT LOADS - HOUSING TO CHAMBER

BLOW-OFF LOAD / BOLT

\[ P_b = \frac{\pi d^2}{40} \times 630 \times 7.6 = 2100 \text{ lbs/bolt} \]

Kick Load

\[ P_K = P_b \times \frac{9.0 - 7.6}{9.3 - 3.0} = \frac{4}{3} P_b = 1.33 P_b \]

Total Load / BOLT

\[ 2.33 P_b = 2.33 (2100) = 4900 \text{ lbs} \]

\[ \frac{1}{4} - 2.9 \text{ BOLTS} = 6900 \text{ lbs} \]

\[ \text{Allen Hex-Head} \]

\[ H.S. = \frac{6900}{4900} - 1 = 0.4 \]

\[ \text{(See C-6)} \]

BREAKING:

\[ \frac{C}{6} = \frac{600}{K} \]

\[ K = 1.375 \]

\[ M = \frac{A P (800 - 77)}{2} = (97.7)(1.3) = 800 \text{ in.-lb} \]

\[ K = \frac{P D - 66 (1.28)}{T D} = \frac{50 - 17}{50} = 0.8 \]

\[ = \frac{6(800)}{1.41(1.63)} = 5000 \text{ psi} \]

\[ F_y = 150,000 \text{ psi} \]

\[ M_y = \frac{1500}{60} - 1 \]
SSRM ENTRANCE CAP DWG # 1147005

By W. Jordan

MATERIAL 4130 STEEL
Fty = 90 KSI
Ftu = 70 KSI

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 STRUCTURAL MANUAL)

THE FINITE ELEMENT MODEL IS SHOWN ON PAGE 3.1.1.2

THE NODAL POINTS 1, 9, 17, 25, 52, 90 & 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 & 73 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.

\[
\text{MAX SKIN STRESS} = 80 \text{ KSI}
\]

\[
M.S. = \frac{70 \times 1.25}{80} - 1 = 0.09
\]

*NOTE: 1.25 BENDING MODULUS

FIG 3.1.7.1
Figure 3.17.2
MATERIAL: SILICA PHENOLIC (MIX 2646) AGE 34.312-1

\[ F_{su} = 5500 \text{ PSI} \]

\[ F_t = 27,000 \text{ PSI} \]

REF FIBERITE HANDBOOK

MARCH 1, 1963 (N.E.C.C.)

---

**LOAD ON PINS**

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

THEN POSSIBLE SHEAR LOAD ON PIN

\[
\frac{13.7 \times 7 (5.92^2 - 4.22^2) - (39.5 + 10.3) \times (5.92 - 4.22)}{2}

= \frac{1517.6 - 712.4}{6} = 131''/PIN

C = \frac{P}{G} = \frac{131}{.7854 \times (225)^2 - (0.7)^2} = 36.49

M. E. = \frac{.55 - 0}{.474.0} - 1 = 4.5 - 1
SSRM SHELL NOZZLE DWG 1147008

BY W. JORDAN

MATERIAL STEEL TYPE 4130 MIL-S-6758 COND C3

\[ F_{t} = 150,000 \text{ PSI} \]

4.8" - 10"

28° HORIZONTAL STRESS \( \sigma = 6.821 \)

\[ \sigma = \frac{PR}{CG2} = \frac{690 \times 6.821}{0.9 \times 74.63} = 53,564 \text{ PSI} \]

M.S. = HIGH

\[ C = \frac{53564}{2910^2} = 0.0018'' \]
**NOZZLE SHELL CONT.**

**BOLT LOAD** 74,690 \times 1.30

\[
\text{BOLT LOAD} \left(\text{inches}\right) = \frac{74,690 \times 1.30}{2 \times \pi \times 7.1} = 2174 \text{ psi}
\]

\[
\sigma = \frac{6M}{t^2} = \frac{6 \times 2174 \times 0.55}{\left(2.25\right)^2} = 114,787 \text{ psi}
\]

\[
\sigma_a = \frac{2174}{2.25} = 9.69 \text{ psi}
\]

\[
M.S. = \frac{150,000}{114,787} - 1 = +.31
\]

**LIP ON NOZZLE SHELL**

\[
t = .295\text{\ inches}
\]

\[
\text{LOAD} = 690 \pi \left(5.8^2 - 4^2\right) = 1143 \text{ psi}
\]

\[
\sigma = \frac{1143 + 6 \times 1143 \times 2.25}{2.75^2} = 3875 + 22457 = 26334 \text{ psi}
\]

M.S. HIGH.
NOZZLE SHELL CONT.

BOLT LOAD = $P \pi \left\{ \frac{a^2 - b^2}{2} \right\}$
WHERE $a =$ SEAL RADIUS = 7.1"
$b = 4"$ (THROAT PINTER SEE PG 3.1.1.1)
$P = 690$ PSI

BOLT LOAD = \[ 690 \times \pi \left( \frac{7.1^2 - 4^2}{2} \right) \]
\[ = 74,590 \times \]

30 - 1/4" DIA BOLTS

LOAD/BOLT = \[ \frac{74,590}{30} \times 2486^2 \] DIRECT LOAD

ASSUME 30% DIRECT LOAD FOR BENDING

LOAD/BOLT = 1.3 \times 2486 = 3282#

1/4" BOLT 28 TPI
TORSION 50-80 IN-LBS
LOAD IN BOLT @ MIN TORQUE

\[ P = \frac{T}{A} \]
\[ A = 0.0326 \text{ in}^2 \]
\[ T = 1000 \text{ in-lbs} \]

\[ \frac{800 \times 1000}{1000 \times 0.0326} = 8998^\circ \] FOR Fs = 160 KSF BOLT.

PITCH OF BOLTS = 1.49"

USE HIGH STRENGTH BOLTS WITH SUITABLE TORSION
TEMP. 5000°F INSIDE SURFACE

COEF. OF THERMAL EXP. \( \alpha = 120 \times 10^{-6} \) IN/IN/°F

REF AGC MATT DATA SHEETS

\[ \Delta = \Delta t L \\
= 120 \times 10^{-6} \times (5000 - 70) \times 1.192 \\
= 0.071'19'' \]

NOTE: THE EXPANSION OF GRAPHITE IS NOT SIMILAR TO THE RUBBER WASHER DWG NUMBER 1147011. ELONGATION IS ABOUT 60% OF \( \Delta t \) ABOVE. (IE ABOUT 0.35').

RUBBER WASHER DWG: 1147011-1

MATERIAL: (V-44) AGC-34161

SHEAR HARDNESS 85A

\[ f_{\text{comp}} = 700 \text{ PSI} \]

\[ t = 0.06 \]

\[ \sigma_{\text{comp}} = 700 \times \frac{1}{0.06} = 292 \text{ PSI} \]

NOTE: INCOMPLETE;

M.S. HIGH THERMAL ANALYSIS REQS.
Material: Glass cloth Style No. 1583 or equivalent

\( F_b = 60,000 \text{ PSI} \) (Warp)

\( E = 3 \times 10^6 \text{ PSI} \)

\( t = 6 \text{ plies} = 6 \times 0.009 = 0.054 \) (Composite)

\( \theta = 16^\circ \)

\[
\sigma_b = \frac{P h}{A} = \frac{29.5 \times 6.1}{0.054 \times 6.12} = 3,466 \text{ PSI}
\]

M.S. = HIGH

\[
\sigma = \frac{6}{E} = \frac{3,466}{9 \times 10^6} = 0.001156 \text{ " per inch}
\]

\( 0.0011 < 0.025 \) OK.

\( \rho = 3.4 \)

\( T = 7.2^\circ \)

\[
\sigma = \frac{3.4 \times 7.2}{1052 \times 0.9612} = 472 \text{ PSI}
\]

M.S. = HIGH.
<table>
<thead>
<tr>
<th>PART</th>
<th>DWG. NO</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>THROAT APPROACH</td>
<td>1147014</td>
<td>THERMAL ANALYSIS OF THIS PART APPEARS IN SEC 3.2</td>
</tr>
<tr>
<td>SLEEVE</td>
<td>1147013</td>
<td>SAME</td>
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<td>SUPPORT, THROAT</td>
<td>1147010</td>
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<td>1147004</td>
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<td>EXIT CONE</td>
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<td>SPACER, THROAT-NOZZLE</td>
<td>1147011</td>
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</tr>
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</table>
THERMAL STRESS ANALYSIS

RESULTS OF FINITE
ELEMENT COMPUTER
PROGRAM E 11405

Figures 3.2 and 3.25 show the
portions of the plate and shroud
evaluated by the computer using
AGC Computer Program E 11405.

