SEMI-ANNUAL STATUS REVIEW

NOVEMBER 1971

NOZZLE

L. A. SHURLEY

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NOZZLE
SIGNIFICANT EVENTS
E/CDSR TO NOVEMBER 1971

○ COMPLETED ANALYSIS OF PHASE I FATIGUE TEST RESULTS
○ COMPLETED 2D THERMAL ANALYSIS OF SELECTED NOZZLE/PV JOINT AND CYLINDRICAL SECTION
○ COMPLETED FINITE ELEMENT STRESS ANALYSIS OF NOZZLE/PV JOINT CYLINDRICAL SECTION AND REFLECTOR/NOZZLE INTERFACE
○ COMPLETED VARIABLE WALL THICKNESS FABRICATION FEASIBILITY PROGRAM
○ REMELTED 4 ARMCO 22-13-5 INGOTS BY ELECTRO SLAG PROCESS
○ COMPLETED ANALYSIS OF EXISTING COOLANT CHANNEL DESIGN TO VERIFY ADEQUACY FOR "E" ENGINE AND STUDY PERIPHERAL CONDITIONS
○ REDESIGNED PV-REFLECTOR LOCATING CYLINDER TO PROVIDE BETTER COOLING OF NOZZLE/PV JOINT
○ UPGRADED RELIABILITY ANALYSIS OF 12 MECHANISMS
○ CHANGED 2D THERMAL ANALYSIS COMPUTER PROGRAMS TO PERMIT DIRECT TRANSFER OF TEMPERATURES TO STRESS ANALYSIS PROGRAMS
○ INITIATED DESIGN OF PHOTOELASTIC TEST SPECIMEN
○ RE-ASSESSED THRUST FEASIBILITY OF 75K AT 4500°F
NOZZLE
PLANNED ACTIVITIES
NOVEMBER 1971 TO MAY 1972

- COMPLETE PHASE II FATIGUE TEST RESULTS ANALYSIS (ASSUMED TEST DATA AVAILABILITY FROM PROJECT 187)
- COMPLETE FINITE ELEMENT STRESS ANALYSIS OF JACKET/TUBE CROSS SECTIONS TO PREDICT COOLANT CHANNEL STRAIN ACCURATELY
- COMPLETE ANALYSES TO DETERMINE IF EXTERNAL BOLT COOLANT MANIFOLD IS REQUIRED (NEED LOW CYCLE FATIGUE DATA ON ARMCO 22-13-5 FROM LeRC)
- COMPLETE DESIGN OF PHOTOELASTIC TEST SPECIMEN AND TEST HARDWARE
- COMPLETE ANALYSIS OF CRES 347 CREEP TEST DATA
- CONTINUE RELIABILITY ANALYSIS
- REVIEW COOLANT CHANNEL CORRELATIONS DEVELOPED IN CY 70 AND UPGRADE COOLANT CHANNEL MODEL
- COMPLETE FABRICATION OF 3 ARMCO 22-13-5 FORGINGS AND DELIVER TO PROJECT 187
- REVIEW NOZZLE C-002 SPECIFICATION AND ANALYZE NOZZLE DESIGN STATUS RELATIVE TO SPECIFICATION REQUIREMENTS
ACTIVITY SCHEDULE - NOZZLE

ACTIVITY

FABRICATE THREE ARMCO 22-13-5 FORGINGS
COORDINATE MATERIALS DEVELOPMENT ACTIVITIES & SELECT NOZZLE MATERIAL
REFINE NOZZLE-PV JOINT CONCEPT
DESIGN PHOTOELASTIC TEST HARDWARE
VARIABLE WALL THICKNESS COOLANT CHANNEL FAB PROGRAM
PREDICT COOLANT CHANNEL FATIGUE & BUCKLING LIFE
NOZZLE COOLANT CHANNEL DESIGN & PERFORMANCE ANALYSIS
ANALYZE NOZZLE-NSS INTERFACE JOINT & CYLINDRICAL SECTION
MAINTAIN NOZZLE MASTER LAYOUTS
CALCULATE PREL. NOZZLE ASSY. RELIABILITY
NOZZLE EXTENSION
SELECTED TECHNICAL TOPICS

- INDUCTION GRAPHITIZING FURNACE
- SUBSCALE INTREMOLD CYLINDERS
- FLANGE CONCEPT GENERATION
- PERFORMANCE LOSS ANALYSES AND TESTING
- DENSIFICATION
ARMCO 22-13-5 SCREENING PROGRAM RESULTS

