NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY

PHASE III

PERFORMANCE REVIEW

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

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LOCKHEED MISSILES & SPACE COMPANY

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FOREWORD

This report contains copies of the material presented by Lockheed Missiles & Space Company at the First Performance Review of Phase III, Nuclear Shuttle System Definition Study, Contract NAS8-24715. It represents a portion of the reporting requirements listed on MSFC-DRL-197 for this study contract. The meeting was held at the George C. Marshall Space Flight Center, Huntsville, Alabama, September 3, 1970.

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PRESENTATION OUTLINE

SUMMARY _____ C. D. McKEREGHAN

MISSION DEFINITION _____ P. HUTCHINSON

OPERATION DEFINITION _____ C. VIVIAN

REUSABLE NUCLEAR VEHICLE CONCEPTS — F. FRIEDLAENDER

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- COMPLETE RNS PHASE A ACTIVITIES
 - ESTABLISH RNS OPERATIONS REQUIREMENTS
 - REFINE RNS SYSTEMS DEFINITION
 - DEFINE RNS DEVELOPMENT REQUIREMENTS
- PERFORM DISCRETE ENGINEERING TRADE STUDIES
 - ENGINE INTERFACE
 - TANK PRESSURIZATION
 - E/STS-2 DESIGN SUPPORT
 - SAFETY

PHASE III STUDY PLAN

INTERIM CONCLUSIONS

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- FACTORY TO LAUNCH SEQUENCE ESTABLISHED
- SPACE SHUTTLE LAUNCH INTEGRATION COMPLETE
- ORBITAL ASSEMBLY PLAN ESTABLISHED
- ORBITAL MAINTENENCE OPERATIONS & DEFINED
- REFERENCE MISSION DEFINED

SYSTEMS DEFINITION

- DESIGN CRITERIA ESTABLISHED

ENGINEERING TRADE STUDIES

- PREPRESSURIZATION REQUIREMENTS ESTABLISHED

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CONDUCT RNS SYSTEMS DEFINITION

- SUBSYSTEM SELECTION
- SYSTEMS INTEGRATION
- RNS DESIGN

TRADE STUDY ANALYSIS

- TANK PRESSURIZATION COMPLETION
- E/STS 2 SUPPORT COMPLETION

MISSION DEFINITION

REFERENCE MISSION VELOCITY BUDGET

The primary application of the RNS will be to transport manned and unmanned payloads between low circular earth orbit and either lunar or geosynchronous orbit, returning in each case to the initial low orbit. The reference low earth orbit was specified as 260 nm circular having an inclination of 31.5 deg. The reference lunar orbit was 60 nm circular at 90° inclination and the geosynchronous a circular equatorial orbit at synchronous altitude, approximately 19,323 nm.

For performance comparison lunar mission transfer times of 108 hr outbound and 72 hr return were specified by MSFC with a 30° plane change maneuver at both lunar orbit arrival and departure. Midcourse correction maneuvers of 50 fps were to be included for each transfer for both missions. A flight performance reserve (FPR) equal to 0.75% of the mission delta-V was also to be included.

The reference mission velocity budgets used in the LMSC performance analyses are shown in the table. To these must be added the gravity losses, which vary as a function of thrust-to-weight ratio, and the FPR allowances.

Delta-V values for the lunar mission assume Moon at maximum distance and 55° between the E-M plane and transfer trajectory plane. Three burn lunar arrival and departure maneuvers were utilized assuming a 36-hr intermediate elliptical orbit.

Velocity budget for the geosynchronous orbit is based on performing approximately 2° of the total plane change at low orbit departure or reinsertion.

REFERENCE MISSION VELOCITY BUDGET

(FOR RNS PERFORMANCE COMPARISON)

LUNAR SHUTTLE			
OUTBOUND		RETURN	
TLI (108 HR)	10,051 FPS	TEI (72 HR) {	LM1 1,917 FPS
MC	50		LM 2 ($\alpha=30^\circ$) 318
LOI ($\alpha=30^\circ$) {	AM 1 1,025		LM 3 1,340
	AM 2 333		MC 50
	AM 3 1,917		EOI 10,158

GEOSYNCHRONOUS SHUTTLE			
OUTBOUND		RETURN	
LV LOW ORBIT	7,866 FPS	LV SYN EQ	6,042 FPS
MC	50	MC	50
AR SYN EQ	6,042	AR LOW ORBIT	7,866

NOTE: GRAVITY LOSS ($f(T/w)$) AND FPR MUST BE ADDED TO MISSION VELOCITY REQUIREMENTS

RNS PROPELLANT OPTIMIZATION (Preliminary Evaluation)

A propellant optimization study was conducted for the reference lunar and geosynchronous shuttle missions to determine the most efficient sizing for the RNS and to provide input needed for the design effort. For the preliminary analyses, constant mass fractions (λ) of 0.75, 0.80, and 0.85 were used so that effects of payload ratio (outbound/return) and could be isolated. The preliminary analyses accounted for gravity losses and included allowances for boiloff and residuals, but did not simulate NERVA startup and shutdown operating characteristics.

For a constant λ' it can be seen that the total payload (outbound + return) is limited due to the high inert weight associated with large propellant capacity. Under these conditions the performance ratio (total payload/total propellant) would favor smaller sizes, in the 225 to 250K range. From the data it can be seen that payload ratio does not severely affect the location of the optimum.

Stage mass fraction, on the other hand, has a marked effect on total payload, and hence the value of the performance ratio. The validity of a constant λ' becomes increasingly in error as the range of propellant capacity increases, varying from about 0.76 at 200K to about 0.85 at 500K, so that while the optimum loading for constant λ' would indicate smaller propellant capacities, accounting for the variable mass fraction will shift the optimum considerably higher.

RNS PROPELLANT OPTIMIZATION

REF LUNAR MISSION
PRELIMINARY EVALUATION - CONSTANT MASS FRACTION

RNS PERFORMANCE OPTIMIZATION (Reference Lunar Mission)

The lunar shuttle mission propellant optimization was repeated using the scaling law $W_D = 42737 + 0.088 W_P$, representative of a single tank RNS, to evaluate the effects of variable λ' on optimum sizing. In addition to gravity losses, NERVA startup, shutdown, and cooling phases were simulated and propellant boiloff and residual vapor estimates revised. Three burn LOI and TEI maneuvers were used requiring eight burns over the mission span in addition to the midcourse maneuvers.

The increasing mass fraction with RNS size resulted in a continuous increase in total payload out to the 800K maximum size evaluated. The point of maximum efficiency shifted to much heavier loadings (500 to 600K) although the peak value of the performance ratio was lowered.

Although large size shuttles would provide improved efficiency for the lunar mission, more trips carrying smaller payloads appears better suited to the logistics requirements and crew rotation needs. If, however, large RNS's are found desirable for interplanetary applications they would not unduly penalize the lunar shuttle operation since they could be flown partially off-loaded at approximately the same performance ratio as the smaller RNS.

RNS PROPELLANT OPTIMIZATION

REFERENCE LUNAR MISSION

RNS PROPELLANT OPTIMIZATION
(Reference Geosynchronous Mission)

The geogynchronous shuttle mission optimization was conducted in the same manner as the lunar case indicating nearly the same optimum loading. Although the two missions have approximately the same total delta-V requirements, the geosynchronous payload capability is considerably above the lunar value indicating the penalty associated with the additional four burns for the lunar mission.

RNS PROPELLANT OPTIMIZATION

REF GEOSYNCHRONOUS MISSION

REFERENCE MISSION PERFORMANCE

Performance data are presented for the reference lunar and geosynchronous missions previously described. Three RNS configurations were used in the evaluation:

Single Tank (300K) RNS -	$W_D = 69,200 \text{ lb}$
Baseline, 7 tank (269.4K) RNS -	$W_D = 71,961 \text{ lb}$
10 tank (290K) RNS -	$W_D = 76,529 \text{ lb}$

Boiloff and vapor residuals were computed using an initial saturation pressure of 18 psi, an operating pressure of 25 psi, and an insulation thickness (not optimized) of 1 inch. For multiple tank concepts the residual vapor was dumped at the completion of individual tank drains.

Gravity losses and FPR allowances were added to each burn. Propellant requirements for full-power engine burns simulate engine startup, steady-state, shutdown, pump tail-off, and pulse flow cooling on an equivalent impulse basis using Phase III engine data as provided by Aerojet Nuclear Systems Company. For the evaluation a 75% recovery of the impulse from the pulsed flow cooling was assumed.

Midcourse maneuvers assumed idle-mode operation at an average I_{sp} of 480 sec. In some cases the middle burn of the three burn LOI and TEI maneuvers are too short for normal full-power engine operation and were simulated as partial power burns with an average I_{sp} of 480 sec. Tank pressurization and TPA operation were assumed for the partial power burns.

To demonstrate the effects of boiloff and residual gas weights, equivalent performance data neglecting these factors are shown for the lunar mission.

REFERENCE MISSION PERFORMANCE

NOMINAL LUNAR SHUTTLE MISSION

A nominal lunar mission has been defined for the purpose of RNS design and mission operation definition, based on transfer opportunity schedules developed during Phase II for the fully synchronized earth reference orbit assuming zero plane change at LOI. Two such transfers occur during each 54.64 day cycle. In one case a return opportunity after approximately 15 days occurs, varying from a 2° departure plane change at 108 hr transfer to 49° at 48 hr. For the alternate case a 0° departure occurs after about 17 days for transfer times of about 80 hours with modest plane changes (14° to 16°) required for earlier or later departures. A 30° departure plane change with a 72-hour transfer time was selected for the nominal mission, since this capability would provide ample performance margin to allow either opportunity to be selected.

To provide safety assurance for return of personnel to earth orbit in the event of emergencies occurring at the moon, a continuous return capability (90° lunar departure plane change) to an earth orbit compatible with space shuttle rendezvous was imposed. A 260-nm, 31.5° inclined circular orbit was assumed without the constraint that the orbit be the same orientation as the departure orbit. Return payload for the emergency case was taken as 20,000 lb, nominal value for a 6-man cislunar crew capsule used during the LMSC Phase II study. A 72-hour return transfer was specified, exclusive of the time consumed during the three burn lunar departure maneuver.

The velocity budgets for both the nominal mission and the emergency return are presented. Velocity losses due to gravity, dependent on both maneuver delta-V and thrust-to-weight ratio, are given for the specific cases evaluated, i.e., maximum outbound payload consistent with the safety requirements and corresponding return payloads.

The performance data include estimated boiloff, tank blowdown, and residual vapor weight for the 7 tank 269.4K RNS. Engine startup, shutdown, and cooling characteristics were included in the simulation assuming a 75% impulse recovery from the pulse flow cooling.

NOMINAL LUNAR SHUTTLE MISSION

(FOR RNS DESIGN EVALUATION)

VELOCITY BUDGET (INCLUDES GRAVITY LOSS & FPR)				
<u>OUTBOUND</u>			<u>RETURN</u>	
			<u>NORMAL ($\alpha=30^\circ$)</u>	<u>EMERGENCY ($\alpha=90^\circ$)</u>
TLI (108 HR)	10,818 FPS	TEI (72 HR)	LM 1	1,919 FPS
MC	50		LM 2	318
LOI	2,874		LM 3	1,368
			MC	50
		EOI		10,330
				10,320

PERFORMANCE (BASELINE RNS)	
PAYLOAD OUTBOUND	106,423 LB
NORMAL RETURN PAYLOAD	25,640
EMERGENCY RETURN PAYLOAD	20,000

RNS INTERORBITAL PERFORMANCE

An alternate mission application for the RNS would be to transfer large payloads such as interplanetary vehicles or vehicle and payload segments from low circular orbit to an intermediate elliptical orbit. The interorbital RNS would then self-return to low orbit leaving the interplanetary system in elliptical orbit from which the earth escape burn could be accomplished at reduced energy.

Phase II data for interorbital performance have been extended and refined to cover a wider range of RNS propellant capacities and elliptical orbit periods. For all transfers the RNS departs from and returns to 260 nm circular orbit.

The performance data presented accounted for gravity losses and simulate NERVA startup, steady-state, shutdown, pump tail-off, and pulsed flow cooling. Stage inert weights were estimated using the following modular RNS scaling law

$$W_D = 48253 + 0.088 W_P$$

RNS INTERORBITAL PERFORMANCE

ONE WAY PAYLOAD - RNS SELF-RETURNS
TO 260 NM STARTUP ORBIT

PLANETARY PROBE PERFORMANCE

The combination of a reusable nuclear shuttle and an expendable chemical upper stage provides an attractive vehicle for boosting large payloads to escape on missions with medium to high energy requirements. The performance capability for this combination was determined using the interorbital data for the baseline 7 tank RNS and a hypothetical chemical stage was assumed to be high enough to permit gravity losses to be neglected.

