FEB 19 1965
Stoney

TID/SNA-4

AEROJET-GENERAL CORPORATION

SACRAMENTO

CALIFORNIA

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004 1000

PROPELLANT FEED SYSTEM

PROGRESS REVIEW

27 January 1965

MASTER

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Approved by:

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NERVA TURBOPUMP PRESENTATION OUTLINE

- I TURBOPUMP MECHANICAL
- II TURBOPUMP BEARING DEVELOPMENT
- III TURBOPUMP MATERIALS
- IV TURBOPUMP STRUCTURES
- V TURBOPUMP ANALYTICAL AND TEST
- VII TURBOPUMP TEST FACILITY
- VIII TURBOPUMP 2ND QUARTER CY65 PLANS

NERVA PROGRAM

NEW DESIGNS IN PROCESS

ITEM	STATUS
One piece floating turbine nozzle	In-process of fabrication
Turbine Manifold	Layout and detailed design in-process
Seals	Improving existing handling buildup and inspection procedures - evaluating new configurations
Turbine Exhaust Collector	Out to Vendors for bids
TPA Demobilizer	Drafting (details)

NERVA PROGRAM

PUMP HOUSING CASTING CHANGE FOR IMPROVED PRESSURE CAPABILITY

MATL:

A 356-T6 ALUMINUM ALLOY
ULTIMATE STRENGTH = 35,000 PSI
YIELD STRENGTH(.2% OFFSET) = 25,000
% ELONGATION = 6%

PROOF PRESSURE 1100 PSIG
BURST 2820 PSIG

BURST TEST PERFORMED ON
FINISHED MACHINED PUMP HOUSING
PRESSURE CONFINED TO VOLUTE AREA

MARK III MOD 3

PROOF PRESSURE 1600 PSIG
BURST 3200 PSIG

BURST PRESSURE CALCULATED
AT NOM. WALL

MARK III MOD 4

NERVA PROGRAM

3.2.1.1

DEF

PUMP HOUSING VOLUTE WALL STRUCTURAL INTEGRITY
Yield Pressure vs Wall Thickness
Material: A356-T6 Aluminum Alloy

* Curves Extrapolated from Analysis of .40 Wall

7075-T73 ROUGH MACHINED IMPELLER
TENSILE TEST DATA

<u>Temp</u>	<u>Location</u>	<u>Type</u>	<u>Ultimate</u>	<u>Yield(0.2%)</u>	<u>% Elongation</u>	<u>% R/A</u>
RT	(4) Vane, Radial	R-4	69.4-68.2	59.0-58.0	7.8-7.0	8.5
-423	(6) Vane, Radial	R-4	82.8-80.4	73.6-68.8	2.7-1.5	6.0- 2.5
-423	(3) Vane, Tangential	R-4	99.2-88.7	79.7-67.2	7.1-4.1	8.5-6.0
-423	(2) Base, Radial	R-1	94.1	72.5-72.29	5.0	8.5-7.8
-423	(3) Base, Radial	R-4	96.5-94.4	71.3-67.7	6.3-5.8	10.9-8.8

The impeller is rough machined, then heat treated to the T73 condition.

Minimum RT requirements: Ultimate 66 KSI
Yield 56 KSI
% Elongation 7%

NERVA PROGRAM

MARK III MOD 4 IMPELLER

PROGRAM:	NERVA	NERVA	TITAN	M-1
ALLOY:	7075-T73	7075-T6	7075-T6	7079-T6
SPECIFIED GRAIN:	NON-DIR.	NON-DIR.	NON-DIR.	NON-DIR.
ACTUAL GRAIN:	AXIAL	NON-DIR.		
ELONGATION - TAN, R : RT:			4.5	5.0 - 6.0
(LONG TRANSVERSE)				
-320:	5.5		1.5	1.5 - 3.0
-423:	5.5 - 2.7	2.0 - 3.0		0 - 2.0
ELONGATION - RADIAL, FT:	7.8	5.5	4.5	4 - 5.5
(SHORT TRANSVERSE)				
-320:		2.5	2.5	2.0
-423:	1.56 - 2.7	2.0 - 3.0		0 - 1.0
RED IN AREA % RADIAL - RT:	8.5	13.8		4.7 - 9.1
(SHORT TRANSVERSE)				
-320:		4.3		1.6 - 5.4
-423:	2.5 - 6	0 - 3.2		0

NERVA PROGRAM

7075 ALUMINUM HANDFORGING

Tensile Specimen Billets
Cut from Areas as Shown

Minimum Print Values:

66 KSI Ult. 56 KSI Yield
10% Elong

Spec	101	102	201	202	301	302	303	304	401	402	403	404
Ult (KSI)	72.2	73.6	73.1	77.0	72.4	72.1	70.9	71.0	72.0	71.9	72.6	72.1
Yield (KSI)	65.9	65.1	64.9	63.9	62.8	62.5	60.9	60.7	61.9	62.9	62.9	62.9
% Elong	6.6	12.1	11.8	11.8	11.1	11.2	13.1	14.9	11.2	12.4	10.8	8.6

NERVA PROGRAM

MARK III MOD 4 IMPELLER SHAKE TEST RESULTS

A. Frequency Survey - Stroboscopic System

<u>Vane</u>	<u>Resonant Frequency cps</u>	<u>Location Maximum Deflection</u>	<u>Nodal Lines</u>
Full	1106	100°	(Cantilever)
Full	1344	95° and 185°	140° Radial
Full	1486	85° and 157°	120° and 194° Radial
Full	1622	80°	118° Tip to 75° Hub
		156° and 200°	172° and 228° Radial
Full	1659	80°, 141°, and 192°	114°, 168°, and 216° Radial
Full	1690	80°, 132°, 184°, and 228°	107°, 160°, 208°, and 248° Radial
Long Partial	2622	Blade Tip	(Cantilever)
Long Partial	4202	1" from Blade Tip	
Long Partial	5681		
Medium Partial	3963		(Cantilever)
Short Partial	Greater than 5700		

B. Blade Deflections - Optron System

<u>Vane</u>	<u>Resonant Frequency cps</u>	<u>Amplitude Inches</u>	<u>Bandwidth Cycle</u>	<u>Location</u>
Full	1102	.0265	4	100°
Long Partial	2643	.0015	43	Tip
Long Partial	5675	.002	Undetermined	Tip

NERVA PROGRAM

SHAKE TEST NODAL LINES - FULL VANE

MARK III MOD 4 WATER TEST RIG

2000 HP Electric Motor Drive
8000 RPM 1500 FT-LB Torque

- 4 Pre-Inducer Static Pressure Taps
- 14 Impeller Contour Static Pressure Taps
- 8 Diffuser Static Pressure Taps
- 11 Impeller Backvane Static Pressure Taps
- 1 Diffuser Dynamic Pressure Probe

Assembly Completed: 13 January 1965

1st Test Target Date: 8 February 1965

NERVA PROGRAM

MARK III MOD 4 IMPELLER SPIN TEST SCHEMATIC

60,000 rpm Capability

100-200 μ H_g Vacuum

Facility Shakedown
(Dummy Impeller) Target
Date:

1 February 1965

1st Mark III Mod 4 Test
Target Date:

8 February 1965

NERVA PROGRAM

NERVA MARK III MOD 4 TURBINE INLET MANIFOLD

Inlet Conditions

$$\frac{\dot{w}}{P_{Ti}} \sqrt{T_{Ti}} = .475$$

Manifold Inlet Mach
Number = .27

Material
(Tentative)

Inconel 718
0.2% Offset
Yield Strength
@ 2000°R =
26,900 psi

Manifold Inlet Mach
Number = .54

Material
Cres Type 347
0.2% Offset
Yield @ 2000°R
= 13,300 psi

NERVA PROGRAM

FIRST STAGE NOZZLE CRACK

CRACK AFTER 7 MINUTES OPERATION
AT A TEMP 1200°R INCLUDING 9
GAS GENERATOR STARTS

DESIGN COMPLETED
FABRICATION IN PROCESS

NERVA TURBOPUMP END USE STATUS

TARGET DATE

COMPLETION DATE

SCHEDULED DELIVERY

CY 65

CY 66

TPA	S/N	END USE	1st	2nd	3rd	4th	1st	2nd	3rd	4th
010		CFDTS								
013		DEV								
014		DEV (120%N)								
015		NRX/EST								
016		NRX/EST (Backup)								
017		LeRC								
018		LeRC								
019		DEV								
020		DEV								
021		DEV								
022		DEV								
023		DEV								
024		XE-1								
025		DEV								
026		XE-2								
027		XE-3								
009		DEV								