The results of the thermal
stress analysis for specified critical
areas are reported in this section.

Component

<table>
<thead>
<tr>
<th>M.S.</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Plate Coupling</td>
<td>N1</td>
</tr>
<tr>
<td>Thrust Bearing</td>
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<tr>
<td>Fintle Thrust</td>
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<tr>
<td>Shroud Thrust</td>
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</tbody>
</table>

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

Preceding Page Blank
Figure 3.2.1.0
SSRM COUPLING

MATERIAL STEEL 4130

FROM COMPUTER CALCULATIONS, MAX STRESS OCCURS AT A-A

ELEM 265 ; 37121 PSI X \pi \left( \frac{.45^2 - .39^2}{2} \right) = 1871 \pi

266 ; 33,493 \pi \left( \frac{.50^2 - .48^2}{2} \right) = 1591 \pi

267 ; 36,824 \pi \left( \frac{.56^2 - .54^2}{2} \right) = 1991 \pi

268 ; 39,911 \pi \left( \frac{.625^2 - .58^2}{2} \right) = 3257 \pi

\text{Cross-section Area} = \pi \left( \frac{.625^2 - .39^2}{2} \right) = .2385 \pi

\text{Average Stress} = \frac{3610 \pi}{.2385} = 36,100 \text{ PSI}

AT B-B

ELEM 265 ; 15044 PSI \text{ Shear Stress}

\text{M.S. A-A} = \frac{150,000}{36,100} - 1 = \frac{H_1}{3}

\text{M.S. B-B} = \frac{80,000}{15,044} - 1 = \frac{H_1}{2}

FIG 8.2.1.1
MATERIAL: TITANIUM ALLOY (GAL-4V)

\[ \sigma_y = 160 \text{ KSI @ Room Temp.} \]

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

NODAL PT NUMBERS (SEE GRID)

<table>
<thead>
<tr>
<th>A</th>
<th>140</th>
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<td>121</td>
</tr>
<tr>
<td>180</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>A</td>
<td>129</td>
<td></td>
</tr>
</tbody>
</table>

ELEMENT NUMBERS (SEE GRID)

For time 8 seconds \( t = 80 \text{°F} \)

Load across A-A:

\[
\begin{align*}
151,900 \times \pi \times (2.7^2 - 1.75^2) &= 6422 \text{ (ft)} \\
76,995 \times \pi \times (1.75^2 - 0.5^2) &= 1588 \text{ (ft)} \\
69,961 \times \pi \times 0.11^2 &= 700 \text{ (ft)} \\
\text{Total Load} &= 8710 \text{ (ft)}
\end{align*}
\]

From drawing, dia. @ undercut = .56 - .01 (in.) = .55 in.

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

Average stress across section = 114800 psi
Report AFFL-TR-69-50, Appendix A

Subject: Retainer Throat Cont.

(* Time 750 Secs  Temp = 200°F

Load across A-A = 151,220 N (27°-176°) = 6348 N
77,955 N (170°-114°) = 1608 N
71,080 N (114°) = 7108 N

A = 0.0762 in²

Average stress across section at A-A

\[ \frac{6348 \text{ N}}{0.0762 \text{ in}^2} = 114,918 \text{ PSI @ 200°F} \]

Temperature degradation factors @ 200°F Refer MIL-HDBK-5

\[ F_{24} = 0.91 \quad F_{24} = 0.86 \]

\[ F_{24} = 150,000 \times 0.86 = 129,000 \text{ PSI} \]

\[ M.S = \frac{129,000}{114918} - 1 = +0.13 \]

Note: All other elements in the titanium throat retainer had stress levels well below that calculated at elements 121, 122 & 123.
**Retaining Throat Cont.**

**Section B-B** (Fig. 3.2.2)

From computer analysis the average shear stress along B-B.

<table>
<thead>
<tr>
<th>ELEM.</th>
<th>STRESS PSI</th>
<th>WIDTH</th>
<th>LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>68,900</td>
<td>.25</td>
<td>17225</td>
</tr>
<tr>
<td>47</td>
<td>36,000</td>
<td>.30</td>
<td>10800</td>
</tr>
<tr>
<td>29</td>
<td>17,300</td>
<td>.25</td>
<td>4325</td>
</tr>
<tr>
<td>19</td>
<td>11,500</td>
<td>.075</td>
<td>863</td>
</tr>
<tr>
<td>10</td>
<td>8310</td>
<td>.175</td>
<td>1454</td>
</tr>
<tr>
<td>3</td>
<td>2090</td>
<td>.31</td>
<td>645</td>
</tr>
</tbody>
</table>

\[
\sigma_{av} = \frac{35,315}{1.36} = 26,000 \text{ PSI}
\]

Max stress at this location is at Element 66

\[= 72,700 \text{ PSI}\]

\[M.S. = \frac{159,000}{72,700} - 1 = .77 \text{ @ Time 750 Secs}\]

M.S. shear = high

**Section C-C** (Fig. 3.2.2)

Max stress = 37,500 PSI

M.S. = high
FIG 3.2.4.2

AV. TEMP OF ELEM.
@ T = 750 SECS

FIG 3.1.11

$E = 32,100 \text{ ksi}$

$M. S. = \frac{2700}{2210} = .24$
BSRH THROAT PINTLE TIME 8 SECS

**Figure 3.2.4.4**

- KIPS/SQ IN (Comp)
  - -20
  - -10
  - 0
  - 10
  - 20

**Figure 3.2.4.5**

- AV. TEMP °F OF OUTBD ELEMENTS
  - 165°F
  - 210°F
  - 250°F
  - 300°F
  - 350°F
  - 400°F
  - 450°F
  - 500°F
  - 550°F
  - 600°F

**Figure 3.2.4.6**

- KIPS/SQ INCH (Hoop)
  - -10
  - 0
  - 10
  - 20
  - 30
  - 40

**Allowable Tension @ 2800°F**

**Element Numbers**

**AV. TEMP. °F OF INBD ELEMENTS**

**Allowable Tensile Strength @ R.T.**

**M.S. = 0.0**

HOOP STRESSES LONG INBOARD SURFACE (AGC type 101)
Figure 3.2.5.0
**Stress (Hoop) Distribution @ t=10 secs.**

Pyrolytic Graphite, External Throat

SSRB Nozzle

**Hoop Calculated Stress**

Tension on Outside Fibers @ T = 10 SECs

Max \( f'_t = 6,183 \) psi @ 295°F

M.S. = 13,000 psi

\( F_t = \frac{13,000}{1.13} = 11,465 \text{ psi} \)

**Compression on Inside Fibers @ T = 10 SECs**

Max \( f'_c = 11,465 \) psi @ 6,000°F

\( F_c = 15,000 \) psi

AV. TEMP °F

295°F - 216°F

219°F - 292°F

900°F - 220°F

224°F - 388°F

1275°F - 225°F

229°F - 392°F

1263°F - 230°F

235°F - 392°F

1238°F - 236°F

241°F - 365°F

1188°F - 242°F

247°F - 340°F

1125°F - 248°F

253°F - 319°F

1058°F - 254°F

259°F - 286°F

**Stress PSI**

10000

0

40000

60000
SSRM PROPULSANT
GRAIN STRESS ANALYSIS
I. DESIGN

REFERENCE DRAWINGS

1146991
1146992

II. DESIGN CRITERIA

A. LOADS

1. STORAGE

T = 0°F

τ = 30 DAYS

2. FIREING

T = 77°F

t<sub>ignition</sub> = 155 m/sec.

P<sub>ignition</sub> = 750 psia.

P<sub>max</sub> = 550 psig.

B. MATERIAL PROPERTIES

1. MOTOR CASE

SHELL: AMS 6431; t<sub>max</sub> = 0.070 IN.