For missions below 30,000 fps excess velocity substantial increases in payload weight can be realized by staging in lower elliptical orbit and using larger chemical stages. For higher energy missions the payload becomes insensitive to intermediate orbit period and higher staging would be preferred to minimize chemical stage size.

PLANETARY PROBE PERFORMANCE

RNS PLUS EXPENDABLE CHEMICAL STAGE
(STARTUP AT 260 NM CHEMICAL ORBIT)

RNS - 7 TANK 269.4 K
CHEM $\lambda' = 0.9$ $I_{sp} = 460$ SEC

PLANETARY PROBE PERFORMANCE

Although the performance capability of the RNS-chemical combination is generally greater if low orbit staging is selected, the ratio of payload to chemical stage propellant, having a direct relationship to mission cost, is significantly improved for the higher orbit staging. Thus, staging should be accomplished in the highest orbit consistent with payload demands.

For comparison purposes the payload which can be delivered by the RNS alone is presented for the reusable and expendable modes, the latter being of interest only as a last mission for the RNS.

In the reusable mode the RNS performs three propulsive maneuvers, the first of which boosts the payload to escape. The second, assumed to occur 1 hour after first burn shutdown, retards the RNS into a 48-hr elliptical orbit with a perigee altitude of 260 nm. The third burn occurs at perigee retarding the RNS into circular orbit.

Effects of NERVA operating characteristics were included in the analyses. Gravity losses were included for the first and third burns only.

PLANETARY PROBE PERFORMANCE

BASELINE RNS-TANK 269.4 K

OPERATIONS DEFINITION

OPERATIONS REQUIREMENTS TASK OBJECTIVES

The primary objective of this task is to develop and define the RNS operational modes for all phases of the operational lifetime. The activities being conducted to accomplish this objective include development and definition of operational modes for all phases of the operational lifetime of the modular RNS; definition of the ground and orbital equipment and facilities necessary to support those operations; and constraints and requirements imposed by the various operational concepts on the RNS design.

OPERATIONS REQ'M'TS TASK OBJECTIVES

- TO DEVELOP AND DEFINE OPERATIONAL MODES FOR ALL PHASES OF THE OPERATIONAL LIFETIME OF THE MULTITANK RNS CONCEPT
- TO DEFINE THE GROUND AND ORBITAL EQUIPMENT AND FACILITIES TO SUPPORT THOSE OPERATIONS
- TO DEFINE THE CONSTRAINTS AND REQUIREMENTS IMPOSED ON THE RNS DESIGN BY THE VARIOUS OPERATIONAL MODES

PRELAUNCH OPERATIONS

The flow of hardware upon completion of fabrication and assembly of the RNS individual module is basically as shown on the opposite page. That is, the RNS module will go from the manufacturing facility to the appropriate test site and then to Kennedy Space Center via Super Guppy or ocean-river barge. It is recommended that the final acceptance testing be accomplished at the manufacturing site to minimize module movement and cost. Transportation modes to be employed would include both ocean and air. Ocean transportation is recommended for the initial shipment of the RNS modules. Subsequent shipment of replacement modules would be by air.

PRELAUNCH OPERATIONS

RNS MODULE CHARACTERISTICS

In general, all modules of the RNS are relatively lightweight but large, approaching the maximum payload envelope of the space shuttle. The dimensions of the major modules, in handling configuration, constitute envelopes which are oversize to normal transportation modes. A discussion of transportation modes follows:

Highway. Various factors act against any ability to transport system components by highway. The tanks are delicate and would require extensive protection against shock and exterior hazards for over-the-road movement. This in turn would increase the maximum "envelope" requiring clearance and permitting. Even with a special transporter designed for the transport of such tanks, it would be nearly impossible to move over highway, and a practical impossibility to move across country from LMSC to Cape Kennedy.

Rail. The delicacy of the tanks and components are again factors against movement by rail. In addition, it would be impossible to clear a rail route permitting cross-country movement of the subject tanks when in a shipping envelope.

Air. In relation to air transport, the Super Guppy aircraft appears to be the only feasible means of air movement. Even on this aircraft, only a single tank, propulsion tank, or the space frame could be moved per trip. The Mini Guppy may be capable of transporting selected modules if some degree of disassembly is practical, particularly for the spaceframe. The NERVA engine is expected to be supplied as GFE and is not being considered in this analysis.

Ocean Transportation. Commercial ocean movement does not seem feasible as on-deck freighter conditions would prevail. These conditions would present extreme difficulty in protecting the RNS segments from wave and water damage. However, a NASA vessel, such as the USNS Point Barrow or Saturn barge system, would be capable of transporting the RNS system under cover. The complete system can be transported in two modified LSD's or barges without the need for double decking of modules. The latter loading technique would be very difficult in these end-loading vessels. From LMSC to Cape Kennedy, the NASA vessel would take approximately 15 days in transit, and some allowance must be made for loading and unloading. It is presumed that this would require a day each. In addition, ferry costs would be involved for moving the vessel to the west coast for loading.

RNS MODULE - CHARACTERISTICS

MODULE	DIMENSIONS (FT)	WT (LB)	REMARKS
PROPELLANT (6 EACH)	14.5 (DIA) X 59.5	5094 EMPTY	DELICATE, EASILY DEFORMED, REQUIRES WEATHER PROTECTION
PROPULSION	14.5 (DIA) X 58	6400 EMPTY	DELICATE, EASILY DEFORMED, REQUIRES WEATHER PROTECTION
SPACEFRAME	60 X 15 X 13.5	3026	MUST NOT BE DISTORTED, CRITICAL FUNCTION SURFACES
SPACEFRAME WITH ELECTRONICS MODULE	60 X 15 X 13.5	6830	SAME AS ABOVE, CORRODIBLE SURFACES
ASTRIONICS MODULE	10x10x7	600	CORROSION WOULD CHANGE OPERATING CHARACTERISTICS, BALANCE, ETC.

ACCEPTANCE TEST OPTIONS

Replacement of modules and components on orbit requires acceptance of those modules and components to rigorous ground acceptance specifications. This acceptance testing will require use of interface simulators. Development of acceptance specifications and interface simulators to make on-orbit module and component replacement feasible also provides the opportunity for ground checkout by major modules without resorting to assembly of all major modules to the complete vehicle on the ground. Establishment of component and module interface tolerances could be accomplished by complete assembly and integrated test of a development test vehicle. This vehicle would also be used to determine systems interactions and to verify satisfactory propellant flow.

The dimensions of the propellant and propulsion modules will be affected considerably by the propellant cryogenic temperatures. This will affect the fit of the propellant interface connectors and various module alignments. Therefore, the interface fit checks of the modules using master tooling and also certain alignments will be conducted while the modules are tanked with liquid hydrogen.

The environment for conducting the required acceptance tests has been determined by a consideration of test results which may be achieved in various environments, as shown on the opposite page. The tabular data indicate generally that manufacturing tests will require ambient and cryogenic conditions, leak tests can be conducted best in a liquid hydrogen environment, and electronics systems can be tested best in the space environment of a temperature-altitude simulation chamber. From the systems involved in the various modules it follows that acceptance tests of the propellant and propulsion modules can be accomplished in a cold flow facility. The tanking with liquid hydrogen will subject the tank to operational cryogenic conditions, and much of the instrumentation experiences the liquid hydrogen temperatures. However, testing of the spaceframe can be accomplished best in the space environment of a temperature-altitude simulation chamber. The chamber, programmed to provide space cold and solar heat, will present the electronics modules and attitude control system with the environment conditions that these systems would experience in orbit. With these exceptions, other tests to be conducted on the propellant, propulsion, and spaceframe modules will be similar.

ACCEPTANCE TEST OPTIONS

TASKS	ORDER OF INCREASING FACILITY COMPLEXITY			
	AMBIENT	LH ₂	TASC	TASC & LH ₂
●ALIGNMENT	GOOD	EXCELLENT	—	—
●FIT CHECKS				
●BATTERIES, ACCESS DOORS	EXCELLENT	EXCELLENT	—	—
●MODULE INTERFACES	GOOD	EXCELLENT	—	—
●ELECTRICAL CONTINUITY	GOOD	EXCELLENT	GOOD	EXCELLENT
●ELECTRONICS SYSTEMS TEST	GOOD	GOOD	EXCELLENT	EXCELLENT
●PROGRAMMED INTEGRATED ACCEPTANCE TESTS	GOOD	GOOD	EXCELLENT	EXCELLENT
●MODULE INTERFACE LEAK TESTS	GOOD	EXCELLENT	GOOD	EXCELLENT
●PROPELLANT SYSTEM LEAK TESTS	GOOD	EXCELLENT	GOOD	EXCELLENT
●INSULATION SYSTEMS PERFORMANCE	—	GOOD	—	EXCELLENT
●PROPELLANT MEASURING SYSTEM CALIBRATION	FAIR	EXCELLENT	FAIR	EXCELLENT

SITE OPTIONS

The basic flow of RNS hardware will be from the manufacturing facility to the final acceptance test facility to KSC. Analyses were undertaken to consider different sites for these functions and different transportation modes. The manufacturing facilities considered were located at LMSC facilities in Sunnyvale, California and NASA's facility at Michoud, La. The final acceptance test facilities considered were at LMSC, KSC, and at the Mississippi Test Facility. The flow sequences for these site options are shown on the opposite page. Transportation modes considered were primarily air and water.

SITE OPTIONS

COST COMPARISON - TRANSPORTATION MODES

If the acceptance testing is done at MTF, the RNS modules must be transported to that facility by barge. Even if the primary transport mode is by air this route must be followed. This is apparent when comparing the LMSC/MTF/KSC, LMSC/KSC/KSC time spans.

It is surprising to note that if two barges can be used simultaneously the travel time by barge is actually less than by air transport. Costs, of course, are considerably less for barge transport.

This does not hold true for a single RNS module. The costs and time are considerably less for air transport.

COST COMPARISON TRANSPORTATION MODES

TRANSPORT MODE	MICH/MTF/KSC	LMSC/MTF/KSC	LMSC/LMSC/KSC	LMSC/KSC/KSC
OCEAN /RIVER				
SINGLE	\$55,000	\$170,000	\$155,000	\$155,000
FULL RNS	\$110,000	\$340,000	\$310,000	\$310,000
ELAPSED TIME*	21(8) DAYS	55(20) DAYS	51(18) DAYS	51(18) DAYS
AIR TRANSPORT				
SINGLE	\$45,200	\$77,000	\$75,400	\$75,400
FULL RNS	\$222,600	\$619,200	\$603,200	\$603,200
ELAPSED TIME*	12 DAYS	24 DAYS	16 DAYS	16 DAYS

* DOES NOT INCLUDE TEST TIME

FACILITIES AND GSE REQUIREMENTS -- PRE-KSC

Of primary importance to the definition of the RNS system is the identification of the GSE and facilities required for support of the RNS operations. The GSE and facilities listed on the opposite page are those items required to support the pre-KSC operational phase from the final acceptance testing, storage, and transportation to the KSC.

FACILITIES & GSE REQUIREMENTS - PRE-KSC

GSE

- TRANSPORTER, ON-SITE
- WATER AND AIR TRANSPORTS
- HANDLING SLINGS AND PROTECTIVE SYSTEMS
- INSULATION PURGE
- TANK PRESSURIZATION AND MONITORING
- MASTER GAGES AND FIXTURES
- MANUFACTURING TOOLING
- CALIBRATION EQUIPMENT
- CONFIGURATION SIMULATORS
- FUNCTIONAL SIMULATORS

FACILITIES

- MANUFACTURING COMPLEX
- STORAGE PROVISIONS
- TRANSPORTATION - WATER DOCK AND AIRFIELD
- COLD FLOW
- TEMPERATURE ALTITUDE SIMULATOR CHAMBER

EARTH LAUNCH OPERATIONS

The RNS modules will arrive at the Kennedy Space Center either by air or ocean transporter, and will flow through various checkout assembly, servicing, and launch operations. The primary activity prior to assembly into Space Shuttle will be to determine status of all equipment mounted on the module and to ascertain that there have been no changes since the final acceptance test at the manufacturing facility or the last test. Once the RNS module is installed in the Space Shuttle orbiter, the sequence of events for the RNS module will be governed by the Space Shuttle.

