NUCLEAR DIVISION

RN-PA-0018

SYSTEMS ENGINEERING AND
TRADE-STUDY-REPORTS MEETING
(BOOK 1 OF 2)

MASTER

NERVA Program

Contract SNP-1

22 and 23 April 1969

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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SYSTEMS-ENGINEERING AND
TRADE-STUDY-REPORTS MEETING
(BOOK 1 OF 2)

NERVA Program

Contract SNP-1

NUCLEAR ROCKET OPERATIONS

22 and 23 April 1969

CLASSIFICATION CATEGORY

UNCLASSIFIED

J. M. Spadley
CLASSIFYING OFFICER

5 May 1969
DATE

AEROJET-GENERAL CORPORATION
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NERVA MANAGEMENT PLAN

D. E. Price

NERVA PROGRAM MANAGEMENT PLAN
FUNCTION/RESPONSIBILITY MATRIX FORMAT

*** What ***

*** How ***

*** Where ***

Functional Event
Number

Description of Function/Output Document

Data Item
Descript.
Form 9 or
Directive

Constraining Input
to Function Number

Who (Operational Discipline)

P	C	P	S	S	M	R	M	Q	D	T	L	Q	S	P	M	T	T	R	F	F	D	C	N	W
R	O	R	T	Y	A	A	F	U	E	H	O	U	A	R	A	E	E	E	A	A	A	O	U	A
O	N	O	R	S	T	D	G	A	S	E	G	A	F	O	N	S	S	L	C	C	T	N	C	N
J	T	G	U	C	E	E	E	L	I	R	I	L	E	C	U	T	T	I	A	S	A	I	A	L
M	A	P	T	N	E	F	N	E	N	O	T	A	Y	R	A	P	P	B	A	N	M	G	N	
G	D	L		G	N	F	G	N			I	S		E	C		I	C	D	M	G	A		
R	M	A	A	R	G		R	G	E	A	C	S		M	T	S	N	L	T	S	M	M	L	
	I	N	N		R	E		R	N	N	S	U		E	U	A	R	I	O		T	G		
	N		A			N			G	A		R		N	R	C	D	T			M			
			L			G			R	L				T	E		S	Y			T			

P = Denotes primary responsibility for execution of function or preparation of output document.

S = Denotes supporting responsibility for execution of function or preparation of output document.

R = Denotes review responsibility for execution of function or preparation of output document.

A = Denotes approval (sign-off) responsibility for execution of function or preparation of output document.

X = Recommendation prerogative of function or output document (considered & disposed of by Program Manager).

PERT STATUS (PDR)

NERVA MANAGEMENT PLAN STATUS

SYSTEMS ENGINEERING

FFD's AND RAS's

S. A. Varga

NERVA SYSTEM ENGINEERING DOCUMENTATION

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TRADE STUDIES	S-54
SCHEMATIC BLOCK DIAGRAMS	S-55
TIME LINE SHEETS	S-56
MISSION DATA BOOK	S-114

TOP LEVEL

NOTE THIS FUNCTIONAL FLOW DIAGRAM IS ANNOTATED WITH *NO GO* PATHS TO REFLECT REQUIREMENTS FOR MAINTENANCE AND SAFETY ACTIONS THESE *NO-GO* PATHS WILL *NOT* BE SHOWN IN LOWER LEVEL EXPANSIONS OF THE *GO* FUNCTIONS HOWEVER, BLOCKS 8.0 AND 9.0 WILL BE EXPANDED TO FACILITATE ANALYSIS OF MAINTENANCE AND SAFETY ACTIONS

FUNCTION 1.1 PERFORM MISSION "B"

FIRST LEVEL

SYSTEM ENGINEERING LEVELS
FOR
BLOCKS 1.0 AND 2.0

TOP LEVEL

GENERAL

FIRST LEVEL

VEHICLE

SECOND LEVEL

STAGES

THIRD LEVEL

ENGINE/AIRFRAME

FOURTH LEVEL

SUBSYSTEM & COMPONENTS

FIFTH LEVEL

COMPONENTS

FUNCTION 2.1 PERFORM LAUNCH AND BOOST OPERATIONS FOR MISSION "B"

SECOND LEVEL

FUNCTION 1.1 PERFORM MISSION "B"

SECOND LEVEL

NERVA PROPULSION SYSTEM CHARACTERISTICS

<u>CHARACTERISTICS</u>	<u>SOURCE</u>
1. MINIMUM STEADY STATE I_{sp}	NPRD
2. MINIMUM STEADY STATE THRUST	NPRD
3. CHILLDOWN PROPELLANT MASS BY RUN AND MISSION	TRADE STUDY
4. STARTUP/THRUST BUILDUP CHARACTERISTICS OF THE PROPULSION SYSTEM IN TERMS OF I_{sp} AND THRUST AS A FUNCTION OF TIME.	TRADE STUDY
5. SHUTDOWN CHARACTERISTICS IN TERMS OF THRUST AND I_{sp} AS A FUNCTION OF TIME FOR THE FOLLOWING CASES: A. INDEPENDENT OF HISTORY, EXTENDED TO COOLDOWN TEMPERATURE. B. DEPENDENT ON HISTORY, EXTENDED TO FIRST FLOW INTERRUPTION.	TRADE STUDY
6. COOLDOWN: A. CONTINUOUS COOLDOWN - USED PROPELLANT MASS B. INTERMITTENT COOLDOWN - PULSED PATTERNS (TIME, THRUST, I_{sp})	TRADE STUDY
7. ENGINE WEIGHT WITHOUT SHIELDING	TRADE STUDY
8. SHIELDING WEIGHT A. INTERNAL TO ENGINE B. EXTERNAL TO ENGINE C. AT PAYLOAD	TRADE STUDY
9. ENGINE LENGTH	TRADE STUDY

NERVA SYSTEM ENGINEERING ITERATION

SCHEMATIC BLOCK DIAGRAM LEVELS

SCHEMATIC BLOCK DIAGRAM LEVELS

SCHEMATIC BLOCK DIAGRAM LEVELS

SCHEMATIC BLOCK DIAGRAM LEVELS

SCHEMATIC BLOCK DIAGRAM LEVELS

SYSTEMS ENGINEERING LEVELS FOR BLOCK 1.0

LEVELS	TYPICAL FFD EXAMPLES	SPD CONSIDERATIONS (TYPICAL)	PERFORMANCE FUNCTIONS TO BE ALLOCATED IN RAS'S	PRIME INFORMATION SOURCE
TOP	1.0 PERFORM MISSIONS (NUCLEAR STAGE OPERATIONS)			TECH. DIV. 69-14 & 69-17 NPRD
1ST	1.1 PERFORM MISSION B	VEHICLE PAYLOAD I-U S-N	ΔV - VELOCITY $\Delta V \text{ FT/SEC} = R(I_t, M)$	MISSION DATA BOOK
2ND	1.1.1 PROVIDE S-N IMPULSE	S-N AIR FRAME/TANK ENGINE EXTERNAL INTERFACES	I_t - TOTAL IMPULSE - LB-SEC M - MASS M = K - EXPENDABLES $I_t = R(F, t)$	MISSION DATA BOOK TRADE STUDIES 010, 003, 011
3RD	1.1.1.6 BUILD UP THRUST	ENGINE PFS PSS NOZZLE I&C TSS PV NSS EXTERNAL INTERFACES	F - THRUST t - TIME $F = R(\dot{w}, T, P, \emptyset)$	TRADE STUDIES 009, 005, 001, 004, 002, 006, 007, 012, 013, & 014
4TH	1.1.1.6.2 DIRECT AND CONTROL PROPELLANT FLOW	PROPELLANT FEED S/S TPA PSOV DSOV TBV TPCV TIL PDL TEL EXTERNAL INTERFACES	$\dot{w}$ - MASS FLOW P = PRESSURE T = TEMPERATURE $\emptyset$ = THRUST ANGLE	TRADE STUDIES - TBD
5TH	1.1.1.6.2.1 PROPELLANT SHUT-OFF VALVE	TPCV ACTUATOR EXTERNAL INTERFACES	SUB-ALLOCATIONS OF $\dot{w}$, P, & T	TRADE STUDIES - TBD

SYSTEMS ENGINEERING

FFD's AND RAS's

L. E. Little

SYSTEMS ENGINEERING LEVELS FOR BLOCK 1.0

LEVELS	TYPICAL FFD EXAMPLES	SPD CONSIDERATIONS (TYPICAL)	PERFORMANCE FUNCTIONS TO BE ALLOCATED IN RAS'S	PRIME INFORMATION SOURCE
TOP	1.0 PERFORM MISSIONS (NUCLEAR STAGE OPERATIONS)			TECH. DIV. 69-14 & 69-17 NPRD
1ST	1.1 PERFORM MISSION B	VEHICLE PAYLOAD I-U S-N	ΔV - VELOCITY ΔV FT/SEC = $R(I_t, M)$	MISSION DATA BOOK
2ND	1.1.1 PROVIDE S-N IMPULSE	S-N AIR FRAME/TANK ENGINE	I_t - TOTAL IMPULSE - LB-SEC M - MASS M = K - EXPENDABLES $I_t = R(F, t)$	MISSION DATA BOOK TRADE STUDIES 010, 003, 011
3RD	1.1.1.6 BUILD UP THRUST	ENGINE PFS PSS NOZZLE I&C TSS PV NSS	F - THRUST t - TIME $F = R(\dot{w}, T, P, \theta)$	TRADE STUDIES 009, 005, 001, 004, 002, 006, 007, 012, 013, & 014
4TH	1.1.1.6.2 DIRECT AND CONTROL PROPELLANT FLOW	PROPELLANT FEED S/S TPA PSOV DSOV TBV TPCV TIL PDL TEL	$\dot{w}$ - MASS FLOW P = PRESSURE T = TEMPERATURE θ = THRUST ANGLE	TRADE STUDIES - TBD
5TH	1.1.1.6.2.1 PROPELLANT SHUT-OFF VALVE	TPCV ACTUATOR	SUB-ALLOCATIONS OF $\dot{w}$, P, & T	TRADE STUDIES - TBD

SYSTEM ENGINEERING LEVELS
FOR
BLOCKS 1.0 AND 2.0

TOP LEVEL	GENERAL
FIRST LEVEL	VEHICLE
SECOND LEVEL	STAGES
THIRD LEVEL	ENGINE/AIRFRAME
FOURTH LEVEL	SUBSYSTEM & COMPONENTS
FIFTH LEVEL	COMPONENTS

REQUIREMENTS ALLOCATION SHEET										
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSIONS (NUCLEAR STAGES OPERATIONS) - 1.0</u> OR										
NOMENCLATURE AND NUMBER OF CEI <u>(A)</u>										
FUNCTION NAME AND NUMBER (B)	DESIGN REQUIREMENTS (C)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FACILITY REQUIREMENTS (D)	EQUIPMENT IDENTIFICATION (E)		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENT (F)				PROCEDURAL DATA REQTS (G)
				NOMENCLATURE (E1)	CEI, ECC OR DETAIL SPEC OR INDEX NO. (E2)	TASKS (F1)	TIME REQD (F2)	PERFORMANCE REQTS (F3)	TRAINING AND TRAINING EQPT REQTS (F4)	
1.0 Perform Missions (Nuclear Stages Operations)	<u>Description of Function</u> This function provides for the application of a nuclear powered stage to manned and unmanned Saturn vehicles to accomplish the following flight missions: a. Mission A - the purpose of this mission is to shuttle man and materials between a low Earth orbit and a satellite station keeping in a synchronous orbit. To complete round trip will be assumed. b. Mission B - thrusting a manned payload to synchronous orbit. - The purpose of this mission is to deliver a large, manned payload to a satellite station keeping in a synchronous orbit. c. Mission C - The purpose of this mission is to place a large, unmanned payload on a trajectory to Jupiter using a direct ascent. In subsequent level, each candidate mission shall be individually analyzed to: a. Establish the performance requirements levied on the Stage Nuclear (S-N) by each mission and translate these performances into design requirements for the nuclear engine and its subsystems. b. Establish the performance requirements levied on other vehicle elements by the S-N for translation of the performance requirements into design requirements for subsystems of the vehicle element. c. Identify the interfaces between the S-N and the Saturn Vehicle (S-V) as well as the interface between the S-N and the payload.									

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FUNCTION 1.1 PERFORM MISSION "B"

SECOND LEVEL

4-19-69

REQUIREMENTS ALLOCATION SHEET										
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSIONS (NUCLEAR STAGE OPERATIONAL PHASE) - 1 0</u> OR NOMENCLATURE AND NUMBER OF CEI <u>(A)</u>										
FUNCTION NAME AND NUMBER (B)	DESIGN REQUIREMENTS (C)	REFERENCE OR TRADE AND DESIGN STUDY NO (H)	FACILITY REQUIREMENTS (D)	EQUIPMENT IDENTIFICATION (E)		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENT (F)				PROCEDURAL DATA REQTS (G)
				NOMENCLATURE (E1)	CEI, ECC OR DETAIL SPEC OR INDEX NO. (E2)	TASKS (F1)	TIME REQD (F2)	PERFORMANCE REQTS (F3)	TRAINING AND TRAINING EQPT REQTS (F4)	
1.1 Perform Mission "B"	<p><u>I. Description of Function</u></p> <p>The objective of this function is to place a manned payload into a synchronous equatorial earth orbit. This function is performed to comply with requirements of NPRD-1</p> <p><u>II. Design Requirements</u></p> <p>A means is required to (1) complete the boosting of a vehicle to a low altitude parking orbit, (2) thrust to achieve a high altitude elliptical orbit, (3) thrust to inject the vehicle into the desired synchronous orbit, (4) separate and dispose of unnecessary equipment, and (5) perform payload operations. The assumed vehicle configuration for satisfying this function is presented in Section III of this RAS. The means must provide the following</p> <p>3.1.1 Functional Performance Characteristics</p> <p>a. Impulse during three thrusting cycles of sufficient magnitude to achieve the synchronous circular orbit</p> <p>b. A life sustaining environment for the astronauts.</p> <p>c. Guidance and control of the vehicle throughout the flight path.</p> <p>d. Safe disposal of expended equipment</p> <p>e. Safe return of the astronauts to earth following completion of mission objectives.</p>	<p>NPRD-1 Appendix B dtd June 1968</p> <p>NPRD-1 Appendix B dtd June 1968</p>								
					Stage Nuclear					
					Payload					
					Instrument- ation Unit					

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FUNCTIONAL DIAGRAM TITLE AND NUMBER PERFORM MISSIONS (NUCLEAR STAGE
NOMENCLATURE AND NUMBER OF CEI OPERATIONAL PHASE) - 1 0

OR
(A)

FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
1.1 - (Continued)		1 - (Continued)	
3.1.2 Operability		3.3 Design and Construction	
3.1.2.1 Reliability - The vehicle shall have a high reliability in support of the man rating requirements associated with Mission B		3.3.1 General Design Features	
3.1.2.2 Maintainability - The vehicle shall be maintainable consistent with the man-rated requirements associated with Mission B		3.3.1.1 The vehicle shall consist of a nuclear (NERVA) propulsion stage, and instrumentation (guidance and control) unit and a manned payload. The vehicle shall be designed to function in response to programmed electrical signals issued by the Instrumentation Unit with provisions for command override by the astronauts in the payload or by ground control. All systems of the vehicle shall be man rated.	
3.1.2.3 Useful Life - The vehicle shall have a useful life consistent with meeting the performance requirements associated with Mission B.	NPRD-1 Sec. III Par. B.1.1	3.3.1.2 Maximum Weight - The vehicle shall have a maximum weight of 426,172 pounds at the beginning of the final thrust cycle.	NERVA Mission Data Book RW-S-0506 Feb. 1969
3.1.2.4 Environmental - The vehicle shall perform the required functions after being submitted to all environments associated with execution of Mission B.		3.3.1.3 Structural Design - The vehicle structures shall be designed and analyzed to assure they are capable of withstanding the loads imposed by this function.	
3.1.2.5 Transportability - N/A		3.3.1.4 Monitoring - The vehicle shall have provisions to monitor all critical parameters which are needed for ground control to evaluate mission performance and make decisions in emergency situations.	
3.1.2.6 Human Performance - The vehicle shall have provisions for remote assessment of operating parameters throughout this function. In addition, the vehicle shall have provisions for command override of the vehicle programmer for the purpose of manual operation. Controls for manual operation may be incorporated in the manned spacecraft or ground control center. Arrangement and labeling of displays and controls shall be in keeping with MIL-STD-1472.		3.3.3 Materials, Parts and Processes - Not applicable to this function.	
3.1.2.7 Safety - To the maximum practical extent, assure that the vehicle design has no single failures or credible combinations of errors, malfunctions or accidents which as an end result could cause injury to the flight crew or the general public.		3.3.5 Moisture and Fungus Resistance - Not applicable to this function.	
3.2.1.2 Detailed Interface Definition - The vehicle shall physically and functionally interface with the boost vehicle as follows:		3.3.6 Corrosion of Metal Parts - Not applicable to this function.	
a. Physical - The vehicle shall have provisions for structural attachment to the boost vehicle.		3.3.7 Interchangeability and Replaceability - Not applicable to this function.	
The vehicle shall mechanically attach to electrical wiring on the boost vehicle.		3.3.9 Electromagnetic Interference - Interference and susceptibility within the vehicle shall be controlled by adequate design provisions to eliminate the undesired responses and emissions from all electronic and electrical subsystems/equipments in or associated with the vehicle regardless of whether the output is electrical, aural, video or mechanical. This requirement applies to the entire frequency ranges utilized by the installed subsystems. This requirement specifically includes operation of subsystems/equipments when operating with their installed sensing elements when performing their intended function in all modes of operation.	Spec. MIL-E-6051 Par. 3.3.9
b. Functional - During flight the vehicle shall functionally interface with the astronauts and with the ground tracking and control station.			