NRX/EST TURBOPUMP

SCHEDULE

TASK	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE
IMPELLER COMPLETE				↑		②			
BEARING HOUSING COMPLETE		↑	◆						
PUMP HOUSING COMPLETE		↑	↑	↑					
TURBINE COMPONENTS COMPLETE		↑	◇	◆		①			
TURBOPUMP ASSEMBLY COMPLETE					▽	↑ ① ②	③		
ACCEPTANCE TEST COMPLETED					▽	↑			
DELIVER TO ENGINE SYSTEM (MRB AND TEST REPORT COMPLETE)							▽		↑

◇ Rescheduled Milestone

◆ Rescheduled Milestone Achievements

○ Backup Turbopump

① Backup Turbopump with Floating Shroud Nozzle

② Backup Turbopump with 1 + Improved Impeller

③ Backup Turbopump with 1 + 2 + Backup Seals

↑ Scheduled Milestone

↑ Milestone Achievement

▽ Max Incentive Fee Milestone

▽ Max Incentive Fee Milestone Achievement

NERVA PROGRAM

MARK III MOD 4 IMPELLER

IMPELLER PART NO.	END USE TPA S/N	USAGE	SCHEDULED IMPELLER DELIVERY											
			1964						1965					
			Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June		
287730-1	880313	Endur. Test		↑										
287730-1	009	Dev. Test			↑	◆								
287730-1	010	CFDTS			↑									
287730-1	880314	Dev. Test			↑	◆								
287730-1	880315	NRX/EST				↑	▽							
287730-1	880316	NRX/EST backup				↑	▽	☆						
287730-1	880317	LERC					◆	↑						
287730-3	880318	LERC							↑					
287730-3	Not Assigned 7 Pieces	Dev. and Spares							↑	↑	↑	↑		
									(1)	(2)	(2)	(2)		
287730-1	Water Test Rig	Pump Dev.				↑	Transferred from Shake Test							
287730-1	Shake Test	Impeller Dev.			◆	↑	Test Complete							
287730-1	Spin Test	Impeller Dev.				↑	↑

Scheduled Milestone
 Rescheduled Milestone
 For Support of Incentive Milestone - Req'd for Max Fee
Milestone Achievement
 Rescheduled Milestone Achievement
 Incentive Milestone Achievement Max Fee

TECHINGE TEMPLATE

TECHINGE TEMPLATE

TECHINGE TEMPLATE

TECHINGE TEMPLATE

TECHINGE TEMPLATE

TECHINGE TEMPLATE

MARK III MOD 4 PUMP HOUSING

S/N	FOUNDRY	EVENT								
		CASTING	WELD CHAPLETS	X-RAY	HEAT TREAT	X-RAY	CASTING PROOF	FINISH MACHINING	ASSEMBLY	FINAL PROOF
422	ARCEE									10/1
421	ARCEE		10/14	10/8	12/1	12/8	1/11	1/15		
002	AGC (1962)					10/9	10/26	11/4	11/6	11/16
103	AGC (1964 Batch 1)				10/9	10/14	10/26	11/9	11/10	11/24
106	AGC (1964 Batch 1)		10/12		10/26	11/5	11/17	12/1		
108	AGC (1964 Batch 2)	10/15		10/19	10/26	10/29	11/4	11/17	11/23	12/1
110	AGC (1964 Batch 2)	10/29	11/16		12/1	12/24	1/7	1/18		
111	AGC (1964 Batch 2)	11/23		1/7	1/18	1/22				
112	AGC (1964 Batch 2)	12/2	12/23	12/29	- Scrapped (Blow in Volute Wall) - For Mat'l Evaluation					
113	AGC (1964 Batch 2)	12/30	1/22							
114	AGC (1964 Batch 2)	1/6								
115	AGC (1964 Batch 2)	1/13								
116	AGC (1964 Batch 2)	1/18								

REPORTS AND TEST PLANS FOR 1ST QUARTER

<u>Report No.</u>	<u>Subject</u>	<u>Date</u>	<u>Status</u>
1.2.3-65-R-001	Mark III Mod 4 Turbopump Endurance Problem Identification Test Plan for P/N 287800-179, S/N 880313	10-05-64	Complete
1.2.3-65-R-002	NERVA Mark III Mod 4 Turbopump P/N 287900-179, S/N 880309 Test Plan	11-16-64	Complete
1.2.3-65-R-004	NERVA Mark III Mod 4 Acceptance Criteria	10-09-64	Revision
1.2.3-65-R-008	NERVA Turbopump Mark III Mod 4 Impeller Shake Test Plan	11-13-64	Complete

NERVA PROGRAM

MARK III TPA ROLLER BEARING

MATERIAL, RACES & ROLLERS	MODIFIED 440 C
BEARING INSIDE DIAMETER	1.9684 IN.
BEARING OUTSIDE DIAMETER	3.5432 IN.
NUMBER OF ROLLERS	16
TYPE OF ROLLERS	CYLINDRICAL, CROWNED
ROLLER SIZE	0.382-IN. DIAMETER X 0.459 IN.
DEPTH, OUTER RACE	20%
BEARING CLEARANCE, DIAMETRAL	0.0019 TO 0.0026 IN.
MATERIAL, CAGES	ARMALON
TYPE OF CAGE	OUTER LAND RIDING
CAGE RADIAL THICKNESS	0.170 IN.
CAGE CLEARANCE, DIAMETRAL	0.014 IN.
BEARING WIDTH	0.7865 IN.

NERVA PROGRAM

MARK III TPA THRUST BEARING SET

MATERIAL, RACES & BALLS	AISI 440 C
BEARING INSIDE DIA	1.9684 IN.
BEARING OUTSIDE DIA	3.5432 IN.
NUMBER OF BALLS & SIZE	12 X 1/2-IN DIAMETER
CONTACT ANGLE	24°
CURVATURE RACE, INNER	54 % GOTHIC ARCH
CURVATURE RACE, OUTER	51 %
BEARING WIDTH	1.5700 IN.
BEARING CLEARANCE, AXIAL	0.008 - IN. MAX
MATERIAL, CAGE	ARMALON
CAGE TYPE	OUTER LAND RIDING
CAGE RADIAL THICKNESS	0.098 IN.,
OUTER CAGE CLEARANCE, RADIAL	0.006 IN.

NERVA PROGRAM

MARK III TPA THRUST BEARING SET - ALTERNATE

MATERIAL, RACES & BALLS	MOD 440 HTST
BEARING INSIDE DIAMETER	1.9684 IN.
BEARING OUTSIDE DIAMETER	3.5432 IN.
NUMBER OF BALLS & SIZE	16 X 7/16 IN. DIAMETER
CONTACT ANGLE	29°
CURVATURE RACE, INNER	52% GOTHIC ARCH
CURVATURE RACE, OUTER	52% GOTHIC ARCH
BEARING WIDTH	1.5700 IN.
BEARING CLEARANCE, AXIAL	0.006 IN. MAX
MATERIAL, CAGE	ARMALON
CAGE TYPE	OUTER LAND RIDING
CAGE RADIAL THICKNESS	0.098 IN.
OUTER CAGE CLEARANCE	0.006 IN.

NERVA PROGRAM

TYPICAL FAILURES ASTR TESTS

60 MIN. IRRADIATION

ASTR-4A
RETAINER

ASTR-5
RETAINER

ASTR-5
BALLS

NERVA PROGRAM

NERVA TURBOPUMP ROLLER BEARING LOAD-LIFE SUMMARY

SHAFT SPEED: 24000 RPM

BEARING SIZE: SAE 210

ARMALON RETAINERS DRY FILM COATED

LH₂ COOLANT FLOW: 8 LB/MIN

OPERATING GOAL: 3 HOURS AT LOAD

<u>RADIAL CLEARANCE INS</u>	<u>LOAD LB</u>	<u>NUMBER BEARINGS TESTED</u>	<u>PERCENT REACHED 1-HOUR</u>	<u>PERCENT REACHED 2-HOURS</u>	<u>PERCENT REACHED 3-HOURS</u>
.0019/.0025	2000	7	100	86	57 ^c
	2000	2 ^a	100	-	-
	500	7	100	100	86 ^c
	500	2 ^a	100	-	-
	125	1	100	100	100
	0	2	100	100	100
.0030/.0035	2000	4	100	100	50 ^b
	500	5	80	80	40 ^b
	0	4	100	50 ^c	0 ^b

a) TWO BEARINGS TESTED SUCCESSFULLY FOR ONE HOUR GOAL RADIATION ENVIRONMENT

b) TWO BEARINGS INCOMPLETE OPERATING TIME - NO FAIL

c) ONE BEARING INCOMPLETE OPERATING TIME - NO FAIL

NERVA PROGRAM

NERVA TURBOPUMP THRUST BEARING LOAD-LIFE SUMMARY

SHAFT SPEED: 24000 RPM

BEARING SIZE: SAE 210

ARMALON RETAINERS DRY FILM COATED

LH₂ COOLANT FLOW: 8 LB/MIN

OPERATING GOAL: 3 HOURS AT LOAD

<u>RACE GEOMETRY</u>	<u>LOAD LB</u>	<u>NUMBER BEARING SETS TESTED</u>	<u>PERCENT REACHED 1-HOUR</u>	<u>PERCENT REACHED 2-HOURS</u>	<u>PERCENT REACHED 3-HOURS</u>
SINGLE GOTHIC	4000	1	100	100	100
	3000	2	100	100	50
	2000	4	100	100	75
	0	2	100	100	50 ^b
DOUBLE GOTHIC	3000	1	100	100	100
	2000	4	100	100	75
	2000	2 ^a	100	-	-
	0.	1	100	0 ^b	0 ^b .