Certain assumptions were made in determining the operations and the sequence of events for the KSC operations. The major assumptions are as follows:

- o Maximum use will be made of Saturn transportation systems, handling facilities, and equipment applicable to the RNS requirements.
- o The Space Shuttle Orbiter will be loaded with RNS modules in the horizontal plane.
- o Reference points on hard pads will be provided for each RNS module design to accomplish weight and center of gravity determinations.
- o Structural members of the RNS modules will incorporate alignment and measurement reference hard points for purposes of module and equipment installation and checks in the Space Shuttle. Reference points in the Space Shuttle shall be identifiable and distinguishable, not only for earth loading and tiedown operations, but for orbital operations as well.
- o Maximum use will be made of GSE checkout, handling, and transportation equipment common to the Space Shuttle program at KSC.
- o The Space Shuttle and/or KSC ground (facility) will be utilized to provide fluid and pneumatic servicing, electrical power and instrumentation requirements for the RNS modules during the launch pad phase.
- o RNS modules will be serviced in the vertical position on the pad.

EARTH LAUNCH OPERATIONS

PROPULSION AND PROPELLANT MODULE

Two basic approaches to establishing operating interfaces with the Space Shuttle were developed. These approaches are based on primary control resting with the Space Shuttle or the facility.

In the Space Shuttle control approach, the propellant or propulsion module is filled and controlled via the normal Space Shuttle systems. Purge, fill and vent fluids would be handled through the normal umbilical and intravehicle connections, with control resting with the Shuttle avionics system.

The ground controlled concept would utilize separate fluid and electrical umbilicals for the RNS hardware. Fluid controls would be under facility control, with communication to the avionics system on the RNS elements. This approach provides a greater degree of LH₂ loading flexibility for the RNS elements but increases the complexity of the Space Shuttle physical interfaces.

PROPULSION & PROPELLANT MODULE

RNS INTERFACES

SPACE SHUTTLE CONTROLS CONCEPT

FACILITY (GROUND) CONTROLS CONCEPT

FACILITIES AND GSE REQUIREMENTS -- KSC

The requirements for GSE and facilities to support the KSC launch operations are primarily for checkout and assembly into the space shuttle. This includes the initial receipt and unloading from the transport vehicle through inspection and checkout of the module, to the final integration of the module into the space shuttle, servicing, and launch countdown.

FACILITIES & GSE REQUIREMENTS - KSC

GSE

- SPACE SHUTTLE UMBILICAL SPOOLS
- FLUID SERVICE SYSTEMS CONTROL
- CHECKOUT EQUIPMENT
- CALIBRATION EQUIPMENT
- ENVIRONMENTAL CONTROL SYSTEMS
- PROTECTIVE AND HANDLING DEVICES
- ON-SITE TRANSPORTER
- MASTER GAGES AND FIXTURES

FACILITIES

- LAUNCH PAD COMPLEX
- FLUID SYSTEMS
- COMMUNICATIONS NETWORK
- DATA AND TRAINING NETWORKS
- DATA AND INFORMATION REDUCTION
- GROUND CONTROL SYSTEM
- SAFETY
- ASSEMBLY AND STORAGE BUILDINGS

CHECKOUT PHILOSOPHY

The acceptance testing or checkout philosophy specifies the testing to be accomplished during manufacturing test and systems test at the manufacturing site, during launch preparation at the launch site, and during validation tests on orbit following final nuclear stage assembly or module replacement. The nuclear stage testing will follow existing test concepts during manufacturing and systems test, but will differ in the extent of testing required at the launch base, and will introduce the opportunity for checkout and test on orbit. One reason for the change in testing concept is that at the time of launch and during ascent the nuclear stage modules are passive in a transported capacity rather than active as a rocket stage. A second reason is that the nuclear stage will be assembled on orbit. To accommodate this on-orbit module assembly the capability has been provided for checkout and failure diagnosis following assembly. These circumstances and capabilities reduce the checkout requirements at the launch base, which will be an interim point rather than the final point for assembly, checkout and corrective action.

CHECKOUT PHILOSOPHY

	MFG & ASSY	TRANS- PORT TO KSC	KSC		SPACE SHUTTLE LAUNCH & BOOST	EARTH ASSEMBLY ORBIT		IN- FLIGHT
			PRE- LAUNCH	LAUNCH PAD		SPACE SHUTTLE PAYLOAD C/O	RNS C/O	
PROPELLANT MODULE	▲ ●	○	○	△ ○	○	△ ○	■	○ ■
PROPULSION MODULE	▲ ●	○	○	△ ○	○	△ ○	■	○ ■
SPACE FRAME MODULE	▲ ●	○	○	△ ○	○	△ ○	■	○ ■
NERVA ENGINE	TBD	TBD	TBD	TBD	TBD	TBD	■	○ ■
REPLACEMENT SUBSYSTEMS (SPACE REPLACEABLE UNITS)	▲ ●	○	○	△ ○	○	△ ○	■	○ ■

LEGEND

- ▲ FUNCTIONAL AND/OR SIMULATED TEST (IN DEPTH)
- △ PARTIAL FUNCTIONAL TEST (MINIMAL)
- ACCEPTANCE TEST
- STATUS MONITORING
- INTEGRATED RNS CHECK
- TBD TO BE DETERMINED BY ENGINE CONTRACTOR

LAUNCH OPERATIONS

All of the RNS modules are compatible with the 15 by 60 cargo bay of the Space Shuttle. As such, all modules maintenance parts and supplies necessary to the RNS operations can be delivered on orbit by the Space Shuttle. Of all the major elements, i. e., Space Station/Base, Space Tug, etc., the Space Shuttle is the only element essential to RNS earth orbital operations.

The Space Shuttle plays a major role, not only in the delivery of the modules to earth orbit, but in the determination that the modules are in flight readiness and ready for assembly. In addition, the Space Shuttle provides the necessary command and control functions during all orbital operations.

LAUNCH OPERATIONS

RNS MODULE DATA INTERFACE

The space shuttle will deliver to earth orbit four distinct units (propellant module, propulsion module, engine, and space frame) which must be ready to go and in good operating condition when assembled.

To ensure prior assembly credibility, certain key checks (performance, environment and tie-down) must be made during delivery which requires space shuttle and RNS delivery unit breakdown interfaces. Applicable questions arising from the above are what support functions are required to be checked during delivery of particular RNS units and whether the capability to perform self-check is inherent in the design or must it be supported or totally provided by the space shuttle.

The chart shows that the space frame during delivery can generally support itself, while the other three units (propellant, propulsion, and engine) will require some support from the space shuttle.

RNS MODULE DATA INTERFACE

RNS SUPPORT FUNCTIONS	RNS DELIVERY BREAKDOWN							
	PROPELLANT PROPULSION				SPACE FRAME		ENGINE	
	EXIST'G	REQ'D	EXIST'G	REQ'D	EXIST'G	REQ'D	EXIST'G	REQ'D
PROVIDE DATA ON ALL FAILURES		△		△		△		△
MONITOR CARGO COMPARTMENT		△		△		△		△
PROVIDE STIMULI	△		△		△		△	
MONITOR PARAMETER LIMITS	△		△		△		△	
PROVIDE ALARM & COMMANDS		△		△	△			△
DETECTION OF SAFETY HAZARDS	△		△		△		△	
RECORD SYSTEM STATUS		△		△	△			△
PROVIDE TREND ANALYSIS		△		△		△		△
PROVIDE PREDICTION		△		△		△		△
PROVIDE TEST & C/O	△		△		△		△	
PROVIDE SYSTEM CONFIGURATION MGMT		△		△	△			△
PROVIDE ELECTRICAL POWER		△		△		△		△
PROVIDE ENVIRONMENTAL CONTROL						△		

NOTE: EXIST'G - FUNCTIONS ARE INHERENT IN MODULE DESIGN
REQ'D - FUNCTIONS MUST BE SUPPORTED TOTALLY OR IN
PART BY SPACE SHUTTLE

PROPELLANT MODULE CHECK-OUT CONCEPTS

On-board subsystem check-out can be performed by means of Built-In-Test Equipment (BITE) or by utilizing a centralized computer controlled check-out system. The RNS centralized check-out system will be incorporated into the on-board DMS. Data from each of the subsystem areas would be available within the DMS as part of its normal function and can be used to determine level of equipment performance. The amount of data processing and computation required to perform in-flight check-out to the replaceable module level may impact the performance of the DMS and must be considered in the DMS design. For some replaceable modules the normal data input to the DMS may not be sufficient to evaluate performance, and additional data transmission to the DMS would be required.

In contrast to the central check-out approach, subsystems can be designed with BITE to detect and isolate malfunctions to any desired level. BITE can be utilized to perform automatic redundancy switching with actions and results reported to the DMS. Redundancy and BITE can be combined to reduce fault isolation time and time-to-return-to-service, as contrasted to providing only redundancy for reliability considerations. Where no periodic ground maintenance would be performed, the BITE must test itself for proper operation and should output a "fail" signal to the DMS upon sensing either a BITE or subsystem failure.

The propellant tanks of the RNS will be replaceable assemblies. The individual tank assembly must be capable of being checked out on the earth, carried into orbit, and inserted into the RNS. Each tank would contain BITE such that it can be checked out independently from the DMS. The BITE would provide the capability of interfacing with the DMS to accept commands and to report status. This form of BITE can be considered to be part of the DMS and will be discussed later in more detail. The same approach can be taken in other subsystem areas as the RNS design progresses.

PROPELLANT MODULE CHECKOUT CONCEPTS

INITIAL ASSEMBLY SEQUENCE

The initial assembly of the RNS system in orbit is accomplished in four basic phases. Launch of the space frame module is the first phase, as it contains the propulsive and intelligence capability necessary to maintain station keeping and establishes readiness for tank assembly and all subsequent autonomous operations. Deployment of the power system, astrionic equipment tank bays that are located in the space frame module, prepares for the next phase of assembly operation, which is to assemble the propellant and propulsion module tanks into the space frame. The engine is deployed by the Space Shuttle and the autonomous docking system is activated and the rendezvous and docking of this RNS subsystem is accomplished. Payload is assembled as required by its configuration and nature. Large payloads would be assembled autonomously through rendezvous and docking or by systems similar to the tank handling devices. Small packages compatible with EVA would be handled in that manner, although it is not anticipated that the payloads would normally be of that nature.

INITIAL ASSEMBLY SEQUENCE

SPACE FRAME

DEPLOYMENT

TANK INSTALLATION

ENGINE INSTALLATION

TANK INSTALLATION

A variety of modular tank concepts were developed, but they are basically quite similar in tank exchange concept. In all modular concepts the propellant modules are connected with forward and aft thrust rings in tiers (one or two, depending on concept), with the propulsion module attached to the aft section of the frame. A typical multiple tank propellant module consists of a propellant tank and support; propellant; insulation system; and propellant management system incorporating ground emergency vent, flight vent, thermal conditioning unit pneumatic system, pressurization system, and propellant feed system. Each tank is supported at three points at the forward and aft ends of the cylinder tank. A common plug-in interface plate incorporates pneumatic pressurization, propellant, and electrical quick disconnects. These tanks are compatible with the space shuttle cargo bay. The space shuttle is equipped with deployment mechanisms to position the various modules for pick-up by RNS handling devices, as shown on the opposite page.

TANK INSTALLATION

VELOCITY PROFILE

If a constant speed motor is used, the tank would achieve a peak velocity in a relatively short time (0.01 sec) and the velocity over the approach distance would be constant. This also means that the deceleration times would be comparable. The spring rate between the tank and the space frame can be determined from the stiffness properties of the 4- and 5-inch bi-stem elements. Considering this spring rate and a peak velocity of 6 ft/min the accelerations resulting would exceed design limits (0.26 to 0.31 g's, respectively).

Since maximum acceleration depends upon the velocity profile, the problem reduces to finding a velocity profile producing the least-maximum acceleration. The smallest maximum acceleration occurs for a linear velocity increase for half its travel, followed by a linear velocity decrease until the mass comes to rest. This velocity profile provides a constant magnitude acceleration for its entire travel.

VELOCITY PROFILE

LOCATION OF PEAK VELOCITY

Tank transfer to the space frame is described utilizing three parameters -- acceleration, maximum velocity, and time of travel. The total length of travel is constant (40 ft). However, the peak velocity location is not constrained at a particular point. The accelerations on the opposite page correspond to the left side of the discontinuous curve shown on the preceding page.