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REQUIREMENTS ALLOCATION SHEET (CONTINUED)		
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSIONS (NUCLEAR STAGE)</u> OR NOMENCLATURE AND NUMBER OF CEI <u>OPERATIONAL PHASE - 1.0</u> (A)		
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)
<p>1.1 - (Continued)</p> <p>III. <u>Assumed Vehicle Configuration</u></p> <p>A. <u>Stage Nuclear</u></p> <p>The Nuclear stage dimensions indicated herein and adopted for use in simulation are consistent with the 14 August 1968 Interim Progress Report from Lockheed to Marshall on the Modular Nuclear Vehicle Study, NAS8-20007.</p> <p>1. Diameter - The external diameter of the nuclear stage or module is constant at 33 ft (396 in). The propellant tank consists of a cylindrical center section with an internal diameter of 32 ft (384 in), an oblate-spheroidal fore closure, and a modified-conical aft closure.</p> <p>2. Volume - The mass of the total nuclear stage or module propellant expended or allotted from liftoff to disposal for chilldown, bootstrap, steady-state thrust, shutdown, cooldown, boiloff, leakage, fluid residuals, and flight performance reserve is denoted by WP. The ullage fraction UF is based on WP and propellant density RHOP --</p> <p>UF = 0.05</p> <p>RHOP 4.2 lb/ft³ (saturated liquid at 30 psia)</p> <p>The total tank volume VT is then</p> <p>VT = (1 + UF) WP/RHOP</p> <p>= 1.05 WP/4.2</p> <p>= (WP/4.0) Ft³</p> <p>3. Length - The length LTC of the cylindrical portion of the tank is given by --</p> <p>LTC (VT - VTE)/STC</p> <p>where VTE is the total volume of the "tank ends", the oblate-spheroidal fore closure and the modified-conical aft closure. The square of the ratio of semi-diameters for the oblate-spheroidal fore closure is taken as 2. The length is then 11.31 ft and the volume is 6066 ft³. The aft closure is a modified cone with slope 30 deg from a line parallel with the longitudinal axis -- the specific modification is called "60 deg prime." The aft portion of the cone is interrupted tangentially by a spherical segment of radius 83.4 in. Height and volume of this spherical segment are 41.7 in or 3.48 ft</p>	<p>NERVA Mission Data Book RM-S-0506 Feb. 1969</p>	<p>1.1 - (Continued)</p> <p>3. Length - (Continued)</p> <p>and 219.7 ft³. Radius at point of tangency is 72.2 in or 6.02 ft. The total height of the aft closure to tangency with the cylindrical portion of the tank is assumed 275.8 in or 22.98 ft. Any radially oriented element of the forward fairing is taken as a circular segment tangent to cylinder and cone. The latter tangency occurs at a radius of 178.7 in or 14.89 ft and a cone frustum height of 184.4 in or 15.36 ft. The volume of the cone frustum is 5592.1 ft³. Radius of the circular segment of the forward fairing is 99.4 in. Height and volume of the aft closure portion encompassed by its forward fairing are 49.7 in or 4.14 ft and 3185.7 ft³. Total volume of the aft closure is then 8997.5 ft³.</p> <p>VTE = 15063.5 ft³</p> <p>LTC = 0.00031085 WP - 18.73 ft.</p> <p>The total length LT of the tank is then --</p> <p>LT = 0.00031085 WP + 15.57 ft.</p> <p>The fore end of the fore closure of the tank is taken as marking the fore end of the nuclear stage. Dimensions indicated herein and adopted for use in simulation of the NERVA Nuclear Engine are consistent with AGC Dwg. 1134502. The distance from the aft end of the modified conical aft closure of the tank to the plane between upper and lower thrust rings is assumed 36.0 in or 3.00 ft. The distance from this plane to another plane touching the extreme end of the nozzle skirt is taken as 343.93 in or 28.66 ft. Finally, a distance of 10.0 in or 0.83 ft is allowed between the nozzle skirt and the aft end of the stage. The overall length LS of the Nuclear Stage is then --</p> <p>LS = 0.00031085 WP + 48.06 ft.</p> <p>The tank skirt is assumed to extend 85.0 in or 7.08 ft aft from the cylindrical portion of the tank. The length LIS of the interstage is therefore:</p> <p>LIS = 580.7 in</p> <p>= 48.39 ft</p> <p>The stage mass WJ is predicted by an equation given in Table 1 of the 14 August 1968 Interim Progress Report from Lockheed to Marshall on the Modular Nuclear Vehicle Study, NAS8-20007 --</p> <p>WJ = 0.0649 WP + 33926</p>

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REQUIREMENTS ALLOCATION SHEET (CONTINUED)																									
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSIONS (NUCLEAR STAGE)</u> OR NOMENCLATURE AND NUMBER OF CEI <u>OPERATIONAL PHASE) - 1.0</u> (A)																									
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)																						
<p>1.1 - (Continued)</p> <p>3. Length - (Continued)</p> <p>This equation reflects an assumed engine/shielding mass of 18340 lb and is therefore adjusted for present purposes --</p> $WJ = 0.0640 WP + 15586$ <p>The computed characteristics of the Nuclear Stage are</p> <table border="0"> <tr><td>Volume, Tank (VT)</td><td>57625 cuft</td></tr> <tr><td>Length, Cyl. Portion (LTC)</td><td>52.92 ft</td></tr> <tr><td>Length, Tank (LT)</td><td>87.22 ft</td></tr> <tr><td>Length, Stage (LS)</td><td>119.71 ft</td></tr> <tr><td>Weight, Propellant (WP)</td><td>230,512 lb</td></tr> <tr><td>Weight, Stage, Dry</td><td>90,081 lb</td></tr> <tr><td>Weight, Engine</td><td>16,000 lb</td></tr> <tr><td>Weight, Int. Shield</td><td>2,500 lb</td></tr> <tr><td>Weight, Ext. Shield</td><td>10,000 lb</td></tr> <tr><td>Weight, Stage, Total</td><td>320,593 lb</td></tr> <tr><td>Weight, Payload (IU & Capsule)</td><td>105,817 lb.</td></tr> </table> <p>B. <u>Instrumentation Unit</u></p> <p>In every launch involving a Nuclear Module there will be present in front of that module an Instrument Unit. One purpose of the Instrument Unit is to provide guidance and control instrumentation for the launch vehicle throughout operations of the chemical-rocket stages. The Instrument unit is 3 ft. long -- as modified to increase its diameter to 33 ft so as to be consistent with the nuclear module. Its mass is 4700 lb. The latter evaluation is consistent with the 14 August 1968 Interim Progress Report from Lockheed to Marshall on the Modular Nuclear Vehicle Study, NAS8-2007. The Instrument Unit (IU) contains a gyro-stabilized platform. Guidance and control computers, flight sequencer, command receiver and decoder measuring system equipment, a telemetry package, tracking transponders, and electrical distributors. The many electronic elements are arranged on cold plates on the inside periphery of a ring structure. The central region of the Instrument Unit is not occupied by elements thereof, however, the nuclear stage tank is assumed to stop just short of intruding in this space.</p> <p>C. <u>Payload</u></p> <p>The vehicle splits three ways in earth-synchronous orbit. The Nuclear Stage is restarted and proceeds unmanned to achieve its own</p>	Volume, Tank (VT)	57625 cuft	Length, Cyl. Portion (LTC)	52.92 ft	Length, Tank (LT)	87.22 ft	Length, Stage (LS)	119.71 ft	Weight, Propellant (WP)	230,512 lb	Weight, Stage, Dry	90,081 lb	Weight, Engine	16,000 lb	Weight, Int. Shield	2,500 lb	Weight, Ext. Shield	10,000 lb	Weight, Stage, Total	320,593 lb	Weight, Payload (IU & Capsule)	105,817 lb.	<p>NERVA Mission Data Book RN-S-0506 Feb 1969</p>	<p>1 1 - (Continued)</p> <p>C. Payload - (Continued)</p> <p>disposal at earth escape velocity. Another separated element is described below as a manned reentry vehicle and chemical-rocket retro propulsion system sufficient to safely return that vehicle to earth surface at the equator from earth-synchronous orbit. Prior to this return the crew may be rotated with another crew from a synchronous-orbit laboratory, or there may be assembly or checkout tasks to be performed. The third portion of the vehicle is unmanned and remains in synchronous orbit. It is quite likely heavy and bulky -- it may feed a laboratory buildup or consist of several large communications/meteorology satellites. In order to size the vehicle this unmanned payload is assumed to have a 33-ft. diameter and an average density of 5 - 8/ft³.</p> <p>1. Reentry Vehicle</p> <p>The reentry vehicle is designed to accommodate six men. The hypersonic lift/drag ratio would be less than 0.50, placing the vehicle in the semi-ballistic category. It would be similar to the Apollo Command Module, but scaled up to a diameter of 16 ft (192 inches). The mass, including crew, equipment, and non-rocket-propulsive landing aids, but not supplementary radiation shielding, is 16,154 lb as given in the 23 May 1968 presentation to the NERVA Shielding Committee. A separate chemical-rocket propulsion system is attached until jettison before reentry into earth atmosphere -- characteristics of this system are inferred by the following --</p> <p>2. Chemical Rocket propulsion</p> <p>Provide for deorbit against the velocity vector in plane from earth-synchronous orbit. Deorbit burn should be as required to produce a reentry flight angle of -6 deg at an altitude of 400,000 ft. Alter initial propulsion system mass to provide for an additional capability of 500 ft/sec -- assume this capability is used as necessary for crossrange and timing correction and does not affect the nominal trajectory. Propulsion system mass fraction is 0.85. Thrust and specific impulse are constant during burn at 8000 lb and 315 sec respectively. Outage and performance reserve are taken into account in the specified mass fraction and additional velocity increment capability.</p>	<p>RN-S-0506 Feb 1969</p>
Volume, Tank (VT)	57625 cuft																								
Length, Cyl. Portion (LTC)	52.92 ft																								
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REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSIONS (NUCLEAR STAGE)</u> OR NOMENCLATURE AND NUMBER OF CEI <u>OPERATIONAL PHASE) - 1.0</u> (A)			
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1 - (Continued)</p> <p>3. Reentry Vehicle Adapter</p> <p>The reentry vehicle is accompanied by an adapter until after separation of the Nuclear Stage in synchronous orbit. The adapter is then separated before reentry vehicle deorbit. In Mission B the adapter is joined to an unmanned payload at an assumed 33 ft diameter. The adapter is taken as a truncated cone joining the reentry vehicle at its maximum 16 ft diameter. The slope of the cone is taken the same as that of the forward face of the reentry vehicle, 33 deg from a line parallel with the vehicle longitudinal axis.</p> <p>Length of reentry vehicle and adapter</p> <p>$33/2 \tan 33 \text{ deg}$</p> <p>- 25.41 ft</p> <p>Length of Adapter - $(33 - 16)/2 \tan 33 \text{ Deg}$</p> <p>- 13.09 ft</p> <p>This adapter is sufficiently long to house the short heat shield portion of the reentry vehicle and the jettisonable deorbit and path-correction propulsion system. Its developed area is 1201 ft². The predicted mass is 3000 lb about 2.5 lb/ft². The reentry vehicle has a total weight of 34,450 lb.</p>			

FIRST LEVEL SBD

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FUNCTION 1.1 PERFORM MISSION "B"

SECOND LEVEL

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REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSION B - 1.1</u>		OR	
NOMENCLATURE AND NUMBER OF CEI <u></u>		(A)	
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1.1.1 - (Continued)</p> <p>3.1.1 Functional Performance Characteristics - (Continued)</p> <p>d. The total impulse for this function is 93,567,161 lb.-sec. This impulse shall be allocated as follows startup - 1,307,231 lb-sec, steady state 91,544,250 lb-sec, shutdown - 715,680 lb-sec.</p> <p>3.1.2 Operability</p> <p>3.1.2.1 Reliability - The stage shall have a high reliability in support of the man rating requirements associated with Mission B.</p> <p>3.1.2.2 Maintainability - The vehicle shall be maintained consistent with the man-rated requirements associated with Mission B.</p> <p>3.1.2.3 Useful Life - The means shall be designed to operate at rated conditions for a minimum of 50 minutes in either one cycle or multiple cycles up to 10 cycles.</p> <p>The stage is required to operate for a 21 minute cycle during this function.</p> <p>3.1.2.4 Environmental - The stage shall perform the required functions after being subjected to all environments associated with the execution of Mission B. The environment during this function is that provided by an Earth altitude of approximately 85 N. miles to 180 N. miles and a velocity ranging from 21,000 ft/sec to 29,000 ft/sec.</p> <p>3.1.2.6 Human Performance - The nuclear stage shall have provisions for remote assessment of operating parameters throughout this function. In addition, the nuclear stage shall have provisions for command override of the engine programmer for the purpose of manual operation. Controls for manual operation may be incorporated in the manned spacecraft or ground control center. Arrangement and labeling of displays and controls shall be in keeping with MIL-STD-1472.</p> <p>3.1.2.7 Safety - To the maximum practical extent, assure that the stage design has no single failures or credible combinations of errors, malfunctions or accidents which as an end result could cause injury to the flight crew or the general public.</p> <p>3.2.1.2 Detailed Interface Definition - The Stage Nuclear shall physically and functionally interface with the Instrumentation Unit as follows</p>	<p>NERVA Mission Data Book RN-S-0506 Feb. 1969</p> <p>NPRD-1 Sec. III Par. B.1</p> <p>NERVA Mission Data Book RN-S-0506 Feb 1969</p>	<p>1.1.1.1 - (Continued)</p> <p>3.2.1.2 Detailed Interface Definition - (Continued)</p> <p>a. Physical - The S-N shall have provisions for structural attachment to the Instrumentation Unit.</p> <p>The S-N shall mechanically attach to electrical wiring on the Instrumentation Unit.</p> <p>b. Functional - The S-N shall functionally interface with the Instrumentation Unit.</p> <p>3.3 Design and Construction</p> <p>3.3.1 General Design Features</p> <p>3.3.1.1 The stage shall be monopropellant tankage, airframe and NERVA Rocket Engine. The stage shall be designed to function in response to programmed electrical signals issued by the Instrumentation Unit with provisions for command override by the astronauts in the payload or by ground control. All systems of the stage shall be man rated.</p> <p>3.3.1.2 Structural Design - The stage structure shall be designed and analyzed to assure they are capable of withstanding the loads imposed by this function. The vehicle mass at the beginning of this function will be approximately 426,000 lbs decreasing to approximately 283,000 lbs. at the completion of this function.</p> <p>3.3.1.3 Monitoring - The stage shall have provisions to monitor all critical parameters which are needed for ground control to evaluate mission performance and make decisions in emergency situations</p> <p>3.3.3 Materials, Parts and Processes - Not applicable to this function.</p> <p>3.3.5 Moisture and Fungus Resistance - Not applicable to this function.</p> <p>3.3.6 Corrosion of Metal Parts - Not applicable to this function.</p> <p>3.3.7 Interchangeability and Replaceability - Not applicable to this function.</p>	

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REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PERFORM MISSION B - 1.1</u> OR NOMENCLATURE AND NUMBER OF CEI <u>(A)</u>			
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
1.1.1 - (Continued) 3.3.9 Electromagnetic Interference - Interference and susceptibility within the stage shall be controlled by adequate design provisions to eliminate the undesired responses and emissions from all electronic and electrical subsystems/equipments in or associated with the vehicle regardless of whether the output is electrical, aural, video, or mechanical. This requirement applies to the entire frequency ranges utilized by the installed subsystems. This requirement specifically includes operation of subsystems/equipments when operating with their installed sensing elements when performing their intended function in all modes of operation. B. <u>Instrumentation Unit</u> 3.1 Performance 3.1.1 Functional Performance Characteristics a. Provide guidance signals for vehicle orientation course correction. b. Provide controls for sequencing the thrusting operations of the stage nuclear. c. Monitor performance and transmit data to payload ground control stations. d. Transmit thrust from the S-N to the payload. 3.1.2 Operability - To be supplied by the Instrumentation unit contractor. 3.2.1.2 Detailed Interface Definition - To be supplied by the Instrumentation Unit Contractor. 3.3 Design and Construction - To be supplied by the Instrumentation Unit Contractor. C. <u>Payload</u> 3.1 Performance 3.1.1 Functional Performance Characteristics a. Provide life support for astronauts	Spec. MIL-E-6051 Par. 3.3.9	1.1.1 - (Continued) 3.1.1 Functional Performance Characteristics b. Provide readout capability for monitored S-N performance data. c. Provide override capability of S-N operating controls by astronaut. 3.1.2 Operability - To be supplied by Payload Contractor. 3.2.1.2 Detailed Interface Definition - To be supplied by Payload Contractor. 3.3 Design and Construction - To be supplied by Payload Contractor.	

S-N TO PAYLOAD
SCHEMATIC BLOCK DIAGRAM
LEVEL 2

FUNCTION 1.1.1 PROVIDE S-N IMPULSE

THIRD LEVEL

4-17-69

REQUIREMENTS ALLOCATION SHEET										
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PROVIDE S-N IMPULSE - 1.1.1</u> OR										
NOMENCLATURE AND NUMBER OF CEI <u>(A)</u>										
FUNCT ON NAME AND NUMBER (B)	DESIGN REQUIREMENTS (C)	REFERENCE OR TRADE AND DESIGN STUDY NO (H)	FACILITY REQUIREMENTS (D)	EQUIPMENT IDENTIFICATION (E)		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENT (F)				PROCEDURAL DATA REQTS (G)
				NOMENCLATURE (E1)	CEI, ECC OR DETAIL SPEC OR INDEX NO. (E2)	TASKS (F1)	TIME REQD (F2)	PERFORMANCE REQTS (F3)	TRAINING AND TRAINING EQPT REQTS (F4)	
1.1.1.6 Buildup Thrust	<p><u>I. Description of Function</u></p> <p>A requirement exists to startup the nuclear engine and build thrust and specific impulse up to rated operating conditions.</p> <p>This function is required in order to satisfy the trajectory requirements of Mission B for the Nuclear Stage to provide impulse.</p> <p><u>II. Design Requirements</u></p> <p>This function shall be satisfied by a nuclear stage having as its main sub-systems a nuclear engine and an airframe/tank assembly. Performances and design requirements for the nuclear stage S-IU and payload shall be apportioned as follows</p> <p>A. <u>Rocket Engine</u></p> <p>3.1 Performance</p> <p>3.1.1 Functional Performance Characteristics</p> <p>3.1.1.1 The engine shall develop $75,000 \pm 2,000$ lbs. thrust at rated conditions</p> <p>3.1.1.2 At rated conditions the engine specific impulse shall be within a 15.36 second band having a 825 second minimum.</p> <p>3.1.1.3 The engine shall be capable of building thrust and specific impulse from pre-start conditioning to rated conditions at a pressure altitude equivalent to 85 N. miles.</p>	<p>NERVA Mission Data Book Feb. 1969</p> <p>NPRD-1 Sec. III Par. I.1 a June 196 and Memorandum 7830 4130 Varga from Petite undated</p> <p>NERVA Mission Data Book Feb 1969</p>								

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FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1.1.6 - (Continued)</p> <p>3.1.1.4 Engine thrust and specific impulse buildup shall be as sketched in the typical curve shown below: The total impulse for this function is 1,307,231</p> <div data-bbox="690 588 1144 850"> <p>Thrust + I_{sp}</p> <p>0 45 sec Time</p> </div> <p>NOTE: A Trade Study is required to determine the thrust and specific impulse vs. time during the thrust buildup phase.</p> <p>3.1.1.5 During thrust buildup the propellant flow rate shall be increased from 4 lbs/sec to 91.5 lbs/sec. (Propellant Feed System)</p> <p>3.1.1.6 Engine chamber pressure shall be increased from approximately 5 psia to 450 psia during this function. (Nozzle Assembly, Pressure Vessel and Closure).</p> <p>3.1.1.7 Engine Chamber temperature shall increase from approximately 550°R to 4613 + 55°R during this function. (Nuclear subsystem, Thrust Structure Assembly).</p> <p>3.1.1.8 The engine shall transmit impulse developed by thrust buildup to the airframe.</p>	<p>Memorandum 7830:4130 To Varga from Petite Undated</p> <p>TS #005</p> <p>Memorandum 7830:4122 Klacking from Buden 11 Apr. 69</p> <p>NPRD-1 Sec. III Par. B.1.a and Memorandum 7830:4130 Varga from Petite Undated</p> <p>NPRD-1 Sec. III Par. B.1.a and Memorandum 7830:4122</p>

FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1.1.6 - (Continued)</p> <p>3.1.1.9 The engine shall be capable of bootstrap starting at anytime and at pressures within the venting range of the propellant tank. The pressure range will be 24 to 30 psia, at saturated propellant conditions in the locked tank mode.</p> <p>Optional modes of bootstrap startup shall be provided. For this function, startup shall provide the highest possible integrated specific impulse, within the (thermal) stress limitations of the reactor structure.</p> <p>3.1.2 Operability</p> <p>3.1.2.1 Reliability - The engine shall be designed so that it will perform its intended function under specified conditions without failure for a period of up to 50 minutes at rated conditions. The operating time shall be utilizable in either one or multiple cycles up to ten.</p> <p>Where increased reliability is necessary, an alternate part, circuit or component should be introduced which can take over if the primary element should fail.</p> <p>The reliability requirement for the Rocket Engine shall be 0.995, i.e., the probability at a 90% confidence level that the engine shall successfully complete 50 minutes rated operation over ten cycles while meeting all mission related requirements shall be 0.995 or greater.</p> <p>3.1.2.2 Maintainability - The Rocket Engine materials and sub-systems and their installation should be designed to permit personnel of average skill to perform required maintenance under all anticipated environmental conditions.</p> <p>3.1.2.2.1 Maintenance and Repair Cycles - Not applicable to in-flight operations.</p> <p>3.1.2.2.2 Service and Access - Not applicable to in-flight operations.</p> <p>3.1.2.3 Useful Life - The time allocation for this function is 45 ± _____ seconds.</p>	<p>NPRD-1 Sec. III Par. B.1.d June 1968</p> <p>NPRD-1 Sec. III Par. B.1.b June 1968 and AFSC Design Handbook DH-1-2 Chapter 1 20 Feb 68</p> <p>NPRD-1 Sec. III Par. B.1.j</p> <p>AFSCM Design Handbook DH-1-2 Chapter 1</p> <p>Memorandum 7830:4130 Varga from Petite.</p>

REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>PROVIDE S-N IMPULSE - 1.1.1</u>		OR	
NOMENCLATURE AND NUMBER OF CEI <u></u>		(A)	
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1.1.6 - (Continued)</p> <p>3.1.2.4 Environmental - The NERVA Engine shall be capable of functioning without degradation of operability and performance limits with</p> <p>A. Natural environments specified in Section <u> </u> of Data Item SO23-CPO90194-F1 entitled, NERVA Engine Natural Environment Report.</p> <p>B. Induced thermal environment specified in Section <u> </u> of Data Item SO31-CPO90194-F1 entitled, NERVA Engine Structural Temperature Report.</p> <p>C. Nuclear environments specified in Section <u> </u> of Data Item S100-CPO90194-F1 entitled, NERVA Engine Radiation and Shielding Analysis Report.</p> <p>D. Vibration, acceleration and acoustics environments specified in Section <u> </u> of Data Item SO38-CPO90194-F1 entitled, NERVA Engine Environmental Vibration and Acoustics Report.</p> <p>3.1.2.5 Transportability - Not applicable to in-flight operations.</p> <p>3.1.2.6 Human Performance - The engine shall have provisions for remote assessment of operating parameters throughout this function. In addition, the engine shall have provisions for command override of the engine programmer for the purpose of manual operation. Controls for manual operation may be incorporated in the manned spacecraft or ground control center. Arrangement and labeling of displays and controls shall be in keeping with MIL-STD-1472.</p> <p>3.1.2.7 Safety - To the maximum extent practical, assure that the Rocket Engine design has no single failures or credible combinations of errors, malfunctions or accidents which as an end result could cause injury to the flight crew or to the general public.</p> <p>The probability of an engine failure which either, (a) causes injury to the crew or damages the spacecraft, or (b) prevents return of the spacecraft to earth shall not exceed 1×10^{-4} per flight.</p> <p>3.2.1.2 Detailed Interface Definition - The engine shall physically and functionally interface with the S-N airframe and the Saturn Instrumentation Unit as follows</p> <p>a. Physical - The engine shall have provisions for structural attachment to the airframe.</p>	<p>MIL-STD-1472</p> <p>NPRD-1 Sec. III Par. B.1 p</p>	<p>1.1.1.6 - (Continued)</p> <p>b. Functional - The engine shall functionally interface with the airframe propellant system.</p> <p>The engine shall functionally interface with the Instrumentation Unit.</p> <p>The engine shall functionally interface with the airframe electrical power supply.</p> <p>The engine shall functionally interface with the airframe subsystem.</p> <p>3.3 Design and Construction</p> <p>3.3.1 General Design Features - The Nuclear Rocket Engine shall be man-rated and consist of the following subassemblies</p> <p>a. Propellant Feed System b. Pressure Vessel c. Nuclear Subsystem d. Nozzle Assembly e. Instrumentation and Control System f. Thrust Structure Assembly</p> <p>3.3.1.1 Structural Criteria - The engine structure shall be designed and analyzed in accordance with applicable portions of Specification SPO-C-1 to assure that the capability to withstand the induced environments described in Paragraph 3.1.2.4 have been satisfied</p> <p>3.3.1.2 Mass Properties Limit - The Rocket Engine shall weigh approximately 27,530 pounds including brim shield, NSC shield and excluding payload shelding and hardware required for mating the engine to the airframe and the destruct system.</p> <p>The overall engine length shall be 413 inches</p> <p>3.3.1.3 Leakage Limits - To minimize leakage the engine shall be designed to minimize joints where leakage may occur. Maximum leakage during all non-operating periods shall not exceed 400 standard cubic inches of hydrogen per minute.</p>	<p>NPRVA Engine Specification Tree NPO-C- T-JB 1 Oct 68</p> <p>NPRD-1 Page 14 Line 19c</p> <p>Memorandum 7410 4122 Flacking from Ruden</p> <p>ACC Dwg. 1135222</p> <p>NPRD-1 Sec. III Par. B.1 g</p>

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REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
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<p>1.1.1.1 - (Continued)</p> <p>3.3.1.4 Fluid Characteristics - The engine shall be designed to operate at rated conditions when supplied with MSFC Spec 356A (liquid) hydrogen propellant at 30 psia, and saturated temperature, containing zero% vapor.</p> <p>3.3.1.5 System Cleanliness - The engine shall be designed to handle any, unlimited flow (rate) of 600 micron or less particles throughout its operating life. The estimated weight to be handled is 220 grams of material with the density of aluminum.</p> <p>3.3.1.6 Shielding - The engine shall include vehicle shields which protect components from radiation degradation of reliability, performance, or endurance.</p> <p>3.3.1.7 Shielding - The engine shall be made for crew shields and installation thereof, to reduce the dose due to engine radiations to 10 rem at the crew location in a standard Apollo Command Module mounted directly above the Return Instrumentation Unit. This design requirements shall be allocated to both the nuclear engine and the payload. A Trade Study Analysis shall be conducted to establish the shielding allocation between the engine and the payload.</p> <p>3.3.1.8 The overall engine design, including reactor, lines and nozzle shall be such as to minimize the penalty for crew radiation protection.</p> <p>3.3.1.9 Monitoring - The engine shall have provision to monitor all critical parameters associated with thrust buildup operation which are needed for ground control and flight control to evaluate thrust buildup performance and make decision in emergency situations.</p> <p>Parameter to be monitored will include, but not be limited to the following</p> <ol style="list-style-type: none"> Reactor inlet temperature Reactor core temperature Propellant flow rate The nuclear reactivity level Engine chamber pressure Engine chamber temperature <p>3.3.3 Material, Parts and Processes - The use of materials which are susceptible to degradation when exposed to a nuclear environment shall be avoided. Where it is not possible, adequate shielding shall be provided.</p>	<p>NPRD-1 Sec. III Par. B.1 a</p> <p>NPRD-1 Sec. III Par. B.5</p> <p>NPRD-1 Sec. III Para. B.1, k</p> <p>T.S. _____</p>	<p>1.1.1.1 - (Continued)</p> <p>3.3.5 Moisture and Fungus Resistance - Not applicable to this function.</p> <p>3.3.6 Corrosion of Metal Parts - Not applicable to this function.</p> <p>3.3.7 Interchangeability and Replaceability - Not applicable to this function.</p> <p>3.3.9 Electromagnetic Interference - Interference and susceptibility within the system shall be controlled by adequate design provisions to eliminate the undesired responses and emissions from all electronic and electrical subsystems/equipments in or associated with the system regardless of whether the output is electrical, aural, video, or mechanical. This requirement applies to the entire frequency ranges (including generated harmonics, spurious emissions, and susceptibilities) utilized by the installed subsystems. This requirement specifically includes operation of subsystems/equipments when operating with their installed sensing elements when performing their intended function in all modes of operation.</p> <p>B. <u>Airframe</u></p> <p>3.1 Performance</p> <p>3.1.1 Functional Performance Characteristic</p> <p>The airframe shall have provisions to contain propellant in the form of saturated liquid hydrogen, which is required for engine operation.</p> <p>The airframe shall have the capability of flowing propellant, which is pressurized at 24 to 30 psia, at an increasing rate of 4 to 91.5 lbs per second while in a locked tank mode.</p>	<p>MIL-E-6059D Par. 3.3.9</p> <p>NPRD-1 Sec. III Par. B.1 d and Memorandum 7830 4122 Klacking from Buden</p>

REQUIREMENTS ALLOCATION SHEET (CONTINUED)			
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NOMENCLATURE AND NUMBER OF CEI _____		(A)	
FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)	FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
1.1.1.6 - (Continued) 3.1.2 Operability - The airframe shall have propellant tank protection such that the combined effects of heating, temperature gradient, and/or vapor content will not degrade engine performance or unduly reduce the payload. 3.2.1.2 Detailed Interface Definition - To be supplied by the airframe contractor, except airframe to engine interfaces shall be as noted in the engine section of this RAS. 3.3 Design and Construction - To be supplied by the airframe contractor. C. <u>Saturn Instrumentation Unit</u> 3.1 Performance 3.1.1 Functional Performance Characteristics - The Instrumentation Unit shall have the capability to a. Issue an electrical signal for the engine to initiate thrust buildup operations. b. Monitor engine thrust buildup operations and relay monitored data to ground control stations. This data shall be the same as that noted in Para. II.A., 3.3.1.7 of this RAS. 3.1.2 Operability - To be supplied by the S-IU Contractor. 3.2.1.2 Detailed Interface Definition - To be supplied by the S-IU Contractor. 3.3 Design and Construction - To be supplied by the S-IU Contractor. D. <u>Payload</u> 3.1 Performance 3.1.1 Functional Performance Characteristics - The Payload shall have capabilities to a. Monitor engine thrust buildup operations. The data to be monitored is the same as that noted in Para. II, A., 3.3.1.7 of this RAS.	NPRD-1 Sec. III Par. B.1.k June 1968	1.1.1.6 - (Continued) 3.1.1 Functional Performance Characteristics - (Continued) b. Override the engine programmer and assume control of engine operations. 3.1.2 Operability - The payload shall have provisions made for crew shields and installation thereof, to reduce the dose due to engine radiations to 10 rem at the crew location. This design requirement shall be allocated to both the payload and the nuclear engine. A trade study analysis shall be conducted to establish the shielding allocation between the engine and the payload. NOTE See Para. II., A., 3.3.1.6 for Trade Study Number Payload Contractor. Other operability features shall be supplied by the 3.2.1.2 Detailed Interface Definition - To be supplied by the Payload Contractor. 3.3 Design and Construction - To be supplied by the Payload Contractor.	NPRD-1 Sec. III Par. B.1.k

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ENGINE SUBSYSTEMS SCHEMATIC BLOCK DIAGRAM LEVEL 3

REVISION _____ ORIGINAL DATE 4-18-69 REVISION DATE _____ APPROVAL RBJ DOCUMENT NO. _____ PAGE NO. 1 OF 1

FUNCTION 1.1.1.6 BUILDUP THRUST

FOURTH LEVEL

REQUIREMENTS ALLOCATION SHEET										
FUNCTIONAL DIAGRAM TITLE AND NUMBER <u>BUILDUP THRUST - 1.1.1.6</u> OR NOMENCLATURE AND NUMBER OF CEI _____ (A)										
FUNCTION NAME AND NUMBER (B)	DESIGN REQUIREMENTS (C)	REFERENCE OR TRADE AND DESIGN STUDY NO (H)	FACILITY REQUIREMENTS (D)	EQUIPMENT IDENTIFICATION (E)		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENT (F)				PROCEDURAL DATA REQTS (G)
				NOMENCLATURE (E1)	CEI, ECC OR DETAIL SPEC OR INDEX NO. (E2)	TASKS (F1)	TIME REQD (F2)	PERFORMANCE REQTS (F3)	TRAINING AND TRAINING EQPT REQTS (F4)	
1.1.1.6.2 Direct and Control Propellant Flow	<p><u>I. Description of Function</u></p> <p>This function provides for the direction of propellant from the engine/airframe interface and controlling its flow rates.</p> <p>This function is necessary in order to build nuclear engine thrust and specific impulse up to rated operating conditions.</p> <p><u>II. Design Requirements</u></p> <p>The engine subsystems which are used to satisfy this function are:</p> <ul style="list-style-type: none"> a. Propellant Feed System b. Brim Shield c. Nozzle Assembly d. PVARA (Pressure Vessel and Closure, and Nuclear Subsystem) e. Instrumentation and Control Subsystem <p>A. Propellant Feed System</p> <p>3.1 Performance</p> <p>3.1.1 Functional Performance Characteristics</p> <p>3.1.1.1 The propellant feed system shall direct propellant flow from the engine/tank interface to the brim shield</p> <p>3.1.1.2 The propellant feed system shall direct propellant flow from the brim shield to the nozzle assembly (skirt)</p> <p>3.1.1.3 The propellant feed system shall direct the flow of propellant from the nozzle assembly (bleed port) to the nozzle assembly (skirt extension).</p>	AGC Dwg. 1135222								
					PSOV Pump Inlet Line Turbopump Pump Dis- charge Line DSOV Brim Shield Discharge Line					

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PROPELLANT FEED SYSTEM
SCHEMATIC BLOCK DIAGRAM
LEVEL 4

SCHEMATIC BLOCK DIAGRAM
LEVEL 5

SYSTEMS ENGINEERING
TRADE STUDY INDEX

T. Pasternak

FUNCTIONAL NAME AND NUMBER (B) AND REQUIREMENTS (TYPE)	REFERENCE OR TRADE AND DESIGN STUDY NO. (H)
<p>1.1.1.6 - (Continued)</p> <p>3.1.1.4 Engine thrust and specific impulse buildup shall be as sketched in the typical curve shown below: The total impulse for this function is 1,307,231</p> <div data-bbox="702 661 1165 934"> </div> <p>NOTE: A Trade Study is required to determine the thrust and specific impulse vs. time during the thrust buildup phase.</p> <p>3.1.1.5 During thrust buildup the propellant flow rate shall be increased from 4 lbs/sec to 91.5 lbs/sec. (Propellant Feed System)</p> <p>3.1.1.6 Engine chamber pressure shall be increased from approximately 5 psia to 450 psia during this function. (Nozzle Assembly, Pressure Vessel and Closure).</p> <p>3.1.1.7 Engine Chamber temperature shall increase from approximately 5500R to 4613 + 550R during this function. (Nuclear subsystem, Thrust Structure Assembly).</p> <p>3.1.1.8 The engine shall transmit impulse developed by thrust buildup to the airframe.</p>	<p>Memorandum 7830:4130 To Varga from Petite Undated</p> <p>TS #005</p> <p>Memorandum 7830:4122 Klackung from Buden 11 Apr. 69</p> <p>NPRD-1 Sec. III Par. B.1.a and Memorandum 7830:4130 Varga from Petite Undated</p> <p>NPRD-1 Sec. III Par. B.1.a and Memorandum 7830:4122</p>

REFERENCE ENGINE

J. M. Klacking

REFERENCE ENGINE DESIGN

1. SCOPE OF DESIGN PACKAGE AT PDR
2. PURPOSE OF REFERENCE ENGINE DESIGN
3. DESIGN EVALUATION AND INTERFACE CONTROL DRAWINGS
4. ENGINE LAYOUT BASELINE CONFIGURATION
5. SUPPORTING DOCUMENTATION FOR PDR
6. PERT TREE SUMMARY.

SCOPE OF DESIGN PACKAGE AT PDR

REFERENCE ENGINE DESIGN

SCOPE OF DESIGN PACKAGE AT PDR

1. FLIGHT AND QUAL ENGINE DESIGN APPROACH SATISFYING ENGINE CEI SPECIFICATION.
2. DESIGN DEPICTED BY LAYOUT, PIPING, INSTRUMENTATION, INSTALLATION AND INTERFACE CONTROL DRAWINGS.
3. SUPPORTING DOCUMENTATION PRESENTING ANALYTICAL JUSTIFICATION OF DESIGN APPROACH.

PURPOSE OF REFERENCE ENGINE DESIGN

REFERENCE ENGINE DESIGN

PURPOSE OF REFERENCE ENGINE DESIGN

1. DRAWINGS PROVIDE BASELINE CONFIGURATION INPUT FOR:
 - A. COMPUTER MODELS (CAM, CRAM, ETM, EDM) TO CONDUCT SYSTEM PERFORMANCE ANALYSES
 - B. CONDUCTING SYSTEMS REQUIREMENTS/DESIGN TRADE STUDIES.
 - C. MAINTAINABILITY/RELIABILITY EVALUATION.
 - D. STRUCTURAL/THERMAL ANALYSIS
2. PREPARE QUAL ENGINE DESIGN DRAWING PACKAGE
3. UPGRADE/REVISE DESIGN DEFINITION FROM 1.B, C, & D AND USE AS BASIS FOR INTERFACES
4. FINALIZE SELECTED DESIGN APPROACH FOR PDR

DESIGN EVALUATION AND INTERFACE CONTROL DRAWINGS

DESIGN EVALUATION AND INTERFACE CONTROL DRAWINGS

1. FLIGHT ENGINE ASSY LAYOUT
2. FLIGHT ENGINE PIPING DIAGRAM
3. FLIGHT ENGINE INSTRUMENTATION
4. FLIGHT ENGINE INSTALLATION
5. QUAL. ENGINE ASSY LAYOUT
6. QUAL. ENGINE PIPING DIAGRAM
7. QUAL. ENGINE INSTRUMENTATION
8. QUAL. ENGINE INSTALLATION
9. TSA/EA LAYOUT
10. FLIGHT ENGINE ICD
11. QUAL. ENGINE ICD
12. NUCLEAR/NON-NUCLEAR ICD

ENGINE LAYOUT BASELINE CONFIGURATION

REFERENCE ENGINE ESTIMATED WEIGHTS

		<u>1134502</u>	<u>1135222</u>
UPPER THRUST STRUCTURE		415	400
THRUST VECTOR SYSTEM		510	300
LOWER THRUST STRUCTURE		760	900
PRESSURE VESSEL		858	1100
PRESSURE VESSEL	858		1100
BRIM SHIELD SHELL	-		835
BRIM SHIELDING MATERIAL	-		4065
NUCLEAR SUBSYSTEM		8565	8844
REACTOR	8565		8844
SHIELDING	1500		3526
NOZZLE ASSEMBLY		2160	2400
PROPELLANT FEED SYSTEM		2055	3200
PNEUMATIC SYSTEM		405	960
ELEC. & INSTRUMENTATION		<u>340</u>	<u>400</u>
ENGINE WEIGHT LESS SHIELDING		16068	18504

REFERENCE ENGINE LAYOUT

P/N 1135222

BASELINE CONFIGURATION

SYSTEM

A. NERVA 75K FLIGHT ENGINE ASSY WITH
DUAL TPA PFS SYSTEM, EXTERNAL
BRIM SHIELD & THRUST NULLING CONCEPTS.

75° TANK 200-IN. CORE C₂-TO-TANK BOTTOM.
100:1 NOZZLE. PSOV's MOUNTED TO TANK
BOTTOM. ENGINE/STAGE INTERFACE AT
PSOV EXIT FLANGE PLANE.

BASIS FOR DESIGN

A. DUAL TPA, BRIM SHIELD, THRUST
NULLING PER SNPO-C DIRECTION

TANK CONFIGURATION PER SNPO-C
LETTER OF 6 JANUARY 1969

200-IN. DIM. PER CURRENT SHIELDING
TRADE STUDIES.

100:1 NOZZLE PER NPRD PARA. IIIB.

PSOV & INTERFACE LOCATION PER
LETTER 7840:L0104 AND MEMO
7840:M-103.

REFERENCE ENGINE LAYOUT DRAWING

P/N 1135222

BASELINE CONFIGURATION
(CONTINUED)

SYSTEM

BASIS FOR DESIGN

B. PROPELLANT FEED SYSTEM - DUAL SYSTEM
FORWARD OF SHIELD. SINGLE LINE
SYSTEM AFT.

B. BASED ON CASE I OF 012 AND 006
TRADE STUDIES AND TECHNOLOGY PROGRAM
VALVE CONCEPTS

1. TURBOPUMP ASSEMBLIES - TWIN SPOOL
CENTRIFUGAL PUMPS. THREE STAGE
AXIAL TURBINE.

2. LINES - PIL, PDL, TIL, DILUENT, TEL

3. VALVES - PSOV, PDKV, TBV, TPCV

C. PRESSURE VESSEL ASSY WITH BRIM SHIELD

C. PV BASED ON COMPONENT LAYOUT 1135330.
BRIM SHIELD PER CONCEPT NO. 1 OF
003 TRADE STUDY.

REFERENCE ENGINE LAYOUT DRAWING

P/N 1135222

BASELINE CONFIGURATION

SYSTEM

D. NOZZLE ASSY - NOZZLE WITH BLEED
PORT, SKIRT, SKIRT EXTENSION

E. THRUST STRUCTURE & TVC

F. NUCLEAR SUBSYSTEM

BASIS FOR DESIGN

D. BASED ON COMPONENT LAYOUT 1136327
AND FOLLOWING DESIGN TRADE STUDIES:

7750:TR:0386 NOZZLE CONCEPTS

7750:TR:0385 NOZZLE MATERIAL

7750:TR:0387 NOZZLE COOLING

E. STRUCTURE BASED ON TECHNOLOGY
PROGRAM EXPERIENCE.
TVC CONCEPT BASED ON STUDIES
REPORTED IN LMSC-A794909, RN-TM-0356
AND RN-TM-0436.