a) TWO BEARINGS TESTED SUCCESSFULLY FOR ONE HOUR GOAL RADIATION ENVIRONMENT

b) ONE BEARING INCOMPLETE OPERATING TIME - NO FAIL

NERVA PROGRAM

NERVA BEARING RADIATION TEST RESULTS

24000 RPM

8 LB/MIN LH_2 COOLANT FLOW

2000 LB RADIAL AXIAL LOADS

ASTR TEST	60-MINUTE RADIATION	10-MINUTE POST RADIATION	POST TEST INSPECTION	INTEGRATED NEUTRON FLUX N/cm^2	INTEGRATED GAMMA DOSE Ergs/gm (C)
4A	COMPLETED SATISFACTORILY	COMPLETED, I _m LARGE AT END	THRUST SET RETAINER POCKET FAILED	83.0×10^{13}	31×10^8
5	COMPLETED SATISFACTORILY	FAILED AT 6 MINUTES	THRUST RETAINER POCKETS FAILED	83.0×10^{13}	31×10^8
NRX/EST	5 MINUTE TEST			1.0×10^{13}	0.1×10^8

NERVA PROGRAM

BEARING TESTER

HIGH SPEED

- TEST SPEED (rpm) _____ 24,000
- AXIAL LOAD (lb) _____ 2,000
- RADIAL LOAD (lb) _____ 2,000

NERVA PROGRAM

NERVA BEARING TEST RESULTS

NON-NUCLEAR VS ASTR TEST

	<u>ACCUMULATED DURATION MINUTES</u>	<u>BEARING CONDITION</u>
1. STANDARD NON-NUCLEAR TEST IN TESTER S/N 004 WITH ASTR-4A - 5 BEARING CONFIGURATION	180	GOOD
2. NON-NUCLEAR TEST IN TESTER S/N 004 WITH ASTR-4A - 5 BEARING CONFIGURATION AND IDENTICAL OPERATING PROCEDURE AS ASTR-5	84	GOOD
3. NUMBER 2 ABOVE CONTINUED TO ACHIEVE 180 MINUTES ACCUMULATED DURATION	159	THRUST RETAINER FAILED
4. ASTR-4A	84	THRUST RETAINER FAILED
5. ASTR-5	77	THRUST RETAINER FAILED

NERVA PROGRAM

NERVA BEARING TESTS DRIVE MOTOR CURRENT AS A FUNCTION OF TIME ASTR TEST AND ASTR-5 SIMULATED NON-NUCLEAR TEST

ULTIMATE STRESS VS TOTAL RADIATION DOSE

LH₂ TEMPERATURE

— ULTIMATE STRESS
--- % ELONGATION

RESULTS WITH METAL RETAINERS AND VARIOUS DRY FILM LUBRICANTS

<u>BEARING</u>	<u>RETAINER</u>	<u>FILM</u>	<u>TEST DURATION</u> (secs)
Ball Thrust	Inconel X	DF-700 Mos ₂ - Graphite Na Silicate	50 @ load
Roller	Inconel X	DF-700 Mos ₂ - Graphite Na Silicate	50 @ load
Ball Thrust	304 S. St.	CBS CDL 5940 Nichrome - Ag - Mos ₂	232
Roller	304 S. St.	CBS CDL 5940 Nichrome - Ag - Mos ₂	232
Roller	Inconel X	DF 900 Metal free Phthalocyanine	66
Ball Thrust	Aluminum	Molykote 321 on sand blasted surface	66
Roller (Rolcon)	Metal Quills	Molykote 321 on side plates only	3.4 Hrs (No Fail)

NERVA PROGRAM

RADIATION RESISTANT RETAINERS

<u>RETAINER</u>	<u>STATUS</u>
1. METAL MATRIX - MoS_2	BOEING COMPANY SEATTLE FABRICATING AVAILABLE ABOUT 1 MARCH 1965
2. METAL RETAINER - MoS_2 RESERVOIRS IN POCKETS - ALSO RACE LAND	M. DEVINE OF NAVAL AIR ENGINEERING CENTER - PHILADELPHIA WILL FAB - AVAILABLE ABOUT 15 MARCH 1965
3. SP-1 OR SP-3 (THRESHOLD DAMAGE AT 7×10^{11} ERGS/gm (C))	TWO SP-1 RETAINERS FOR THRUST SET ON ORDER - DELIVERY APRIL-MAY
4. GLASS CLOTH LAMINATE WITH MoS_2 IMPREGNATION	DISCUSSION STAGE - BINDER COULD BE PROBLEM
5. METAL RETAINER WITH VARIOUS COATINGS: TFE, TFE CONTAINING MoS_2 AND GLASS FIBERS, KEL-F TUNGSTEN	DISCUSSION STAGE

NERVA PROGRAM

NERVA BEARING TEST SCHEDULE

Tester Serial No.

	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>
A. Variables								
1. Operating								
a. Load Effect	5,6,8	8,6	8,4,4	8,5,6	9,7,6	5,9	6,7	8,8
b. Speed Effect			6	6,7,8	5,9	5,7	8,7	7
c. Coolant Flow Rate Effect					8	8,6	6,9	9
d. Coolant Pressure Effect							5	6,7
2. Development								
a. Radiation resistant retainers, lubricating techniques, geometry, source, etc.		6,8	6,8,6,8	5,9	5,8	9,7	5	5
B. Radiation Effects Tests								
1. Texas	4	4						
2. Acceptance	4

NERVA PROGRAM

NERVA BEARINGS ON HAND AND ON ORDER

<u>BEARING TYPE</u>	<u>BEARING P/N</u>	<u>ON HAND</u>	<u>ON ORDER</u>	<u>EXPECTED DELIVERY</u>
THRUST SET	287810	5	36	02/01/65
	290122-9	14		
	290124	24	25	03/15/65
ROLLER	290152	20	24	02/15/65
	290153	14		
	290165		30*	02/08/65
	290169		30*	02/08/65
ARMALON RETAINER	287808-1	52	75	02/01/65
	290126	50	75	02/01/65
	290156-1	36	100	02/09/65

* AT METROLONICS, LOS ANGELES, CALIFORNIA BEING MEASURED.

NERVA PROGRAM

NERVA BEARING REPORTS

<u>TITLE</u>	<u>NUMBER AND DATE</u>
1. NERVA BEARING DEVELOPMENT EFFECT OF LOAD ON LIFE AND RELIABILITY	1.2.4-65-R-002 17 NOVEMBER 1964
2. NERVA BEARING TEST PLAN	1.2.4-65-R-006 4 NOVEMBER 1964
3. NERVA BEARING TESTER S/N 004 BU RET ACCEPTANCE TEST 3.5-08-NNW-002	1.2.4-65-R-007 6 NOVEMBER 1964
4. ASTR-4A PRELIMINARY REPORT	1.2.4-65-R-004 19 OCTOBER 1964
5. ASTR-5 PRELIMINARY REPORT	1.2.4-65-R-009 20 NOVEMBER 1964
6. NERVA BEARING TEST PLAN REVISED	1.2.4-65-R-010 8 JANUARY 1965
7. ASTR-4A, ASTR-5 FINAL REPORT	IN PROCESS
8. NERVA BEARING FIRST QUARTER PROGRESS REPORT	IN PROCESS
9. MOLYBDENUM DISULPHIDE - AN EFFECTIVE LUBRICANT FOR ROLLING CONTACT BEARINGS OPERATING IN LIQUID HYDROGEN	IN PROCESS