INSULATION: GEN-GARD 4010

E<sub>case</sub> = 29 x 10<sup>6</sup> psi

α<sub>case</sub> = 4.3 x 10<sup>-6</sup> in./in./°F
2. PROPELLANT GROW (REFERENCE (1))

2. AAP 3318

\[ T_{\text{cure}} = 135^\circ F \]
\[ \alpha = 6.4 \times 10^{-5} \text{in./in./}^\circ F \]
\[ E_{\text{storage}} = 315 \text{ psi} \quad @ \quad T = 0^\circ F \]
\[ t = 30 \text{ min.} \]
\[ E_{\text{firing}} = 500 \text{ psi} \quad @ \quad T = 77^\circ F \]
\[ t = 155 \text{ m.sec.} \]
\[ E_{\text{storage}} = 220 \text{ psi} \quad @ \quad T = 77^\circ F \]
\[ t = 24 \text{ hrs.} \]

C. ALLOWABLES

1. AAP 3319

Q. STORAGE (0°F)

(1) INNER BORE NOSE STRAIN
\[ \epsilon_0 = 12 \% \]

(2) INTERFACE BOND STRENGTH:
\[ \tau_c = 44 \text{ psi} \]
\[ \tau_{KL} = 28 \text{ psi} \]
b. Firing (77°F)

1) Inner bore hoop strain
\[ \varepsilon_0 = 55 \% \]

2) Interface bond stresses
\[ T_{fs} = 188 \text{ psi} \]

II. Geometrical Parameters

A. Geometry

FIG. 3.3.1
B. PARAMETERS

\[ \alpha = \frac{10.00}{2.24} = 4.48 \]

\[ \beta = \frac{28.47}{10.91} = 2.60 \]

III. ANALYSIS

A Preliminary stress and strain analysis of the grain is conducted on the basis of the parameter curves given in Reference (2).

1. 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 min slots terminate.

3. AAP-3336 grain located between 0-7% of grain length has material properties and allowable comparable to AAP-3318.
E. PARAMETRIC STRESSES

1. STORAGE
   a. AAR 3318
      \( E_0 = 4.15 \% \)
      \( \sqrt{K} = 37.9 \text{ PSI} \)
      \( T_{eq} = 18.5 \text{ PSI} \)

   b. AAR 3336
      \( E_0 = 2.08 \% \)
      \( \sqrt{K} = 67.9 \text{ PSI} \)
      \( T_{eq} = 18.5 \text{ PSI} \)

2. FIRING
   a. AAR 3318
      \( E_0 = 2.86 \% \)
      \( T_{eq} = 10.3 \text{ PSI} \)

   b. AAR 3336
      \( E_0 = 1.73 \% \)
      \( T_{eq} = 10.3 \text{ PSI} \)
C. BASIC STEEL SELLS

1. STORAGE

\[ AT = -\left[135 - 0\right] = -135 \, ^\circ F \]

\[ a = 1.15 \times \frac{-135}{79} = 7.1 \, \% \]

\[ \sqrt{a} = 6.79 \times \frac{315}{1000} \times \frac{-135}{79} = 37 \, \% \]

\[ T_2 = 18.5 \times \frac{315}{1000} \times \frac{-135}{79} = 10.0 \, \% \]

2. HEATING 177 \, ^\circ F

\[ AT = -\left[135 - 77\right] = -58 \, \% \]

\[ a = 2.08 \times \frac{77}{79} = 2.6 \, \% \]

\[ \sqrt{a} = 67.9 \times \frac{315}{1000} \times \frac{-135}{79} = 37 \, \% \]

\[ T_2 = 18.5 \times \frac{315}{1000} \times \frac{-135}{79} = 10.0 \, \% \]

\[ \epsilon_0 = 2.9 \, \% \]

\[ \epsilon_0_{\text{TEMP}} = 4.15 \times \frac{59}{79} = 2.0 \, \% \]

\[ \epsilon_0_{\text{TOTAL}} = 2.9 + 5.0 = 5.9 \, \% \]
\[ \tau_2 = 10.3 \times \frac{500 - 58}{1000 - 79} = 5.2 \text{ PSI} \]
\[ \tau_2 = 18.5 \times \frac{220 - 58}{1000 - 79} = 3.0 \text{ PSI} \]
\[ \tau_{3.0} = 5.2 + 3.0 = 8.2 \text{ PSI} \]

b. Minp 3336
\[ \epsilon_0 = 1.7\% \]
\[ \epsilon_0 = 2.08 \times \frac{-58}{-79} = 1.5\% \]
\[ \epsilon_{\text{Total}} = 1.7 + 1.5 = 3.2\% \]
\[ \tau_2 = 8.2 \text{ PSI} \]

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 4.19 for the propellant-insulation bond tensile stress during storage at 0°F.
IV. REFERENCES


2. AFROJET STRUCTURES MANUAL
Summary of Propellant Grain

Stress Analysis

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>INNER BORE TENSILE HOOP STRAIN ((^%))</th>
<th>BOND SHEAR STRESS (PSI)</th>
<th>BOND TENSILE STRESS (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAXIMUM</td>
<td>ALLOWABLE</td>
<td>M.S.</td>
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<tr>
<td>STORAGE *</td>
<td>7.1</td>
<td>12</td>
<td>4.69</td>
</tr>
<tr>
<td>(30 DAYS @ 0°F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIRING</td>
<td>5.9</td>
<td>55</td>
<td>HIGH</td>
</tr>
<tr>
<td>(P = 750 PSIA @ 77°F</td>
<td>5.18</td>
<td>.155 ksi)</td>
<td></td>
</tr>
</tbody>
</table>

\(T_{\text{cure}} = 135^\circ \text{F}\)

FIGURE 332
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.
# TABLE OF MARGINS OF SAFETY

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>TYPE</th>
<th>MARGIN OF SAFETY</th>
<th>REF.</th>
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<tbody>
<tr>
<td>FUEL CLOSURE</td>
<td>CROWN SECTION SHEAR</td>
<td>HIGH</td>
<td>3.A.4</td>
</tr>
<tr>
<td></td>
<td>CROWN SECTION BENDING</td>
<td>+1.3</td>
<td>3.A.4</td>
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<tr>
<td>NOZZLE</td>
<td>POLE HOOP STRESS</td>
<td>+ .27</td>
<td>3.B.1</td>
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<td></td>
<td>BORE MERIDIONAL STRESS</td>
<td>+ .29</td>
<td>3.A.11</td>
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<td>BORE HOOP STRESS</td>
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<td>3.B.2</td>
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<td>BORE MERID STRESS</td>
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<td>3.B.2</td>
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<td>AFT CLOSURE</td>
<td>THREADED JOINT HOOP STRESS</td>
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<td>THREADED JOINT MERID STRESS</td>
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<td>3.C.3</td>
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<td>3.C.3</td>
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<td>JOINT BENDING &amp; TENSION</td>
<td>+ .17</td>
<td>3.C.7</td>
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<td></td>
<td>MEMBRANE STRESS</td>
<td>+ .28</td>
<td>3.C.8</td>
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<td>FLANGE BOLT STRESS</td>
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<td>3.C.9</td>
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<tr>
<td></td>
<td>FLANGE BENDING</td>
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<td>3.C.11</td>
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<tr>
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<td>THROAT SUPPORT STRUT, STRAIN</td>
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<td>3.C.10</td>
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<td>PLASTIC PARTS</td>
<td>EXIT CONE SHEAR (STEEL)</td>
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<td>3.D.3</td>
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<td>EXIT CONE BENDING (STEEL)</td>
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<tr>
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<td>FACILITATOR, NAS-560-3-0-H1</td>
<td>HIGH</td>
<td>3.D.8</td>
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<td>SHEAR IN MX 2625 IN EXIT CONE</td>
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<td>BENDING IN MX 2625 IN EXIT CONE</td>
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<td>THROAT RETAINER SHEAR</td>
<td>+ .23</td>
<td>3.D.1</td>
</tr>
<tr>
<td></td>
<td>BENDING</td>
<td>+ .03</td>
<td>3.D.2</td>
</tr>
<tr>
<td>BY</td>
<td>CHK BY</td>
<td>DATE</td>
<td></td>
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<tr>
<td>----</td>
<td>--------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>EXIT CONE LINER SHEAR</td>
<td>HIGH</td>
<td>3.0.3</td>
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</tr>
<tr>
<td>BENDING</td>
<td>HIGH</td>
<td>3.0.4</td>
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<tr>
<td>CLOSURE LINER ELONGATION</td>
<td>ADEQUATE</td>
<td>3.0.6</td>
<td></td>
</tr>
<tr>
<td>ENTRANCE CAP</td>
<td>NO LOADS</td>
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<tr>
<td>THROAT CLEARANCE REQ'D TO PERMIT FREE THERMAL EXPANSION</td>
<td>0.036&quot;</td>
<td>3.0.6</td>
<td></td>
</tr>
<tr>
<td>INSULATOR HOOP STRAIN</td>
<td>+.90</td>
<td>3.0.7</td>
<td></td>
</tr>
</tbody>
</table>