F. BASED ON NSS LAYOUT 939J685 FROM
WANL.

REFERENCE ENGINE LAYOUT DRAWING

P/N 1135222

BASELINE CONFIGURATION
(CONTINUED)

SYSTEM

BASIS FOR DESIGN

G. THRUST NULLING

G. PRELIMINARY CONCEPT FROM TRADE STUDY
002.

H. PNEUMATIC SUBSYSTEM

H. FROM TRADE STUDY 201.

SUPPORTING DOCUMENTATION FOR PDR

<u>DATA ITEM</u>	<u>TITLE</u>	<u>SCOPE</u>
E-105	ENGINEERING DATA (CATEGORY A) FOR DESIGN EVALUATION	DRAWING PLUS NARRATIVE DISPLAYING SATISFACTION OF SYSTEM REQUIREMENTS AT THIS STAGE TO JUSTIFY SELECTED DESIGN APPROACH
E-106	ENGINEERING DATA (CATEGORY B) INTERFACE CONTROL	BASELINE DEFINITION OF INTERFACES
S-1	SYSTEM ANALYSIS SUMMARY REPORT	ENGINE PERFORMANCE ANALYSIS VS REQUIREMENTS
S-31	THERMAL & FLUID FLOW ANALYSIS REPORT	THERMAL ANALYSIS OF DESIGN APPROACH FOR SUPPORTING INPUT TO S-36
S-36	STRUCTURAL ANALYSIS REPORT	WITH INPUTS FROM S-31, -38, -39, AND -47 AND ANALYSIS OF DESIGN APPROACH, DETERMINES NO GROSS STRUCTURAL INADEQUACIES EXIST
S-38	ENVIRONMENTAL VIBRATION AND ACOUSTIC LOADING REPORT	DYNAMIC ANALYSIS OF DESIGN APPROACH FOR SUPPORTING INPUT TO S-36.

REFERENCE ENGINE DESIGN SUPPORTING DOCUMENTATION FOR PDR
(CONTINUED)

<u>DATA ITEM</u>	<u>TITLE</u>	<u>SCOPE</u>
S-39	LOADS REPORT	ANALYSIS OF DESIGN APPROACH FOR LOAD DISTRIBUTIONS FOR SUPPORTING INPUT TO S-36.
S-47	MASS PROPERTIES STATUS REPORT	ANALYSIS OF DESIGN APPROACH FOR WEIGHTS, C.G., AND MOMENTS OF INERTIA SUPPORTING INPUT TO S-36
S-54	REQUIREMENTS/DESIGN TRADE STUDY REPORTS	PRESENTS TRADE STUDY RESULTS SUPPORTING SELECTED DESIGN

PERT TREE SUMMARY

REFERENCE ENGINE PERTREE

TRADE STUDIES
TOLERANCES AND CONTROL

D. Buden #1

OBJECTIVES

1. ESTABLISH NOMINAL COMPONENT REQUIREMENTS
AND THREE SIGMA TOLERANCE
2. ESTABLISH PRIMARY CONTROL MEASUREMENT SYSTEM.
3. ESTABLISH MAXIMUM CHAMBER INLET TEMPERATURE REQUIREMENTS.

CRITERIA

1. MEET NPRD PERFORMANCE REQUIREMENTS
2. UTILIZE EXTENSION OF EXISTING TECHNOLOGY.

OPERATING MAP

PRD REQUIREMENTS

ESTABLISH THAT ENGINE CAN MEET PERFORMANCE REQUIREMENTS AT RATED CONDITIONS. THESE ARE DEFINED IN NPRD-1 (5 JUNE 1968) FOR A NOZZLE EXPANSION RATIO OF 100:1 AS:

	<u>PERFORMANCE</u>	<u>CONTROLLABILITY</u>
(1) THRUST, F	75,000 $\pm$ 2000 LB	$\pm$ 2%
(2) MIN. MIXED MEAN CHAMBER INLET TEMP., T_C	4500 $^{\circ}$ R	
(3) NOMINAL CHAMBER PRESSURE, P_C	450 PSIA	
(4) MIN. OVERALL SPECIFIC IMPULSE, I_{SP}	825 LB-SEC/LB	
(5) SPECIFIC IMPULSE		$\pm$ 0.75%

BACKGROUND INFORMATION

HOT BLEED

HOT BLEED

CHAMBER INLET TEMPERATURE REQUIREMENTS
BASED ON SPECIFIC IMPULSE MEASUREMENT SYSTEM

BASED ON MINIMUM $I_{SP} = 825 \text{ SEC}$

SINGLE TPA

DUAL TPA

A. MINIMUM CHAMBER INLET TEMPERATURE BASE POINT

4500⁰R

4500⁰R

B. EFFECT OF DUAL TPA CONFIGURATION

C. MEASUREMENT AND CONTROLLER (RSS D & E)

D. MEASUREMENT

E. CONTROLLER

F. NOMINAL T_C (A + B + C)

G. MEASUREMENT, CONTROLLER AND ENGINE-TO-ENGINE
(RSS D, E & H)

H. ENGINE-TO-ENGINE

I. MAXIMUM T_C (F + G)

J. MINIMUM T_C (F - G)

MAXIMUM CHAMBER INLET TEMPERATURE
BASED ON CHAMBER TEMPERATURE MEASUREMENT SYSTEM

	<u>SINGLE TPA</u>	<u>DUAL TPA</u>
BASIC	4500 ⁰ R	4500 ⁰ R
CHAMBER TEMPERATURE CONTROLLER		
TOTAL		
GUARANTEE ACHIEVE 825 SEC I_{SP}		
MAXIMUM TEMPERATURE		

ASSUME MINIMUM CHAMBER INLET TEMPERATURE OF 4500⁰R

	<u>SINGLE TPA</u>	<u>DUAL TPA</u>
BASIC I_{SP}	825 SEC	825 SEC
NOMINAL I_{SP}		
CHAMBER TEMPERATURE MEASUREMENT		
ENGINE-TO-ENGINE VARIATION		
EFFECT OF TPA		
GUARANTEED I_{SP}		

TRADE STUDIES
TOLERANCES AND CONTROL

W. W. Madsen

COMPONENT SPECIFICATION DIAGRAM

75K NERVA ENGINE FLOW SCHEMATIC

NOZZLE TUBE ΔP VARIATION
 TURBINE INLET TEMPERATURE = 1660°R = CONSTANT
 DESIGN ΔP = 190.1 PSID

NOZZLE

A. DESIGN GOAL

TO OBTAIN THE MINIMUM PRESSURE DROP AND WEIGHT CONSISTENT WITH THE REQUIRED RELIABILITY.

B. LIMITS

	<u>VALUE</u>	<u>REASON</u>
MAXIMUM WALL TEMP.		
CRYO-SKIRT TUBES	1200°F	MATERIAL CONSTRAINTS
NOZZLE TUBES	1620°F	

C. OPERATION AT DESIGN

	<u>PRESSURE</u>	<u>TEMPERATURE</u>		<u>PRESSURE</u>	<u>TEMPERATURE</u>
1. CRYO-SKIRT			2. NOZZLE TUBES		
IN	897.5 PSIA	52.3°R	IN	886 PSIA	82.7°R
OUT	886 PSIA	82.7°R	OUT	699.4 PSIA	206.9°R
DELTA	11.5 PSID	30.4°R	DELTA	186.6 PSID	124.2°R
		FLOW 65.8 LBM/SEC			

A. DESIGN GOAL

TO OBTAIN THE MINIMUM BLEED RATIO AND WEIGHT CONSISTENT WITH THE REQUIRED TURBOPUMP RELIABILITY.

B. LIMITS

	<u>VALUE</u>	<u>REASON</u>
MAXIMUM RPM	25,500	CAVITATION; BEARING MATERIAL, TURBINE MATERIAL; CRITICAL SPEED
PUMP STALL NPSP	15% QUALITY	PUMP OPERATING CHARACTERISTICS
TURBINE INLET TEMP.	1720	MATERIAL LIMITATION

C. OPERATION AT DESIGN

	<u>PRESSURE</u>	<u>TEMPERATURE</u>		<u>PRESSURE</u>	<u>TEMPERATURE</u>
1. PUMP			2. TURBINE		
IN	29.5 PSIA	39.3 °R	IN	363.2 PSIA	1660°R
OUT	931.6 PSIA	52.1 °R	OUT	27.0 PSIA	1274°R
DELTA	902.1	12.8 °R	DELTA	335.4 PSID	386°R
SPEED 24,588 RMP					
EFFICIENCY	72.9%		EFFICIENCY	45.7%	
FLOW	90.4 LBM/SEC		FLOW	3.6 LBM/SEC	

ENGINE CYCLE ANALYSIS

ENGINE CYCLE ANALYSIS

HOT BLEED

ENGINE PC = 450 PSIA, TC = 4548°R, THRUST = 75,135 LBS, IMPULSE = 831.2 SEC,
POWER LEVEL = 1564 MW, TPCV = 45.23 DEGREES

TURBOPUMP

		<u>PUMP</u>	<u>TURBINE</u>
SHAFT SPEED, RPM		24,588	24,588
POWER, MW		5.2	5.2
EFFICIENCY, PERCENT		72.9	45.7
<u>STATE POINT DESCRIPTION</u>	<u>FLOW LB/SEC</u>	<u>PRESSURE PSIA</u>	<u>TEMPERATURE °R</u>
DEWAR OUTLET	90.4	30.0	40.0
PUMP INLET	90.4	29.5	39.3
PUMP LEAKAGE	0.5		
PUMP OUTLET	89.9	931.6	52.1
STRUCTURAL SUPPORT INLET	21.1	902.5	52.3
BOLT COOLANT	3.0		
SKIRT INLET	65.8	897.5	52.3
SKIRT OUTLET	65.8	86.0	82.7
NOZZLE INLET	65.8	886.0	82.7
NOZZLE OUTLET	65.8	699.4	206.9
REFLECTOR INLET	66.2	699.4	201.4
REFLECTOR OUTLET	66.2	648.5	301.5
PERIPH, SHIELD OUTLET	66.2	637.6	310.0
STRUCTURAL OUTLET	21.1	637.6	288.4
SUPPORT PLATE INLET	87.3	637.6	304.5
TOP SHIELD INLET	87.3	627.3	310.5
CORE INLET	87.3	616.3	315.5
CORE OUTLET	87.3	450.0	4548.0
NOZZLE CHAMBER	86.2	450.0	
DILUENT BLEED INLET	2.47	699.4	201.4
DILUENT BLEED OUTLET	2.47		
HOT BLEED	1.13	450.0	4542.0
MIXING RING OUTLET	3.60		
TPCV INLET	3.60		
TURBINE INLET	3.60	363.2	1660.0
TURBINE OUTLET	3.60	27.8	1274.0
SKIRT EXTENSION INLET	4.10	19.7	1119.9

HOT BLEED CYCLE TOLERANCE

STATE POINT COMPARISON FOR VARIABLE ΔP @ REFLECTOR INLET

DESCRIPTION	NOMINAL			REFLECTOR $\Delta P = 79.1$ PSID		
	FLOW (LB/SEC)	PRESSURE (PSIA)	TEMP. (°R)	FLOW (LB/SEC)	PRESSURE (PSIA)	TEMP. (°R)
DEWAR OUTLET	91.491	30.0	40.0	92.161	30.0	40.0
PUMP INLET	91.491	29.5	39.3	92.161	29.5	39.2
PUMP OUTLET	90.998	937.6	53.3	91.660	958.0	53.6
STRUCTURAL SUP. IN.	21.21	907.4	53.6	22.22	927.8	53.8
STRUCTURAL SUP. OUT	21.21	638.1	286.1	22.22	637.8	274.2
BOLT COOLANT	2.985			2.990		
SKIRT TUBE INLET	66.799	902.3	53.6	65.953	922.8	53.82
SKIRT TUBE OUTLET		890.4	83.2		911.2	83.9
NOZZLE TUBE INLET	66.799	890.4	83.2	65.953	911.2	83.9
NOZZLE TUBE OUTLET		700.2	204.9		727.7	207.0
REFLECTOR INLET	66.883	700.2	199.6	65.869	727.7	201.5
PERIPH. SHIELD IN.	66.883	649.0	298.4	65.869	648.6	301.9
SUPPORT PLATE INLET	88.097	638.0	301.6	88.084	637.8	301.1
TOP SHIELD	88.097	628.6	307.4	88.084	628.4	306.9
CORE INLET	88.097	616.5	312.3	88.084	616.4	311.8
CORE OUTLET		449.9	4498.6		449.9	4498.0
NOZZLE CHAMBER	86.766			86.763		
DILUENT FLOW	2.900			3.075		
HOT BLEED FLOW	1.332			1.321		
TURBINE INLET	4.232	316.7	1659.9	4.396	322.4	1594.2
TURBINE OUTLET		42.3	1305.8		43.0	1244.2
PUMP LEAKAGE	0.495			0.501		
SKIRT EXTENSION OUTLET	4.726	-	1576.8	4.897	--	1520.6

$T_{ti} = 1660^{\circ}\text{R} = \text{CONSTANT}$
DESIGN $\Delta P = 50.2 \text{ PSID}$

DESIGN $\Delta P = 50.2$ PSID

$T_{ti} = 1660^\circ R = \text{CONSTANT}$

DESIGN $\Delta P = 50.2$ PSID

DESIGN $\Delta P = 190$ PSID

$T_{ti} = 1660$ °R = CONSTANT

DESIGN $\Delta P = 190.1$ PSID

	COMPONENT	$(\partial I_{sp} / \partial F)_{PD}$	$(\partial Thrust / \partial F)_{PD}$
Δ PRESSURE	PUMP INLET LINE	-.01	.70
	PUMP DISCHARGE LINE	-.0121	.853
	NOZZLE TUBES	-.0136	1.044
	REFLECTOR	-.0097	.775
	PERIPH. SHIELD	-.0093	.727
	CORE SUPPORT PLATE	-.0100	.609
	TOP SHIELD	-.0110	.774
	CORE	-.0122	.930
	SKIRT	-.0101	.7733
	STRUCTURAL SUPPORT	-.0157	1.194
Δ TEMPERATURE	NOZZLE TUBES	-.0149	1.143
	REFLECTOR	-.003	.225
	PERIPH. SHIELD	-.0431	3.971
	CORE SUPPORT PLATE	-.0338	2.635
	TOP SHIELD	0	0
	SKIRT	-.0282	2.199
	STRUCTURAL SUPPORT	-.0016	.127
	SKIRT EXTENSION	.00684	.02736
	CORE	.00455	.367
MISC.	PUMP EFFICIENCY	.2583	-27.69
	TURBINE EFFICIENCY	.3517	-39.17
	BEARING COOLANT	-6.0	55.0
	THROAT	-.1367	11.89
	BOLT COOLANT	.0487	-.96
	DILUENT LINE	-4.10	444.0
	$\Delta H / N^2$	-3.3×10^{-6}	361×10^{-6}
	TURBINE PRESSURE RATIO	.543	-49.9

ENGINE-TO-ENGINE INFLUENCE COEFFICIENTS

COMPONENT	$(\partial I_{sp} / \partial F)_{EE}$	$(\partial Thrust / \partial F)_{EE}$	$(\partial T_{ti} / \partial F)_{EE}$
PUMP INLET LINE	-.0048	.670	1.311
PUMP DISCHARGE LINE	.008	-0.333	1.346
NOZZLE TUBES	.004	.786	1.541
REFLECTOR	-.036	1.750	2.50
PERIPH. SHIELD	-.038	1.070	2.25
CORE SUPPORT PLATE	-.043	1.538	2.5556
TOP SHIELD	-.041	1.010	2.50
CORE	-.043	1.155	2.440
SKIRT	.004	.581	1.4286
STRUCTURAL SUPPORT	-.032	1.400	1.4038
NOZZLE TUBES	.0391	.2097	.128
REFLECTOR	-.009	.288	-0.5243
PERIPH. SHIELD	-.008	1.000	0
CORE SUPPORT PLATE	-.008	1.000	0
TOP SHIELD	0	0	0
SKIRT	.0564	.830	6.846
STRUCTURAL SUPPORT	-.003	.112	-0.1558
SKIRT EXTENSION	.0068	.0274	0
CORE	.013	-0.507	.7833
PUMP EFFICIENCY	.0133	-21.8	-22.3
TURBINE EFFICIENCY	-.0061	-23.9	-21.2
BEARING COOLANT	-6.0	55.0	0
THROAT	-.1367	-11.89	6.22
BOLT COOLANT	-.042	-1.75	6.1157
DILUENT LINE	-5.20	338.0	110.0
$\Delta H/N^2$	0	266.7×10^6	223×10^6
TURBINE PRESSURE RATIO	-.011	-58.7	-38.7

I. ESTABLISH NOMINAL STATE POINT BASED ON PRD REQUIREMENTS USING:

(A) SYSTEM INFORMATION PARTIAL DERIVATIVES, I.E., $\left[\frac{\partial I_{sp}}{\partial F} \right]_{PD}, \left[\frac{\partial T_{11}}{\partial F} \right]_{PD}$

(B) COMPONENT DESIGN INFORMATION.

II. ESTABLISH COMPONENT TOLERANCE BASED ON:

(A) SYSTEMS ANALYSIS USING PARTIAL DERIVATIVES, I.E. $\left[\frac{\partial I_{sp}}{\partial F} \right]_{EE}, \left[\frac{\partial T_{11}}{\partial F} \right]_{EE}$

$$\text{TOTAL} \equiv \sqrt{\sum_{N=1}^K \left[\frac{\partial I_{sp}}{\partial F_N} \right]_{EE}^2} \sigma_N^2$$

(B) COMPONENT MATERIAL CONSTRAINTS

(C) EXPERIENCE WITH MANUFACTURING TOLERANCES

(D) DESIGN AND TESTING UNCERTAINTIES

III. SCHEDULES, COST, WEIGHT, AND RELIABILITY.

	COMPONENT	$\Delta T_{ti} = 60^\circ R$	THRUST $\Delta F = 2000 \text{ lb}$	IMPULSE $I_{sp} = 3.1 \text{ sec}$
$\Delta \text{PRESSURE}$	PUMP INLET LINE	9.76	238.6	28.7
	PUMP DISCHARGE LINE	9.50	419.6	23.7
	NOZZLE TUBES	8.30	342.8	21.1
	REFLECTOR	5.12	461.8	29.6
	PERIPH. SHIELD	5.69	492.3	30.9
	CORE SUPPORT PLATE	5.01	587.7	28.7
	TOP SHIELD	5.12	462.4	26.1
	CORE	5.24	384.8	23.5
	SKIRT	8.95	462.8	28.4
	STRUCTURAL SUPPORT	9.11	299.7	18.3
$\Delta \text{TEMPERATURE}$	NOZZLE TUBES	3.10	313.1	19.3
	REFLECTOR	24.4	1590.7	95.6
	PERIPH. SHIELD	*	90.1	6.7
	CORE SUPPORT PLATE	*	135.8	8.5
	TOP SHIELD	*	*	286.9
	SKIRT	1.87	162.8	10.2
	STRUCTURAL SUPPORT	82.1	2818.1	179.3
	SKIRT EXTENSION	*	*	41.9
	CORE	16.3	975.2	63.1
	PUMP EFFICIENCY	0.57	12.93	1.11
	TURBINE EFFICIENCY	0.60	9.14	0.82
	BEARING COOLANT	0.71	0.89	0.048
	THROAT AREA	0.80	30.10	2.1
	BOLT COOLANT	2.09	90.38	5.9
	DILUENT LINE	0.71	0.50	0.060
	$\Delta H/N^2$	$.57 \times 10^{-7}$	$.99 \times 10^{-6}$	$.87 \times 10^{-7}$

* Negligible influence

<u>TEST NUMBER</u>	<u>REFLECTOR ΔP</u>	<u>SHIELD ΔP</u>	<u>CORE ΔP</u>
A2	39.2	11.5	113.9
A3	41.6	13.2	105.1
EST	38.7	8.9	106.3
A5	35.8	10.7	118.7
A6	34.3	10.6	102.0

STATISTIC

$\bar{X}$	37.92	10.98	109.20
σ	2.89	1.56	6.88
3σ	8.67	4.68	20.64
3σ (%)	23%	43%	19%