**HYDROGEN EMBRITTLEMENT (NOTCH TENSILE)**

<table>
<thead>
<tr>
<th>ATMOSPHERE</th>
<th>NO. TESTS</th>
<th>PRESSURE</th>
<th>TEMPERATURE</th>
<th>AVG $F_{tu}$ (KSI)</th>
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<tbody>
<tr>
<td>$H_e$</td>
<td>4</td>
<td>1200 PSIG</td>
<td>70°F</td>
<td>130.1</td>
</tr>
<tr>
<td>$H_2$</td>
<td>8</td>
<td>1200 PSIG</td>
<td>70°F</td>
<td>129.7</td>
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</table>

CONCLUSION: NO HYDROGEN EMBRITTLEMENT EFFECTS IN TENSILE LOADING CONDITION

**IRRADIATION EFFECTS (20 SPECIMENS TESTED)**

<table>
<thead>
<tr>
<th>HEAT TREAT</th>
<th>FLUENCE</th>
<th>TEST TEMP.</th>
<th>ELONG (%)</th>
<th>AVG $F_{tu}$ (KSI)</th>
<th>AVG $F_{tu}$ (KSI)</th>
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<tbody>
<tr>
<td>AS RECEIVED</td>
<td>0</td>
<td>-320°F</td>
<td>53.3</td>
<td>118.7</td>
<td>213.3</td>
</tr>
<tr>
<td></td>
<td>$6.8 \times 10^{18}$ NVT $&gt;1.0$ MEV</td>
<td>-320°F</td>
<td>35.0</td>
<td>174.3</td>
<td>239.6</td>
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<tr>
<td>3 NERVA BRAZE CYCLES</td>
<td>0</td>
<td>-320°F</td>
<td>15.2</td>
<td>118.8</td>
<td>195.7</td>
</tr>
<tr>
<td></td>
<td>$6.8 \times 10^{18}$ NVT $&gt;1.0$ MEV</td>
<td>-320°F</td>
<td>12.2</td>
<td>175.8</td>
<td>230.5</td>
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</table>

CONCLUSION: ELONGATION ADEQUATE FOR THE DESIGN APPLICATION
REFLECTOR LOCATING CYLINDER/PV INTERFACE

FLOW

REFLECTOR-LOCATING CYLINDER

REFLECTOR

PRESSURE VESSEL

NOZZLE
THERMAL FATIGUE TEST RESULTS
NO HOLD TIME
PHASE 1

NOZZLE CYCLIC LIFE

ESTIMATED COOLANT CHANNEL STRAIN

.99/95% LOWER BOUND DATA ($\bar{x} - \bar{k}\sigma$)

FATIGUE LIFE, $N_f$ (CYCLES)

TOTAL STRAIN RANGE, $\Delta \xi$

1000°F

1000°F

HASTELLOY X
CRES 347

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HASTELLOY X CYCLES TO FAILURE VS TEMP.
- NO HOLD TIME -
NOZZLE - PRESSURE VESSEL JOINT TEMPERATURES

- SPECIFICATION EXTREME CONDITIONS
- FLIGHT HEATING RATES
- EOL COOLANT PARAMETERS
- ARMCO 22-13-5 NOZZLE
- 7075-T73 PRESSURE VESSEL

-228°F
-226°F
-246°F
200°F
638°F
722°F
100°F
11°F
.60
.88
1.0
2.4
GAS SIDE WALL TEMPERATURE $f(T_c)$ VS CHAMBER PRESSURE
(MAX HEAT FLUX LOCATION)

REF: 1137400E ENGINE
NETAP DATA

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NEW LIMIT BASED ON LOW CYCLE THERMAL FATIGUE DATA (ZERO HOLD TIME)
COOLANT TUBE LEG HEIGHT INCREASE
VS
PRESSURE DROP AND MAX GAS SIDE WALL TEMPERATURE
NORMAL END OF LIFE

GAS SIDE WALL TEMPERATURE
MAX, $T_{WG}$ ($^\circ$F)

PRESSURE DROP,
$\Delta P$ (PSIA)

H, LEG HEIGHT INCREASE (IN)

REF: N8500:R:71-1367
DTD 26 AUG 1971

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CONCLUSIONS

- Method of reducing wall thickness is satisfactory - ± .001 tolerances can be maintained
- Cold work induced during thinning operation caused warpage - annealing cycle required
- Existing Phoebus tooling did not maintain forming tolerance due to differences in springback characteristics between CRES 347 and Hastelloy X
- Basic tooling approach is satisfactory
- Methods for forming the divergent section to the RAO contour will have to be developed
- No metallurgical anomalies resulted from fab processes
## RELIABILITY ANALYSIS PROGRESS