PLASTIC PARTS (CONT'D)
20 PULSE IGNITER

SECTION II DESIGN CRITERIA

A LOADS: 20 CYCLES

MAX. EXPECTED OPERATING PRESS (MEOP) = 2000 PSI
THUST = 1500*

FACTOR OF SAFETY (SF) = 1.25

DESIGN LOAD = 1.25 x 2000 PSI = 2500 PSI
THUST = 1.25 x 1500* = 1875*

B MATERIAL PROPERTIES:

4130 STEEL

F_c = 180,000 PSI
F_t = 163,000 PSI
F_s = 109,000 PSI
E = 29 x 10^6 PSI

C. GEOMETRY

[Diagram of loadings and design criteria]

FIGURE II-2
SECTION III  STRESS ANALYSIS

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

\[ P = 3750 \, \text{psi} \] (Design Pressures)

Material: 4130 Steel

\[ F_y = 160,000 \, \text{psi} \]
\[ F_u = 180,000 \, \text{psi} \]
\[ E = 80 \times 10^6 \, \text{psi} \]

\text{FULL SCALE}

Fig III-1
IGNITER PERFORMED CLOSURE - CONTINUED

It is apparent that the crown section midway between the two perforations is a critical area. For the purpose of preliminary analysis, the best identification of the structural response is to imagine the assembly simulating a peel having the indicated section, length, and loads as follows:

\[
\begin{align*}
P &= 3.75 \times 1.5(1.5) = 87.5 \text{ lbf} \\
\text{primary load (200 ksi)} &= \frac{87.5}{0.3} = 1460 \text{ lbf/in} = F_2 \\text{lb f/in} \\
F_1 &= 0.344(3750) = 1290 \text{ lbf/in} \\
\text{total applied loading load} &= F_2 + F_1 = 2(1460) + (1290) \\
&= 4210 \text{ lbf/in} \\
\text{total tensile load} &= P = 4210(1.5) = 6315 \text{ lbf}
\end{align*}
\]
**FIG III-3**

<table>
<thead>
<tr>
<th>A</th>
<th>Y</th>
<th>AY</th>
<th>AY^2</th>
<th>I_0</th>
<th>(Y - Y)^2</th>
<th>T_0 + A(Y - Y)^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>.0121</td>
<td>.273</td>
<td>.003580</td>
<td>.001041</td>
<td>.0000537</td>
<td>.2086</td>
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<tr>
<td>.0845</td>
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<td>.000280</td>
<td>.0000272</td>
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<tr>
<td>.0237</td>
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<td>.000038</td>
<td>.0000028</td>
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<td>.1281</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

\[ \bar{Y} = \frac{\Sigma AY}{\Sigma A} = \frac{.00768}{.1281} = .0602 \text{ in.} \]

Neutral axis at .0602 in. up from X-X.

\[ I = \sum [I_0 + A(Y - \bar{Y})^2] = .00465 \]
**IGNITER**

**IGNITER PEEROCATED CLOSURE - CONT'D**

**SIMPLY SUPPORTED BEAM**

\[ M_{max} = \frac{4L^2}{8} = \frac{4 \times 4210^2}{8} = 1230 \text{ in-lb} \]

**FIXED END BEAM**

\[ M_{max} = \frac{9L^2}{12} = \frac{9 \times 4210^2}{12} = 8201 \text{ in-lb} \]

The beam will approximate the fixed end condition, but assume avg. of two.

\[ M_{max} = \frac{1}{2}(1230 + 8201) = 1025 \text{ in-lb} \]

\[ \sigma = \frac{M_{o}}{I} = \frac{1025(956)}{0.0465} = \frac{965}{0.0465} = 79,000 \text{ psi} \]

\[ M_S = \frac{192,000}{7.5} = 1.3 \]

**STRAIN ENERGY OF SAFETY FACTOR IN MECHANICAL ANALYSIS**

**SNL's LIP**

\[ \sigma_5 = \frac{1460}{0.115} = 12,760 \text{ psi} \]

\[ F_{SU} = 103,000 \]

\[ M_S = \text{LARGE} \]

**FIG III-5**
IGNITION ROSS-CLOSING JUIN

\[ P = \frac{F_e}{2} = \frac{3750(160)}{2} = 3000 \text{ lb/in} \]

\[ P_2 = 0.66(3750) = 2470 \text{ lb/in} \]

\[ \alpha = 35^\circ \]

\[ \beta = 1.74 \]

\[ \gamma = 1.74(4.61) = 8.00 \text{ in} \]

\[ 6\text{ in} \neq \frac{250}{8.00} \]

\[ \gamma = 18^\circ \]

\[ T = \frac{F_e}{2} = \frac{3750(8.0)}{2} = 15,000 \text{ lb/in} \]
**Report AFRPL-TR-69-50, Appendix B**

**AGREE. SSX-13 Circulating Joint-Gay't**

---

**Fig III-7**

\[ \lambda_1 = 0.099(216) = 0.212 \quad \lambda_2 = 0.392 \]

\[ \lambda_1 = \frac{2}{3}(192)(216) = 0.0380 \quad \lambda_2 = 0.356 \]

\[ \lambda_1 = 0.0355(115) = 0.0385 \quad \lambda_2 = 0.265 \]

\[ \lambda_3 = 0.184(45) = 0.0828 \quad \lambda_4 = 0.052 \]

\[ \lambda_5 = 0.0497 \quad \lambda_6 = 0.0345 \]

\[ \lambda_7 = 0.208(180) = 0.090 \]

\[ I_{11} = \frac{1}{12}(0.099(216)^3) = 0.000824 \quad I_{01} = \frac{1}{12}(0.054(115)^3) = 0.00044 \]

\[ I_{00} = \frac{1}{12}(0.082(45)^3) = 0.00235 \]

---

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>AREA</th>
<th>(y)</th>
<th>(Fy)</th>
<th>(AY^2)</th>
<th>(I_{0})</th>
<th>(X)</th>
<th>(AX)</th>
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<tbody>
<tr>
<td>1</td>
<td>0.0212</td>
<td>0.392</td>
<td>0.00830</td>
<td>0.00325</td>
<td>0.000264</td>
<td>0.1264</td>
<td>0.019</td>
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<td>2</td>
<td>0.0280</td>
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<td>0.01359</td>
<td>0.00542</td>
<td>0.000875</td>
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</tr>
<tr>
<td>5</td>
<td>0.0097</td>
<td>0.0345</td>
<td>0.00030</td>
<td>0.00001</td>
<td>—</td>
<td>0.197</td>
<td>0.03415</td>
</tr>
<tr>
<td>6</td>
<td>0.0374</td>
<td>0.090</td>
<td>0.00337</td>
<td>0.00030</td>
<td>0.000104</td>
<td>1.290</td>
<td></td>
</tr>
</tbody>
</table>

\[ \overline{Y} = \frac{\sum Y \cdot A}{\sum A} = \frac{0.0349}{2.276} = 0.153 \text{ in}. \]

\[ \overline{X} = \frac{\sum X \cdot A}{\sum A} = \frac{1.259}{1.956} = 0.653 \text{ in}. \]

\[ I = \sum \left[ I_{0} + A(y - \overline{Y})^{2} \right] = 0.00235 + 0.000875 + 0.001235 + 0.00030 + 0.000104 + 0.000264 = 0.00400 \]
ENGINEERING MECHANICS