<u>FOR NERVA 75K</u>	<u>REFLECTOR ΔP</u>	<u>PERIPH. SHIELD ΔP</u>	<u>TOP SHIELD ΔP</u>	<u>CORE ΔP</u>
X	50.9	10.9	12.0	166
3σ	12.1	5.5	6.0	31.9
3σ (%)	23%	50%	50%	19%

NOZZLE TUBE PRESSURE DROP
TYPICAL TEST DATA (TYPICAL POINTS)

<u>TEST</u>	<u>ΔP MEASURED</u>	<u>1 - RATIO</u>
NRX-A3	136	
NRX-A5 EP 3	136.5	
NRX A5 EP 4	139	
NRX EST EP IV	165	
NRX EST EP IV A	170.3	
$\bar{X}$ (IN TUBE DROP ONLY TECHNOLOGY ENGINE)		
σ TECHNOLOGY ENGINE		8.5 PSID = 6.2%
75K ENGINE (IN TUBE DROP ONLY)		100 PSI
σ 75K ENGINE		6.2 PSI
3 σ 75K ENGINE		18.6 PSI

	COMPONENT	NOMINAL	3 σ ESTIMATE OR PAST PERFORMANCE	VARIATION WITH PAST PERFORMANCE DATA			
				ΔI_{sp}	ΔF	ΔT_{ti}	$\Delta T_{ti} = +60^{\circ}R$
Δ PRESSURE	PUMP INLET LINE	0.533	0.5	.0024	.8350	.6555	0.5
	PUMP DISCHARGE LINE	30.0	2.0	.0160	.6660	2.692	2.0
	NOZZLE TUBES	190.0	18.6	.0744	14.62	28.66	9.1
	REFLECTOR	51.0	12.1	.4356	21.17	30.25	5.6
	PERIPHERAL SHIELD	11.0	5.5	.2090	5.885	12.37	5.5
	CORE SUPPORT PLATE	9.0	4.5	.1935	6.921	11.50	4.5
	TOP SHIELD	12.0	6.0	.2460	6.06	15.00	5.6
	CORE	166.0	31.9	1.371	36.84	77.83	5.8
	SKIRT	12.0	3.0	.0120	1.743	4.286	3.0
	STRUCTURAL SUPPORT	270.0	64.0	2.048	89.60	89.84	10.0
Δ TEMPERATURE	NOZZLE TUBES	122.0	15.0	.5865	3.146	61.92	3.4
	REFLECTOR	100.0	30.0	.27	8.64	15.73	26.8
	PERIPHERAL SHIELD	8.0	2.6	.0192	2.4	0	2.6
	CORE SUPPORT PLATE	6.0	1.8	.0144	1.8	0	1.8
	TOP SHIELD	5.0	1.5	0	0	0	1.5
	SKIRT	30.0	6.0	.3384	4.980	41.07	2.1
	STRUCTURAL SUPPORT	233.0	70.8	.212	7.93	11.03	70.8
	SKIRT EXTENSION	407.0	60.0	.4104	1.642	0	18.0
MISC.	CORE	4188.0	*				
	PUMP EFFICIENCY	72.9	5%	.0665	109.0	111.5	0.63
	TURBINE EFFICIENCY	45.6	6%	.0366	143.4	127.2	0.66
	BEARING COOLANT	0.495	0.5	3.00	330.0	0	0.288
	BOLT COOLANT	2.98	0.3	.0126	.5250	1.835	0.3
	THROAT	96.996	1.43	.1949	16.96	8.866	1.43
	DILUENT LINE	2.9	0.5	2.6	169.0	55.0	0.285
	H/N ²	2.58 x 10 ⁻⁶	*				
RMS =				4.79	425.0	232.4	

* NO DATA AVAILABLE

VARIABLE TURBINE INLET TEMPERATURE PERFORMANCE

75K NERVA - NOMINAL 1660°R T_{11}

EFFECT OF TURBINE INLET TEMPERATURE ON SYSTEM I_{SP}

IF THE COMPONENT ALLOWABLE 3σ LIMITS ARE RESTRICTED TO MEET A POSSIBLE 3σ VARIATION IN SYSTEM I_{SP} OF ± 3.1 SEC, A RMS VARIATION IN TURBINE INLET TEMPERATURE OF $\pm 244.3^\circ\text{R}$ WILL RESULT.

AN UPPER LIMIT OF 1720°R RESULTS IN A NOMINAL TURBINE INLET TEMPERATURE OF $1475.7 \pm 244.3^\circ\text{R}$.

DEGRADING THE NOMINAL TURBINE INLET TEMPERATURE BY 184 WILL DEGRADE THE NOMINAL I_{SP} BY 2.4 SEC.

DESIGN MATRIX - CONTROLLED TURBINE INLET TEMPERATURE

		Past Performance		System	System	System	System
				3σ	3σ	3σ	3σ
		3σ	ΔI _{sp}	2.0 sec(+18°R)	3.1 sec(+28°R)	4.32 sec(+39°R)	5.0 sec(+45°R)
Δ PRESSURE	PUMP INLET LINE	0.5	.005	0.5	0.5	0.5	0.5
	PUMP DISCHARGE LINE	2.0	.0242	2.0	2.0	2.0	2.0
	NOZZLE TUBES	18.6	.2530	18.6	18.6	18.6	18.6
	REFLECTOR	12.1	.1174	12.1	12.1	12.1	12.1
	PERIPHERAL SHIELD	5.5	.0512	5.5	5.5	5.5	5.5
	CORE SUPPORT PLATE	4.5	.045	4.5	4.5	4.5	4.5
	TOP SHIELD	6.0	.066	6.0	6.0	0 6.0	6.0
	CORE	31.9	.3892	31.9	31.9	31.9	31.9
	SKIRT	3.0	.0303	3.0	3.0	3.0	3.0
STRUCTURAL SUPPORT		64.0	1.005	64.0	64.0	64.0	64.0
Δ TEMPERATURE	NOZZLE TUBES	15.0	.2235	15.0	15.0	15.0	15.0
	REFLECTOR	30.0	.0900	30.0	30.0	30.0	30.0
	PERIPHERAL SHIELD	2.6	.1121	2.6	2.6	2.6	2.6
	CORE SUPPORT PLATE	1.8	.0608	1.8	1.8	1.8	1.8
	TOP SHIELD	1.5	0	1.5	1.5	1.5	1.5
	SKIRT	6.0	.1692	6.0	6.0	6.0	6.0
	STRUCTURAL SUPPORT	70.8	.1133	70.8	70.8	70.8	70.8
	SKIRT EXTENSION	60.0	.4104	60.0	60.0	60.0	60.0
	CORE	--	--	0	107.0	233.4	258.0
MISC.	PUMP EFFICIENCY	5.0	1.2915	5.0	5.0	5.0	5.0
	TURBINE EFFICIENCY	6.0	2.1102	6.0	6.0	6.0	6.0
	BEARING COOLANT	0.5	3.0	0	0.081	0.177	0.205
	BOLT COOLANT	0.3	0.0146	0.3	0.3	0.3	0.3
	THROAT	1.43	0.1955	1.43	1.43	1.43	1.43
	DILUENT	0.5	2.05	0	0.100	0.220	0.255
	ΔH/N ²	.32 x 10 ⁻⁶	--	0	.15 x 10 ⁻⁶	.32 x 10 ⁻⁶	.37 x 10 ⁻⁶

RMS = $\sqrt{4.57 (+ 41^0R)}$

	<u>COMPONENT</u>	<u>NOMINAL</u>	<u>3σ TOLERANCE</u>
<u>Δ PRESSURE</u>	PUMP INLET LINE	0.533	0.5
	PUMP DISCHARGE LINE	30.0	2.0
	NOZZLE TUBES	190.0	18.6
	REFLECTOR	51.0	12.1
	PERIPHERIAL SHIELD	11.0	5.5
	CORE SUPPORT PLATE	9.0	4.5
	TOP SHIELD	12.0	6.0
	CORE	166.0	31.9
	SKIRT	12.0	3.0
	STRUCTURAL SUPPORT	270.0	64.0
<u>Δ TEMPERATURE</u>	NOZZLE TUBES	122.0	15.0
	REFLECTOR	100.0	30.0
	PERIPHERIAL SHIELD	8.0	2.6
	CORE SUPPORT PLATE	6.0	1.8
	TOP SHIELD	5.0	1.5
	SKIRT	30.0	6.0
	STRUCTURAL SUPPORT	233.0	70.8
	SKIRT EXTENSION	407.0	60.0
	CORE	4188.0	107.0
<u>MISC.</u>	PUMP EFFICIENCY	72.9	5.0
	TURBINE EFFICIENCY	45.6	6.0
	BEARING COOLANT	0.495	0.081
	THROAT	96.996	1.43
	BOLT COOLANT	2.98	0.300
	DILUENT LINE	2.9	0.100
	$\Delta H/N^2$	2.58×10^{-6}	0.15×10^{-6}

TRADE STUDIES
TOLERANCES AND CONTROL

J. H. Altseimer

PART IV MEASUREMENT SYSTEMS

SPECIFIC IMPULSE AND TEMPERATURE

- TRADE STUDY, OCTOBER 1968: SCOPE AND CONCLUSIONS
- TEMPERATURE ERROR ANALYSES
- WEIGHT FLOW RATE ERROR ANALYSES
- COMPARISON MATRIX OF SIX CANDIDATE SPECIFIC IMPULSE MEASUREMENT SYSTEMS
- CONCLUSIONS AND RECOMMENDATIONS

4 OCTOBER 1968

SCOPE:

- STUDY THE MEASUREMENT SYSTEMS AND ANALYSES NECESSARY TO SHOW THAT THE ENGINE MEETS THE SPECIFIC IMPULSE REQUIREMENTS

PROGRAM OBJECTIVES:

- MINIMIZE T_C RANGE
- COMPATIBILITY WITH ETS-1

SPECIFIC IMPULSE MEASUREMENT SYSTEMS STUDIED:

- CHAMBER GAS TEMPERATURE
- THRUST $\div$ FLOW RATE: LOAD CELL THRUST MEASUREMENT
- THRUST $\div$ FLOW RATE: WALL PRESSURE THRUST MEASUREMENT
- THRUST $\div$ FLOW RATE: THRUST CALCULATED USING THRUST COEFFICIENT, CHAMBER PRESSURE AND THROAT AREA
- USE OF EXHAUST GAS VELOCITY
- USE OF VEHICLE FLIGHT DYNAMICS

RESULTS OF CHAMBER TEMPERATURE ERROR ANALYSIS

FROM

NRX-A6 AND NRX PROGRAM DATA ANALYSIS REPORT

REFERENCE: RN-S-0464, JULY 1968

OVERALL CHOKED FLOW ERROR EQUATION:

$$E = \frac{A_E Z P_C}{W \sqrt{T_C}}$$

VARIATION MODEL EQUATION:

$$\frac{\sigma_E^2}{E^2} = \frac{\sigma_{AE}^2}{A_E^2} + \frac{\sigma_Z^2}{Z^2} + \frac{\sigma_{P_C}^2}{P_C^2} + \frac{\sigma_W^2}{W^2} + \frac{\sigma_{T_C}^2}{4T_C^2}$$

INPUTS FROM NRX TEST DATA:

$$\sigma_{P_C} = 1.7 \text{ PSIA}$$

$$\sigma_W = 0.68 \text{ LB/SEC}$$

$$\sigma_{T_C} = 27^\circ\text{R (A-2 TO A-5)}$$

ESTIMATED INPUT:

$$\sigma_{AE} = 0.3 \text{ IN}^2$$

$$\sigma_Z = 0.0005$$

	OVERALL NOZZLE CHOKED FLOW ERROR				PERCENT OF OVERALL ERROR				
	UNCORRECTED DATA		CORRECTED DATA		A_E	Z	P_C	$\dot{w}$	T_C
	$\sigma_{(E)}$	BIAS	$\sigma_{(E)}$	BIAS					
MEASURED T_C :									
TEST DATA	0.0241	-0.0042	0.0169	-0.0024					
FULL POWER			0.0124		17.3	8.6	5.9	61.1	7.1
INTERMEDIATE POWER			0.0188		17.6	3.8	8.5	76.1	4.0
LOW POWER			0.0241		4.7	2.2	12.5	75.5	5.1

USING DIFFERENT MEASUREMENT LOCATIONS

	$\sigma(^{\circ}\text{R})$	$3\sigma(^{\circ}\text{R})$	COMMENTS
T_C (DIRECT MEASUREMENT)	27	81 (1.98%)	BASED ON NRX TESTS A-2 TO A-5
T_C (EXTRAPOLATED $T_{\text{CORE EXIT}}$)	35 TO 88	105 TO 264	CORE EXIT TEMPERATURES WERE AVAILABLE FOR A6 ONLY
T_C (EXTRAPOLATED T_{26})	140	420	
T_C (STATISTICALLY COMBINED)	≤ 25	≤ 76 (1.86%)	

FOR CLUSTER EXTRAPOLATION: $T_C = f(H_{CF}, P_C)$

$$\text{WHERE, } H_{CF} = (1 - W_S - W_{TR}) H_F + W_{TR} H_{TR} + W_S H_S$$

FOR T_{26} EXTRAPOLATION:

$$T_C = \frac{\bar{T}_{26}}{0.93}$$

$$\text{WHERE, } T_{26} \text{ (INDIVIDUAL)} = A_1 + A_2 r^2 + A_3 r^3 + A_4 r^4$$

MAJOR CRYOGENIC FLOW FACILITIES

LIQUID HYDROGEN FLOWMETER CALIBRATION CAPABILITIES

<u>PLACE</u>	<u>APPROXIMATE MAXIMUM FLOW (LB/SEC)</u>	<u>MAXIMUM SYSTEM PRESSURE (PSIG)</u>	<u>TYPE OF CALIBRATION</u>	<u>ESTIMATED ACCURACY (30)</u>
WYLE LABS	12	100	GRAVITY	0.23%
ROCKETDYNE (J-2 TEST STAND)	*	*	VOLUMETRIC	1.0%
PRATT-WHITNEY	12	*	GRAVITY	0.36%
AEROJET (M-1 PUMP STAND)	290	100	VOLUMETRIC	2-3%
LASL	97	100	VOLUMETRIC	1.64-3.72% **
AEROJET (NERVA) (WITH PUMP)	97	100	GRAVITY	0.5%

* UNKNOWN

** REPORTED MAXIMUM PERCENTAGE ERROR (1.64 AND 3.72% CORRESPOND TO 6,000 AND 1.000 GPM, RESPECTIVELY)

75 K PUMP IN H-5

FLOWMETER CALIBRATION UNCERTAINTY
AS A FUNCTION OF AMOUNT OF LH₂ OUTFLOW

VH-11

UNCERTAINTY IN %, 3 σ

FOR
SPECIFIC IMPULSE DETERMINATION

<u>PARAMETERS</u>	<u>ESTIMATED ATTAINABLE 3σ ACCURACY (%)</u>
ENGINE WEIGHT FLOW RATE	0.55
CHAMBER TEMPERATURE	1.86
NOZZLE THRUST COEFFICIENT	0.26 + 00.52
THROAT AREA	0.30
CHAMBER PRESSURE	0.08 + 00.43
THRUST BY LOAD CELLS IN ETS-1	> 0.77
THRUST BY USE OF WALL PRESSURES	0.42
THRUST OF SKIRT FROM 29 TO 100 AREA RATIO	0.9
TURBINE EXHAUST THRUST	4.5

CANDIDATE SYSTEM NO. 1

I_{SP} FROM CHAMBER GAS TEMPERATURE AND TURBINE EXHAUST NOZZLE MEASUREMENTS

BASIC EQUATIONS:

$$1. \quad (I_{SP})_N = \sqrt{\frac{2}{g} \left(\frac{k}{k-1} \right) \frac{RT_1}{M} \left[1 - \left(\frac{p_e}{p_1} \right)^{\frac{k-1}{k}} \right]} + \frac{p_e - p_o}{\dot{w}_N} A_e$$

$$2. \quad (I_{SP})_T = \frac{C_{FT} \times A_t \times p_T}{\dot{w}_T}$$

$$3. \quad (I_{SP})_{ENGINE} = \frac{(I_{SP})_N \times \dot{w}_N + (I_{SP})_T \times \dot{w}_T}{\dot{w}_N + \dot{w}_T}$$

CANDIDATE SYSTEM NO. 1

I_{SP} FROM CHAMBER GAS TEMPERATURES AND TURBINE EXHAUST NOZZLE MEASUREMENTS

BEST ATTAINABLE UNCERTAINTIES

		<u>+ % T (3σ)</u>	<u>+ % I_{SP} (3σ)</u>
CHAMBER TEMPERATURE MEASUREMENT		1.98	1.00
TEMPERATURE BIAS		0.24	0.12
NOZZLE			0.52
	<u>UNCERTAINTY %</u>		
NON-UNIFORM FLOW	0.27		
HEAT TRANSFER AND FRICTION....	0.06		
CHEMICAL KINETICS	0.21		
AREA RATIO SCALING			
(29 TO 100)	0.02		
	R.S.S. = 0.35		
	ESTIMATED <u>2σ</u>		
TURBINE THRUST CONTRIBUTION			<u>0.11</u>
	Σ R.S.S.		1.14

CANDIDATE SYSTEM NO. 2

THRUST : ENGINE WEIGHT FLOW RATE

THRUST BY LOAD CELL MEASUREMENT

SUMMARY OF UNCERTAINTIES

ITEM	<u>3 σ ACCURACY (%)</u>	<u>TARE LOADS (LB)</u>	<u>PERCENT OF 75K</u>	<u>ERRORS ELIMINATED BY TARE LOAD CALIBRATION</u>
1. LOAD CELLS (4 REQ'D)	0.25	---	---	NO
2. CALIBRATING LOAD CELLS (4 REQ'D)	0.25	---	---	NO
3. DATA ELECTRONICS	0.11	---	---	NO
4. THRUST ROD BELLOWS (ENGINE FIRING)		300	0.4	YES
5. THRUST ROD BELLOWS (ATM. PRESS)		6000	8.0	YES
6. THRUST ROD BELLOWS (WATER LOAD)		750 - 1500	1.0 to 2.0	YES
7. PROPELLANT LINE PRESSURE EFFECTS		1000 - 1500	1.5 to 2.0	YES
8. ENGINE WET WEIGHT	0.007	---	---	NO
9. THERMAL AND NUCLEAR RADIATION HEATING	UNDETERMINED	---	---	NO
10. GIMBALLING LOADS	---	0	0	---
11. EXTRAPOLATION OF A.R. (29 to 100)	0.02	---	---	NO
12. ENGINE FLOW RATE	0.55	---	---	NO

NEGLECT ITEM NO. 9:

R.S.S. (1 + 2 + 3 + 11), THRUST UNCERTAINTY = $\pm 0.77\%$

R.S.S., SPECIFIC IMPULSE = $\pm 0.95\%$

CANDIDATE SYSTEM NO. 3

THRUST ÷ ENGINE WEIGHT FLOW RATE

THRUST VIA WALL PRESSURE THRUST DETERMINATION

$$\text{ENGINE } I_{SP} = \frac{1}{\dot{W}} \left[\int_{A_i} P_i dA_i + F_{\text{TURB. EXHAUST}} \right]$$

3σ UNCERTAINTY SUMMARY:

	<u>% THRUST CONTRIBUTION</u>	<u>% UNCERTAINTY BASED ON THRUST CONTRIB.</u>
1. WALL PRESSURES		
FWD. WALL - SUBSONIC NOZZLE	13.6	+0.004
THROAT AREA	8.3	0.249
THROAT PROJECTION ON FWD. WALL	60.4	0.034
SUPERSONIC AREA	17.7	0.006
R.S.S. WALL PRESSURES		+0.25%
2. PROJECTED AREAS		0.30
3. FRICTION CORRECTION		0.08
4. TURBINE EXHAUST THRUST		0.11
5. EXTRAPOLATION OF AREA RATIO FROM 29 TO 100		0.02
6. WEIGHT FLOW RATE		0.55