NERVA PROGRAM

ROOM TEMPERATURE FATIGUE TESTS - 7075-T73 FORCED IMPELLER

NERVA PROGRAM

ROOM TEMPERATURE FATIGUE TESTS - 7075-T73 FORGED IMPELLER

CONTINUED EVALUATION OF FORGED 7075 - T73

1. RELATE PERFORMANCE TESTS TO MECHANICAL PROPERTIES AND MICROSTRUCTURE
ESTABLISH DESIGN ACCEPTANCE LIMITS
2. CONDUCT TENSILE AND FATIGUE TESTS ON FORGING WITH EQUIAXIAL GRAIN PATTERN
3. FATIGUE LIFE:
 - A. TESTS AT CRYOGENIC TEMPERATURE
 - B. SHOT - PEENING IMPROVEMENT
 - C. EFFECTS OF ANODIZING (INFLUENCE OF SEALING TREATMENT)

NERVA PROGRAM

FORGED D-979 CREEP TESTS IN HYDROGEN ATMOSPHERE

TEMPERATURE	SPECIMEN TYPE	STRESS KSI	TOTAL STRAIN PERCENT		MINIMUM CREEP RATE % PER HR.
			ON LOADING	50 HOURS	
1000°F	RADIAL	85.0	0.461	0.504*	0.00008
	RADIAL	95.0	0.549	0.583*	0.00008
1100°F	TANGENTIAL	75.0	0.360	0.382	0.00008
	RADIAL	85.0	0.362	0.374	0.00025
	RADIAL	95.0	0.520	0.586	0.00075
1200°F	TANGENTIAL	75.0	0.413	0.585	0.00120
	RADIAL	85.0	0.512	1.180	0.02100
	RADIAL	95.0	0.536	**	0.04900

* OVERAGED 2 HOURS AT 1300°F, THEN TEMPERATURE REDUCED TO 1000°F FOR TEST

** RUPTURED IN 24 HOURS
 2.4 % ELONGATION
 5.7 % AREA REDUCTION

EXPECTED RUPTURE TIME OF 90 HOURS IN AIR ATMOSPHERE

NERVA PROGRAM

ESTIMATED CREEP OF D-979 TURBINE ROTOR (IN HYDROGEN)

NERVA PROGRAM

CONTINUED EVALUATION OF FORGED D 979

1. TENSILE TESTS:

CRYOGENIC TEMPERATURES (-320 AND -423°F)
ELEVATED TEMPERATURES
RADIATION EFFECTS

2. SHEAR TESTS:

ROOM TEMPERATURE
CRYOGENIC TEMPERATURES
RADIATION EFFECTS

3. FATIGUE TESTS:

ROOM TEMPERATURE
ELEVATED TEMPERATURE

4. CREEP TESTS:

HYDROGEN ATMOSPHERE
RADIATION EFFECTS

NERVA PROGRAM

PROPERTY VS. SPECIMEN LOCATION, PUMP HOUSING S/N 109

Parting Line ○
Cope Volute Wall ×
Drag Volute Wall ●
Drag Heavy Section □

NERVA PROGRAM

PUMP HOUSING S/N 109 A356-T6 CASTING

NERVA PROGRAM

CONTINUED EVALUATION OF A 356-T6 PUMP HOUSINGS

1. TENSILE TESTS AT -423°F

2. - CONTINUOUS MONITORING OF R.T. TENSILE PROPERTIES

NERVA PROGRAM

MECHANICAL PROPERTIES TESTING OF BEARING CAGE MATERIALS

1. TENSILE

2. BEARING

3. FLEXURE

TENSILE, BEARING AND FLEXURE TESTS OF ARMALON 510-128 BALL BEARING CAGES

	NEW CAGE	IRRADIATED CAGE 10 ⁹ ERGS/GM (C)
TENSILE ULTIMATE STRENGTH KSI	13.0 - 17.8 (14.8 AV.)	20.4 - 23.6 (21.9 AV.)
BEARING ULTIMATE STRENGTH KSI	4.5	4.6 - 4.9 (4.8 AV.)
FLEXURAL STRENGTH		
ULTIMATE - KSI	15.3 - 21.2 (17.3 AV.)	20.6 - 29.7 (24.7 AV.)
YIELD - KSI	9.5 - 12.0 (10.9 AV.)	13.3 - 14.3 (13.9 AV.)

NERVA PROGRAM

NERVA BEARINGS - REON MATERIALS DEPARTMENT SUPPORT PLAN

OBSERVATIONS	POSSIBLE CAUSES		INTENDED ACTION
1. FATIGUE CRACKING A. OUTER RACE B. INNER RACE	ROLLER - END ACTION ROLLER PRESSURE	+ POOR MICROSTRUCTURE + NOTCH SENSITIVITY	EVALUATE OTHER BEARING MATERIALS HAVING HIGHER ENDURANCE LIMIT; LESS NOTCH SENSITIVITY Q/C FOR MICROSTRUCTURE
2. DISCOLORATION	OVERHEATING + LACK OF LUBRICATION + EXTRANEIOUS ELEMENTS IN SFL		IMPROVE SOLID LUBRICATION OF RACES AND CAGES ELIMINATE EXTRANEIOUS ELEMENTS
3. QUENCH OR GRIND TYPE CRACKING	HIGH PRESSURE + OVERHEATING + FATIGUE CRACKING		EVALUATE OTHER BEARING MATERIALS HAVING HIGHER ENDURANCE LIMIT; LESS NOTCH SENSITIVITY Q/C FOR MICROSTRUCTURE
4. EXCESSIVE ROLLER END WEAR	ROLLER SKEWING + EXCESSIVE RETAINED AUSTENITE		ESTABLISH & SPECIFY THE HEAT TREATMENT TO INCLUDE CRYOGENIC CYCLING. DETERMINE CRYOGENIC MECHANICAL PROPERTIES
5. POOR MICROSTRUCTURE A. HIGH DIRT - COUNT B. MASSIVE CARBIDES	AIR MELTING	USE VACUUM	USE VACUUM MELTED MATERIAL ESTABLISH & SPECIFY THE HEAT TREATMENT TO INCLUDE CRYOGENIC CYCLING. DETERMINE CRYOGENIC MECHANICAL PROPERTIES Q/C FOR MICROSTRUCTURE
C. CARBIDE STRINGERS	HEAT TREATMENT, TEMP. TOO HIGH POOR MELTING PRACTICE

NERVA PROGRAM

NERVA BEARINGS - REON MATERIALS DEPARTMENT SUPPORT PLAN

OBSERVATIONS	POSSIBLE CAUSES	INTENDED ACTION
6. HIGH RETAINED AUSTENITE	HEAT TREATMENT	ESTABLISH AND SPECIFY THE HEAT TREATMENT TO INCLUDE CRYOGENIC CYCLING. DETERMINE CRYOGENIC MECHANICAL PROPERTIES.
7. CAGE RUPTURE	DELAMINATED MATERIAL AND INFERIOR QUALITY + RADIATION EFFECTS	DETERMINE AND SPECIFY DESIRED MECHANICAL PROPERTIES TEST IRRADIATED MATERIAL

NERVA PROGRAM

STRUCTURAL ANALYSIS STATUS

1. PUMP HOUSING
2. IMPELLER
3. TURBINE ROTORS
4. CRITICAL SPEED

NERVA PROGRAM

CROSS-SECTION OF PUMP HOUSING CASTING

SECTION H-H

MAXIMUM MERIDIONAL STRESS

$$(\sigma_{\xi})_i = 30,900 \text{ psi}$$

$$(\sigma_{\xi})_o = -13,200 \text{ psi}$$

$$(\sigma_{\xi})_i = 17,700 \text{ psi}$$

$$(\sigma_{\xi})_o = -6,800 \text{ psi}$$

SECTION C-C

Design curves used in selection of volute wall thickness for the pump housing casting are presented. These design curves are obtained by means of the following procedure.

(1) Computer program 1040 is used to determine the stresses in the volute wall. The maximum stresses occur at section H-H and are based on an internal pressure of 1500 psi and nominal wall thickness of 0.40 in.; i.e.,

inner surface meridional stress (σ_{ξ}) = 30,900 psi

outer surface meridional stress (σ_{ξ}) = -13,200 psi

Expressed in terms of direct stress, σ_a , and bending stress, σ_b , the above stresses become

$$\sigma_{\xi} = 8,850 \pm 22,050 \text{ psi}$$

where the upper sign is used for the inner surface and the lower sign is used for the outer surface.

(2) Now for small changes in wall thickness that affect geometry of cross sections only slightly, the maximum stresses in step (1) can be extrapolated as follows:

In general

$$\sigma_{\xi} = \frac{N_{\xi}}{t} \pm \frac{6M_{\xi}}{t^2}$$

so that

$$\begin{aligned} &= \frac{N_{\xi}}{t_0} \left(\frac{t_0}{t} \right) \pm \frac{6M_{\xi}}{t_0^2} \left(\frac{t_0}{t} \right)^2 \\ &= \sigma_a \left(\frac{t_0}{t} \right) \pm \sigma_b \left(\frac{t_0}{t} \right)^2 \\ &= \sigma_a^1 \pm \sigma_b^1 \end{aligned}$$

where N_{ξ} = meridional stress resultant, lb/in.

t_0 = thickness for original analysis, in.