Bendingmoment equations:

$$E_{c}= \frac{F_{c}}{2} \sum M_{c} = \frac{2.028}{.0048} \sum M_{c} = 507 \sum M_{c}$$

$$E_{w} = \frac{F_{w}}{B} \sum Q_{w} = \frac{2.028}{.2276} \sum Q_{w} = 8.92 \sum Q_{w}$$

$$\sum M_{c} = 2.50M + 3000 (1496(160)+15000 (.06)(2.50))$$
$$= 2.50M + 2390 + 2250 = 2.50M + 4640$$
$$E_{c} = 807[250M + 4640] = 1270M + 2350000$$

$$\sum Q_{w} = 2.50Q + (15000 \times \sin 15\circ)(2.50)$$
$$= 2.50Q + 35,600$$

$$E_{w} = 8.92[2.50Q + 25600]$$
$$= 22.3Q + 317000$$

Fig. D1-2
IGNITER PASS - CLOSURE JOINT - CONT'D

3. The pass shell function:

\[ E_W = E_W 0 - x E_D \]

\[ x = \frac{180}{2} = \frac{.159 - .050}{.063} \]

\[ E_W = 22.30 Q + 317,000 - .063 [1270 M + 22.30 50,000] \]

\[ = 22.30 Q + 317,000 - (80 M + 140,000) \]

\[ = - 80 M + 22.30 Q + 169,000 \]

**SHELL DISPLACEMENT EQUATIONS:**

\[ E_D = - \frac{M}{2 \Phi} - \frac{Q}{20 \Phi^2} + \frac{26.5 M^2}{2} \]

\[ E_W = - \frac{M}{20 \Phi^2} - \frac{Q}{20 \Phi^2} + .02 \Phi^2 \]

\[ \beta = \frac{1285}{1.49^2} = \frac{1285}{1.801} = \frac{1285}{1.801} = 1.26 \quad \text{(For } \lambda = 1) \]

\[ D = \frac{\lambda^3}{104.2} = \frac{(103)^3}{104.2} = .000301 \]

\[ D_2 = \frac{0.0020(1.26)}{126} = .000353 \]

\[ D_2 = \frac{0.0020(1.26)}{126} = .000319 \]

\[ D_3 = \frac{0.0030(1.26)}{126} = .000404 \]

\[ \frac{1}{D_2} = \frac{0.00253}{.000353} = 35.50 \]

\[ \frac{1}{D_2} = \frac{0.000319}{.000353} = 15.70 \]

\[ \frac{1}{D_3} = \frac{0.000404}{.000353} = 12.40 \]

\[ \frac{265 \Phi^2}{\lambda} = \frac{265(375 \times 9.6)}{126} = 332,000 \]

\[ \frac{1.2 \Phi^2}{\lambda} = \frac{1.2(375 \times 9.6)}{126} = 122,000 \]
NEW & ARCS - CLOSURE JOINT - CADDIM

\[ EB = -3850M - 1570Q + 352000 \]
\[ EW = -1570M - 1240Q + 122000 \]

**EQUATIONS FOR TYPICAL POINT AT JUNCTION:**

\[ EB = EB_{sheel} \]
\[ 1270M + 2300000 = -3850M - 1570Q + 352000 \]
\[ 5220M + 1570Q + 1000000 = 0 \]
\[ M + 301Q + 191 = 0 \]

\[ EW = EW_{sheel} \]
\[ -80M + 22.3Q + 169000 = -1570M - 1240Q + 122000 \]
\[ 1490M + 1262Q + 47000 = 0 \]
\[ M + 847Q + 316 = 0 \]

\[ \begin{align*}
M + 301Q + 191 &= 0 \\
M + 847Q + 32 &= 0 \\
-546Q + 191 &= 0
\end{align*} \]

\[ Q = 291 \text{ LBS/IN} \]
\[ M = -301(291) - 191 \]
\[ = -278 \text{ IN-LB.} \]
Stress \( \sigma = \frac{Z}{2l} \times \frac{1}{5} \\
Z^2 = 1.5
\)

**Hoop Stress:**

\[
\sigma_{hoop} = \frac{20,000 + 22.30Q + 169,000}{2.50} \quad \text{REF. P. 3A.8}
\]

**Bending Stress**

\[
\sigma_{bending} = \frac{1.8(278)}{1.19} = 13,900 \quad \text{PSI}
\]

\[
\Sigma \sigma_{bending} = 76,800 + 13,900 = 90,700 \quad \text{PSI}
\]

Fr. = 163,000 PSI

\[
M = \frac{163,000}{90,700} - 1 = +.80
\]
MERIDIONAL STRESSES

Direct Stresses:

\[ F_{DM} = \frac{F}{Z} \]

\[ F_{DM} = \frac{15,000}{1.9} = 7900 \text{ psi} \]

Bending Stresses:

\[ F_{BM} = \frac{M}{Z^2} \]

\[ M = 278 \text{ in-lb} \]

\[ F_{BM} = \frac{278}{(190)^2} = 47500 \text{ psi} \]

\[ F_M = 7900 + 47500 = 126500 \text{ psi} \]

\[ F_I = 163000 \text{ psi} \]

\[ \frac{F_I}{F_M} = \frac{163}{126} - 1 = +0.29 \]

LENGTH OF TRANSITION

\[ L_{TM} = \frac{1}{2} \]

\[ L = 1.57 \]

\[ 1 = 1.26 \text{ in} \]

\[ 1.25 \]

\[ 1.26 \]

\[ 1.35 \]
RECEPTACLE CONNECTOR

DESIGN PRESSURE 5000 PSI

CASE 22. TABLE X

\[ W = \pi (0.616 + 0.4)^2 = 5000 \times \pi \times (6.56)^2 = 6760 \text{ in}^2 \]

\[ b = 5.625 \]

\[ a = 0.57 \]

\[ S_T = \frac{3W}{2\pi \times 10^6} \left[ \frac{2a^2(m+1) \log \frac{a}{b} + a^2(m-1) - b^2(m-1)}{a^2(m+1) + b^2(m-1)} \right] \]

\[ = \frac{3 \times 6760}{2 \times 7.1 \times 10^6} \left[ 2 \times (5.625)^2 \times \log \frac{5.625}{0.57} + (5.625)^2(2.3) - (5.625)^2(2.3) \right] \]

\[ = \frac{322.8}{7.1 \times 10^6} \left[ 1.035172 + 0.019657 \right] \]

\[ S_T = \frac{322.8}{7.1 \times 10^6} \times 1.054727 = 0.0089 \]

\[ S_T = 10,478 \text{ PSI} \]
TOTAL LOAD = 6760

LOAD / INCH = \frac{6760}{27\times.5625} = 1914 / INCH

\begin{align*}
\sigma_s &= \frac{3}{2} \times 1914 \times \frac{2871}{t} \\
\sigma &= 0.094 \pm 0.005 = 0.099 \text{ MIN}
\end{align*}

\sigma_s = \frac{2871}{0.099} = 32,258 \text{ PSI}

F_{w1} = 56,000

F_{w2} = 33,500

F_{w3} = 35,000 \text{ PSI}

M.S = \frac{35,000}{32,258} - 1 = 0.08

F_{w2} = 33,500 \text{ PSI}
MATERIAL G130

- Fy = 168,000 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 INFINITE ELEMENT ANALYSIS
AS DESCRIBED IN TECHNICAL MEMORANDUM NO. 93, AEROJET-
GENERAL CORPORATION.