R.S.S. OF THRUST = +0.42%

R.S.S. OF I_{SP} = +0.69%

ISP USING CHAMBER PRESSURE AND PROPELLANT WEIGHT FLOW RATE

$$\text{NOZZLE } I_{SP} = \frac{C_F A_t P_c}{\dot{w}}$$

FOR A 1-D, ISENTROPIC, PERFECT GAS:

$$C_F = \sqrt{\frac{2}{k-1} \left(\frac{2}{k+1} \right)^{\frac{k+1}{k-1}} \left[1 - \left(\frac{P_e}{P_1} \right)^{\frac{k-1}{k}} \right]} + \left(\frac{P_e}{P_1} \right) \left(\frac{A_e}{A_t} \right)$$

3 σ UNCERTAINTY SUMMARY:

NOZZLE C_F :

		Using Pressure Transducer Accuracy = <u>+1.14%</u>	Using Pressure Accuracy = <u>+0.15%</u> and Improving C_F Accuracy By Test
GAS STREAMING	<u>+0.27%</u>		
HEAT TRANSFER AND FRICTION.....	0.06		
CHEMICAL KINETICS	0.21		
EXTRAPOLATION, 29 TO 100 A.R.....	0.02		
R.S.S. <u>+0.35%</u> (2 σ)		<u>+0.52%</u>	<u>+0.26</u>
PRESSURE.....		<u>+0.43</u>	<u>+0.057</u>
FLOW RATE.....		<u>+0.55</u>	<u>+0.55</u>
AREA.....		<u>+0.30</u>	<u>+0.30</u>
TURBINE THRUST		<u>+0.11</u>	<u>+0.11</u>
R.S.S. <u>+0.93</u>		<u>+0.93</u>	<u>+0.69</u>

CANDIDATE SYSTEM NO. 5
USE OF EXHAUST GAS VELOCITY MEASUREMENTS

$$\text{THRUST CHAMBER } I_{SP} = \frac{U}{g}$$

UNCERTAINTIES

1.	MEASUREMENT OF MASS FLUX AND DYNAMIC HEAD	NOT WELL ESTABLISHED
	A. PITOT TUBES ($U^2 \rho$) + MASS FLUX ($U \rho$)	
	B. CALCULATE USING SUPERSONIC SHOCK RELATIONSHIPS	
2.	SPECTROSCOPIC TECHNIQUES	EXPECTED = $\pm$ 2%
3.	LASER VELOCIMETER	AIR VELOCITIES AT 1000
FT/SEC = $\pm$ 3%
4.	ELECTROMAGNETIC TECHNIQUES.....	ACTUAL $\pm$ 5%
ESTIMATED $\pm$ 1%

CANDIDATE SYSTEM NO. 6
USE OF VEHICLE FLIGHT DYNAMICS

$$I_{SP} = \frac{(t_2 - t_1)}{g \left(\frac{1}{\alpha_1} - \frac{1}{\alpha_2} \right)}$$

BASIC ASSUMPTION: THRUST = CONSTANT AND GRAVITY EFFECTS = 0

ACTUAL FLIGHT EXPERIENCE:

	<u>3 σ UNCERTAINTIES</u>
1. THOR, ATLAS, TITAN	<u>± 0.15 TO 0.75%</u>
2. DISCOVERER SATELLITE FLIGHTS.....	<u>± 0.67%</u>

EQUATIONS FOR IN-FLIGHT SPECIFIC IMPULSE CALCULATIONS

BASIC ASSUMPTIONS:

$$1. \quad \left| \vec{T} - \vec{D} \right| = \text{CONSTANT}$$

$$2. \quad \dot{m} = \text{CONSTANT}$$

EQUATIONS:

$$m\vec{a} = \vec{T} - \vec{D} - m\vec{g} \quad (1)$$

$$\text{LET,} \quad \vec{\alpha} = \vec{a} + \vec{g}$$

$$\begin{aligned} \text{THEN,} \quad m\vec{\alpha} &= m\vec{a} + m\vec{g} \\ &= \vec{T} - \vec{D} = \vec{F} \end{aligned} \quad (2)$$

$$\text{OR,} \quad m\alpha = F \quad (3)$$

WHERE, α = THRUST ACCELERATION MEASURED BY ON-BOARD ACCELEROMETERS

F = ALL FORCES EXCEPT GRAVITY

$$m = m_o - \dot{m} (t - t_o) \quad (4)$$

$$\frac{1}{\alpha} = \frac{m_o}{F} - \frac{\dot{m}}{F} (t - t_o) \quad (5)$$

$$\frac{1}{\alpha_1} - \frac{1}{\alpha_2} = \frac{\dot{m}}{F} (t_1 - t_2) = - \frac{\dot{w}}{Fg} (t_1 - t_2) \quad (6)$$

$$I_{sp} = - \frac{(t_1 - t_2)}{g \left(\frac{1}{\alpha_1} - \frac{1}{\alpha_2} \right)} \quad (7)$$

COMPARISON MATRIX - METHODS OF ENGINE I_{SP} DETERMINATION

CANDIDATE SYSTEM CRITERIA	1	2	3	4	6	7
	CHAMBER TEMPERATURE	THRUST BY LOAD CELLS	THRUST BY WALL PRESSURE	$I_{SP} = \frac{C_F P_C A_t}{\dot{w}}$	IN-FLIGHT DYNAMICS	COMBINATION OF SYSTEMS (1) & (4)
3 σ I_{SP} UNCERTAINTY (VACUUM) (A.R.=100)	$\pm 1.08\%$ IGNORING A-6 DATA	$\pm 0.95\%$ MINIMUM	$\pm 0.69\%$	± 0.93	$\pm 0.67\%$	$\pm .70$
PAST EXPERIENCE	NONE, BUT GOOD T_C EXPERIENCE IN NRX TESTS	EXTENSIVELY USED ON SIMPLER STANDS	USED PRIMARILY FOR NOZZLE FLOW STUDIES	EXTENSIVELY USED ALONG WITH THRUST MEASUREMENTS	EXTENSIVELY USED BY NASA & AF	SEE COMMENTS FOR (1) & (4)
EASE OF INCORPORATION INTO ETS-1	GOOD TEMP. MEAS. TECHNOLOGY WELL DEVELOPED	POOR THRUST RODS AVAILABLE BUT CLOSED CELL IS DIFFICULT	GOOD PRESS. MEAS. TECHNOLOGY WELL DEVELOPED	EXCELLENT	N/A	EXCELLENT
EASE OF ETS-1 TEST OPERATION	EXCELLENT	POOR	GOOD	EXCELLENT	N/A	EXCELLENT
COSTS OF GROUND FACILITIES & TEST OPERATIONS	LOW	HIGH	MODERATE	MODERATE	LOW	MODERATE

NOTE: METHOD NO. 5, "USE OF EXHAUST GAS VELOCITY MEASUREMENTS," WAS DELETED SINCE IT IS STILL IN DEVELOPMENT STAGE.

ENGINE SPECIFIC IMPULSE STUDY
CONCLUSIONS AND RECOMMENDATIONS

1. PFRT ENGINE SPECIFIC IMPULSE CAN BE OBTAINED TO $\pm 0.70\%$ (3 σ) USING "CHAMBER TEMPERATURE" AND "THRUST COEFFICIENT" METHODS.
2. MEASUREMENT IMPROVEMENTS SHOULD BE PLANNED:
 - a. CHAMBER PRESSURE: USE HIGH ACCURACY TRANSDUCERS.
 - b. THROAT AREA: STUDY OPERATIONAL EFFECTS AND USE ACCURATE MEASUREMENT INSTRUMENTS.
 - c. FLOW RATE: USE VH-11 CALIBRATION FACILITY AND SIMULATE ETS-1 CONDITIONS. COMBINE WITH COMPONENT TESTING.
3. STUDY USE OF SUB-SCALE, REACTOR AND ENGINE TESTS TO IMPROVE VALUE OF NOZZLE THRUST COEFFICIENT. INCORPORATE RESULTS IN NERVA PROGRAM PLANS.
4. BASED ON CURRENT VEHICLES, FLIGHT I_{SP} TO $\pm 0.67\%$ (3 σ) CAN BE OBTAINED. STUDY METHOD FOR NUCLEAR STAGE.
5. INCORPORATE I_{SP} TRIM CONTROL ON ENGINE CONTROL SYSTEM.

TRADE STUDIES
TOLERANCES AND CONTROL

D. Buden #2

4600.

NRX/EST EP-IV A

4200.

3800.

5000.

NRX/A5 EP-IV

4600.

4200.

3800.

TEMPERATURE (°R)

AVERAGE NOZZLE CHAMBER TEMP

NOZZLE CHAMBER TEMPERATURES

TEST NO. XE-P-EP-3

DATE: 17 APRIL 1969

SCALE A (OEG B)

1 NOZZLE CHAMBER TEMP-AVG. TE150. E

(SP97)

TEMPERATURE CONTROL TOLERANCE
(EXCLUDES MEASUREMENT SYSTEM)

TEMPERATURE CONTROL LOOP SIGNAL DEMAND GENERATOR	$\pm 4.5^{\circ}\text{R}$
TEMPERATURE CONTROL LOOP REFERENCE SIGNAL POTENTIOMETER	$\pm 4.5^{\circ}\text{R}$
TEMPERATURE CONTROL LOOP SUMMING JUNCTION RESISTOR ERROR	$\pm 4.5^{\circ}\text{R}$
TEMPERATURE CONTROL LOOP AVERAGING AMPLIFIER	$\pm 4.5^{\circ}\text{R}$
TEMPERATURE CONTROL LOOP VARIATION DUE TO DRUM POSITION TOLERANCE	$\pm 9.0^{\circ}\text{R}$

$$\text{RSS} = \pm 12.75^{\circ}\text{R}$$

$$\text{RSS (I}_{\text{SP}}) = \pm 1.42 \text{ SEC}$$

$$\text{OR } 0.172\%$$

TURBOPUMP OPERATING POINTS PARALLEL PUMPS

DUAL VS SINGLE TURBOPUMPS PERFORMANCE SUMMARY

PARAMETER	CONFIGURATION			
	SINGLE SPOOL/ SINGLE PFS		SINGLE SPOOL/DUAL PFS	
	SINGLE PFS	DESIGN	NOMINAL	MALF.
PUMP PRESSURE RISE (PSI)	915	1000	915	915
PUMP FLOW RATE (LB/SEC)	91	67	46	91
SHAFT SPEED (RPM)	19000	19000	18100	19000
PUMP SPECIFIC SPEED	791	635	533	791
PUMP EFFICIENCY (%)	69	68	66	66
SHAFT HORSEPOWER (HP)	7260	6450P 7610T	3805/ 7610	7610
TURBINE TIP SPEED (FT/SEC)	1200	1200	1140	1200
TURBINE INLET TEMPERATURE (°R)	1660	1460	1660	1460
TURBINE PRESSURE RATIO	7:1	7:1	4.1:1	7:1
TURBINE U/Co	.105	.113	.115	.113
TURBINE EFFICIENCY (%)	52	51	52	51
W _t (INLET) (LB/SEC)	3.94	4.87	2.72/5.44	4.87
W _{LEAK} (LB/SEC)	.50	-	0.5/1.00	.50
W _t (EXIT) (LB/SEC)	4.44	-	6.44	5.37
W _t /W _p (%)	4.88	-	7.08	5.89
ΔI _{sp} (SEC)	BASE	-	-9.9	-4.5

	BASED ON MINIMUM $I_{sp} = 825 \text{ SEC}$	
	<u>SINGLE TPA</u>	<u>DUAL TPA</u>
A. MINIMUM CHAMBER INLET TEMPERATURE BASE POINT	4500°R	4500°R
B. EFFECT OF DUAL TPA CONFIGURATION	0	72
C. MEASUREMENT AND CONTROLLER (RSS D & E)	53	53
D. MEASUREMENT $\pm 51.2^\circ\text{R} (\pm 0.70\% I_{sp})$		
E. CONTROLLER $\pm 12.7^\circ\text{R} (\pm 0.17\% I_{sp})$		
F. NOMINAL T_C (A + B + C)	4553	4625
G. MEASUREMENT, CONTROLLER AND ENGINE-TO-ENGINE (RSS D, E & H)	60	60
H. ENGINE-TO-ENGINE $\pm 28^\circ\text{R}$		
I. MAXIMUM T_C (F + G)	4613	4685
J. MINIMUM T_C (F - G)	4483*	4565

*NPRD SPECIFIES MINIMUM OF 4500°R

MAXIMUM CHAMBER INLET TEMPERATURE
BASED ON CHAMBER TEMPERATURE MEASUREMENT SYSTEM

	<u>SINGLE TPA</u>	<u>DUAL TPA</u>
BASIC	4500 ⁰ R	4500 ⁰ R
CHAMBER TEMPERATURE CONTROLLER		
MEASUREMENT ($\pm 84.6^{\circ}\text{R}$), CONTROLLER ($\pm 12.7^{\circ}\text{R}$)	172	172
TOTAL	4672	4672
GUARANTEE ACHIEVE 825 SEC I_{SP}	5	77
MAXIMUM TEMPERATURE	4677	4749

ASSUME MINIMUM CHAMBER INLET TEMPERATURE OF 4500⁰R

	<u>SINGLE TPA</u>	<u>DUAL TPA</u>
BASIC I_{SP}	825 SEC	825 SEC
NOMINAL I_{SP} (BASED ON $\pm 86^{\circ}\text{R}$)	+9.6	+9.6
CHAMBER TEMPERATURE MEASUREMENT		
ENGINE-TO-ENGINE VARIATION ($\pm 28^{\circ}\text{R}$)	RSS $\pm 92^{\circ}\text{R}$ -10.2	-10.2
EFFECT OF TPA	--	- 8
GUARANTEED I_{SP}	824.4	816.4

OBJECTIVES

1. ESTABLISH NOMINAL COMPONENT REQUIREMENTS AND THREE SIGMA TOLERANCE
2. ESTABLISH PRIMARY CONTROL MEASUREMENT SYSTEM
3. ESTABLISH MAXIMUM CHAMBER INLET TEMPERATURE REQUIREMENTS

CRITERIA

1. MEET NPRD PERFORMANCE REQUIREMENTS
2. UTILIZE EXTENSION OF EXISTING TECHNOLOGY

ENGINE NOMINAL COMPONENT REQUIREMENTS
 NERVA REFERENCE ENGINE PER DRAWING NO. 1135222

Component	Inlet Conditions			Design Requirements				
	Pressure (psia)	Temp. (°R)	Flow (lb/sec)	Pressure Drop (psia)	ΔTemp. (°R)	Flow (lb/sec)	Efficiency (%)	ΔH/N ²
Pump Inlet Line (each unit)	30	40	45.75	0.5 ± 0.5	0 ± 0.1			
Pump (each unit)	29.5	39.3	45.75	959.5 ±	9.05 ± 1		66.8 ± 5	4.35 × 10 ⁻⁵ -5
Bearing Coolant (each unit)	989	54.5	0.3			0.3 ± 0.1		± 0.016 × 10 ⁻⁵
Pump Discharge Line (each)	989	54.5	45.45	30 ± 2	0 ± 0.1			
Brim Shield	959	54.5	90.9	10 ± 2	6.2 ± 1			
Structural Support Assembly	954	54.7	21.0	268 ± 34.5	220 ± 66			
Line, Brim Shield to Skirt	949	60.7	69.9	5 ± 2	0 ± 0.1			
Skirt	944	60.7	66.9	14 ± 3	29.3 ± 6			
Nozzle	930	90	66.9	193 ± 14	127 ± 15	(Throat Area 97.398 ± 1.43 in ²)		
Bolt Coolant	944	60.7	3.0	207 ± 2.07	0 ± 0.1	3 ± 0.3		
Reflector	737	212	67.1	51 ± 4.5	95 ± 25.2			
Extension Shield	686	311	88.1	16 ± 1.6	3 ± 1			
Dome Baffle	670	314	88.1	17 ± 1.7	0 ± 0.1			
Central Shield	653	314	88.1	19 ± 2.1	2 ± 1			
Support Plate	634	316	88.1	13 ± 1.13	4 ± 1			
Core	621	320	88.1	171 ± 44	4293 ± 119			
Diluent Line to HBP Mixing Chamber	706	212	2.82	263 ± 26.3	0 ± 4	2.82 ± 0.13		
Turbine Inlet Line	450	1660		224 ± 2.2	0 ± 4			
Turbine (each unit)	216	1660	2.025				55.5 ± 6	
Turbine Exhaust Line (each	30	1111	2.325	2 ± 1				
Skirt Extension	28	1111	4.65	22 ± 2	1379 ± 60			

1. REQUIRES HIGH ACCURACY FLOW CALIBRATION SYSTEM. THE NERVA TEST AREA FACILITY SHOULD BE ABLE TO SATISFY THIS REQUIREMENT.
2. IN ORDER TO DEMONSTRATE SPECIFIC IMPULSE DURING PFRT, A COMBINATION OF MEASUREMENTS CAN BE UTILIZED. THIS INCLUDES TEMPERATURES AND CHAMBER PRESSURE AND FLOW RATE AS A BASIC SYSTEM TO COMPUTE SPECIFIC IMPULSE. CHAMBER TEMPERATURE MEASUREMENT SHOULD SATISFY CONTROL SYSTEMS REQUIREMENTS.
3. IN ORDER TO CONFIRM VALUE OF THRUST COEFFICIENT, C_f IT IS DESIRABLE TO INCLUDE WALL PRESSURE TAPS IN EARLY R AND E TEST.
4. IN FLIGHT, FURTHER VERIFICATION OF SPECIFIC IMPULSE IS OBTAINED WITH ACCELERATION DATA. THIS CAN BE USED AS A TRIM ON THE CONTROLLER DEMAND.

MAXIMUM CHAMBER INLET TEMPERATURE

TO OBTAIN 825 SEC SPECIFIC IMPULSE, AT A NOZZLE AREA RATIO
OF 100:1 MAXIMUM CHAMBER INLET TEMPERATURE CONSIDERING
MEASUREMENT, CONTROLS AND ENGINE-TO-ENGINE UNCERTAINTIES
FOR DUAL TURBOPUMPS IS 4685°R (NOMINAL IS 4625°R)

POST ENGINE OPERATIONS

W. J. Houghton

HIGHLIGHTS OF
PHASE I OF
POST SHUTDOWN OPERATIONS TRADE STUDY

PRESENTATION TO SNPO ON APRIL 23, 1969

POST SHUTDOWN OPERATIONS TRADE STUDY
OUTLINE OF PRESENTATION

1. SCOPE AND ORIGIN OF REQUIREMENTS.
2. COOLDOWN DESIGN APPROACHES AND COMPARISONS.
3. THRUST NULLING APPROACHES AND COMPARISONS.
4. SUBSYSTEM INTEGRATION AND EVALUATION.

POST SHUTDOWN OPERATIONS

TRADE STUDY

REQUIREMENTS FROM NPRD

III.B.d STARTUP AND SHUTDOWN

"AFTER (TBD) SECONDS OF COOLANT FLOW, THE SYSTEM SHOULD PROVIDE FOR EITHER USING THE AVAILABLE IMPULSE OR FOR DISSIPATING THE COOLANT FLOW WITH ZERO THRUST"

"DURING THE SHUTDOWN TRANSIENT, IMPULSE LOST BY USING PROPELLANT AT LESS THAN FULL I_{sp} SHALL BE MINIMIZED"

III.B.e CONTROLLABILITY

(3) SHUTDOWN

(A) TOTAL IMPULSE	$\pm 20,000$ LBS-SEC (INCLUDING PULSE COOLDOWN)
(B) TIME	± 15 SEC

PRINCIPAL REQUIREMENTS FROM THE RAS's

1. ASSESS THE EFFECT ON PAYLOAD OF THE PULSE COOLDOWN METHOD.
2. DETERMINE THE EFFECTS OF REACTION-CONTROL SYSTEM PROPELLANT REQUIREMENTS ON THE METHOD OF PULSE COOLDOWN.
3. DETERMINE GIMBAL ACTUATOR POWER REQUIREMENTS WHICH ALLOW SATISFACTORY THRUST VECTOR CONTROL DURING COOLDOWN THRUSTING.
4. DETERMINE ON-BOARD AND GROUND CONTROL REQUIREMENTS FOR THE ENGINE DURING COOLDOWN.