0.3
allowable

LOCATION PEAK VELOCITY

PEAK VELOCITY VS. TIME

The time of travel for various maximum approach velocities is presented on the opposite page. The travel time is independent of maximum velocity location because of the linear nature of the transfer motion.

The actual maximum velocity will not exceed 10 ft/min. Therefore, the maximum acceleration from Plot 1 is only 10^{-4} g's. Since the tank transfer acceleration to the space frame is very small, a slosh analysis is not needed for this event.

PEAK VELOCITY VS TIME

MISMATCH PENALTIES

A primary way in which the orbital propellant storage depot can potentially effect cost savings is in its ability to maximize the propellant delivery capacity of the space shuttle. The space shuttle -- and especially dedicated-tanker versions of the shuttle designed for maximum propellant delivery to the RNS -- may be mismatched to the RNS capacity in that, on the last fueling mission before an RNS flight the space shuttle may be able to transfer only a portion of its LH_2 to the nearly-full RNS. Without a dewar to "level out" the propellant deliveries from the space shuttle, this excess hydrogen would be wasted (disregarding the possibility of flying the RNS offloaded). Shown here is the cumulative cost penalty, at \$5 million per space shuttle mission, for providing one extra space shuttle flight per RNS mission to deliver a partial propellant load.

MISMATCH PENALTIES

COST IMPLICATIONS OF DEWAR ALTERNATIVES

Two general classes of propellant resupply dewars were considered -- dedicated systems designed exclusively for propellant storage in orbit, and "spare-RNS" systems in which the principal elements of a Reusable Nuclear Stage (less engine) would function as the dewar. Two configurations were considered for each class of dewar -- single-tank concepts launched by the INT-21, and multiple-tank configurations launched by the space shuttle and assembled in orbit.

The program alternatives, cost elements, and estimated costs associated with fulfilling the maximum propellant-delivery objective with an orbital propellant depot are presented on the next page. Note that the development (nonrecurring) costs of the dedicated dewars make these concepts higher in cost than the extra-RNS concepts. In addition, the INT-21 launch vehicle costs tend to drive the total cost of single-tank dewar systems higher than comparable multi-tank configurations.

COST IMPLICATIONS OF DEWAR ALTERNATIVES

OBJECTIVE	ALTERNATIVES	COST ELEMENTS	COSTS	
			SINGLE TANK	MULTIPLE TANK
ACCUMULATE PROPELLANT IN ORBIT TO TAKE MAXIMUM ADVANTAGE OF SPACE SHUTTLE CAPACITY	DEVELOP A DEDICATED DEWAR	DEWAR NONRECURRING COSTS	\$ 300 M	\$ 300 M
		DEWAR RECURRING COSTS	61*	58*
		LAUNCH VEHICLE & LAUNCH OPNS COSTS	216	45
			\$ 577 M	\$ 403 M
	ADD ONE EXTRA RNS TO THE FLEET	EXTRA RNS RECURRING COST (LESS ENGINE)	\$ 65 M*	\$ 62 M*
		RNS LAUNCH VEH & LAUNCH OPNS COSTS	216	45
			\$ 281 M	\$ 107 M

* FOR ONE DEWAR ONLY
MULTIPLE ORBIT MODES REQUIRE MORE DEWARs

INFORMATION MANAGEMENT CLASSES

The classes of roles are based on the need for specific functions to be performed, inherent capability to perform these functions, and the levels of support and backup required to meet emergencies, equipment failures, traffic, schedule conflicts, loading and/or loss of capability out of communications range.

The intent of the chart is to illustrate generally the type of functions that constitute a management role and when certain classes of vehicles/terminals would be expected to participate.

In primary and primary backup control, man is always in the loop, participating in all major decisions, and performing all essential functions.

Secondary control can generally perform most functions required by primary or primary backup, except tracking and ranging. It may be manned or unmanned.

Secondary control backup and tertiary control may be manned or unmanned. A vehicle or terminal having tertiary control performs fewer functions and has a lower level hierarchy control and extremely limited capability, e.g., it does not perform mission direction (crew members on EVA). Passive is a subdued role or semiactive and not a control, e.g., only status monitoring. All control areas are expected to be capable of status monitoring.

Communications Carrier only is also a subdued role in that it performs no control over mission or any function directly related. The role is strictly one of passing on all information that it has received.

INFORMATION MANAGEMENT CLASSES

MANAGEMENT FUNCTIONS	PRIMARY CONTROL	PRIMARY CONTROL BACKUP	SECONDARY	SECONDARY CONTROL BACKUP	TERTIARY CONTROL	PASSIVE	COMMUNICATIONS CARRIER ONLY
MAINTAIN SAFETY _ _ _ _ _	X	X	X	X	X		
MISSION DIRECTION _ _ _ _ _	X	X	X	X			
GENERAL COMMAND & CONTROL _ _ _ _ _	X	X	X				
SPECIFIC CONTROL _ _ _ _ _			X	X	X		
COMMUNICATIONS _ _ _ _ _	X	X	X	X	X		
CHECKOUT _ _ _	X	X	X		X		
TRACKING & RANGING _ _ _ _ _	X	X					
SUPERVISE RENDEZVOUS & DOCKING _ _ _ _ _	X	X	X	X*	X*		
RELAY DATA _ _ _							X
GENERAL STATUS MONITORING ONLY _ _ _ _ _	X	X	X	X	X	X	
INOPERATIVE _ _ _ _ _						X	

VEHICLE TERMINAL INTERFACE CAPABILITY

There are seven distinct types of network elements which must interface in varying degrees with each other.

This chart shows a typical example of the vehicles and terminals and what external interface capability they require with the RNS and the multiplicity of communications links to enhance this capability.

VEHICLE & TERMINAL INTERFACE CAPAB.

VEHICLES/ TERMINALS	RNS MODULE					COMM CAPABILITY				COMMUNICATION
	MONITOR	SAFETY	CALIB	C/O	ABORT ANAL	VOICE X&R	CMMD X&R	DATA X&R	TRACK X&R	
SPACE SHUTTLE	•	•	•	•	•	•	•	•	•	
SPACE STATION	•	•	•	•	•	•	•	•	•	
COMSAT								•		
TUG	•	•	•	•	•	•	•	•	•	
EARTH SUR. STA.	•	•	•	•	•	•	•	•	•	
EVA		•								
RNS	CAPABILITY AS NOTED ABOVE									

NETWORK ELEMENTS -- EARTH ORBIT PHASE

Although the RNS is required to have the essentials of launch and mission control and will operate autonomously, in this concept it will nevertheless receive certain instructions and directions from the network element empowered to control the operation.

This chart shows the network elements in earth orbit operations, typical modes of operation, and the relative position of control of each network element.

NETWORK ELEMENTS - EARTH ORBIT PHASE

MODE	SPACE SHUTTLE	TUG	SPACE STATION	EARTH SUR STA	RNS	EVA	COMSAT
RENDEZVOUS	PC	T	SC	PCB	P	P	CO
DOCKING	PC	T	SC	PCB	P	P	CO
C/O & UNLOAD	PC	T	SC	PCB	P	P	CO
ASSY & C/O	PC	SCB	SC	PCB	T	T	CO
PRELAUNCH & LAUNCH	P	SCB	PCB	PC	SC	P	CO

KEY: PC PRI CONTROL
 PCB PRI CONTROL/BACKUP
 SC SEC CONTROL
 SCB SEC CONTROL/BACKUP

T_ TERTIARY
 P PASSIVE
 CO CARRIER ONLY

NETWORK FREQUENCY ALLOCATIONS

The RNS will be designed to travel between earth orbit and geosynchronous orbit, lunar orbit or on an interplanetary trip and therefore must be capable of communicating with any network element when required.

Using the lunar mission as a reference, the chart relates those opportunities (operating modes) requiring the RNS to communicate with other network elements.

Therefore, the use of F_1 through F_{10} as typical application of frequencies to particular links is not to be restricted only to those links. Adequacy and flexibility are key parameters to be included in RNS communications system design.

ALLOCATIONS NETWORK FREQUENCY

OPERATING MODE	FREQUENCIES									
	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	F ₇	F ₈	F ₉	F ₁₀
SPACE SHUTTLE RENDEZVOUS (EARTH ORBIT)										
RNS RENDEZVOUS (LUNAR ORBIT)										
SPACE SHUTTLE DOCKING (EARTH ORBIT)										
RNS MODULE C/O & UNLOAD (EARTH ORBIT)										
RNS ASSEMBLY & C/O										
RNS PRELAUNCH & LAUNCH								N/A		
RNS GEOSYNC ORBIT										
RNS TRANS LUNAR					N/A					
RNS LUNAR ORBIT						N/A			N/A	
RNS TRANS EARTH					N/A					
RNS EARTH ORBIT										

F₁ RNS - EARTH SURFACE STA

F₂ RNS - LUNAR SURFACE STA

F₃ RNS - EARTH ORBIT SPACE STA

F₄ RNS - LUNAR ORBIT SPACE STA

F₅ RNS - EARTH OR LUNAR EVA

F₆ RNS - EARTH ORBIT TUG

F₇ RNS - LUNAR ORBIT TUG

F₈ RNS - SPACE SHUTTLE

F₉ RNS - COMSAT

F₁₀ RNS - SAFETY

☐ DEFINITELY REQUIRED

☒ MAY BE REQUIRED

FLIGHT OPERATIONS SUMMARY

The RNS operating profile during the reference mission was developed. This included the functional and time relationships for all phases of the flight profile. Of particular emphasis was the sequence of events and relationships of the various RNS subsystems and functions during the start-up, steady-state, and shut-down operations. The following pages describe, in summary, the Leave Earth (LE) events for the reference Lunar mission, from initiation of chilldown to the first coast period.

FLIGHT OPERATIONS SUMMARY

EVENT NO.	EVENT
LE-1	ENABLE PRE-CONDITIONING
LE-14	INITIATE PRE-CONDITIONING
LE-19	START BOOT-STRAP
LE-23	BEGIN RAMP UP
LE-29	BEGIN STEADY STATE
LE-34	TANK BLOW-DOWN
LE-36	INITIATE SHUT-DOWN
LE-42	SCRAM
LE-50	BEGIN COOL-DOWN
LE-66	BEGIN COAST

FLIGHT OPERATIONS

The baseline vehicle consists of six propellant modules, a propulsion module, space frame, and engine. These are assembled in flight. A schematic is shown on the opposite page.

The propulsion module incorporates all subsystems necessary for in-space dormant storage and integrates into the complete modular system. Loading is accomplished through the feed disconnect. A pre valve is placed upstream of this disconnect for tank shutoff, rather than by making the disconnect checking. This facilitates in-space mating with the engine and reduces line boiloff.

A zero-gravity vent is included to permit in-flight venting if needed, without entraining liquid. Also, the mixer motor of the in-flight vent will be turned on to mix the tank contents as required.

When tank pressure rises unduly, due to stratification or for any other reason, mixing is initiated. The vent valve will not open until after a period of mixing has taken place, and then only if tank pressure remains excessive. The flight vent also serves to provide subcooled, two-phase hydrogen coolant for the sump heat exchanger. Sump cooling is necessary, since liquid hydrogen under the sump containment device does not mix with the bulk. Coolant flow will be continuous and may have to be modulated if weight penalties are too high.

FLIGHT OPERATIONS

FLIGHT OPERATIONS (Cont)

LE - 1. The pneumatic start valve is opened prior to any other component operation to ensure that a supply of pneumatic helium is available for pneumatically operated valves.

LE - 2. The pneumatic propellant module feed valves for the first four propellant tanks are opened. This permits liquid to flow into the space frame feed manifolding (the space frame feed lines are evacuated). The feed lines will thereby chill down up to the space frame feed isolation valve. Although vapor will be formed in relatively large quantities initially, this vapor will largely be recondensed as complete chilling takes place. Eight minutes has been provided for this conditioning period of time.

LE - 3. At five minutes prior to engine start the space frame feed isolation SOV is opened to permit chilling of the space frame feed line down to the propulsion module isolation valve. This portion of the line is also pre-chilled in order to reduce gysering and pressure surges.

LE - 4. The space frame pressurization isolation valve is opened and locked in position for the remainder of the mission.

LE - 5. The propellant module flight vents are deactivated to ensure that propellant is not vented overboard during engine burn. The flight vent pressure setting is lower than the tank operating pressure during burn and would be opened during the entire burn if not deactivated.

LE - 9. The propulsion module interstage feed valve is the final link required to ready the interstage feed systems and is opened two minutes prior to temperature conditioning. Other prestart operations are performed within the engine, which includes opening of the turbine bypass loop, structural support cooling loop, and engine purge.