M_{ξ} = meridional stress couple, in.-lb/in.

t = thickness for extrapolation, in.

Also, for various pressures

$$\begin{aligned} \sigma_{\xi} &= \frac{p}{p_0} \left[a \left(\frac{t_0}{t} \right) \pm b \left(\frac{t_0}{t} \right)^2 \right] \\ &= \frac{p}{p_0} \left[\sigma_a^1 \pm \sigma_b^1 \right] \end{aligned}$$

where p_0 = pressure for original analysis, psi

p = pressure for extrapolation, psi

(3) The extrapolated maximum stresses of step (2) can now be used to determine the predicted yield pressure. The yield pressure is defined as the pressure at which the maximum stress equals the .2% offset yield strength of the material and is determined by setting the margin of safety equal to zero, i.e.,

$$M.S. = \frac{p}{p_o} \left[\frac{\sigma_a^1}{F_{tu}} + \frac{\sigma_b^1}{B_y} \right] - 1 = 0$$

so that

$$p_y = \frac{1}{\frac{\sigma_a^1}{F_{ty}} + \frac{\sigma_b^1}{B_y}}$$

where

p_y = yield pressure, psi

F_{ty} = yield stress at which permanent strain equals 0.2% psi

B_y = yield bending modulus for a rectangular cross section, psi

A yield bending modulus is used to account for the fact that in the inelastic range, the strain distribution is still linear but the stress distribution is non-linear, due to plastic effects.

Also, a linear interaction curve is used for the margin of safety since the direct stress, σ_a^1 and bending stress, σ_b^1 , add algebraically.

(4) The extrapolated maximum stresses of step (2) are also used to determine the predicted burst pressure. The burst pressure is defined as the pressure at which the maximum stress equals the ultimate strength of the material and is determined by setting the margin of safety equal to zero; i.e.,

$$M.S. = \frac{p}{p_o} \left[\frac{\sigma_a^1}{F_{tu}} + \frac{\sigma_b^1}{B_u} \right]$$

so that

$$P_b = \frac{p_o}{\frac{\sigma_a^1}{F_{tu}} + \frac{\sigma_b^1}{B_u}}$$

where

P_b = burst pressure, psi

F_{tu} = ultimate tensile stress, psi

B_u = ultimate bending modulus for a rectangular cross section, psi

An ultimate bending modulus and linear interaction curve are used for reasons similar to those of step (3).

(5) The design requirements for yield and burst pressure are determined by the following criteria :

$$\frac{\text{proof pressure}}{\text{max. working pressure}} = 1.09$$

$$\frac{\text{yield pressure}}{\text{Proof pressure}} = 1.15$$

$$\frac{\text{burst pressure}}{\text{proof pressure}} = 1.25$$

$$\left(\frac{\text{proof pressure}}{\text{at } -423^{\circ}\text{F}} \right) = \left(\frac{\text{proof pressure}}{\text{at R.T.}} \right) \frac{(F_{ty} \text{ at } -423^{\circ}\text{F})}{(F_{ty} \text{ at R.T.})}$$

YIELD PRESSURE vs WALL THICKNESS

BURST PRESSURE vs WALL THICKNESS

NERVA MARK III MOD 4 PUMP IMPELLER
AT 24,000 RPM
TANGENTIAL STRESS vs RADIUS

NERVA MARK III MOD 4 PUMP IMPELLER
AT 24,000 RPM
RADIAL STRESS vs RADIUS

STRESS	LOADING	
	PRESSURE	ROTATION*
DIRECT	0	5 400
BENDING	26 600	0

IMPELLER VANE ANALYSIS - FULL VANES -

TOTAL STRESS = 32 000 PSI

* SHAFT SPEED = 24 000 RPM

RELATION OF VARIABLE AND MEAN STRESS COMPONENTS

RELATION OF VARIABLE AND MEAN STRESS COMPONENTS

NOTCHED FATIGUE STRENGTH (10^6 CYCLES)
OF INDUCER SECTION
FULL VANES

TEMPERATURE = - 423 °F

SHAFT SPEED = 24000 RPM

$K_t = 3.15$

UNNOTCHED FATIGUE STRENGTH (10^6 CYCLES)
OF INDUCER SECTION
FULL VANES

TEMPERATURE = -423°F
SHAFT SPEED = 24,000 RPM

FATIGUE STRENGTH OF 7075-T6 ALUMINUM

MAXIMUM SEAL RING
 ROTATIONAL STRESSES VS SHAFT SPEED
 (RADIUS = 1.5 IN.)
 (RADIUS = 1.5 IN.)

PROFILE OF FIRST STAGE ROTOR - COMBINED MECHANICAL STRESSES

PROFILE OF FIRST STAGE ROTOR - COMBINED MECHANICAL STRESSES

PROFILE OF SECOND STAGE ROTOR - COMBINED MECHANICAL STRESSES

PROFILE OF SECOND STAGE ROTOR - COMBINED MECHANICAL STRESSES

MARK III MOD 4 TURBOPUMP

<u>ITEM</u>	<u>WEIGHT (LBS.)</u>	
	SYSTEM	TOTAL
TURBOPUMP ASSEMBLY		345
PUMP	155	
POWER TRANSMISSION	50	
TURBINE	140	

ACTUAL	10%
CALCULATED	75%
ESTIMATED	15%

NERVA PROGRAM

I. SUMMARY

THIS PRELIMINARY REPORT SUMMARIZES THE STRUCTURAL VIBRATION
ANALYSIS PERFORMED ON THE NERVA MARK III MOD 4 TURBOPUMP
AND ITS ASSOCIATED TEST STRUCTURES.

NERVA PROGRAM

II. INTRODUCTION

THE OBJECTIVES FOR STUDYING THE NERVA TURBOPUMP STRUCTURAL VIBRATION:

1. TO EXAMINE THE CRITICAL SPEED CHARACTERISTICS OF THE TURBOPUMP ASSEMBLY UNIT.
2. TO INVESTIGATE THE SYMMETRICAL, UNSYMMETRICAL OR FLEXURAL VIBRATION OF THE TURBINE DISK
3. TO EXAMINE THE BASIC STRUCTURAL DYNAMIC CHARACTERISTICS OF THE TEST STRUCTURES ASSOCIATED WITH THE TURBOPUMP
4. TO STUDY THE STRUCTURAL VIBRATION COUPLING PHENOMENA BETWEEN THE TURBOPUMP CRITICAL SPEED AND THE VIBRATION OF THE TEST STRUCTURE.

NERVA PROGRAM

IMPELLER - ROTOR SHAFT SYSTEM

NERVA PROGRAM

RIGIDITY EI VS. TPA STATION X

NERVA PROGRAM

EFFECTIVE CROSS SECTIONAL AREA FOR SHAFT RIGIDITY NERVA TPA

MARK III

MOD 4

NERVA PROGRAM

NODAL REPRESENTATION OF TPA TURBINE DISK VIBRATION

n = Diameter Nodal Line
 s = Circular Nodal Line

NERVA PROGRAM

UNCOUPLED CRITICAL SPEED VS. ROLLER BEARING SPRING STIFFNESS

NERVA PROGRAM

NATURAL FREQUENCY VS. TURBOPUMP INLET + EXHAUST PIPELINE STIFFNESS

NERVA PROGRAM

PREDICTED, UNCOUPLED CRITICAL SPEED AS A FUNCTION OF BEARING STIFFNESS

NERVA TPA MARK III MOD 4 (UPPER CRITICAL SPEED LIMIT)

SPRING STIFFNESS LB./IN.	MODE NO.	b RPM	b _s RPM	b _r RPM	b _g RPM	b _{sr} RPM	b _{srg} RPM
10 ⁴	1ST	2,154	2,154	2,154	2,322	2,010	2,322
	2ND	3,690	3,690	3,690	3,714	3,678	3,714
	3RD		74,340	49,782		3,678	
10 ⁵	1ST	6,780	6,780	6,360	7,320	6,300	7,320
	2ND	11,520	11,520	11,460	11,580	11,460	11,520
	3RD	77,280	75,360	50,400	145,800	50,220	125,220
10 ⁶	1ST	20,760	20,520	19,200	22,740	18,900	22,500
	2ND	31,920	31,560	30,660	32,880	30,420	32,520
	3RD	87,960	85,920	59,400	151,800	59,160	131,700
3.4 X 10 ⁶ NERVA TPA	1ST	35,280	34,080	31,680	39,840	30,600	38,460
	2ND	44,220	43,260	38,160	50,400	37,680	48,660
	3RD	116,340	112,560	87,300	166,320	85,200	146,400
10 ⁷ q	1ST	46,560	44,640	38,700	57,060	12,600	53,460
	2ND	54,600	51,600	44,400	69,960		64,140
	3RD	168,600	155,640	137,220	196,980		172,620
10 ⁸	1ST	50,160	48,420	40,380	68,760	39,780	62,880
	2ND	76,020	66,660	55,560	138,780	50,460	97,440
	3RD	236,040	199,860	183,360	308,820	171,720	221,940
10 ⁹	1ST	50,520	49,960	40,260	70,380	40,020	63,780
	2ND	79,380	69,060	59,760	173,640	51,480	105,660
	3RD	243,120	204,240	183,900	340,740	172,380	230,820