COOL DOWN

DEPENDENCE OF COOLDOWN EFFICIENCY ON CHAMBER TEMPERATURE DURING COOLDOWN

ALL BURNS OF MISSION A-I

PAYLOAD
WEIGHT
CHANGE

EQUIVALENT
 I_{sp} CHANGE

COOLDOWN AND NULLING
FUNCTIONAL SCHEMATIC
TANK PRESSURE
REFERENCE SYSTEM

FUNCTIONAL SCHEMATIC
COOLDOWN & NULLING
AUXILIARY PUMP PRESSURE - PARALLEL CONFLUENT STEMS
SYSTEM NO. 5b

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FUNCTIONAL SCHEMATIC
 NOMINAL STEMS, REFLECTOR, ETC. WITH PUMP PRESSURE
 HOT BLEED ENGINE
 SYSTEM NO. 5

EFFECT OF COOLDOWN CONCEPTS ON ENGINE PERFORMANCE

MISSION A-I

<u>CONCEPT</u>	<u>PEAK T_C, °R</u>	<u>EQUIVALENT ΔI_{sp}, sec</u>	<u>Δ FAILURE RATE, %</u>
REFERENCE STEM LIMIT USED IN THE PAST	1600	$\equiv 0$	$\equiv 0$
REFERENCE NEW STEM LIMIT WHICH MAY BE SPECIFIED	1250	- 20	0
PUMP PRESSURE CONCEPT	2000	+ 10	≤ 18

IMPULSE CONTROLLABILITY

COOLDOWN TEMPERATURE PROFILE VS TIME FOR IMPULSE CONTROLLABILITY

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IMPULSE CONTROLLABILITY TECHNIQUES

MISSION B

<u>TECHNIQUE</u>	<u>ΔI_{sp}, SEC FIRST BURN</u>	<u>ΔI_{sp}, SEC ALL BURNS</u>
NULL END OF COOLDOWN	-32	~ -49
VARY T_c DURING COOLDOWN	-13	~ -20
USE FISSION HEATING	- 3	~ - 5

LONG TERM COOLDOWN

CHARACTERISTICS OF LONG COOLDOWN PERIODS
MISSION A-1, 2nd BURN

<u>EVENT</u>	<u>TIME AFTER SCRAM</u>	<u>POWER LEVEL</u>	<u>PROPELLANT USED IN INTERVAL</u>
LOWER POWER PULSE THRUSTING	1.85 HRS	500 KW	2253
STOP PULSE THRUSTING	24 HRS	25 KW	0
RESTART	30 DAYS	LOW	

CONCEPTS WHICH ELIMINATE
VEHICLE VELOCITY CHANGE
DURING LONG COOLDOWN

1. THRUST NULLING BY STEM COOLING.
2. TUMBLING THE VEHICLE.
3. AFTERHEAT REMOVAL USING A RADIATOR.

FUNCTIONAL SCHEMATIC
RADIATOR SUBSYSTEM NO. 2

RADIATOR SUBSYSTEM OPERATING CHARACTERISTICS

<u>ITEM</u>	<u>RADIATOR NO. 1</u>	<u>RADIATOR NO. 2</u>
RADIATOR MATERIAL	AL + SS	BE + SS
REACTOR OUTLET TEMPERATURE °R	1160	1300
REACTOR INLET TEMPERATURE °R	497	649
REACTOR INLET PRESSURE PSI	600	600
RADIATOR INLET TEMPERATURE °R	1113	1252
RADIATOR OUTLET TEMPERATURE °R	450	600
THERMAL POWER RADIATED KW	500	500
SUBSYSTEM WEIGHT LBS	3300	1350

PERFORMANCE COMPARISON OF LONG TERM COOLDOWN CONCEPTS

MISSION A-I: INITIATE OPERATION AT 500 KW

THRUST NULLING
BY STEM COOLING

TUMBLING

RADIATOR NO. 1

RADIATOR NO. 2

MORE EXPLICIT THRUST NULLING

COOLDOWN AND NULLING
FUNCTIONAL SCHEMATIC
TANK PRESSURE
REFERENCE SYSTEM

COOLDOWN AND NULLING
FUNCTIONAL SCHEMATIC
TANK PRESSURE
SYSTEM β

4-18-69

AGC-ND

FUNCTIONAL SCHEMATIC
SPLIT FLOW
THRUST NULLING SYSTEM NO. 10

FUNCTIONAL SCHEMATIC
SPLIT FLOW
HOT BLEED ENGINE
SYSTEM NO. 10

4-18-69

AGC-ND

FUNCTIONAL SCHEMATIC
BALANCED THRUST END PLATE
THRUST NULLING SYSTEM NO. 12

FUNCTIONAL SCHEMATIC
BALANCED THRUST END PLATE
HOT BLEED ENGINE
SYSTEM NO. 12

SHORT TERM THRUST NULLING
SYNCHRONOUS ORBIT
MISSION A-I SECOND BURN

CONTINUED THRUST NULLING PERFORMANCE MISSION B FIRST BURN

BASIS FOR REJECTING
THRUST NULLING SCHEMES
THAT INVOLVE MODIFICATIONS TO THE NOZZLE

1. THESE SCHEMES ARE BEST FOR LONG NULLING PERIODS.
2. WHEN LONG TIME COOLDOWN IS NEEDED IN TYPICAL MISSIONS,
IT IS DONE BETTER BY:
 - a. RADIATORS
 - b. TUMBLING
3. THERE IS NO JUSTIFICATION FOR FURTHER STUDIES OF
NOZZLE MODIFICATIONS.

A KEY TRADE-OFF THAT WILL OCCUR IN THIS STUDY

THE STUDY WILL YIELD

INCREASES IN PAYLOAD

DECREASES IN RELIABILITY

THE REFERENCE ENGINE WILL BE ABLE TO

INCREASE RELIABILITY

DECREASE PAYLOAD

THE STUDY MAKES THE BEST OVERALL CHOICE TO GET

INCREASES IN PAYLOAD

SPECIFIED RELIABILITY

THE IMPACT OF THE TRADE STUDY ON ENGINE PERFORMANCE

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PROPELLANT FEED SYSTEM

W. E. Campbell

STATUS REVIEW
PROPELLANT FEED SYSTEM TRADE STUDY

- OBJECTIVES, SCOPE OF TRADE STUDY
- OVERALL PROGRAM LOGIC
- SUMMARY OF PERTINENT CANDIDATE CASES
- CURRENT STATUS OF STUDY

INTERMEDIATE STUDY

FULL SCOPE TRADE STUDY

PFS TRADE STUDY OBJECTIVES

- DEFINE THE RECOMMENDED CONCEPTUAL CONFIGURATION
TURBOMACHINERY, LINES, VALVES
RELATED: CONTROLS, COOLDOWN SYSTEM, THRUST STRUCTURE, ETC.
- DEFINE SPEC EXTREME STATE POINTS FOR CEI/ECC SPECS
- PREDICT SYSTEM R & I_{spe}
- IDENTIFY CRITICAL ASSUMPTIONS REQUIRING ANALYSIS OR TEST EVALUATION
- CORRELATE WITH OTHER STUDIES AND REQUIREMENTS
THROTTLING, SAFETY, MAINTAINABILITY, FACILITIES

PFS INTERFACE BOUNDARIES

PROPELLANT FEED SYSTEM TRADE STUDY
OVERALL LOGIC

PROPELLANT FEED SYSTEM TRADE STUDY
OVERALL LOGIC

PROCEDURE FOR SELECTING THE PFS

CANDIDATE PROPELLANT FUEL SYSTEMS TWO TURBOPUMP SYSTEMS

TWIN SPOOL/CENTRIFUGAL/ $\beta_2 = 90^\circ$

TWIN SPOOL/CENTRIFUGAL/ $\beta_2 = 28^\circ$

SINGLE SPOOL/AXIAL

SINGLE SPOOL CENTRIFUGAL/ $\beta_2 = 45^\circ$

TURBINE INLET OPTIONS

TURBINE EXIT OPTIONS

PUMP INLET OPTIONS

PUMP EXIT OPTIONS

CANDIDATE PROPELLANT FEED SYSTEM
THREE TURBOPUMP SYSTEMS

SINGLE SPOOL/CENTRIFUGAL/ $\beta_2 = 90^\circ$

SINGLE SPOOL/CENTRIFUGAL/ $\beta_2 = 28^\circ$

TURBINE INLET OPTIONS

TURBINE EXIT OPTIONS

PUMP INLET OPTIONS

PUMP EXIT OPTIONS

PROPELLANT FEED SYSTEM TRADE STUDY
CASES FOR ANALYTICAL EVALUATION

CASE

I	TWO TURBOPUMPS; TWIN-SPOOL; $B_2 = 90^\circ$; INDIVIDUAL TURBINE POWER CONTROL
IB	TWO TURBOPUMPS; TWIN-SPOOL; $B_2 = 28^\circ$; INDIVIDUAL TURBINE POWER CONTROL
IC	TWO TURBOPUMPS; TWIN-SPOOL; COMMON TURBINE POWER CONTROL
IIA	THREE TURBOPUMPS; SINGLE-SPOOL; $B_2 = 90^\circ$; COMMON TURBINE POWER CONTROL
IIB	THREE TURBOPUMPS; SINGLE-SPOOL; $B_2 = 28^\circ$; COMMON TURBINE POWER CONTROL
IIIA	TWO TURBOPUMPS; SINGLE-SPOOL AXIAL; INDIVIDUAL TURBINE POWER CONTROL
IIIB	TWO TURBOPUMPS; SINGLE-SPOOL AXIAL; COMMON TURBINE POWER CONTROL
IV	SINGLE TURBOPUMP; SINGLE-SPOOL; $B_2 = 90^\circ$; INDIVIDUAL TURBINE POWER CONTROL
V	TWO TURBOPUMPS; REMOTE BOOST PUMPS

PUMP CHARACTERISTICS - DUAL PUMP SYSTEMS

PUMP CHARACTERISTICS - TRIPLE PUMP SYSTEMS

NOMINAL MODE TURBOPUMP PERFORMANCE COMPARISON

	BASE*	DUALS			TRIPLES	
PARAMETER	SINGLE/ CENT/ 45°	TWIN/ CENT/ 90°**	TWIN/ CENT/ 28°**	SINGLE/ AXIAL -	SINGLE/ CENT/ 90°	SINGLE/ CENT/ 28°
PUMP FLOW RATE, LB/SEC	91	45.5	45.5	45.5	30.3	30.3
PUMP PRESSURE RISE, PSI	902	902	902	902	902	902
SHAFT SPEED, RPM	25000	24600	26010	18900	34600	33000
PUMP SPECIFIC SPEED	1070	761	804	-	855	816
TURBINE INLET PRESSURE, PSIA	360	206	222	220	271	287
TURBINE PRESSURE RATIO	12	6.52	6.81	7.86	8.46	8.94
TURBINE INLET TEMPERATURE, °R	1660	1660	1660	1660	1660	1660
PUMP EFFICIENCY, %	73.0	68.2	66.7	70.8	67.0	53.2
TURBINE EFFICIENCY, %	47.2	61.0	60.5	45.5	50.3	49.0
TURBINE INLET FLOW RATE, TOTAL LB/SEC	3.56	4.00	4.16	4.20	3.79	4.02
BEARING COOLANT LEAKAGE, TOTAL LB/SEC	.50	.61	.62	.74	.65	.63
RELATIVE PERFORMANCE W/LEAKAGE, ΔI_{sp} SEC	0	-3.10	-4.02	-5.17	-.28	-3.34

* BASE CASE FROM SINGLE PUMP ENGINE STUDIES

** MAINSTAGE PARAMETERS ONLY

MALFUNCTION ANALYSIS CASES

DUAL TURBOPUMP SYSTEM

CASE I/IB

<u>ANALYSIS NUMBER</u>	<u>DESCRIPTION</u>
1.	TPCV FAILS FULL OPEN (ONE LEG)
2.	TPCV SHIFTS BIAS (ONE LEG)
3.	TPCV FAILS IN PLACE (ONE LEG)
4.	TPCV FAILS CLOSED ON RAMP (ONE LEG)
5.	TBV FAILS CLOSED (ONE LEG)
6.	PSOV FAILS CLOSED (ONE LEG) AT STEADY-STATE, RATED, NOMINAL
7.	PSOV RAMPED CLOSED (ONE LEG) AFTER BELLOWS FAILURE (ONE LEG)
8.	PSOV FAILS TO OPEN (ONE LEG) ON START
9.	PDKV FAILS CLOSED ON START (ONE LEG)
10.	PDKV FAILS TO CLOSE ON SHUTDOWN LEG
11.	TPA FAILS; UNEXPECTED SHUTDOWN
12.	TPA CONTROLLED MALFUNCTION SHUTDOWN
13.	TPCV FAILS CLOSED ON RAMP (ONE LEG) AT 60% THRUST
14.	TBV FAILS CLOSED (ONE LEG) AT 60% THRUST
15.	LOSS OF PRESSURE CONTAMINANT BETWEEN PUMP AND PDKV (ONE LEG)

PUMP STABILITY SUMMARY

21-APR-69

PRELIMINARY RESULTS
MALFUNCTION ANALYSIS - CASE IB

MALFUNCTION

RESULTS

	<u>MALFUNCTION LEG</u>	<u>SURVIVING LEG</u>	<u>ENGINE</u>
● TPCV STEPPED CLOSED CLOSED LOOP P_C , T_C NO CORRECTIVE ACTION	● PUMP STALLS AT .045	● PUMP SLOWS ● PUMP RECOVERS AT .700	P_C TO 382 AT .200 P_C RECOVERS T_C DROPS SLIGHTLY
● TPCV STEPPED OPEN OPEN LOOP NO CORRECTIVE ACTION	● SPEED INCREASES ● TURBINE TEMP INCREASES BY 400°	● PUMP MOVES TOWARD STALL ● SPEED INCREASES ● TURBINE TEMP INCREASES BY 400°	P_C TO 666 AT .700 T_C TO 5368 AT .700
● TPCV STEPPED OPEN CLOSED LOOP P_C , T_C NO CORRECTIVE ACTION	● TPCV CLOSSES WITH DAMPED OSCILLATION ● PUMP STALLS AT .137 ● TURBINE TEMP INCREASES BY 400°	● SPEED INCREASES ● TURBINE TEMP INCREASES BY 400°	P_C OK T_C OK
● TPCV STEPPED OPEN CLOSED LOOP P_C , T_C MDS CLOSSES TBV IN .125	● PUMP STALLS AT .213 ● TURBINE TEMP INCREASES BY 400	● TPCV STARTS CLOSED, THEN OPENS BY .700 ● PUMP MOVES TOWARD STALL, THEN RECOVERS ● TURBINE TEMP INCREASES BY 400	P_C TO 477 AT .240, TO 372 AT .470, RECOVERY T_C OK

RELIABILITY MODELS PROPELLANT FEED SYSTEM

SINGLE TURBOPUMP SYSTEM

$$R_{PFS,S} = R_{TPA} \times R_{PSOV} \times R_{PDL} \times R_{TIL} \times R_{TPCV} \times R_{TBV} \times R_{TEL}$$

DUAL TURBOPUMP SYSTEM

$$R_{PFS,D} = 1 - ((1 - R_{PFS,S}) + Q_{PDKV})^2 \times R_{DMM} \times R_{MDS} \times R_{MLC} \times R_{MSS}$$

WHERE:

Q_{PDKV} = PROBABILITY OF FAILURE OF PUMP DISCHARGE CHECK VALVES

R_{DMM} = RELIABILITY DEGRADATION DUE TO MALFUNCTION MODE OPERATION

R_{MDS} = RELIABILITY OF MALFUNCTION DETECTION SENSORS

R_{MLC} = RELIABILITY OF MALFUNCTION LOGIC CIRCUIT

R_{MSS} = RELIABILITY OF MALFUNCTION SWITCHOVER SYSTEM

RELIABILITY PREDICTION MATRIX

CASE	R TPA	R PFS-TPA	R MDS/SWITCH SYSTEM	R PFS
SINGLE PFS				
HISTORICAL BASE	.9980	.99928	-	.997280
DESIGN-FOR-RELIABILITY & RESTRAINTS	.9991	.99960	-	.998700
MAXIMUM POSSIBLE	.9996	.99984	-	.999440
DUAL PFS				
	PER LEG	PER LEG		
HISTORICAL BASE	.9960	.99931	.99994	.999919
DESIGN-FOR-RELIABILITY & RESTRAINTS	.9990	.99960	.99997	.999968
MAXIMUM POSSIBLE	.99925	.99984	.99999	.999989

PFS APPORTIONMENT = .99887

SAFETY-RELIABILITY RELATIONSHIP

PROPELLANT FEED SYSTEMS

NERVA FEED SYSTEM CONCEPT

NERVA FEED SYSTEM CONCEPT

NERVA FEED SYSTEM CONCEPT

REMAINING EFFORT
PROPELLANT FEED SYSTEM TRADE STUDY

DISMISS CASE I, CONVERT TO IB

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, CASE IB

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, CASE IC

SELECT BETWEEN CASES IB AND IC - ADJUST REFERENCE ENGINE

EVALUATE STABILITY OF CASES IIA AND IIB, SELECT BEST

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, SELECTED CASE II

SELECT TURBINE CONTROL FOR CASE III FROM CASE IB/IC RESULTS

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, SELECTED CASE III

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, CASE IV

COMPLETE MALFUNCTION ANALYSIS, R & I_{sp} PREDICTION, CASE V

RECOMMEND SYSTEM; ADJUST REFERENCE ENGINE

TWO TPS's IN TEST CELL "C"

W. E. Campbell

DUAL TURBOPUMP TESTING IN TEST CELL "C"

I. BASIS FOR STUDY

II. PROGRAM OBJECTIVES

III. FACILITY CONSIDERATIONS

IV. SCHEDULE

V. ROM COST ESTIMATE

SNPO-C TECHNICAL DIRECTIVE 69-12

GROUND RULES

- TEST PROGRAM SHALL BE CONDUCTED IN TEST CELL "C"
- INITIAL TESTS SHALL BE WITH TECHNOLOGY (TYPE) HARDWARE
- TESTING AT TEST CELL "C" SHALL BE MANAGED BY NTO

FEED SYSTEM TEST PROGRAM OBJECTIVES

- PROVIDE PERFORMANCE AND OPERATING CHARACTERISTICS DATA FOR THE ENGINE ANALYSIS ACTIVITY FOR UPGRADING OF STEADY-STATE AND TRANSIENT MODELS

- PROVIDE PERFORMANCE AND OPERATING CHARACTERISTICS DATA FOR COMPONENT DESIGN, INCLUDING:
 - PUMP
 - TURBINE
 - VALVES AND LINES
 - COMPONENT FLUID AND MECHANICAL INTERACTIONS
 - MALFUNCTION AND TRANSIENT RESPONSE

NERVA FEED SYSTEM CONCEPT

NERVA FEED SYSTEM CONCEPT

NERVA FEED SYSTEM CONCEPT

DATA DESIRED FROM FEED SYSTEM TEST PROGRAM

- PERFORMANCE AT HIGH OR FULL POWER
 - FLOW SPLITS
 - SYSTEM STABILITY
 - TRANSIENT BEHAVIOR
 - MALFUNCTION BEHAVIOR
- PERFORMANCE AT LOW POWER
 - START TRANSIENTS
 - SHUTDOWN TRANSIENTS
 - ROOTSTRAP THRESHOLDS

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

PHASE 1A - SINGLE-SPOOL TURBOPUMP, HIGH NPSP

TEST OBJECTIVES:

- STEADY-STATE PERFORMANCE MATCHING. EVALUATE NEED FOR
INDIVIDUAL TURBINE POWER CONTROL
- SYSTEM STABILITY, DUAL PUMP MODE. DETERMINE STABILITY
THRESHOLD, SINGLE PUMP MODE
- MALFUNCTION DYNAMICS, DUAL PUMP TO SINGLE PUMP MODE,
VARIOUS MALFUNCTIONS

TEST CONFIGURATION:

- SINGLE-SPOOL TURBOPUMPS, MODIFIED PUMP
- XE AND/OR FACILITY TURBINE VALVES
- FACILITY PUMP IMPEDANCE VALVE
- XE OR TEST CELL "C" PUMP CHECK VALVES

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

PHASE 1B - PRE-PROTOTYPE TWIN-SPOOL TURBOPUMPS, HIGH & ZERO NPSP

TEST OBJECTIVES:

- CAPABILITY OF DUAL TO SINGLE PUMP MODE[\] FLOW AT
ZERO NPSP
- ENGINE THROTTLING CAPABILITY, DUAL AND SINGLE PUMP MODE
- MATCHING, STABILITY, DYNAMICS, TRANSIENTS AT POSITIVE
AND ZERO NPSP

TEST CONFIGURATION:

- PRE-PROTOTYPE TWIN-SPOOL TURBOPUMPS
- TURBINE VALVE(S) TO BE DECIDED FROM PHASE 1A
- FACILITY PUMP IMPEDANCE VALVE
- XE OR TEST CELL "C" PUMP CHECK VALVES

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

PHASE IIA - PRE-PROTOTYPE TWIN-SPOOL TURBOPUMPS, SIMULATED VEHICLE,
TANK, ZERO NPSP

TEST OBJECTIVES:

- COMPONENT/PART INTERACTIONS DURING RATED, TRANSIENT, AND MALFUNCTION CONDITIONS.
- PERFORMANCE VARIATION DUE TO ASSYMMETRY - DUAL PUMP MODE.
- START AND SHUTDOWN TRANSIENT INFORMATION.
- DETERMINATION OF CHILLDOWN ADEQUACY/BOOTSTRAP ENERGY THRESHOLD.
- PERFORMANCE CAPABILITY - SATURATED FLUID IN TANK, DUAL AND SINGLE PUMP MODE.
- VAPOR INGESTION THRESHOLD, DUAL AND SINGLE PUMP MODE.
- DETERMINATION OF FEED SYSTEM AMPLIFICATION OF TANK INDUCED SYSTEM PERTURBATIONS (POGO).
- DETERMINATION OF STAGE BAFFLING CRITERIA.