FLIGHT OPERATIONS (CONT)

FLIGHT OPERATIONS (Cont)

TEMPERATURE CONDITIONING

LE - 14. The TSOV is opened at the referenced time, T_o and is engine start.

LE - 15. Approximately one second after the TSOV is opened propellant settling will begin at a very low level. The one second delay accounts for valve response and pressure build-up within the engine lines.

LE - 17. Propellant module pressurization valves are enabled prior to the bootstrap phase. These valves will therefore open, since tank pressure at this time is lower than the tank operating pressure baled during engine operation.

LE - 18. Enable reactor temperature control.

FLIGHT OPERATIONS (CONT)

FLIGHT OPERATIONS (Cont)

BOOTSTRAP

LE - 21. Pressurization begins at approximately 21 seconds after the beginning of bootstrap operation, whereby pressure is building up within the engines. Tank pressure will be the operating pressure prior to initiation of ramp up, which is at 30 seconds after engine start. The precise time that pressurization begins is a function of the bootstrap operation and pressurization line check valve cracking ΔP . The tank will come up to operating pressure as a function of ullage volume and engine pressurization flow rate capability (not designated at this time). A detailed study will have to be performed in order to describe vehicle pressure requirements.

RAMP

LE - 23, LE - 24. Ramp up begins 30 seconds after engine start and terminated at 56 seconds after engine start. No vehicle functions are required during this time other than modulation of bleed pressurant gas pressure which is automatically performed by the pressurization valves and their pressure switches. Engine operations are dictated by the engine manufacturer.

LE - 25. Complete drum rollout.

LE - 27. Fully open turbine discharge control valve.

FLIGHT OPERATIONS (CONT)

FLIGHT OPERATIONS (Cont)

STEADY STATE

LE - 29. At this point propellant in tanks 1, 2, 3, 4 has been completely expelled for nominal propellant loading and nominal engine performance. However, due to slight differences in pressure drops from one tank feed line to another, the tanks will deplete at slightly different intervals. As soon as ullage is injected from one tank into the feed line manifold, pressure drop from the propellant module to propulsion module will be drastically reduced because of gas flow rather than liquid flow. Draining from the remaining tanks will then be via gravity feed rather than pressure transfer. A period of five seconds is therefore allowed to permit gravity feed to completely eliminate all liquid from the manifold prior to isolation of the tanks.

LE - 30. The last propellant module pressurization valves are activated near the end of the leave earth burn in order to prepare for isolation of the propellant module tankage system. This valve is activated prior to propellant module isolation to ensure a smooth transition with a minimum of tank pressure surging.

LE - 31. Propellant module feed valves are closed so that the tanks can be vented to space. Pressurization valves and the propulsion module feed isolation valves are closed soon after that.

LE - 34. The propellant module main vent valves are opened to permit blowdown to vacuum and are then closed.

LE - 37. Throttling hold begins.

LE - 41. Temperature retreat is initiated.

LE - 43. Pump tailoff begins, to complete shut-down.

FLIGHT OPERATIONS (CONT)

NETWORK ELEMENTS -- FLIGHT PHASE

The elements as shown are almost self-explanatory in that the same set of elements (space station, COMSAT, RNS and Earth Surface Station) are used when leaving Earth as are used when approaching. Likewise, the same elements (RNS, Space Station, Lunar Surface Station) are used when nearing lunar orbit as are used when leaving.

One aspect of information management which is quite different from the above inference of two distinct and separate operations is the handover (earth to lunar network) while in transit to the Moon (translunar) and the handover (lunar to earth network) while in transit to the earth (trans-earth). The handover requires good network coordination and is extremely essential.

NETWORK ELEMENTS - FLIGHT PHASE

MODAL CONTROL DURING TRANSIT & LUNAR ORBIT PHASES

MODE		EARTH SPACE STATION	LUNAR SPACE STATION	LUNAR ORBIT TUG	EARTH SURFACE STATION	LUNAR SURFACE STATION	RNS	EVA	COMSAT
TRANSIT	TRANSLUNAR	SC / SCB	SCB / SC	P	PC / PCB	PCB / PC	T	P	CO
	TRANSEARTH	SCB / SC	SC / SCB	P	PCB / PC	PC / PCB	T	P	CO
LUNAR ORBIT		SCB	SC	T	PCB	PC	T	T	CO

KEY: PC PRIMARY CONTROL
 PCB PRIMARY CONTROL/BACKUP
 SC SECONDARY CONTROL
 SCB SECONDARY CONTROL/BACKUP

T TERTIARY
 P PASSIVE
 CO CARRIER ONLY

NETWORK ELEMENTS -- LUNAR ORBIT PHASE

In lunar orbit as in earth orbit, information management activity is very high and the maximum variety of network elements possible are in use. Here, the RNS must rendezvous with the space station and other space elements, uncouple its payload, and take on another. While EVA and the tug are the two added exceptions to the Flight Phase, their use would not be precluded if required.

NETWORK ELEMENTS - LUNAR ORBIT PHASE

MODAL CONTROL DURING TRANSIT & LUNAR ORBIT PHASE

MODE		EARTH SPACE STATION	LUNAR SPACE STATION	LUNAR ORBIT TUG	EARTH SURFACE STATION	LUNAR SURFACE STATION	RNS	EVA	COMSAT
TRANSIT	TRANSLUNAR	SC SCB	SCB SC	P	PC PCB	PCB PC	T	P	CO
	TRANSEARTH	SCB SC	SC SCB	P	PCB PC	PC PCB	T	P	CO
LUNAR ORBIT		SCB	SC	T		PC	T	T	CO

KEY: PC PRIMARY CONTROL
 PCB PRIMARY CONTROL / BACKUP
 SC SECONDARY CONTROL
 SCB SECONDARY CONTROL / BACKUP

T TERTIARY
 P PASSIVE
 CO CARRIER ONLY

DISC SHIELD EXTENSION

From a shielding standpoint, the disc extension appears preferable to the shaped jacket configuration. In addition to its lower weight, the disc extension should provide significant protection from skirt and extension activation. Attachment of this shield to the engine also appears simpler.

The disc shield extension (1.54×10^5 sec decay time) can be expected to alternate incident dose rates due to Fe-59 and Cr-51 by factors of about 7×10^4 and 10^{30} , respectively. However, neither the unattenuated dose rate nor the fraction of emitted photons which bypass the extended disc are known at present.

DISC SHIELD EXTENSION

■ EXTENSION (U-238)

DISC SHIELD (5-69 CRAM)

DECAY TIME (SEC)	1.54 (F)	1.05 (C)	100
$T_1 - G/CM^2$	26	16	0
$T_2 - G/CM^2$	185	168	58
WEIGHT - LB	25,000	22,000	7300

SHAPED PVARA JACKET SHIELD

Rough estimates have been made of shielding required for post-shutdown access to engine and vehicle components above the NERVA disc shield. The access region treated is a cone of 28° half-angle, with apex 70 inches below Station 0. Shield configurations were selected for minimal weight capable of providing exposure rates of ≤ 200 mrad/hr within the cone and above the plane of the disc shield. Gamma activity in the skirt and skirt extension is neglected in the computations.

The two configurations considered are shown on the opposite page and the two pages following that.

SHAPED PVARA JACKET SHIELD

DECAY TIME = 1.54×10^5 SEC (~43 HRS)

■ DISC SHIELD (5-69 CRAM)
 ■ JACKET SHIELD (U-238)
 * MEAN RADIUS - 27.5"

i	T_i (g/cm ²)	* WEIGHT-LB
1	110	6200
2	139	6700
3	152	4700
4	138	4000
5	115	4250
6	67	4850
	TOTAL	30.7K

ENGINE FLY-AWAY CONTROL

It is desirable to have the initial assembly point coincide with the remote separation joint. If the RNS structure is powered up and has minimum maneuvering capability, the engine assembly could be released from the space shuttle at a stand-off location and the automatic docking system used to fly the assembly in. No EVA should be required.

The engine should be remotely separable and attitude stabilized (internally) for fly-away operations. Using this system the fly-away maneuvers could be done in the following manner. After main engine propellant lines are vented, the fly-away system is switched to internal power and a fault/status check made by the RNS computer. If all systems check, the engine remote separation joint is uncoupled. The RNS laser engine docking radar is slaved to track the receiver and the RNS CNC computer used to compute maneuvering commands for the engine. During the separation, the computer will generate error signals to be coded PCM on the laser signal and demodulated by the pod receiver. The 25-lb thrusters (2) are used to generate the 2 ft/sec separation rate. During the transit time the engine will be attitude stabilized by the LOS angle errors. After the engine has reached its storage station and been stopped, all residual translation will be removed to within the accuracy of the laser radar. At this point the engine system can be turned off (with the exception of the command receiver and rate limiting stabilization circuits) to conserve power.

When it is desired to return the engine, a two-stage acquisition is required. The RNS laser must first acquire the 360° coverage corner reflectors on the engine. When the engine is acquired, a turn on-acquisition command is transmitted via TLM to the engine. At that point the acquisition sensors, coupled in an analog bridge, will point the laser receiver toward the transmitted beam. When the LOS angle is less than 15° , the receiver will acquire the beam and the return maneuver will essentially be a reversal of the fly away. During terminal docking, the measured roll misalignment (relative roll index) angle will be transmitted to the engine along with rate commands.

During storage the engine would not be attitude stabilized but rate limited to prevent excessive rotation from building up. If analysis indicates that these rates for a two-week period would not be excessive (or a rate damper is added, 5-10 lb), the rate sensor could be turned off and power reduced to less than 1 watt, cutting battery weight by 2/3.

ENGINE FLYAWAY CONTROL

EQUIPMENT ARRANGEMENT

The self-contained approach requires a separable engine interface pod as an integral part of the engine thrust cone structure. All power, propulsion, control, and communications subsystems required for engine handling would be included in this pod and separated with the engine when removal is required. The following design goals will govern concept analysis:

- Totally autonomous operation (i.e., no EVA or manual control)
- Simple maintenance/resupply
- RNS systems commonality
- Power/weight efficiency
- Technical feasibility

EQUIPMENT ARRANGEMENT

PROPELLANT SIZING

ASSUMPTIONS

ENGINE WT $\cong$ 850 SLUGS

I_{sp} (MMH- N_2O_4) $\cong$ 250 SEC

MANEUVER ΔV = 2 FT/SEC MAX

SEPARATION AND RETURN MANEUVER

• ΔV -ACCELERATION & DECELERATION	28.8
• MISC STATION-KEEPING (25 %)	7.2
• ATTITUDE MANEUVERS	10
TOTAL	46 LB
CONTINGENCY (50 %)	23
TOTAL PROPELLANT	69 LB
• TANKS - (MMH- N_2O_4) ~ 6 IN. DIA	5
• TANK (N_2 + TANK WT)	4
• VALVES, COUPLING, ETC	7
• THRUST CLUSTERS - 3 MOTORS (5 LB THRUST)	10
2 MOTORS (25 LB THRUST)	16
TOTAL PROPELLANT SYSTEM WT	120 LB

TOTAL SYSTEM WEIGHT

ENGINE PORTION

RCS - SPS (INCLUDES CONTINGENCY)

PROPELLANT	70
INERT GAS	50
	<u>120 LB</u>

LASER RECEIVER 26

CORNER REFLECTORS (2, 180° x 180° PASSIVE) 5

COMMAND RECEIVER AND ANTENNA 2

ACQUISITION SENSOR(S) 1

CONTROL ELECTRONICS 10

BATTERY (RECHARGEABLE) 4.0 KW-HR 80

RNS PORTION

244 LB

LASER RADAR TRANSMITTER 30

PROPELLANT SUPPLY LINES, VALVES AND COUPLINGS 10

MISC. STRUCTURE AND ELEC. HARNESS AND CONNECTORS 10

50 LB

DOCKING STRUCTURE NOT INCLUDED

ENGINE HANDLING CONCEPT ASSESSMENT

In this rudimentary evaluation it would appear that the fly-away concept has a clear advantage over the tug/shield approach in the majority of categories evaluated. The larger differences in such costly areas as ground launch weight per separation, logistics constraints, and development costs would indicate that the fly-away system is the logical choice for engine handling. Further study into integration of the fly-away system with the RNS RCS-SPS design could reduce the system weight estimates considerably. Final selection, however, will depend on the capability of the system to function in the nuclear environment or on radiation hardening.