NERVA PROGRAM

COUPLED CRITICAL SPEEDS AT UPPER LIMIT
TPA MOUNTED ON THE H₆ TEST STRUCTURE

NERVA PROGRAM

COUPLED CRITICAL SPEEDS AT LOWER LIMIT
TPA MOUNTED ON THE H₆ TEST STRUCTURE

NERVA PROGRAM

PREDICTED BEARING LOAD VS. TURBOPUMP SPEED

NERVA PROGRAM

PREDICTED MAXIMUM AMPLITUDE OF VIBRATION OF H₆ TEST STRUCTURE VS. TURBOPUMP SPEED

MARK III MOD 4

NERVA PROGRAM

ELECTROMAGNETIC - SHAKER TEST PLAN FOR CONDUCTING A LATERAL VIBRATION SURVEY

NERVA MARK III MOD 4 TPA ASSEMBLY UNIT

I. TEST OBJECTIVES

- A. TO OBSERVE AND TO DETERMINE THE FIRST THREE LATERAL RESONANT FREQUENCIES OF THE NERVA TPA MARK III MOD 4 (SIMPLY TPA HERE-AFTER) ROTOR - IMPELLER ASSEMBLY UNIT.
- B. TO CONFIRM THE ESTIMATE ON THE TPA ELASTIC RIGIDITY AND HENCE THE PREDICTION ON THE THEORETICAL CRITICAL SPEED RANGE OF THE TURBOPUMP UNIT.

II. INSTRUMENTATION AND TEST EQUIPMENT

- A. ELECTROMAGNETIC SHAKER AND A SPECIAL TEST FIXTURE
- B. ACCELEROMETERS
- C. DISPLACEMENT TRANSDUCERS / VIBROMETERS
- D. STRABOSCOPIC LIGHT AND CAMERA
- E. AUTOMATIC RECORDER UNIT ASSOCIATES WITH ACCELERATION DISPLACEMENT INPUTS AND RESPONSES

NERVA PROGRAM

SCHEMATIC DIAGRAM - TEST SPECIMEN AND ELECTROMAGNETIC SHAKER

NERVA PROGRAM

ELECTROMAGNETIC - SHAKER TEST PLAN FOR CONDUCTING A LATERAL VIBRATION SURVEY

NERVA MARK III MOD 4 TPA ASSEMBLY UNIT

IV. MEASUREMENT AND RECORDING

- A. SINGLE AND DOUBLE AMPLITUDES WITH RESPECT TO TPA STATION, TIME, INPUT "G" LEVEL, AND FORCED FREQUENCY.
- B. "G" LOAD RESPONSE TO EXCITATION WITH RESPECT TO TPA STATION, TIME INPUT "G" LEVEL AND FORCED FREQUENCY.
- C. MODAL RESPONSE PHOTOGRAPHICALLY RECORDED.

NERVA PROGRAM

ELECTROMAGNETIC - SHAKER TEST PLAN FOR CONDUCTING A LATERAL VIBRATION SURVEY

NERVA MARK III MOD 4 TPA ASSEMBLY UNIT

V. MEASUREMENT LOCATION AND DIRECTION

A. DISPLACEMENT RESPONSE -

NORMAL TO THE TPA AXIAL DIRECTION

B. ACCELERATION RESPONSE -

NORMAL TO THE TPA AXIAL DIRECTION

NERVA PROGRAM

ELECTROMAGNETIC - SHAKER TEST PLAN FOR CONDUCTING A LATERAL VIBRATION SURVEY

NERVA MARK III MOD 4 TPA ASSEMBLY UNIT

VI. TEST PROCEDURE

- A. HAVE ALL INSTRUMENT UNITS ADJUSTED AND SECURED.
- B. VARY THE ACCELERATION INPUT LEVEL OVER THE FREQUENCY RANGE FROM 10 CPS TO 600 CPS TO LOCATE THE FIRST TPA LATERAL - MODE RESONANT FREQUENCY. THE PREDICTED FIRST TPA LATERAL - MODE RESONANT FREQUENCY IS APPROXIMATELY 510 CPS. OBSERVE IF THE RESONANT FREQUENCY IS A FUNCTION OF "G" INPUT.
- C. VARY THE ACCELERATION INPUT LEVEL OVER THE FREQUENCY RANGE FROM 600 CPS TO 900 CPS TO LOCATE THE SECOND TPA LATERAL RESONANT FREQUENCY. THE PREDICTED SECOND TPA LATERAL - MODE FREQUENCY IS APPROXIMATELY 628 CPS. OBSERVE IF THE RESONANT FREQUENCY IS A FUNCTION OF "G" INPUT.
- D. VARY THE ACCELERATION INPUT LEVEL OVER THE FREQUENCY RANGE FROM 900 CPS TO 3000 CPS TO LOCATE THE THIRD TPA LATERAL RESONANT FREQUENCY. THE PREDICTED THIRD TPA LATERAL - MODE RESONANT FREQUENCY IS APPROXIMATELY 1420 CPS. OBSERVE IF THE RESONANT FREQUENCY IS A FUNCTION OF "G" INPUT.

NERVA PROGRAM

ROTATIONAL STRESSES VS SHAFT SPEED (RADIUS = 1.5 IN.)

PROFILE OF FIRST STAGE ROTOR PRESSURE STRESSES

~~1- Rotor~~

PROFILE OF SECOND STAGE ROTOR PRESSURE STRESSES

PROFILE OF SEAL RING
ROTATIONAL STRESSES

PROFILE OF FIRST STAGE ROTOR
ROTATIONAL STRESSES

RADIUS, IN.

PROFILE OF SECOND STAGE ROTOR
ROTATIONAL STRESSES

INCIDENCE TO VANE ANGLE RATIO VS FLOW PARAMETER

NERVA PROGRAM

NERVA MARK III PUMP PERFORMANCE

Q/N vs $\Delta H/N^2$

NERVA PROGRAM

PUMP PERFORMANCE CAVITATION PARAMETER VS SOLIDITY

$$K = \frac{H_{sv} - \frac{C_m^2}{2g}}{\frac{W^2}{2g}}$$

$$\sigma = \frac{\text{vane chord length from inducer tip to first partial vane}}{\text{vane chord spacing at inducer tip}}$$

NERVA MARK III MOD 3 TURBOPUMP

$$\sigma = 1.036$$

NERVA PROGRAM

NERVA MARK III MOD 4

$$\sigma = 1.85$$

NERVA PROGRAM

MARK III MOD 3 TURBOPUMP LH₂ PUMPING PERFORMANCE STALL LIMITS

NERVA MARK III MOD 4 TURBOPUMP LH₂ PUMPING PERFORMANCE STALL LIMITS

NERVA MARK III MOD 4 PUMP PERFORMANCE ESTIMATED AND EMPIRICAL DATA

PRESSURE RISE VS FLOW RATE

SYMBOLS INDICATE TEST DATA (2.0-12-NNP-002)

	RPM	NPSP	SP DENSITY
△	6000	16 psi	4.37 lb/ft ³
○	8400	16 psi	4.37 lb/ft ³
□	9000	15.5 psi	4.37 lb/ft ³
▽	12200	15.5 psi	4.37 lb/ft ³
◇	15300	15.4 psi	4.37 lb/ft ³
◇	18000	14 psi	4.37 lb/ft ³

ESTIMATED, 1.2.3-65-C-066,
NPSP = 15 psi, SP DENSITY = 4.30 lb/ft³

NERVA PROGRAM

LH₂ PERFORMANCE DOCUMENTATION
TEST OBJECTIVES

1. DOCUMENTATION OF MARK III MOD 4 PUMP PERFORMANCE AND OPERATING CONSTRAINTS FOR SPEEDS RANGING FROM 3000 TO 27,500 RPM AND OVER THE RANGE OF CONDITIONS REQUIRED FOR THE XE-1 ENGINE.
2. DOCUMENTATION OF THE TIME REQUIRED TO OBTAIN LIQUID AT THE PUMP INLET AFTER THE PROPELLANT SHUTOFF VALVE (PSOV) IS OPENED (THE VALVE IN THE STATION 75 RUN TANK).
3. DEMONSTRATION OF TURBOPUMP OVERSPEED AND TURBINE OVER-TEMPERATURE CAPABILITY.
4. DOCUMENTATION OF TURBOPUMP ROTOR THRUST AS REQUIRED TO CONFIRM PREDICTIONS.
5. DOCUMENTATION OF PRESSURES REQUIRED TO CALCULATE BEARING COOLANT FLOW RATE.