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

TEST HARDWARE:

- PRE-PROTOTYPE TWIN-SPOOL TURBOPUMPS.
- SIMULATED VEHICLE TANK BOTTOM - SPECIFIC CONFIGURATION
TO BE DETERMINED.
- TURBINE VALVE(S) TO BE DECIDED FROM PHASE I.
- FACILITY PUMP IMPEDANCE VALVE.
- XE OR TEST CELL "C" PUMP CHECK VALVES.

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

PHASE IIB PROTOTYPE (NERVA) TWIN SPOOL TURBOPUMPS, SIMULATED VEHICLE TANK, ZERO NPSP

TEST OBJECTIVES:

- COMPONENT/PART INTERACTIONS DURING RATED TRANSIENT AND MALFUNCTION CONDITIONS, PARAMETRIC VALUES ABOUT NOMINAL.
- CONFIRMATION OF ENGINE ANALYSIS MODELS UPGRADED BASED UPON PHASE IIA.
- PERFORMANCE VARIATION DUE TO ASSYMMETRY DUAL PUMP MODE.
- START/SHUTDOWN TRANSIENT INFORMATION.
- DETERMINATION OF CHILLDOWN ADEQUACY BOOTSTRAP ENERGY THRESHOLD.
- PERFORMANCE CAPABILITY SATURATED FLUID IN TANK, DUAL AND SINGLE PUMP MODE.
- VAPOR INGESTION THRESHOLD, DUAL AND SINGLE PUMP MODE.
- DETERMINATION OF FEED SYSTEM AMPLIFICATION OF TANK INDUCED SYSTEM PERTURBATIONS (POGO).
- DETERMINATION OF STAGE BAFFLING CRITERIA.

GENERAL TEST OBJECTIVES AND HARDWARE DESCRIPTION

TEST HARDWARE:

- PROTOTYPE TWIN-SPOOL TURBOPUMPS.
- SIMULATED VEHICLE TANK BOTTOM.
- PROTOTYPE TURBINE VALVES.
- FACILITY PUMP IMPEDANCE VALVE.
- PROTOTYPE CHECK VALVES.

TENTATIVE TEST PLAN FOR PHASE 1A

● SYSTEM STABILITY

1. DETERMINE REQUIRED TURBINE FLOW RATE AND SPEED TO DELIVER SPECIFIED PUMP FLOW RATE AND PRESSURE, SINGLE AND DUAL PUMP MODE
2. PERTURB SYSTEM PRESSURES IN DUAL PUMP MODE, OBSERVE DAMPING OF PUMP DISCHARGE PRESSURE:
STEP TPCV, ONE LEG
CYCLE TPCV, ONE LEG
CYCLE PDV
CYCLE BYPASS VALVE, ONE LEG
EP #1
3. SURVEY WITH SINGLE PUMP AND MEASURE DAMPING CHARACTERISTICS AS A FUNCTION OF THE SLOPE OF THE ΔP VS $\dot{W}$ CURVE. PERTURB SYSTEM WITH VARIOUS DISCHARGE IMPEDANCE CHARACTERISTICS
EP # 2

TENTATIVE TEST PLAN FOR PHASE 1A

● STEADY-STATE PERFORMANCE MATCHING:

1. DETERMINE SPEED AND PUMP FLOW RATIOS IN DUAL PUMP MODE

A. UNBALANCE PUMP SPEEDS BY ORIFICE IN TURBINE INLET
TO SIMULATE UNEQUAL TURBOPUMP EFFICIENCY (η_P, η_T ,
TURBINE FLOW PARAMETER). UNBALANCE LEGS BY 6σ
VARIATION; OBSERVE SPEEDS, PUMP FLOW RATES, AND
STABILITY WITH COMMON TURBINE POWER CONTROL.

EP #3

B. SIMULATE PUMP HEAD COEFFICIENT VARIATION BY
ORIFICE IN ONE PUMP INLET TO REDUCE PUMP EXIT
PRESSURE (AT FIXED ΔP). MAINTAIN NONCAVITATING
NPSP, BUT UNBALANCE LEGS.

EP #4

TENTATIVE TEST PLAN FOR PHASE 1A

MALFUNCTION DYNAMICS, DUAL PUMP TO SINGLE PUMP MODE

1. OBSERVE SYSTEM PRESSURE, FLOW RATE, AND SPEED

TRANSIENTS WHEN SYSTEM IS MALFUNCTIONED WITH

THE FOLLOWING:

TPCV FULL OPEN

TPCV FULL CLOSED

TBV FULL CLOSED

EP #5

TENTATIVE TEST PLAN FOR PHASE 1A

CHILLDOWN, STARTUP/SHUTDOWN - DUAL PUMP MODE

1. STARTUP WITH VARIOUS CHILLDOWN TIMES TO SIMULATE REFLECTOR CHILLDOWN TEMPERATURES.

EP #6

2. STARTUP WITH FRANZ SCREEN IN PUMP INLET OF ONE LEG TO REDUCE DENSITY TO SIMULATE UNSYMMETRICAL CHILLDOWN.

EP #7

3. STARTUP WITH UNEQUAL BYPASS FLOW RATES TO SIMULATE UNEQUAL TURBOPUMP EFFICIENCIES OR PUMP HEAD COEFFICIENTS.

EP #8

4. STARTUP WITH NO CHILLDOWN AND DETERMINE BYPASS FLOW RATE NECESSARY TO AVOID STALL.

EP #9

TOTAL NUMBER OF EP'S, PHASE 1A = 9

FACILITY SELECTION CONSIDERATIONS

- NEAR AND LONG TERM REQUIREMENTS.
- FLEXABILITY AND GROWTH WITHIN THE POSITION ITSELF.
- IMPACT UPON OTHER PROGRAMS BEING CONDUCTED IN THE SAME
GENERAL TIME PERIODS.
- COSTS.

TEST CELL "C" SCHEDULE

AEROJET NRO ACTIVITY IN TEST CELL "C"

FACILITY POSITION CONSIDERATIONS

EXISTING POSITION

- MOUNTED IN MK-25 FRAME
- MOUNTED IN NEW FRAME
- MOUNTED ABOVE MK-25 FRAME
- MOUNTED OUTBOARD OF MK-25 FRAME
- MOUNTED AT DIFFERENT ELEVATIONS IN MK-25 FRAME

NEW POSITION

- TANK MOUNTED ON ROOF
- TANK MOUNTED INSIDE ROOM
- TANK MOUNTED THROUGH ROOF

EXISTING MK 25 POSITION

NEW POSITION CONSIDERATIONS

SUCTION LINE

- PROVISIONS FOR ADDITION OF TANK FOR PHASE IIA

PUMP DISCHARGE LINE

- FLOW MEASUREMENTS IN EACH LINE
- BYPASS VALVES IN EACH LINE
- CHECK VALVES IN EACH LINE
- FLOW MEASUREMENT IN COMMON LINE
- IMPEDANCE VALVE AT LOCATION OF IMPEDANCE IN ENGINE

TURBINE INLET LINE

- COMMON CONTROL VALVE
- INDEPENDENT CONTROL VALVES
- INDEPENDENT BLOCK VALVES
- INDEPENDENT FLOW MEASUREMENT

TURBINE EXHAUST

- COMMON LINES LIKE ENGINE

DUAL TURBOPUMP INSTRUMENTATION

	<u>SINGLE SPOOL</u>	<u>TWIN SPOOL</u>
PRESSURE	28	44
TEMPERATURE		
RTT	9	15
THERMOCOUPLE	12	12
FLOWMETER	3	3
SHAFT SPEED	4	8
ACCELEROMETERS	<u>6</u>	<u>10</u>
<u>TOTAL</u>	62	92

ROM COST ESTIMATE FOR TEST CELL "C"

		CY '69	CY '70
PHASE 1A	XE MOD TPA'S		
	HARDWARE/TEST	\$515,000.	
	HYDROGEN	126,900 LBS	380,700 LBS
PHASE 1B	TWIN-SPOOL TPA'S		
	HARDWARE/TEST		\$411,500..
	HYDROGEN		507,600 LBS*
PHASE 11A	TWIN-SPOOL TPA'S		
	WITH SIM. TANK		
	HARDWARE		\$100,000.

* ESTIMATE BASED ON PHASE 1A PREDICTION

BREAKDOWN OF HARDWARE/TEST COSTS FOR CY 1969

1.	MODIFICATION OF "XE" TURBOPUMPS	\$ 81, 500.
2.	PROJECT ENGINEERING 3 PERMANENT	42, 000.
3.	MODIFICATIONS TO EXISTING TWIN-SPOOL TPA	25, 000.
4.	TEST CELL "C" MODIFICATIONS	308, 000.
5.	NTO MANPOWER 1 PERMANENT (DESIGN)	14, 000.
6.	LASL MANPOWER 1 PERMANENT (DESIGN)	14, 000.
7.	EGG/PAN AM/OTHER 2 PERMANENT + 2 ON R DAY	30, 000.
8.	TEST OPERATION (LASL/NTO) 5 PERMANENT	NC
9.	PFS INSTALLATION/MAINTENANCE (NTO) 2 PERMANENT	NC
10.	TEST MATERIALS	500.
		<hr/>
		\$515, 000.

BREAKDOWN OF HARDWARE/TEST COSTS FOR CY '70

1.	MODIFICATION OF XE TURBOPUMPS TO TWIN-SPOOL (3)	\$200,000.
2.	PROJECT ENGINEERING	\$ 83,000.
3.	TEST CELL "C" MODIFICATION TO TSTPA	\$ 5,000.
4.	EGG/PAN AM/OTHER 2 PERMANENT + 2 ON R DAY	\$ 70,000.
5.	TEST OPERATION (LASL/NT0 5 MY)	NC
6.	SIMULATED TANK BOTTOM	\$100,000.
7.	PFS INSTALLATION/MAINTENANCE (NT0) 2 PERMANENT	NC
8.	TEST MATERIALS	\$ 3,500.
	REQUAL OF TWIN-SPOOL TPA, H-6	\$ 50,000.
		<hr/>
		\$511,500.

MAJOR COMPONENTS REQUIRED FOR PROPOSED FACILITY

PUMP SUCTION

BELLOWS (2 EACH) \$300. EACH 4 WEEKS

PUMP DISCHARGE

IMPEDANCE VALVE AVAILABLE
BYPASS VALVES (2 EACH) AVAILABLE
SHUT OFF VALVES (2 EACH) AVAILABLE
CHECK VALVES (2 EACH) AVAILABLE
FLOW METERS (3 EACH) AVAILABLE
GIMBALS (12 EACH) \$1,000. EACH 8 WEEKS

TURBINE DRIVE

COMMON DRIVE VALVE AVAILABLE
TPCV (2 EACH) AVAILABLE
TBV (2 EACH) AVAILABLE
BELLOWS (4 EACH) \$200. EACH 4 WEEKS

TURBINE EXHAUST

BELLOWS (8 EACH) \$250. EACH 4 WEEKS

SUPPLY TO TES

SHUT-OFF VALVE AVAILABLE
CHECK VALVE AVAILABLE

CONCLUSIONS
DUAL TURBOPUMP TESTING IN TEST CELL "C"

EARLY TESTING IS DESIRABLE TO FURNISH NERVA DATA

OVERALL FACILITY CAPABILITIES ADEQUATE

CONTROLS SYSTEM

DATA SYSTEM

PROPELLANT SYSTEM

TURBINE DRIVE SYSTEM

TESTING CAN COMMENCE IN SEPTEMBER/OCTOBER 1969

RECOMMEND NEW TEST POSITION

RETAINS REACTOR TEST CAPABILITY WITH MK-25

OFFERS PROGRAM/CONFIGURATION VERSATILITY

COST/SCHEDULE COMPETITIVE

ROM COSTS

CY 1969 - \$515,000

CY 1970 - \$512,000

SHIELDING

E. A. Warman

SUMMARY SHIELD WEIGHT PER MISSION
(BEST AVAILABLE INFORMATION @ 4/22/69)

<u>MISSION</u>	<u>PAYLOAD ATTN.</u>	<u>SHIELD WEIGHT (LBS)</u>		
		<u>INTERNAL</u>	<u>EXTERNAL</u>	<u>TOTAL</u>
GRAND TOUR	--	3,300	--	3,300
SUB. SYN. ORBIT FERRY	3	3,300	17,700	21,000 (4 BURNS)*
		3,300	14,700	18,000 (3 BURNS)*
ONE WAY SYN. ORBIT	30	3,300	1,700	5,000
	>50	3,300	--	3,300
DIRECT LUNAR LANDING	30	3,300	2,700	6,000
	>50	3,300	--	3,300

*RESIDUAL LH₂ IS 7,500 LBS FOR 4 BURNS AND 38,800 LBS FOR 3 BURNS;
SHIELD WEIGHTS ARE BASED ON SEPARATION OF CREW AFTER 3RD OR 4TH BURN.

SUB. SYN. ORBIT FERRY MISSION
CONFIGURATION WITH VARIOUS SHIELD CONFIGURATIONS

DISK SHIELD ENVELOPE CURVES WITH 60° TANK AND 75° TANK FOR 200" S.D.,
 FERRY MISSION CONFIGURATION, PAYLOAD ATTENUATION FACTOR = 1.0,
 3300 LB. INTERNAL SHIELD
 (7500 LB. RESIDUAL LB. AT END OF FIRING)

TABLE 1

COMPARISON OF NRO AND WANL SUB. SYN. ORBIT FERRY
PAYLOAD RADIATION PREDICTIONS - APRIL 8, 1969

SOURCE	NRO - CREW DOSE (REM FOR COUCH LOCATION WITH 75° TANK, 200" SEPARATION DISTANCE, 7500 LB. RESIDUAL LH ₂ (PAYLOAD ATTENUATION = 1.0)	WANL - TANK TOP DOSE, 75° TANK, 186" SEPARATION DIS- TANCE, 7500 LB. RESIDUAL LH ₂
PVARA DIRECT	348	340
PVARA SCATTERED	443	488
LH ₂ CAPTURE	<u>23</u>	<u>6</u>
PVARA TOTAL	814	834
NOZZLE DIRECT*	57	52
NOZZLE SCATTERED*	192	253
TIL DIRECT	57	73
TIL SCATTERED	59	61
TEL (HAST C) DIRECT (2)	107	127
TEL (HAST C) SCATTERED (2)	99	94
PDL (A1 7039) DIRECT	19	26
PDL (A1 7039) SCATTERED	<u>28</u>	<u>38</u>
LINES & NOZZLE TOTAL	<u>618</u>	<u>724</u>
TOTAL DOSE	1432	1558

*INCLUDES SKIRT AND SKIRT EXTENSION

NRO DETECTOR AXIAL LOCATION Z = 3088 CM }
WANL DETECTOR AXIAL LOCATION Z = 2732 CM } CRAM MODEL
COORDINATE SYSTEM

NOTE: NRO DETECTOR LOCATED APPROXIMATELY 11 FT.
ABOVE TANK TOP, ∴ THE CORRESPONDING TANK TOP
VALUES WOULD BE SLIGHTLY HIGHER THAN THESE DATA.
THERE IS NO SPACECRAFT ATTENUATION IN EITHER SET
OF DATA.

SUMMARY OF CREW DOSE CONTRIBUTIONS
FOR TWO INTERNAL SHIELD WEIGHTS

<u>CONTRIBUTING SOURCE</u>	<u>DOSE (REM)</u>	
	<u>3300 LB. INTERNAL SHIELD</u>	<u>5300 LB. INTERNAL SHIELD</u>
PVARA DIRECT	348	40
PVARA SCATTERED	443	259
LH ₂ CAPTURE	<u>23</u>	<u>3</u>
PVARA SUBTOTAL	814	302
LINES DIRECT	183	183
LINES SCATTERED	186	186
NOZZLE, SKIRT, AND SKIRT EXTENSION		
DIRECT	57	57
SCATTERED	<u>192</u>	<u>192</u>
LINES & NOZZLE SUBTOTAL	<u>618</u>	<u>618</u>
TOTAL DOSE	1432	920

SUBSTITUTE SYNCHRONOUS ORBIT FERRY
MISSION PAYLOAD CONFIGURATION

COMPARISON OF NRO & WANL
SHIELD WEIGHTS FOR 35" RADIUS CAPSULE SHIELD
BASED ON POINT KERNEL COMPUTER CODES

SUB. SYN. ORBIT FERRY MISSION
CONFIGURATION WITH VARIOUS SHIELD CONFIGURATIONS

SUB. SYN. ORBIT FERRY MISSION
CONFIGURATION WITH VARIOUS SHIELD CONFIGURATIONS

SUB. SYN. ORBIT FERRY MISSION
CONFIGURATION WITH VARIOUS SHIELD CONFIGURATIONS

SUBSTITUTE SYNCHRONOUS ORBIT FERRY
MISSION PAYLOAD CONFIGURATION

SUBSTITUTE SYNCHRONOUS ORBIT FERRY
MISSION PAYLOAD CONFIGURATION

SUBSTITUTE SYNCHRONOUS ORBIT FERRY
MISSION PAYLOAD CONFIGURATION

Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

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Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

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Plan View of Sub. Syn. Orbit Ferry
Mission Payload With Two Capsule Shields

>1000 Rem

DOSE AT FORWARD COUCH OF SUB. SYN. ORBIT FERRY MISSION
VS. RADIAL DISTANCE FROM $\bar{C}$ WITH 35" RADIUS LEAD CAPSULE SHIELD

- NOTES: (1) 75° Conical Tank
(2) 7500 lbs Residual LM_2
(3) 200" Core Center/Tank Bottom Sep. Dist.
(4) 3300 lbs Int. Shield in PVARA
(5) 8800 lbs Total Shield Weight
(6) Point Kernel Scatter Code with no Scatter Surfaces Fwd of Tank Top

SUMMARY OF CREW DOSE CONTRIBUTIONS
FOR TWO INTERNAL SHIELD WEIGHTS

CONTRIBUTING SOURCE	DOSE (REM)	
	<u>3300 LB. INTERNAL SHIELD</u>	<u>5300 LB. INTERNAL SHIELD</u>
PVARA DIRECT	348	40
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LE ₂ CAPTURE	<u>23</u>	<u>3</u>
PVARA SUBTOTAL	814	302
LINES DIRECT	183	183
LINES SCATTERED	186	186
NOZZLE, SKIRT, AND SKIRT EXTENSION		
DIRECT	57	57
SCATTERED	<u>192</u>	<u>192</u>
LINES & NOZZLE SUBTOTAL	<u>618</u>	<u>618</u>
TOTAL DOSE	1432	920