ENGINE HANDLING CONCEPT ASSESSMENT

	TUG / SHIELD	FLY AWAY STAGE
LAUNCH WEIGHT PENALTIES	● EXTRA SPACE SHUTTLE LAUNCHES	● PAYLOAD PENALTY 250 - 300 LB.
DEVELOPMENT RISK	● TUG / SHIELD PARALLEL DEVELOPMENT	● DEVELOPMENT COMMONALITY
LOGISTICS REQUIREMENTS	● REQUIRES DEDICATED ORBITS	● ALWAYS AVAILABLE
RNS OPERATIONS CONSTRAINTS	● TEMPORARY STATION KEEPING	● TEMPORARY STATION KEEPING
SYSTEMS AUTONOMY	● TUG / SHIELD REQUIRES DUPLICATE AUTONOMY	● COMPLETE
SYSTEM REFURBISHMENT	● LARGER QUANTITIES OF EXPENDABLES	● EXPENDABLES RESUPPLIED FROM RNS
SYSTEM MAINTENANCE	● MAJOR MAINTENANCE (SYSTEM)	● MINOR (SUBSYSTEM)

TOTAL REFUELING - SPACE SHUTTLE

The data on the opposite page presents the pressure profile to be anticipated during a refueling operation direct from the shuttle. The pressure profile on the right indicates the final pressure at the end of the fill operation for each tank and the final pressure at the end of filling the entire assembly. The initial tank conditions are as follows:

- o Initial tank pressure = 0 psia
- o Initial propellant in propulsion module = 5200 lb
- o Initial propulsion module temperature = 40°R
- o Tank heat rate = 612 Btu/hr
- o Propulsion module heat rate = 594 Btu/hr

The main advantage of this refueling approach is that the umbilicals will have less frequent make and break and, of course, less tank handling. The primary disadvantages are that there are more frequent "hard" dockings with a major vehicle, and an inspection after each mission cannot be made. Maintenance activities can be performed as required by bringing only the specific tanks that require maintenance and refurbishment activities back to earth.

TOTAL REFUELING BY SHUTTLE

RNS MAINTENANCE OPERATIONS

Based on the analyses conducted in this study it seems apparent that no single EVA work system category is optimal across all operational conditions and requirements. The selected approach consists of a combination of techniques. Criteria utilized in selecting the preferred approach include crew safety, performance capabilities, development time and cost, weight, and required space shuttle cargo space for EVA work systems. Based on these considerations, deployment, assembly and checkout operations are essentially autonomous. Man's role in these operations is strictly one of inspecting the adequacy of these autonomous operations and, where possible, performing a contingency backup action that would prevent a mission abort, e.g., manual assist in unfolding a space frame arm that did not deploy automatically.

Man's largest contribution is seen in performing both scheduled and unscheduled maintenance on RNS systems. Here two EVA work system candidates seem to offer the most promise -- aided manual EVA and small manned auxiliary vehicles with remote manipulators. The aided manual EVA option is selected because of the superior visual and dexterity capabilities of the astronaut compared with remote manipulator systems, relative system simplicity, and hence lesser development time and cost and minimal impact on RNS design in terms of layout and component selection penalties. Selection of the aided manual EVA mode involves acceptance of the slightly lower degree of astronaut safety as compared with enclosed capsule EVA systems.

Nuclear radiation hazards associated with the engine offer the most stringent problems. These hazards argue strongly for unmanned auxiliary vehicles with teleoperator remote manipulator control or the alternative of remotely commanding the radioactive "hot" engine a safe distance away from the operational site. This latter alternative was selected as a simpler and less costly approach than the teleoperator system.

MAINTENANCE OPERATIONS

EXTRAVEHICULAR WORK SYSTEMS

The RNS concept development requires a detailed consideration of the role of man in maintenance, assembly and refurbishment operations. Man is seen as an available resource which may significantly impact system reliability, cost, flexibility, and complexity. Accordingly, an analysis was made of the extravehicular work systems available to support RNS operations, the applicability of these extravehicular modes to RNS specific functions and the nature of the crew system interface between RNS, the space shuttle and the space station. In addition, preliminary design concepts to facilitate EVA maintenance were formulated.

Five categories of extravehicular work systems were considered as shown on the opposite page:

- a. Unaided Manual EVA - Suited astronaut activities in the free space environment utilizing handholds, tethers, rails at a fixed work-site.
- b. Aided Manual EVA - The suited astronaut is provided supplementary means for translating to an EVA worksite, cargo or astronaut transport, auxiliary illumination, and docking/stabilization aids.
- c. Primary Vehicle/Remote Manipulator - The operator conducts operations from the interior of a primary vehicle by means of a remote manipulator system comparable to advanced underwater submersible systems.
- d. Manned Auxiliary Vehicle/Remote Manipulator - Small vehicle which encapsulates the astronaut with a remote manipulator system.
- e. Unmanned Auxiliary Vehicle/Remote Manipulator - Vehicle and manipulator are remotely controlled by a teleoperator located within a primary vehicle, the space station or a ground base.

EXTRAVEHICULAR WORK SYSTEMS

UNAIDED MANUAL
EVA

AIDED MANUAL EVA

PRIMARY VEHICLE-
REMOTE MANIPULATOR

MANNED AUX.
VEHICLE-REMOTE
MANIPULATOR

UNMANNED AUX. VEH
REMOTE MANIPULATOR

RNS PREPARED WORK SITE

At the worksite a lightweight work platform will be erected, as shown on the opposite page. This work platform incorporates "Dutch" shoes which have been proven effective for anchoring an astronaut so that he can exert maximum work forces. The platform also contains side and front rails allowing the astronaut to tether himself to the platform. The platform is designed to ride along a channel track located three feet below the edge of the equipment packages shown. The channel permits the astronaut to position himself with relative ease anywhere along the periphery of the equipment section. A control along the platform guard rail allows the astronaut to lock the platform into position. The worksite platform is stored within the space frame adjacent to the equipment bay modules.

RNS PREPARED EVA WORK SITE

WORK SYSTEM CHARACTERISTICS

This chart summarizes the physical and performance characteristics of the various work system approaches. The details of the appropriate systems will provide interface requirements for the RNS and other major program elements.

EVA WORK SYSTEM CHARACTERISTICS

	UNAIDED MANUAL	AIDED MANUAL	PRIMARY REMOTE	ASSISTED AUXILIARY	UNMANNED AUXILIARY
<i>EVA DURATION</i>	<i>1-3 HR</i>	<i>3-10 HR</i>	<i>8-30 HR</i>	<i>4-30 HR</i>	<i>LONG TERM</i>
<i>RANGE</i>	<i>60 FT</i>	<i>40-10,000 FT</i>	<i>LONG</i>	<i>1000-10,000 FT</i>	<i>LONG</i>
<i>STOWED VOLUME</i>	<i>23K IN.³</i>	<i>43-216 FT</i>	<i>LARGE</i>	<i>43 FT³</i>	<i>LARGE</i>
<i>MASS</i>	<i>296 LB</i>	<i>1000-2000 LB</i>	<i>20,000 LB UP</i>	<i>260 LB</i>	<i>540-7500 LB</i>
<i>CREW REQUIREMENT</i>	<i>2</i>	<i>1-2</i>	<i>1</i>	<i>1</i>	<i>REMOTE</i>
<i>ILLUMINATION</i>	<i>PORTABLE</i>	<i>BUILT-IN</i>	<i>BUILT-IN</i>	<i>BUILT-IN</i>	<i>BUILT-IN</i>
<i>EQUIPMENT OPERATIONAL LIFE</i>	<i>HIGH</i>	<i>1-5 YR</i>	<i>UNKNOWN</i>	<i>UNKNOWN</i>	<i>3 YR</i>

PRIMARY VEHICLE REMOTE MANIPULATION

This class of space work systems encompasses remote manipulators affixed to a primary space vehicle. The remote manipulator is operated by an astronaut located internally within the primary space vehicle. Visual access to the worksite may be either direct through a viewport or indirect by means of a video display. The primary vehicle provides transportation to the worksite, stabilization, and life support provisions for the operator. This system offers a major safety advantage over manual EVA approaches in that the operator is afforded the protective envelope of the vehicle in combatting hazards associated with the space environment (vacuum, temperature, radiation, and meteorites). It also permits longer duration work periods than the suited astronaut can endure. This type of space system would be analogous to advanced underwater submersible systems with remote manipulators.

Depicted here are several conceptual remote manipulator concepts operated from a primary space vehicle. The Serpentuator system is an alternate version of the one shown earlier to support aided manual EVA. Here the control system is exercised by the man internal to the vehicle as opposed to an EVA astronaut at the terminal end. A possible adaptation of the Storable Tubular Extendible Member system is shown. Also illustrated is a conventional manipulator, e.g., master-slave type, incorporated within a primary vehicle. This concept, as opposed to the two previous ones, is more appropriate where a restricted worksite area is available.

PRIME VEHICLE - REMOTE

SERPENTUATOR SYSTEM

STEM SYSTEM

MANIPULATOR ARMS

UNMANNED AUXILIARY VEHICLE

Unmanned auxiliary vehicles with remote manipulators operated from a teleoperator station located within a primary vehicle, space station, or ground station have the following advantages:

- They permit EV operations in a hazardous environment with no risk to man, e.g., severe radiation environments near nuclear engines.
- These vehicles do not require crew system habitability provisions.
- Longer continuous operational periods are possible.

Lockheed SCHMOO. The Space Cargo Handler and Manipulator for Orbital Operations (SCHMOO) is an unmanned vehicle concept capable of performing space operations in a hostile environment such as a nuclear power engine. The SCHMOO, shown here, is 18 ft long, 15 ft wide and 12 ft high. Its dry weight is 7,500 lb and its wet weight is 11,300 lb. It houses two manipulator arms and two docking/stabilization arms. The vehicle and manipulators are operated remotely from an orbital or ground station. The SCHMOO is equipped with two video systems -- one for visual monitoring of approach and docking and the other for tasks performed by the manipulator.

GE Remote Manipulator Spacecraft. The GE system weighs only 540 lb and is approximately 12 inches deep by 40 inches wide by 75 inches high. It has two bilateral manipulator arms that are slave to a master control system in a remote site, as well as two docking stabilization arms. The system has a payload capability of 500 lb and a mission duration of 10 hours. The video system consists of two cameras for docking and task monitoring.

UNMANNED AUXILIARY VEHICLE

LOCKHEED SCHMOO SYSTEM

G. E. REMOTE MANIPULATOR SPACECRAFT

MANNED CAPSULE

Interest in small, special-purpose enclosed vehicles permitting manned remote manipulator operations in space goes back to the early 1960's. In a 1962 report entitled, "Survey of Remote Handling in Space", prepared by the Behavioral Sciences Laboratory, Wright-Patterson AFB, a variety of preliminary concepts are described. Since that time, some of these EVA work system concepts have advanced to the mockup and early prototype stage. These concepts offer the obvious primary advantage of enveloping the astronaut in a protective shell that exceeds the protection offered by the space suit.

Several early cylindrical and spherical vehicle concepts were generated by Lockheed, as shown on the opposite page. These concepts included provisions for remote manipulator arms or pressurized gauntlets. Other concepts in this category included the following:

- (1) Remora Capsule - Bell Aerospace
- (2) Humpty Dumpty Capsule - Douglas
- (3) Space Taxi - LTV

MANNED CAPSULE

CYLINDRICAL VEHICLE
CONCEPT

SPHERICAL VEHICLE CONCEPT

CYLINDRICAL WITH
FABRIC ARMPIECES

UNAIDED EVA

Of the five categories of extravehicular work systems enumerated, actual space experience has been obtained primarily with the aided and unaided manual mode associated with Gemini flights.

Based on the Gemini experience, it was concluded that extravehicular operation in free space is feasible and can be used for productive tasks if adequate attention is given to body restraints, task sequence workload control, realistic simulation, and proper training. Principal problems encountered in the Gemini EVA activities included: (a) Space suit mobility restrictions; (b) encumbrance of the ELSS chestpack; (c) inadequate rejection of metabolic heat accompanied by astronaut discomfort; (d) work levels and metabolic rates exceeded the design limits of the ELSS; and (3) equipment retention during EVA was a problem for all items which were not tied down or securely fastened.

None of these problems was considered serious or insuperable in terms of future EVA attempts and the Apollo Applications Program requires EVA in connection with the Apollo Telescope Mount (ATM) mission. The ATM mission is considering the use of EVA to remove and replace film cassettes. Looking to the future, it has been estimated that about one-half of the 1200 space experiments proposed through 1980 will logically require some level of EVA to satisfy the overall mission.

