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SEMI-ANNUAL STATUS REVIEW

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NOZZLE

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MASTER

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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°R

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

[illegible]

**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)

ATMOSPHERE	NO. TESTS	PRESSURE	TEMPERATURE	AVG F_{tu} (KSI)
H _e	4	1200 PSIG	70°F	130.1
H ₂	8	1200 PSIG	70°F	129.7

CONCLUSION: NO HYDROGEN EMBRITTLEMENT EFFECTS IN TENSILE LOADING CONDITION

◦ IRRADIATION EFFECTS (20 SPECIMENS TESTED)

HEAT TREAT	FLUENCE	TEST TEMP.	ELONG (%)	AVG F_{ty} (KSI)	AVG F_{tu} (KSI)
AS RECEIVED	0	-320°F	53.3	118.7	213.3
	6.8×10^{18} NVT > 1.0 MEV	-320°F	35.0	174.3	239.6
3 NERVA BRAZE CYCLES	0	-320°F	15.2	118.8	195.7
	6.8×10^{18} NVT > 1.0 MEV	-320°F	12.2	175.8	230.5

CONCLUSION: ELONGATION ADEQUATE FOR THE DESIGN APPLICATION

REFLECTOR LOCATING CYLINDER/PV INTERFACE

THERMAL FATIGUE TEST RESULTS

NO HOLD TIME

PHASE 1

CRES 347 CYCLES TO FAILURE VS TEMP.

- NO HOLD TIME -

HASTELLOY X CYCLES TO FAILURE VS TEMP.

- NO HOLD TIME -

NOZZLE - PRESSURE VESSEL JOINT TEMPERATURES

- SPECIFICATION EXTREME CONDITIONS
- FLIGHT HEATING RATES
- EOL COOLANT PARAMETERS
- ARMC0 22-13-5 NOZZLE
- 7075-T73 PRESSURE VESSEL

GAS SIDE WALL TEMPERATURE $f(T_c)$ VS CHAMBER PRESSURE (MAX HEAT FLUX LOCATION)

REF: 1137400E ENGINE
NETAP DATA

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

VARIABLE WALL THICKNESS COOLANT CHANNEL
FABRICATION FEASIBILITY PROGRAM RESULTS

AFT END

THROAT

FWD END

(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			
		ARMCO JACKET - 22-13-5 TUBES - CRES 347	CRES 347
FMA VII	PROPELLANT DELIVERY	NOV 71 VALUES	MAY 71 VALUES
A	INLET MANIFOLD	SOL > .9 ₉ 5	.9 ₉ 0
B	COOLANT INLET ELBOW STRUCTURE FAILURE	SOL > .9 ₉ 5	> .9 ₉ 6
C	COOLANT INLET ELBOW WELD	SOL > .9 ₉ 5	TBD
D	COOLANT TUBE EROSION	EOL .9 ₉ 7	.9 ₆ 2
E	COOLANT TUBE RUPTURE AFT END	SOL .9 ₇ 5	.9 ₇ 5
F	COOLANT TUBE THERMAL BUCKLING	NT - EOL .9 ₇ 8	.9 ₆ 7
G	COOLANT TUBE FATIGUE	SOL .9 ₄ -.9 ₇	.76
H	COOLANT MANIFOLD STRUCTURE FAILURE	SOL > .9 ₉ 5	.9 ₇ 6
I	END CAP STRUCTURAL FAILURE	SOL > .9 ₉ 5	> .9 ₉ 5
J	END CAP BRAZE .030 INSERTION	SOL .9 ₁₀ ⁰	TBD
K	END CAP WELD	SOL .9 ₈ 8	TBD
M	JACKET RUPTURE (AFT END)	EOL > .9 ₉ 5	< .9 ₂
N	COOLANT TUBE BRAZE JOINT FAILURE (.044 DEEP)	SOL .9 ₁₀ ⁰	TBD
O	INLET MANIFOLD WELD	SOL .9 ₆ 0	TBD
Q	BOLT COOLANT MANIFOLD WELD	SOL > .9 ₉ 5	TBD

RELIABILITY ANALYSIS PROGRESS (CONT.)

			PRELIMINARY PROBABILISTIC ANALYSIS	
			*2.4 INCH ARMCO	**2.0 INCH ARMCO
			NOV 71 VALUES	MAY 71 VALUES
FMA VIII	NOZZLE IS AFT CLOSURE FOR PV AND CORE			
A	FLANGE FAILURE BETWEEN BOLT HOLES	SOL	> .9 ₁₀	.9 ₃₅
B	SHEAR LIP FAILURE	SOL	> .9 ₉₅	> .9 ₉₅
C	ATTACHING BOLT FAILURE	SOL	.9 ₁₀₄	> .9 ₉₅
D	JACKET WALL FAILURE	SOL	.9 ₇₅	.9 ₈₇
E	CORE SUPPORT FAILURE	SOL	.9 ₆₀	.9 ₉₅
FMA MODES IV, V, VI & IX			TBD	

	SEPT. 70	MAR. 71	SEPT. 71	
			CAT. III	CAT. IV
NOZZLE RELIABILITY ALLOCATION	.9 ₃₈₈₄	.9 ₅₈₀₉	.9 ₆₀	.9 ₉₈
NOZZLE ASSEMBLY RELIABILITY ALLOC.	.9 ₃₇₅₈	.9 ₅₆₄₅	.9 ₅₈	.9 ₉₂
MECHANISM RELIABILITY GOAL	.9 ₅₆₄	.9 ₇₅₆₅	TBD	TBD

* 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 $TC = 4500^{\circ}R$

- RELIABILITY ANALYSIS - NOZZLE MEETING GOALS, ASSESSMENT CONTINUING

PROGRAM STATUS

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