### PRELIMINARY PROBABILISTIC ANALYSIS

<table>
<thead>
<tr>
<th>FMA VII</th>
<th>PROPELLANT DELIVERY</th>
<th>ARMCO JACKET - 22-13-5</th>
<th>CRES 347</th>
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<tbody>
<tr>
<td>A</td>
<td>INLET MANIFOLD</td>
<td>SOL</td>
<td>&gt; .995</td>
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<td>.990</td>
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<td>B</td>
<td>COOLANT INLET ELBOW STRUCTURE FAILURE</td>
<td>SOL</td>
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<td>&gt; .996</td>
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<tr>
<td>C</td>
<td>COOLANT INLET ELBOW WELD</td>
<td>SOL</td>
<td>&gt; .995</td>
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<td>TBD</td>
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<td>D</td>
<td>COOLANT TUBE EROSION</td>
<td>EOL</td>
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<td>.975</td>
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<td>F</td>
<td>COOLANT TUBE THERMAL BUCKLING</td>
<td>NT - EOL</td>
<td>.978</td>
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<td>.967</td>
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<td>G</td>
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<td>I</td>
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<td>SOL</td>
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<td></td>
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<td>&gt; .995</td>
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<td>J</td>
<td>END CAP BRAZE .030 INSERTION</td>
<td>SOL</td>
<td>.9100</td>
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<td>K</td>
<td>END CAP WELD</td>
<td>SOL</td>
<td>.988</td>
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<td>M</td>
<td>JACKET RUPTURE (AFT END)</td>
<td>EOL</td>
<td>&gt; .995</td>
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<td>&lt; .92</td>
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<td>N</td>
<td>COOLANT TUBE BRAZE JOINT FAILURE (.044 DEEP)</td>
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<td>O</td>
<td>INLET MANIFOLD WELD</td>
<td>SOL</td>
<td>.960</td>
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<td>TBD</td>
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<td>Q</td>
<td>BOLT COOLANT MANIFOLD WELD</td>
<td>SOL</td>
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NOV 71 VALUES | MAY 71 VALUES
> .995 | > .995
> .995 | TBD
.978 | TBD
.94-.97 | TBD
> .995 | TBD
.9100 | TBD
.988 | TBD
> .995 | < .92
.9100 | TBD
.960 | TBD
> .995 | TBD

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RELIABILITY ANALYSIS PROGRESS (CONT.)

<table>
<thead>
<tr>
<th>FMA VIII</th>
<th>NOZZLE IS AFT CLOSURE FOR PV AND CORE</th>
<th>NOV 71 VALUES</th>
<th>MAY 71 VALUES</th>
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<tr>
<td>A</td>
<td>FLANGE FAILURE BETWEEN BOLT HOLES</td>
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<tr>
<td>B</td>
<td>SHEAR LIP FAILURE</td>
<td>SOL</td>
<td>&gt; .995</td>
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<td>C</td>
<td>ATTACHING BOLT FAILURE</td>
<td>SOL</td>
<td>&gt; .910</td>
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<td>D</td>
<td>JACKET WALL FAILURE</td>
<td>SOL</td>
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<td>E</td>
<td>CORE SUPPORT FAILURE</td>
<td>SOL</td>
<td>.960</td>
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<td>FMA MODES IV, V, VI &amp; IX</td>
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<thead>
<tr>
<th>PRELIMINARY PROBABILISTIC ANALYSIS</th>
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<td>*2.4 INCH ARMCO</td>
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<td>NOV 71 VALUES</td>
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<table>
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<tr>
<th>NOZZLE RELIABILITY ALLOCATION</th>
<th>SEPT. 70</th>
<th>MAR. 71</th>
<th>SEPT. 71</th>
<th>CAT. III</th>
<th>CAT. IV</th>
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<td>NOZZLE RELIABILITY ALLOC.</td>
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<td>MECHANISM RELIABILITY GOAL</td>
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* STRESS FROM FINITE ELEMENT PROGRAM
** STRESS FROM P.E.T.S. PROGRAM AND RING THEORY
NOZZLE
SUMMARY AND CONCLUSIONS

TECHNICAL RESULTS

○ NOZZLE/PV JOINT DESIGN IS ADEQUATE FOR PHOTOELASTIC TEST COMMITMENT

○ VARIABLE WALL THICKNESS COOLANT CHANNELS

CAN BE SUCCESSFULLY FABRICATED

CYCLIC LIFE ADEQUATE BASED ON LOW CYCLE THERMAL FATIGUE DATA
(MINIMUM TO BE ESTABLISHED WITH HOLD TIMES)

NOZZLE CAN OPERATE FOR 24 CYCLES AT TC = 4500°R

○ RELIABILITY ANALYSIS - NOZZLE MEETING GOALS, ASSESSMENT CONTINUING

PROGRAM STATUS

○ NOZZLE PROGRAM IS ON SCHEDULE, EXCEPT FOR ARMCO 22-13-5 FORGINGS