MAXIMUM EXPECTED OPERATING PRESSURE = 3000 PSI
FACTOR OF SAFETY = 1.25
DESIGN PRESSURE = 1.25 x 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

For Min. t, \( \sigma_h = 119.500 \left( \frac{526}{.490} \right) = 127,000 \) PSI

M.S. = \( \frac{127,000}{127,000} - 1 = .27 \)

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

<table>
<thead>
<tr>
<th>EL.</th>
<th>154,000 PSI</th>
<th>156,700</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>157,500</td>
<td>157,100</td>
</tr>
<tr>
<td></td>
<td>158,300</td>
<td></td>
</tr>
</tbody>
</table>

AV. 156,100 BASED ON T = .110
20 PULSE IGNITER FWDP CLOSURE

F(1) MIN. $t = 0.100$

$$J_M = 156100 \left( \frac{110}{1.00} \right) = 174,000 = 31$$

BASED ON NOMINAL THICKNESS $t = 0.110$

$$M.S. = \frac{162,000}{156,100} = 1 = +.93$$


<table>
<thead>
<tr>
<th>EL.</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>51,400</td>
<td>+51</td>
</tr>
<tr>
<td>27</td>
<td>63,400</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>75,200</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>87,200</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>99,600</td>
<td></td>
</tr>
<tr>
<td><strong>AV</strong></td>
<td><strong>75,300</strong></td>
<td></td>
</tr>
</tbody>
</table>

BASED ON MIN. $t = 0.100$

$$J_M = 75,300 \left( \frac{110}{1.00} \right) = 83,000 \text{ psi}$$

$$M.S. = \frac{162,000}{83,000} - 1 = +.96$$
MATERIAL: STEEL 4130

\[ F_{u} = 163000 \text{ PSI MIN} \]

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 PSI = 3750 PSI.

THE HIGHEST STRESSES OCCURRED IN THE CYLINDRICAL SECTION AT ELEMENTS 131 THRU 136

\[
\begin{align*}
\text{ELEM} & \quad 131 & \sigma_n &= 162440 \text{ PSI} \\
& & 132 & \sigma_n &= 162920 \text{ PSI} \\
& & 133 & \sigma_n &= 162410 \text{ PSI} \\
& & 134 & \sigma_n &= 161900 \text{ PSI} \\
& & 135 & \sigma_n &= 161380 \text{ PSI} \\
& & & & 812870 \text{ PSI} \\
& & & & \text{AVG} = 162410 \text{ PSI FOR } t = 0.110
\end{align*}
\]

MIN \( t = 0.110 - 0.010 = 0.100 \) "

\[
\sigma_\text{m} = \frac{162410 \times 0.110}{0.10} = 178,650 \text{ PSI}
\]

BASED ON NOMINAL THICKNESS \( t = 0.110 \)”

\[
\text{M.S.} = \frac{163000}{162410} - 1 = 0.004
\]

MERIDIONAL STRESS IN CLOSURE AT ELEMENTS 1 THRU 6

\[
\begin{align*}
\text{ELEM} & \quad 1 & \sigma_n &= 110000 \text{ PSI} \\
& & 2 & \sigma_n &= 109000 \text{ PSI} \\
& & 3 & \sigma_n &= 109000 \text{ PSI} \\
& & 4 & \sigma_n &= 107000 \text{ PSI} \\
& & 5 & \sigma_n &= 107000 \text{ PSI} \\
& & & & \text{AVG} = 108200 \text{ PSI FOR } t = 0.130 \)
\]

A 1966 report from the U.S. Air Force, discussing the analysis of a pulse igniter aft closure joint using a digital computer program. The analysis focuses on determining the stresses in the joint under expected operating conditions, with calculations showing the maximum stress to be 178,650 PSI. The report also includes nominal thickness calculations and averaged stresses for different elements. The joint materials are specified as Steel 4130, and the design life is highlighted with factors of safety and design pressures. The report aims to ensure the joint can withstand operational pressures safely.
Figure III-11
AFT CLOSURE CONT.

AVERAGE STRESS = 108,000 psi $\text{t} = 0.130''$

$$M.S. = \frac{163,000}{108,200} - 1 = 0.502$$

THREADED JOINT

$F_s = 109,000$ psi

9.7-10 UNS - 2A THREAD

PITCH DIA: 9.63''

$\bar{L} = 0.864''$

ASSUME FIRST & LAST THREAD TO BE INEFFECTIVE

THEN LENGTH OF ENGAGEMENT $\bar{L} = 0.864$

$$\text{AREA IN CHEEK} = 2.57 \times 0.24 = 0.61$$

$$\text{LOAD/INCH} = \frac{F_K}{2} = \frac{2.753}{2} = 1.12$$

$$\bar{F} = \frac{3}{2} = \frac{1.5 \times 1.12}{0.56} = 24.40$$

$$M.S. = \text{HIGH}$$
THREADED JOINT CONT.

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

\[ W_L = -\frac{0.85 PR^2}{E_t} + \frac{1}{2D\beta^3} Q_L - \frac{1}{2D\beta^2} M_L \]

\[ \beta = \frac{1.285}{\sqrt{Rt}} \cdot \frac{4.87 \times 2}{4.97 \times 0.2} \]

\[ D = \frac{E_t^2}{10.92} = \frac{29 \times 10^4 \times (1.2)^3}{10.92} = 0.02124 \times 10^6 \]

\[ \frac{1}{D\beta} = \frac{1}{2124 \times 1.3019} = 36.16272 \times 10^{-6} \]

\[ \frac{1}{2D\beta^2} = 13.8272 \times 10^{-6} \]
THREADED JOINT CONT

\[
\frac{1}{2DB^3} = 10.66749 \times 10^{-6}
\]

\[
\Theta_L = \left[-13.8882 Q_L + 36.16272 M_L\right] \times 10^{-6}
\]

\[
W_L = -\frac{0.85 P L^2}{E t} + \frac{1}{2DB^3} Q_L - \frac{1}{2DB^2} M_L
\]

\[
W_L = \left[-58.97 + 10.667 Q_L - 13.888 M_L\right] \times 10^{-6}
\]

\[
\Theta_L = \frac{MCG T^2}{EIYY}
\]

\[
W_R = \left(\Theta_R \times \frac{L}{2}\right) - \frac{Q L^2}{E A}
\]

\[
I_{YY} = \frac{964 \times 28^3}{12} = 0.0158 \text{ N}^4
\]

\[
e = \frac{9.165 - 9.63}{2} = 0.8675
\]

\[
P = \frac{PR}{2} = \frac{3750 \times 4.215}{2} = 9028 \text{ ft/inch}
\]

\[
M = 9028 \times 16.75 = 1512 \text{ in-lb/inch}
\]

\[
T = 4.9825
\]

\[
MCG = (-M - Q \frac{L}{2} + 1512)
\]

\[
\Theta_L = \frac{(-M - 0.432 Q + 1512)(4.9825)^2}{29 \times 0.0158} \times 10^{-6}
\]

\[
= 541.8 \times 10^{-6} \left(-M - 0.432 Q + 1512\right)
\]

\[
\Theta_L = \left[-541.8 M - 234 Q + 819.202\right] \times 10^{-6}
\]
Report AFRL-TR-69-YN, Appendix B
20 PULSE IGNITER

THREADED JOINT CONT.

\[ W_R = \frac{A P_{GO}}{E A} \times \frac{L}{2} - \frac{Q R^2}{EA} \]

\[ A = 0.866 \times 0.28 = 0.24248 \]

\[ \frac{Q R^2}{EA} = \frac{Q (4.8925)^2}{29 \times 2.4248} \times 10^{-4} = 3.03 \times 10^{-6} \]

\[ \frac{L}{2} = 0.432 \]

\[ W_R = 0.432 \left[ -541.8M - 234Q + 819202 \right]10^{-6} \]

\[ W_R = \left[ -234M - 104Q + 35387 \right]10^{-6} \]

\[ \Theta_L - \Theta_R = \Theta_L \]

FROM (1) \( \Theta \)

\[ -13.88Q + 36.162M = -541.8M - 234Q + 819202 \]

\[ 577.96M + 220Q - 819202 = 0 \]

\[ W_L = W_R \]

FROM (2) \( \Theta \)

\[ -58.97 + 0.667Q - 13.88Q = -234M - 104Q + 35389 \]

\[ 220.11 + 114.7Q - 35379 = 0 \]

MULT (2) \( \times 1.918 \)

\[ 422M + 690.095 = 0 \]

\[ 577.96M + 220Q - 819202 = 0 \]

\[ 155.96M + 129107 = 0 \]

\[ M = 828 \text{ in-lbs} \]