NERVA PROGRAM

PREDICTED MARK III MOD 4 TURBOPUMP PERFORMANCE TEST FLUID: WATER

$$\frac{H_{sv}}{N^2} = 2.0 \times 10^{-6} \frac{\text{ft}}{\text{Rpm}^2} \quad \rho = 62.4 \frac{\text{lb}}{\text{ft}^3}$$

NERVA PROGRAM

MARK III MOD 4 MODIFIED PUMP HOUSING

NERVA PROGRAM

DIFFUSER FLOW PATH

ENTIRE VANE - MARK III MOD 3 DIFFUSER

DARKENED AREA - MODIFIED DIFFUSER

LIST OF SYMBOLS

<u>SYMBOL</u>	<u>NOMENCLATURE</u>
A	Area
C_m	Through Flow Velocity
D_T	Tip Diameter
g	Gravitational Constant
H_{sv}	Net Positive Suction Head
ΔH	Pump Head Rise
i	Incidence Angle
K	Pump Performance Cavitation Parameter
N	Rotational Speed
Q	Volumetric Flow Rate
U	Blade Tip Speed
β_F	Fluid Angle
β_V	Vane Angle
ϕ	Flow Parameter
ψ	Head Parameter
σ	Solidity

NERVA PROGRAM

BASIC RELATIONSHIPS

$$C_m = \frac{Q}{A}$$

$$\phi = \frac{C_m}{u}$$

$$u = \frac{ND_t}{229}$$

$$\phi = \frac{g}{N^2} H$$

$$\sigma = \frac{\text{Vane chord length to first partial}}{\text{vane spacing at inducer inlet}}$$

$$\beta_F = \tan^{-1} \frac{C_m}{u}$$

$$i = \beta_v - \beta_F$$

$$\frac{i}{\beta_v} = 1 - \frac{\beta_F}{\beta_v}$$

NERVA TPA AND H₆ STRAIGHT - INLET - PIPE TEST STRUCTURE

NERVA MARK III MOD 4 RUN 2.0-12-NNP-002

TPA ACCELEROMETER DATA - "G'S"

f/10 cps	255	265	275	285	295	305	315	325	335	345	355	365	375	385	395	405	415	425	435	445	455	465	475	485	495
RPM	AXIS																								
9000	X ₁																								
	X ₂																								
	Y ₁																								
	Y ₂																								
	Z																								
12000	X ₁																							29	
	X ₂																							10	
	Y ₁																							45	
	Y ₂																							82	
	Z																							13	
15000	X ₁																				9				
	X ₂																				5				
	Y ₁																				11				
	Y ₂																						14		
	Z																						12		
18400	X ₁			5																				5	
	X ₂	6			6						8								5				6		
	Y ₁											6									5				
	Y ₂																				11				
	Z			4				4			5			5		4			4						4

NERVA PROGRAM

NERVA MARK III MOD 4 RUN 2.0-12-NNP-002
TEST STAND FRAME ACCELEROMETER DATA - "G'S"

f/10-cps		255	265	275	285	295	305	315	325	335	345	355	365	375	385	395	405	415	425	435	445	455	465	475	485	495
RPM	AXIS																									
9000	FX ₁																									
	FX ₂																									
	FY ₁																									
	FY ₂																									
	FZ												14													
12000	FX ₁																								27	
	FX ₂																								10	
	FY ₁																								20	
	FY ₂																								13	
	FZ																								10	
15000	FX ₁						8																			
	FX ₂																									
	FY ₁																									
	FY ₂																									
	FZ						15																			
18400	FX ₁												28													
	FX ₂												10													
	FY ₁												10													
	FY ₂												11													
	FZ												14

NERVA PROGRAM

PROJECTS
H-6 TPA HOT GAS DRIVE
SCHEMATIC

PROJECTS

HOT GAS DRIVE

H-6 TPA MALFUNCTION ANALYSIS

Problem	Cause	Preventative Measures
1. Overspeed Pump	<ol style="list-style-type: none"> 1. Velan fails to control 2. Non liquid condition at pump inlet 	<ol style="list-style-type: none"> 1. Turbine overspeed trip 26,000 $\pm$ 250 rpm 2. Monitor turbine inlet press not to exceed 920 psig
2. Overheat turbine	<ol style="list-style-type: none"> 1. Heater control valve fails to control 	<ol style="list-style-type: none"> 1. Monitor turbine inlet temp not to exceed 1540°F 2. Heat control has automatic shutdown in the event of temp runaway
3. PTi rise rate in excess of 100 psi/sec	<ol style="list-style-type: none"> 1. Velan valve fails to regulate 	<ol style="list-style-type: none"> 1. Velan opening rate is determined prior to testing
4. Non liquid condition at pump inlet during start transient	<ol style="list-style-type: none"> 1. Failure to monitor LH₂ temp at pump inlet 2. Malf of instrumentation 	<ol style="list-style-type: none"> 1. Monitor is visual and called for on test checkoff sheet 2. Each RTT has backup 3. Turbine overspeed trip
5. Hi-frequency instability	<ol style="list-style-type: none"> 1. Pump stall condition 2. Internal pump failure 	<ol style="list-style-type: none"> 1. Monitor Q/N 2. Manual kill when 4.5 MILS pk to pk movement either horz. or vertical @ freq. 110 cps and above
6. Turbine exhaust pressure in excess of 150 psig	<ol style="list-style-type: none"> 1. Velan valve fails to control turbine inlet pressure 2. Exhaust line collapse 	<ol style="list-style-type: none"> 1. Turbine overspeed trip 2. Visual observation of exit pressure

NERVA PROGRAM

PROJECTS

HOT GAS DRIVE

H-6 TPA MALFUNCTION ANALYSIS

Problem	Cause	Preventative Measures
7. Failure to terminate test before tank is depleted of LH_2	1. Failure to monitor tank capacity probes	1. Terminate test with 10% tank capacity remaining (visual)
8. Excessive Turbopump flange loading	1. Lines not properly secured 2. Excessive vibration	1. Have manual kill if vibration in excess of 4.5 MILS pk to pk either horiz. or vert. @ freq. of 110 cps or greater
9. Bearing temperature increase at a rate in excess of 50°F/sec	1. Bearing coolant flow filter failure 2. Bearing coolant flow rate partially restricted 3. LH_2 contains contamination 4. Bearing failure	1. Visual observation-manual kill 2. Tank fill system has 10 micron filter
10. Pump discharge load control valve fails during run	1. Hydraulic electric failure 2. Servo control failure Note: Valve remains in position that failure occurred. Valve has a tendency to creep closed	1. Monitor Q/N for stall condition 2. Visual observation/manual kill 3. Facility backed up by bank of batteries.
11. Catch tank VH-10 fills prior to test termination	1. Failure to evacuate tank prior to run	1. Test check-list calls for filling tank VH-11 from VH-10.
12. Failure to terminate purge pressure prior to start transient	1. Failure to manually terminate purge pressure	1. Purge press termination included as part of test checkoff sequence during countdown

NERVA PROGRAM

PROJECTS

HOT GAS DRIVE H-6 TPA MALFUNCTION ANALYSIS

Problem	Cause	Preventative Measures
13. TSOV Closes during run	1. Loss of facility power 2. Mechanical failure	1. Facility power backed up by a bank of batteries 2. Turbine overspeed trip
14. Failure of facility hardware upstream of pump (FM, valves, seals, etc.)	1. Component fatigue	1. Physical layout of stream acts as natural trap
15. Low bearing pressure drop Pbh-PgGt	1. Turbine exit pressure exceeds bearing housing exit pressure	1. Visually monitor Pgh-PgGt (Manual kill)
16. Velan valve leakage	1. Valve seat galling 2. Valve seat contamination	1. TPCV added for extra safety 2. Leak check valve prior to run 3. Vent between velan and TPCV
17. Excessive facility line vibration	1. Improper line tie-down	1. Physically inspect facility tie-downs prior to run
18. Catch tank valve fails during run	1. Power failure 2. Mechanical failure	1. Facility power backed-up by a bank of batteries