Despite the proven feasibility of EVA during the Gemini program and subsequent neutral buoyancy simulations, there has arisen some resistance to programming EVA on future missions unless it is absolutely necessary. This resistance is attributable primarily to the increased potential astronaut hazards associated with free space activities, as well as a possible over-reaction to the fatiguing nature of EVA experience on some of the Gemini flights due to inadequate restraints and astronaut body heat rejection.

UNAIDED EVA

*HAND-HELD
MANEUVERING UNIT*

*ASTRONAUT
MANEUVERING UNIT*

AIDED MANUAL EVA

This EVA mode primarily involves the provision for powered translation capability. In addition, advanced EVA aids can take the form of additional cargo or tool transport capability, advanced devices for anchoring the astronaut to a work site, and extended life support and illumination aids. Aided, as well as unaided translation was evaluated as part of the Gemini space flight series. Typical concepts include the following:

Serpentuator. A moveable platform for transporting an EVA astronaut plus cargo which is attached to a base on the primary spacecraft. This conceptual device consists of a series of connected, individually controlled and powered, articulated links with a roll-ring at the base and a payload cargo rack and control station at the terminal end. This system was designed for possible application to the ATM film cannister retrieval and replacement task. One investigation concluded that a 54-foot long, 10-link serpentuator could accelerate a 500-lb mass at a rate of $.025 \text{ fps}^2$.

Bendix Modulator EVA Work Platform. The Bendix work platform is an independent maneuverable system for transporting an astronaut and cargo. The platform is capable of an incremental velocity of 300 fps and can perform a 4-hour mission with an additional 4-hour emergency reserve capability. Normal operating ranges are 1,000 to 7,000 ft with the capability of adding modules which extend this range to 10,000 ft. Stabilization is provided by an automatic attitude control. The platform serves as a portable work site and can be fitted with manipulator arms to increase the reach and maintain and amplify forces provided by the astronaut. Work site anchors are also provided to connect the platform to available structures in the worksite area.

LTV Maneuvering Work Platform (MWP). Like the Bendix work platform, the LTV MWP is an open mobility unit independent of the primary space vehicle. Manipulators are provided for mass handling, grappling stabilization and docking. The unit has a range of 6,500 ft., weights 1689 lb and has an operational life of 8 hours plus 2 hours contingency.

AIDED EVA

EVA WORK SYSTEM COMPARISON

Each EV work system category was analyzed in terms of the following characteristics: EVA duration, range of operations from the crew support base, volume, mass, crew requirements, expendables, cargo handling capability, illumination aids, and operational life. In comparing the various EV work system types, the following general conclusions were drawn:

- Beyond unaided manual and rudimentary aided-EVA there are no off-the-shelf systems for accomplishing the large magnitude of EVA activities forecast for the future.
- Unaided manual EVA should only be considered as a backup emergency mode of operations.
- Aided manual EVA work systems offer the most promise for the RNS operational period. These relatively simple and cost-effective systems permit the astronaut to directly apply his superior manual dexterity and visual capabilities to work site operations at a possible slight sacrifice in overall safety compared to vehicle encapsulated environments.
- Primary vehicles with remote manipulators do not appear to have the flexibility required for maneuvering in and around representative space worksites without severely impacting the space structure design.
- Manned auxiliary vehicles with remote manipulators offer considerable operational flexibility, a greater degree of astronaut protection than manual EVA, and it is likely that this class of EVA work systems will be developed in parallel with Aided manual EVA work systems.
- Unmanned auxiliary vehicles with teleoperator control have special applications in severely hazardous environments, e.g., in the vicinity of a radioactive unshielded nuclear engine.

EVA WORK SYSTEM COMPARISON

	UNAIDED MANUAL EVA	AIDED MANUAL EVA	PRIMARY VEHICLE REMOTE MANIPULATOR	MANNED AUXILIARY VEHICLE REMOTE MANIPULATOR	UNMANNED AUXILIARY VEHICLE REMOTE MANIPULATOR
▲ SUPERIOR					
○ FAIR					
◆ INFERIOR					
ASTRONAUT SAFETY	○	○	▲	▲	▲
VISIBILITY-INSPECTION	▲	▲	○	○	◆
DEXTERITY	▲	▲	◆	◆	◆
RANGE-TRANSLATION	◆	○	▲	▲	▲
EVA MISSION DURATION	◆	○	▲	▲	▲
CARGO-TOOL TRANSPORT	◆	▲	▲	▲	▲
SYSTEM DEVELOPMENT COST	▲	○	◆	◆	◆
EVA SYSTEM COMPLEXITY	▲	○	◆	◆	◆
ASTRONAUT ENERGY EXPENDITURE	◆	○	▲	▲	▲
RELIABILITY	▲	○	▲	?	?
DESIGN IMPACT ON SPACE STRUCTURE	▲	▲	○	○	◆
IMPACT ON SUPPORT VEHICLE	▲	○	◆	◆	◆
ACCESS AT WORK SITE	▲	▲	◆	◆	◆
WEIGHT, POWER, VOLUME	▲	○	◆	◆	◆
OPERABLE IN SEVERE RADIATION ENVIRONMENT	◆	◆	◆	◆	▲

WORK SYSTEM EFFECTIVENESS

DEPLOYMENT OPERATIONS

Deployment operations may include a visual inspection of the RNS component being delivered to orbit prior to separation from the space shuttle. This will be especially important in those cases where the flight to orbit may have exceeded design environment limits. When the cargo size and configuration provide sufficient access within the cargo bay, these visual inspections may be performed by the EVA-suited astronaut within the space shuttle payload compartment. Where access is limited, the EVA astronaut may inspect cargo status with the space shuttle payload bay hatches open and the cargo on the elevated platform. The astronaut may also have an involvement in releasing equipment tie-down mechanisms.

TRANSLATION TO AND FROM RNS WORKSITES

The EVA astronaut must negotiate the distance between the space shuttle or space station and the various possible RNS worksites. A minimum separation distance of 40 feet between space shuttle and RNS has been assumed and a minimum separation of 200 feet has been postulated between RNS and the space station. These separations are required to avoid potential collision hazards. The smaller separation distance assumed for the space shuttle is due to the capability of the space shuttle to conduct collision avoidance maneuvers. Collision hazards may occur as a result of RNS attitude control failures.

In addition to these separation distances, the EVA astronaut must traverse the distance between the space shuttle exit point and the worksite location on the approximately 140-foot RNS. The relationship between RNS and space shuttle will also be limited by the requirement to stay within safe operational limits of the post-activated nuclear engine. In summary, the EVA astronaut must transport himself, tools, and cargo up to 200 feet from the space shuttle and up to 350 feet from a space station, depending on the orientation of the two vehicles in question.

EVA WORK SYSTEM EFFECTIVENESS

COMPARISON

COMPARISON		AUTONOMOUS UNAIDED	MANUAL EVA AIDED	MANUAL EVA PRIMARY VEH. REM. MANIP.	MANNED AUX. VEH. - REM. MANIP.	UNMANNED AUX VEH. - REM. MANIP.	
DEPLOYMENT							
VISUAL INSPECTION		N/A	3	3	1	2	2
RELEASE TIE-DOWN MECHANISMS		3	3	3	1	3	3
SPACE FRAME DEPLOYMENT		3	0	2	1	2	2
PROPELLANT & PROPULSION MODULE		3	0	0	1	2	2
NUCLEAR ENGINE & SHIELDING		3	0	0	1	2	2
TRANSLATION							
TO RNS WORKSITES		N/A	1	3	2	3	3
SPACE STATION TO RNS		N/A	1	3	2	3	3
CONTROL OF TRANSLATION DIRECTION, VELOCITY, AND ORIENTATION		N/A	1	3	3	3	3

0 - NO CAPABILITY
1 - MINIMUM CAPABILITY

2 - MODERATE CAPABILITY
3 - EXCELLENT CAPABILITY

WORK SYSTEM EFFECTIVENESS (Cont)

INSPECTION AND CHECKOUT

Subsequent to autonomous assembly operations, and prior to system activation, the EVA astronaut can provide a visual inspection to ensure that all units are properly assembled and all connections (electrical, mechanical, and fluid) are properly mated. Visual inspections will be performed periodically throughout the operational life of the RNS as part of the maintenance regime. Checkout and fault isolation, beyond visual inspection, will be an autonomous RNS function. RNS status information may be relayed to the RNS payload module, space shuttle, space station or a ground base.

MAINTENANCE

Scheduled and unscheduled maintenance activities are seen as the most important contribution that the EVA astronaut can perform in support of RNS operations. The use of EVA work systems for maintenance can significantly impact the degree of system redundancy, sophistication, and cost required to meet reliability goals. Maintenance operations will largely take the form of removal and replacement of astrionic packages. The level of maintenance will be influenced by the supporting space platform. If the RNS is located in the vicinity of the space station, the repair and maintenance capabilities of the space station can be applied to sub-modular repairs, thereby alleviating the general spares problem. If maintenance activities are to be performed in the EV environment, maintenance will be limited primarily to the removal and replacement of modules.

EVA WORK SYSTEM EFFECTIVENESS (CONT)

COMPARISON

	AUTONOMOUS	UNAIDED MANUAL EVA	AIDED MANUAL EVA	PRIMARY VEH. REM. MANIP.	MANNED AUX. VEH.-REM. MANIP.	UNMANNED AUX. VEH.-REM. MANIP.
INSPECTION						
CONNECTOR MATING VERIFICATION	3	3	3	1	2	2
MODULE ATTACHMENT VERIFICATION	3	3	3	1	2	2
DAMAGE DETECTION - DOCKING	2	3	3	1	2	2
SPACE ENVIRONMENT DAMAGE DETECTION	2	3	3	1	2	2
OPERATION VERIFICATION (ANTENNA DEPLOYMENT)	3	3	3	2	2	2
MAINTENANCE						
UNSCHED. MAINTENANCE-DEFECTIVE MODULE REPLACEMENT	N/A	3	3	2	2	2
SCHEDULED MAINTENANCE - MULTIPLE MODULE RECYCLING	N/A	2	3	2	3	3
MODULE DISCONNECT & RECONNECT	N/A	3	3	2	2	2
ELECTRICAL CONNECTOR DISCONNECT & MATING	N/A	3	3	1	2	2
VALVE REPLACEMENT	N/A	3	3	1	2	2

0-NO CAPABILITY

2-MODERATE CAPABILITY

1-MINIMUM CAPABILITY

3-EXCELLENT CAPABILITY

WORK SYSTEM EFFECTIVENESS (Cont)

CARGO TRANSFER

EVA operations will require transfers of modules and tools to RNS worksites to effect maintenance and repair operations. The size of these modules will have a bearing on cargo transfer mechanism selected to support EVA. For contingency maintenance, modules may vary from a 3-inch cube to a 3-foot cube solar array (undeployed). For major overhauls, where the equipment bay modular compartments are replaced, package sizes will be in the order of 3 by 3 by 2-ft. Replenishment of expendibles, e.g., fuel for the RCS system, may also entail manipulation of relatively large fuel bottles.

ASSEMBLY OPERATIONS

Assembly operations, involving large structures, are essentially autonomous. The space frame is automatically deployed from the space shuttle and self-erecting frame arms are unfolded by motors. Similarly, fuel modules are incorporated into the space frame by extendible booms from the frame that attach to the module which is elevated from the space shuttle payload bay. The nuclear engine is also remotely and autonomously assembled to the RNS structure. Man's role in assembly operations is largely a backup one. If a space frame arm does not fully unfold, he may be able to manually correct the problem in lieu of aborting this mission segment and returning the assembly back to a ground base. The astronaut may also have a role in correcting misalignments between extendible booms and fuel modules and securing the attachment of the boom and module.

EVA WORK SYSTEM EFFECTIVENESS (CONT)

COMPARISON

	AUTONOMOUS	UNAIDED MANUAL EVA	AIDED MANUAL EVA	PRIMARY VEH. REM. MANIP.	MANNED AUX VEH. - REM. MANIP	UNMANNED AUX. VEH. - REM. MANIP.
SMALL CARGO TRANSFER						
REPLACEMENT MODULES	1	1	3	2	3	3
TOOLS	N/A	2	3	3	3	3
REFURBISHMENT SUPPLIES	1	1	3	3	3	3
ASSEMBLY OPERATIONS						
SPACE FRAME ERECTION	3	1	2	2	2	2
PROPELLANT & PROPULSION MODULE ATTACHMENT	3	0	0	2	2	2
NUCLEAR ENGINE & SHIELDING INSTALLATION	3	0	0	1	2	2
BACKUP MANUAL ASSIST, E.G., UNFOLD FRAME ARM	N/A	2	3	2	3	3
ENSURE MATING OF EXTENDIBLE BOOM AND CARGO MODULE	N/A	3	3	0	2	1

0 - NO CAPABILITY

1 - MINIMUM CAPABILITY

2 - MODERATE CAPABILITY

3 - EXCELLENT CAPABILITY

WORK SYSTEM EFFECTIVENESS (Cont)

REFURBISHMENT

Refurbishment operations will consist primarily of replacing large expended fuel modules. Replacement of these large modules is autonomous and by means of the extendable boom system employed for initial assembly operations. Man may play a role in the refurbishment of smaller elements of the system. For example, the RCS system requires a periodic exchange or refill of N_2O_4 bottles. These RCS tanks hold 1000 pounds of fuel and 1000 pounds of oxidizer.