FROM (5)

\[ 1795.5 + 220Q - 819202 = 0 \]

\[ 220Q = 34065 \]

\[ Q = 15.48 \]
M = 828 in·lbs/inch

\[ Q = 1548 \] psi

\[ \sigma_\text{M} = \frac{6M}{d^2} = \frac{6 \times 828}{0.205^2} = 118,216 \text{ psi} \]

\[ \sigma_\text{S} = \frac{P}{A} = \frac{1548}{0.205^2} = 75,570 \text{ psi} \]

\[ \sigma_\text{t} = \frac{PR}{2t} = \frac{375 \times 4.37}{2 \times 0.205} = 44,543 \text{ psi} \]

\[ \sigma_\text{e} = \frac{P}{A} + \frac{MC}{I} \]

\[ = \frac{44,543 + 118,216}{162758} = 162,758 \text{ psi} \]

\[ \frac{M \cdot S}{K} = \frac{44,543 + 118,216}{162758} - 1 \]

\[ = 0.17 \]
20 PULSE IGNITER

AFT CLOSURE  DWG# 1147019

F(t) 168000 PSI
R = 4.5"
α = 8.989

F(t) = \frac{4.5}{8.989} \alpha

For 2:1 Ellipse \frac{N(t)}{N(t)} = 0.9 \quad \frac{N(t)}{N(t)} = 0.71

For P = 3750 PSI

N(t) = 0.9 \times 2.750 \times 8.989 = 15'170^*

\theta = \frac{15'170}{(130-0.01)} = 126,420 PSI (based on M.I.N.T)

M.S = \frac{163000}{126420} = 1.28
20 PULSE IGNITER

AFT FLANGE DWG # 1147019

Material: Steel 4130

F_{uy} = 169,000 PSI (MIN.)
F_{tu} = 180,000 PSI
F_{su} = 109,000 PSI

Loading Conditions:
(a) Firing of Igniter
\[ P_{D} = P_{d1} \pi (1.14)^2 = 3750.7 \times 1.3 \]
(b) Motor
\[ P_{D} = P_{m1} \pi (1.5)^2 = 2907.9 \times 2.25 \]
(c) Hydro Test
\[ P_{D} = P_{m1} \pi (1.6)^2 = \frac{3750.7 \times 2.55}{18} \] (CRIT.)

Direct Bolt Load
\[ \frac{3750.7 \times 2.55}{18} = 167.6 \] 

Assume \( P_{c} = 100\% \) \( P_{D} \)

\[ P = 2 \times P_{D} = 2 \times 167.6 = 335.2 \]

\[ P_{ull} = 6190^w \]

\[ M.S. = H1 \]
20 PULSE IGNITER

AFT Flg CONT.

SECTION A-A

TOTAL BOLT LOAD = 3862

PITCH OF BOLTS = \( \frac{\pi \times 6.0}{15} = 1.047" \)

METAL BETWEEN BOLTS = 1.047 - .281 = .766"

MOMENT PER = 3.25 - 3.0 = .25"

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

\[ C = \frac{6M}{\ell^2} = \frac{6 \times 1094}{(.766)^2} = 46,677 \text{ PSI} \]

\[ M/S = \frac{163.00}{446.77} - 1 = M/S \]

THROAT SUPPORT STRUCTURE

MATL: 4130 STL.

MINT = \( \frac{4.72 - 4.035}{2} = .342" \)

CRITERIA STRAIN \( \leq .0025 \)

\[ E = \frac{PR}{2CE} = \frac{3750 \times 2.017 \times 10^{-6}}{2 \times .342 \times 29} \]

\[ = 381 \times 10^{-6} \]

\[ M/S = M/S \]
AFT FLG 6 CONT.

SECTION "B-B" IGNITER FIRING

EVALUATING \( P \) TO REFLECT LOAD ON THE INSERTS

\[
P = \frac{3750 \pi (2.01^2 - 1.14^2)}{\pi (2.01^2 - 1.14^2)} = 5243 \text{ PSI}
\]

STRESS: - Ref Romke Table 5 - Case 17

\[
\gamma_b = \frac{2.01}{1.14} = 1.75
\]

\[
f_b = \frac{\beta \sigma_t^2}{t^2}
\]

\[
\beta \text{ for } \sigma_y = 0.370
\]

\[
\sigma_t = 5243
\]

\[
t = 0.281
\]

\[
f_b = \frac{37 \times 5243 \times (2.01)^2}{(0.281)^2} = 99,260 \text{ PSI}
\]

\[
MIS = \frac{163,000}{99,260} - 1 = 1.64
\]
Section III-D

Retainer Igniter Throat  DWG 1147021

Material WB 8217. Carbon Phenolic (See W.B. Catalog.)

@ Section A-A.

*Estimate of Ejection Load @ P = 3750 PSI

\[ P_{es} = \pi (1.07^2 - 1.5^2)(3750 - 450) = 3045 \pi \text{ lb} \]

Shear @ Sect A-A

\[ f_s = \frac{3 \times P_{es}}{2 \times A} \]

\[ A = 2\pi r t = 2\pi \times 1.07 \times 0.338 = 7.28 \text{ in}^2 \]

\[ f_s = \frac{3 \times 3517}{2 \times 7.28} = 7296 \text{ PSI} \]

\[ F_s = 0.5 F_e = 0.5(19,000) = 9500 \text{ PSI} \]

M.S. = \[ \frac{9500}{7296} - 1 = 0.23 \]

Bending @ Sect. A-A

\[ f = \frac{6M}{E I} \]
20 PULSE IGNITER

RETAINER IGNITER THROAT CONT.

\[ M = \frac{P_e T}{2} \left( \frac{1}{1.125 + 0.03} - \frac{1}{1.070 - 0.06} \right) \]

\[ = \frac{3095 \times 146}{2.14} = 210' \text{#/in} \]

\[ t = 0.338 \]

\[ f_b = \frac{6M}{t^2} = \frac{6 \times 210}{(0.338)^2} = 11,030 \text{ PSI} \]

\[ F_b = 18,000 \text{ PSI} \]

\[ M/S = \frac{18,000}{11,030} - 1 = +.63 \]
Exit Cone Linen - 1st Revision

$F_{ij} = \frac{F_{ij}}{A_{ij}}$

$F_{ij} = 2030 \text{ in}^2 \quad \text{REF P} \quad 3$

$A_{ij} = \frac{2\pi (2.0 + 4.00)}{2} \quad \text{in}^2$

$= 6.28 \times (2.25) = 14.65 \text{ in}^2$

$= \frac{2030}{14.65} = 1600 \text{ psi}$

$F_{sh} = 5 \times 15(9.50) = 4275 \text{ psi}$

$M.S. = \frac{4275}{1600} = 2.7$

$CHFA = -0.05 \times 1020 = 51.0$

$F_{sh} = \frac{F_{sh} \times 1020 \times 8 \times 20}{2.25} \text{ in}^2$

$= 1600 \times 0.275 \times 6.0$

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

$F_{sh} = 35000 \text{ psi}$

$M.S. = \frac{35000}{3750} = 9.3$
Bending: 5.25 (Approximate)

\[
M > \frac{6.25}{E} = 3750 \text{ in. Ib} = 10 \text{ kN}
\]

\[
F_t = 35,000 \text{ psi}
\]

\[
M.S. = \frac{35,000}{10^6} = 35 \times 10^{-6}
\]

Bending: Mx = 2625 (Approximate)

\[
M > \frac{6.25}{E} = 1000 \text{ in. Ib} = 440 \text{ kN}
\]

\[
F_t = 10,000 \text{ psi}
\]

\[
M.S. = \frac{10,000}{9600} = 1.04
\]
**Liner Igniter Closure**

- Liner: 72025 Nylon
- This is adequate

**Entrance Aid**

- 1147023 W/B 8217 Carbon Bellum
- No apparent pressure load

**Throat Igniter**

- 1147022 Pyro

---

**Fig III-20**

Gap check for axial thermal growth

\[
\Delta T = 0.014 \times 10^{-6} \times 140 = 0.036
\]

This indicates that 0.036" clearance is required at installation to permit free thermal expansion of the Pyro.
70 Pulse Igniter

**Insulator - Closure**

**WB 2233**

**Silica Phenolic**

Estimated hoop strain in Steel Closure

\[
\varepsilon_{hoop} = \frac{F_{hoop}}{E_{steel}}
\]

\[
F_{hoop} = 300 \times 10^6 \text{ psi}
\]

\[
\varepsilon_{hoop} = 0.025\ %
\]