NERVA PROGRAM

VELAN VALVE CROSS-SECTION

SCHEMATIC VELAN VALVE

TURBOPUMP MECHANICAL MAJOR EFFORT IS 2ND QUARTER CY 65

Engineering:

1. Continue Impeller Material Improvement
2. Continue Redesign of Turbine Manifold
3. Design Handling and Storage Container
4. Continue Work on Back-Up Seals
5. Initiate Work on Turbopump Model Spec

Testing:

1. Endurance Test Turbopump and Evaluate
2. Conduct Spin Tests on Impeller

NERVA PROGRAM

TURBOPUMP BEARING DEVELOPMENT MAJOR EFFORTS 2ND QUARTER CY 65

1. Effects of Overspeed
2. Effects of Thrust Loads up to 4000 lbs
3. Effects of Coolant Flow Rate
4. Performance of Back-Up Roller Bearings
 - (a) RBEC-7 Class Instead of RBEC-5
 - (b) 440C Mod CEVM Material
 - (c) Roller Elements - Inner Roll Guided
- Outer Race Guided
 - (d) Rolling Element Guide Shoulder Angle
Increased from 0° to ½°-1½°

NERVA PROGRAM

TURBOPUMP ANALYTICAL MAJOR EFFORTS 2ND QUARTER CY 65

1. Turbopump Performance Testing and Analysis
2. Document Bearing Axial Thrust by Testing
3. Water Testing of Mark III Mod 4 Pump
4. Water Test Data Analysis (Normalized)
5. Instrumentation Evaluation

NERVA PROGRAM

TURBOPUMP MATERIAL DEVELOPMENT MAJOR EFFORTS 2ND QUARTER CY 65

1. Pump Impeller - Correlate properties, tensile and fatigue at room temperature and cryogenic (-423°F) (continued)
2. Pump Housing - Establish casting properties and ductility at room temperature and cryogenic (-423°F) (continued)
3. Turbine - Investigate high temperature Creep (continued)
- Investigate cryogenic properties
4. Bearings - Investigate cryogenic properties of metal parts
- Mechanical properties of Irradiated Cates (Armalon)

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TURBOPUMP STRUCTURES DEVELOPMENT MAJOR EFFORTS 2ND QUARTER CY 65

1. Complete Impeller Stress Analysis
2. Complete Final Turbopump Vibration Report
3. Continue Development of Computer Program for Turbine Vibration Analysis -
Raleigh-Ritz
4. Continue Refinement of Axisymmetric Computer Program for Stress
Analysis - Finite Element Method
5. Analyze Impeller Spin and Burst Data
6. Analyze Lateral Vibration Survey Data

NERVA PROGRAM

NRX/EST VALVE SELECTION

<u>SYSTEM REQUIREMENT</u>	<u>PRIME CANDIDATE</u>	<u>ALTERNATE CANDIDATE</u>	<u>STATUS AT 22 JANUARY</u>
Propellant Shutoff Valve	None	Pacific 8" gate Velan 8" gate Flomatics 8" ball	Preliminary LH ₂ evaluation test complete on Pacific valve
Discharge Shutoff Valve	Rocketdyne OBV-86	AGC Titan II redesign	OBV-86 for NRX/EST ordered from WANL. AGC Titan II redesign in progress
Discharge Check Valve	Loud per SCD 285994	None	Check valve low flow LH ₂ tests completed
Turbine Power Control Valve	TPCV with NT-C2 Bendix Actuator	None	Hot gas leak and cycle tests in process
Turbine Inlet Line Shutoff Valve	TPCV with Pneumatic Actuator	None	Actuator functionally checked with GN ₂
Purge Check Valve (Elevated Temp)	Vacco	AGC	Valves on order
Purge Check Valve (Cryogenic Temp)	Circle Seal	Vacco	Valves on order
Diluent Valve	TPCV with NT-B4 Bendix Actuator	AGC Titan II redesign	TPCV submerged in LN ₂ - design analysis complete Titan redesign LN ₂ functional tests in progress
Pump Inlet and Pump Discharge Vent Valves	Flomatics	Vacco	Valves on order

NERVA PROGRAM

NRX/EST PRIME VALVE AND LINES

COMPONENT	Requirements Established	Spec. Control Dwg. Complete	EST Selection	Fab & Assy Dwgs. Complete	Design Report	Test Plan	Eval. Units Available	Initial Func- tional Tests	Operational Tests	EST Items Available	Test Report	Acceptance Test EST Items	Acceptance Report	Delivery
Turbine Power Control Valve (TPCV with NT-C2 Actuator)		X												
Turbine Inlet Shutoff Valve (TPCV with HGDV Actuator)		X												
Turbine Inlet Vent Valve (TPCV with HGDV Actuator)		X												
Diluent Control Valve (TPCV with NT-B4 Actuator)		X												
Discharge Shutoff Valve (OBV-86)														
Discharge Check Valve (Loud)														
Vent and Purge Valves (Flomatics)														
Purge Check Valves (Vacco and Circle Seal)														
PSOV Spool Replacement		X				X	X	X	X		X			
Pump Inlet Line		X				X	X	X	X		X			
EST Inlet Line		X				X	X	X	X		X			
Turbine Exhaust Line		X				X	X	X	X		X

NERVA PROGRAM

NRX/EST ALTERNATE VALVES

COMPONENT		Requirements Established	Spec. Control Dwg. Complete	EST Selection	Fab & Assy Dwgs. Complete	Design Report	Test Plan	Eval. Units Available	Initial Functional Tests	Operational Tests	EST Items Available	Test Report	Acceptance Test EST Items	Acceptance Report	Delivery
Pump Inlet Shutoff Valve	Pacific														
	Valen														
	Flomatics														
Discharge Shutoff Valve	5" Titan Redesign														
Diluent Control Valve	3" Titan Redesign														
Purge Check Valve	AGC (Elevated & Cryogenic)														
	Vacoco (Cryogenic)														
Vent and Purge Valve	Vacoco

NERVA PROGRAM

LINE AND VALVE FABRICATION AND PROCUREMENT

FABRICATION AND PROCUREMENT COMPLETED:

48 SPARE CONOSEAL FLANGES FOR VALVE TEST TOOLING

PUMP INLET LINE FOR CFDT'S

PARKER 6" BALL VALVE FOR ENGINEERING EVALUATION

PACIFIC 8" GATE VALVE FOR ENGINEERING EVALUATION

TWO 3" LH₂ CONTROL VALVES FOR ENGINEERING EVALUATION

FOUR TPCV'S WERE ASSEMBLED

NERVA PROGRAM

VALVE TESTS COMPLETED 1ST QUARTER 1965

<u>COMPONENT</u>	<u>TYPE OF TEST</u>	<u>RESULTS</u>
TPCV	Hydraulic actuator Actuation timing	Showed valve actuator could be closed in 50 milliseconds for H ₂ heater use.
TPCV	Leakage	Demonstrated ambient leakage with lap-gap piston ring configuration to be half that of present ring configuration.
TPCV with NT-B4 Actuator	CFDTS acceptance	Torque, leakage, and proof tests were acceptable, gate position - calibrated, and response characteristics documented.
ECCV	CFDTS acceptance	Proof, leak, crack and reseating pressures were acceptable.
Diluent Valve (redesigned Titan II)	LN ₂ Functional	LN ₂ leak and mechanical function were satisfactory - ambient positioning tests resulted in a feasible control system.

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TPCV GATE SEAL RINGS

TYPE: LAP GAP
VENDER P/N: AAG - 6796
MATERIAL: HAYNES 25
RC 38 MIN.
VENDER: DOVER CORP, COOK
AIRTOMIC DIV.

STEP GAP
3-7400-3
HASTELLOY C
RC 38 - 40
PRECISION PISTON RING, INC.

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LN₂ CYCLE TEST: 3" DILUENT CONTROL VALVE SCHEMATIC

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NRX/EST DISCHARGE SHUTOFF VALVE (OBV-86)

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TURBINE POWER CONTROL VALVE WITH ACTUATOR

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2 INCH SHUTOFF VALVE (FLOMATICS)

NRX/EST PUMP INLET LINE

NRX/EST TURBINE EXHAUST LINE

SUBTASK 1.2 NRX/EST SEAL AND COUPLING REQUIREMENTS

<u>Nominal Joint Size</u>	<u>Part Number</u>		<u>Number Required</u>
	<u>Seal</u>	<u>Coupling</u>	
8"	283426	284105	4
7"	283557	284052	1
5"	283418	284048	1
5"	283414	284044	8
4"	283410		16
		284040	8
		Marman 59629-450	8
	276065		1
3"	263957	284081	8
2"	263961	284085	8

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