Allowable hoop strain, finalist

\[
\varepsilon_{allow} = \frac{\varepsilon_{hoop}}{K}
\]

\[
E = 30 \times 10^6 \text{ psi}
\]

\[
F = 30 \times 10^6 \text{ psi}
\]

\[
K = 0.14 \times 2.0 = 0.475
\]

\[
\varepsilon_{allow} = 0.00475
\]

\[
\varepsilon_{allow} = 0.0095\ %
\]

\[
\frac{\varepsilon_{allow}}{0.025} = 0.38
\]

**NOT REPRODUCIBLE**
Pulse Igniter

By H. Front

FAMEUR
NAS 500-3 00 FK

Tall: 2800 ft
P= 1370 ft

M.S.: \( \frac{2800}{1370} - 1 = 2 \)
APPENDIX C

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

\[ Q_i = \sum_{j=1}^{N} F_j \sigma (T_{j,i}^4 - T_{m,i}^4) \]

- \( Q_i \) = Total incident heat flux on the membrane surface at time \( i \) (Btu/ft\( ^2 \)-sec)
- \( F_j \) = Configuration factor from the membrane to the individual sections (\( j \))
- \( T_{j,i} \) = Temperature of an individual section at time \( i \) (\( ^\circ \)R)
II, Discussion (cont.)

\[ T_{m,i} = \text{Frontside temperature of the membrane at time } t_i \left( ^\circ \text{R} \right) \]
\[ \sigma = \text{Stefan-Boltzmann constant} \]

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: AP-3316
- Flame Temperature: 6048°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.

Page 3
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/°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.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (Btu/ft·sec·°F)</th>
<th>Specific Heat (Btu/lb·°F)</th>
<th>Density (lb/ft$^3$)</th>
<th>Factor ($\mu$m/sec)</th>
<th>E/R (°F)</th>
<th>Order of Reaction</th>
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<tr>
<td>Nylon</td>
<td>0.00004</td>
<td>0.40</td>
<td>71.0</td>
<td>1.85 x 10$^{13}$</td>
<td>47,100</td>
<td>1.0</td>
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<td>V-4010</td>
<td>0.000036</td>
<td>0.45</td>
<td>68.2</td>
<td>1.252 x 10$^{3}$</td>
<td>14,660</td>
<td>1.219</td>
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<tr>
<td>RTV-60</td>
<td>0.00005</td>
<td>0.39</td>
<td>90.0</td>
<td>5.31 x 10$^{10}$</td>
<td>39,400</td>
<td>1.0</td>
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<td>0.00007</td>
<td>0.3</td>
<td>110.0</td>
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MAXIMUM BACKSIDE TEMPERATURE INCREASE OF IGNITER MEMBRANE VS. THICKNESS (SSCR IGNITER)

INITIAL TEMPERATURE = 90°F

THICKNESS (INCHES)

0.16

0.14

0.12

0.10

0.08

0.06

0.04

0.02

0

M. 00

100

50

200

MAXIMUM TEMPERATURE INCREASE OF IGNITER

Figure C-1
Report AFAPL-TR-69-50, Appendix C

Front and Backside Temperature of Igniter Membrane vs. Exposure Time for SSCE Igniter

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)

TERMINDATION OF FIRST CYCLE BEGINNING OF SECOND CYCLE

EXPOSURE TIME (SECONDS)

AEROPHYSICS
JUNE 27, 1968
APPENDIX D

PINTLE THERMAL ANALYSIS FOR SSCR
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
chosen nodes indicated in Figures Appendix D-I and -II. The various duty cycles investigated were:

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<tr>
<th>Figure Number</th>
<th>No. of Pulses</th>
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<th>Pulse off Time, Sec</th>
<th>Pintle Material</th>
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<tr>
<td>III-1 thru 5</td>
<td>1</td>
<td>26</td>
<td>474</td>
<td>(Backup) MX 4926</td>
</tr>
<tr>
<td>IV-1 thru 6</td>
<td>1</td>
<td>26</td>
<td>474</td>
<td>All AG Carb 101</td>
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<tr>
<td>V-1 thru 5</td>
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<td>10</td>
<td>30</td>
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</tr>
<tr>
<td>VI-1 thru 5</td>
<td>24</td>
<td>1</td>
<td>30</td>
<td>&quot;</td>
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<tr>
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<td>1</td>
<td>&quot;</td>
</tr>
<tr>
<td>VIII-1 thru 6</td>
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<tr>
<td>X - 1 thru 6</td>
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<td>10</td>
<td>10</td>
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Report AFRL-TR-69-50, Appendix D

Fig. App. D-1
Fig. App. D-2
Figure III-4
Figure III-6
Figure IV-1
Figure IV-6
Figure V-3
Figure V-5
Figure V-6
Figure VI-2
Figure VI-3
Figure VII-1
Figure VII-3
Figure VII-5
Figure VIII-1
Figure VIII-2
Figure VIII-3
Figure VIII-4
Figure VIII-5
Figure VIII-6
Figure IX-1
Figure IX-4
Figure IX-5
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Figure IX-6
Figure X-1
Figure X-2
Figure X-3
Figure X-6
Figure XI-2
Report AFRPL-TR-69-50, Appendix E

APPENDIX E

THERMAl STUDY OF THE SINGLE CHAMBER STOP/START PROPELLANT ENVIRONMENT
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.
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
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.
Figure E-1
INCLINE HEAT PULL
AT TYPICAL MET PROPELLANT STATIONS

Figure E-2

(Relative to pulse burnout)
TYPICAL THERMAL RESPONSE FOR V-AICO INSULATION

TIME RELATIVE TO 1ST PULSE IGNITION (SEC)

0.0
13.0
30.0

DEPTb, IN.
(RELATIVE TO FINAL SURFACE)

Figure E-6
APPENDIX F

RE-IGNITION ANALYSIS OF THE SINGLE-CHAMBER STOP/START
CONTROLLABLE SOLID ROCKET MOTOR
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.
SECTIOII 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, $t_i$, 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.
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,

\[ t_{\gamma} = t_o + t_c \]

\[ t_{\gamma} = \ln q - \ln \left( q - 0.21977 \left( 490 - T_{amb} \right) \right) + \frac{1}{0.05 \left( P - 45 \right)} \]

where:
- \( t_{\gamma} \) = seconds
- \( q \) = Btu/ft\(^2\)-sec
- \( T_{auto} \) = 490\(^\circ\)F
- \( P^* \) = 45 psia

By inspection, it is seen that there are two quantities which tend to make \( t_{\gamma} \) approach infinity:

1. \( q - 0.21977 \left( 490 - T_{amb} \right) = 0; \ln q = -\infty \)
2. \( P - 45 = 0; \lim_{P \to 45} \frac{1}{P - 45} = \infty \)

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 Btu/ft\(^2\)-sec.

Using this information and propellant ignitability data, with an assumed
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:

$$P = \sum \frac{\dot{m}}{A_t C_w} = \frac{1}{A_t C_w} \left( \rho r_a A_b + \dot{W}_{\text{pyrolysis}} \right)$$

- $A_t =$ throat area, 39 in.$^2$
- $\rho =$ density, lbm/in.$^3$
- $r_a =$ ablation rate, in./sec
- $A_b =$ total propellant surface area, in.$^2$
- $C_w =$ assumed flow coefficient, lbm/lbf·sec

$$P = \frac{1}{39(1012)} \left( 0.063 \times 0.004 \times (1400) + 0.175 \right) = 1.13 \text{ psia}$$

$$P \leq 2.0 \text{(assumed)}$$
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.

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<th>Quantity</th>
<th>Maximum Predicted Value</th>
<th>Critical Value</th>
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<td>$P_{\text{induced}}$, psia</td>
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<td>45</td>
</tr>
<tr>
<td>$A_{\text{induced}}$, Btu/ft$^2$-sec</td>
<td>35</td>
<td>91</td>
</tr>
</tbody>
</table>

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.
Report AFRPL-TR-69-50, Appendix F

Figure F-1

Single Chamber Stop/Start Motor
Propellant Temperature vs Depth
**UNCLASSIFIED**

**DOCUMENT CONTROL DATA - R & D**

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**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.

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.
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