RESCUE OPERATIONS

An essential element of all manned EVA work systems is to provide for astronaut rescue in the event of an accident. For unaided and aided EVA, two men, working cooperatively at the EVA worksite, can employ the "buddy system." A third astronaut, wearing an AMU, should assume a standby or backup role at the open EVA hatch of the space shuttle or space station, ready to provide emergency assistance as required.

Selection of the EVA work system should consider the capability for retrieving and transporting an injured astronaut back to the base of operations. The question of astronaut retrieval also applies to manned auxiliary vehicles such as the space taxi.

EVA WORK SYSTEM EFFECTIVENESS (CONT)

COMPARISON

	AUTONOMOUS UNAIDED MANUAL EVA	AIDED MANUAL EVA	PRIMARY VEH. REM. MANIP.	MANNED AUX. VEH.-REM. MANIP.	UNMANNED AUX. VEH.-REM. MANIP.
NUCLEAR ENGINE REMOVAL					
TEMPORARY MOVEMENT OF NUCLEAR ENGINE	3	0	0	0	3
REFURBISHMENT					
LARGE FUEL TANKS	3	0	0	2	2
SMALL TANK REFILL OR REPLACEMENT	1	1	3	3	2
EVA ASTRONAUT RESCUE					
RETURN INJURED EVA ASTRONAUT TO BASE	1	1	3	3	3

0 - NO CAPABILITY

1 - MINIMUM CAPABILITY

2 - MODERATE CAPABILITY

3 - EXCELLENT CAPABILITY

EVA SEQUENCE

The operational and design implications of denitrogenation or preoxygenation requirements are clear. If we are operating from the space shuttle as a base for EVA operations, the EVA crew should be preoxygenating for two to four hours before arrival on station. The airlock could provide a pure oxygen environment at 3.5 psi to allow denitrogenation to take place. This requires that the airlock be large enough to serve as a compartment which allows for suit donning/doffing and seating for all EVA members (two to four). In addition, in order not to disturb the denitrogenated state of EVA personnel, habitability provisions must be included in this compartment to allow 10 to 12 hours of EVA support time. For example, over a 12-hour period it is likely that a 2- or 3-hour EVA operation would be followed by a rest period of at least one hour, prior to a second EVA sortie. During this rest, feeding, and waste management period, the cargo crew could not resort to the waste management and food stations in the two-gas crew compartment. Therefore, food and waste provisions would be required in the EVA compartment. Perhaps a small airlock separating the flight crew and EVA crew compartments could serve for the transfer of food and wastes, thereby minimizing the need for redundant food and waste management systems. Another alternative would be to store sufficient food, water, and waste containers (portable waste management unit) in the airlock prior to EVA operations. These EVA considerations would apply to the expanded space shuttle airlock, payload crew module, or Space Station airlock approaches. Of prime concern here is the additional fire hazard imposed by the pure oxygen environment of the airlock. This consideration is important in terms of the EVA support systems and their flamability and fire inducing characteristics.

EVA SEQUENCE

EVA WORK SCHEDULE

The selected EVA work system requires three of four men for a nominal 12-hour space shuttle based mission. Two astronauts will perform EVA tasks at the RNS worksite utilizing the "buddy system." A third man remains at the space shuttle egress hatch opening within visual and communications contact with the EVA astronauts. He prepares elements of space shuttle cargo for delivery to the RNS worksite and is available to conduct emergency rescue operations by means of an Astronaut Maneuvering Unit backpack. The fourth man may be required for extended EVA operations beyond nine hours duration within the 12-hour mission stay time. The opposite page depicts several possible EVA crew activity schedules. These schedules call for a maximum of 3 hours continuous EVA.

EVA WORK SCHEDULE

3 MAN EVA CREW			
TIME	A	B	C
1	EVA	EVA	SHUTTLE
2	MWP	RNV	BACKUP
3	OPS	WORK SITE	OPS
4	REST, FOOD AND WATER, WASTE MGT IN PRESSURIZED SHUTTLE AIRLOCK		
5			
6	SHUTTLE	EVA	RNV
7	BACKUP	MWP	WORK SITE
8	OPS	OPS	OPS
9	REST, FOOD AND WATER, WASTE MGT IN PRESSURIZED SHUTTLE AIRLOCK		
10			
11	EVA	SHUTTLE	EVA
12	RNV	BACKUP	MWP
	WORK SITE	OPS	OPS

9 HOURS EVA TIME

4 MAN EVA CREW			
TIME	A	B	C
1		RNV	SHUTTLE
2	MWP	WORK SITE	BACKUP
3	OPS	OPS	REST
4	SHUTTLE	REST	
5	BACKUP		MWP
6	REST	SHUTTLE	OPS
7		BACKUP	WORK SITE
8	RNV		OPS
9	WORK SITE	MWP	SHUTTLE
10	OPS	OPS	BACK
11		REST	REST
12	SHUTTLE		SHUTTLE
	BACK		BACK
	REST	SHUTTLE	
		BACK	RNV
			WORK SITE
			MWP
			OPS

12 HOURS EVA TIME

* REST IN PRESSURIZED SUIT

CREW ACCOMMODATION CONCEPTS

The RNS design is strongly influenced by space shuttle characteristics and capabilities, since the space shuttle will be utilized extensively for delivery of RNS components and crew support to space. Conversely, since RNS assembly, maintenance, and refurbishment will be a prime mission of the space shuttle, RNS requirements may considerably shape the design of the space shuttle. In considering this interface, one of the important issues to resolve is the degree to which the special requirements of the RNS can mold the design of the space shuttle. As originally conceived, the space shuttle was to be designed based on current airline practices. This would imply that the space shuttle would, as in the case of a modern cargo transport aircraft, simply provide cargo or payload space for mission support. All mission peculiar requirements would be strictly charged to the payload.

Alternatives to this approach are displayed pictorally on the opposite page and can be described as follows:

- They incorporate provisions for 2 to 4 cargo handles in the basic space shuttle crew compartment.
- They provide an expanded airloc which accommodates RNS support personnel and facilitates EVA operations.
- They provide a special crew module within the cargo compartment.

CREW ACCOMMODATION CONCEPTS

- FOUR-MAN CREW,
TWO-MAN AIRLOCK

- SIX-MAN CREW,
FOUR-MAN AIRLOCK

- TWO-MAN CREW, TWO-MAN
AIRLOCK, FOUR MAN P/L

- TWO-MAN CREW COMPARTMENT
WITH COMBINATION AIRLOCK

EVA SUPPORT COMPARISON

An alternative approach to adapting the space shuttle for crew support for RNS assembly, maintenance, and refurbishment activities is to rely on the Space Station/Base. This approach offers a number of advantages. Among these are:

- a. The Space Station/Base provides accommodations for long-term space habitation. Therefore, men would be available to support RNS operations over relatively long periods of time. The shuttle mission stay time would be in the order of 10 to 12 hours. Longer periods of space shuttle orbital stay would tie up the shuttle, whereas the Space Station/Base is committed to orbital operations.
- b. The Space Station/Base, as presently conceived, will have rather large EVA airlocks which would be available to support RNS operations.
- c. The Space Station will have a maintenance and repair facility and capability. This capability could be readily extended to support the RNS.
- d. The Space Station/Base concept might be altered to allow for incorporation of a teleoperator station to control remote manipulators on an unmanned Space Tug to operate in the hazardous radiation environment of the RNS engine.

In summary, it would appear that the use of the Space Station as a base of operations to conduct RNS assembly and maintenance operations offers less interface problems than the space shuttle modifications required to support RNS independent of a space station. However, there are mission-related disadvantages associated with total RNS dependence on the Space Station/Base. If the RNS is tied to the orbit and inclination angle of the Space Station/Base, we would lose mission flexibility for the RNS in terms of scheduling opportunities for lunar missions. Therefore, the best approach to provide crew support for the RNS appears to be a dependence on the Space Station/Base for the RNS initial assembly and checkout. Thereafter, the RNS should rely primarily on the space shuttle for periodic maintenance and refurbishment exclusive of major "overhauls".

EVA SUPPORT COMPARISON

PARAMETER	SPACE SHUTTLE	SPACE STATION
●EVA MISSION DURATION	●10-12 HRS CONTINUOUS	●UNLIMITED AS REQUIRED
●CREW SUPPORT	●3-4 PAYLOAD PERSONNEL	●HABITABILITY PROVISIONS FOR ADDITIONAL MEN AVAILABLE
●REPAIR CAPABILITY	●NONE	●REPAIR & MAINT. PROVISIONS
●MAN POWER AVAILABILITY CONTINGENCIES	●SPECIAL LAUNCH	●MEN ON STATION CONTINUOUSLY
●INTERFACE IMPACT	●OVER SIZED AIRLOCK FOR 3-4 MEN REQUIRED	●EVA PROVISIONS AVAILABLE
●MISSION FLEXIBILITY	●ANY ORBIT	●LIMITED TO ONE ORBIT

-Base

CONCLUSIONS

- *OCEAN/RIVER AND AIR TRANSPORT ARE MOST FEASIBLE TRANSPORTATION MODES*
- *OVERLAND TRANSPORTATION SHOULD BE LIMITED TO ON SITE*
- *AIR TRANSPORT TO NRDS IS FEASIBLE*
- *FINAL ACCEPTANCE TESTING SHOULD BE ACCOMPLISHED AS CLOSE TO MFG FACILITY AS POSSIBLE*
- *INITIAL RNS MODULES SHIPPED VIA BARGE AND REPLACEMENT MODULES SHIPPED VIA SUPER GUPPY*

CONCLUSIONS (CONT)

- *SPACE SHUTTLE MUST PROVIDE COMMAND, CONTROL, AND CHECKOUT FUNCTIONS*
- *AUTONOMOUS MODE FOR LARGE-STRUCTURE ASSEMBLY, CHECKOUT, AND ENGINE HANDLING*
- *AIDED EVA LOGICAL MODE FOR SMALL MODULE MAINTENANCE, HANDLING, AND TROUBLE-SHOOTING*
- *TOPPING CAPABILITY ON ORBIT MUST BE PROVIDED*

REUSABLE NUCLEAR VEHICLE CONCEPTS

RNS CONCEPT COMPARISON

Two derivatives of the baseline modular vehicle have been defined. The enclosed tank concept consists of a configuration completely enclosed by a shell. In the exposed tank concept all of the tanks have individual environmental protection. A comparison was made of these two concepts. Although the enclosed concept is somewhat lighter, it is somewhat more complex. An extra launch is required for the enclosed concept to deliver the segmented outer shell and structure. The exposed tank concept has somewhat more mission flexibility since each tank can be adapted for a mission application during the earth-based maintenance and refueling cycle. However, better environmental control can be maintained with a completely enclosed system.

RNS CONCEPT COMPARISON

	EXPOSED MODULES	ENCLOSED MODULES
RNS DRY OPERATIONAL WEIGHT	73,475 LB	73,334 LB
MODULE COMPLEXITY	✓	✓✓
ORBITAL ASSEMBLY	✓✓	✓
MAINTENANCE	✓✓	✓
MISSION VERSATILITY	✓✓	✓
ENVIRONMENTAL CONTROL	✓	✓✓
RELIABILITY	✓	✓
COST	✓✓	✓

✓✓ BEST

RNS - ENCLOSED TANK CONCEPT

RNS-EXPOSED TANK CONCEPT

TYPICAL PAYLOADS

The RNS has considerable flexibility in payload carrying capability. For the nominal lunar shuttle application, performance calculations indicate 106K outbound and 26K return makes a compatible payload mix. A large 33-foot diameter payload such as the Lunar Orbital Space Station can be readily carried utilizing an appropriate adapter. A more modular payload can also be carried. The utilization of a space frame, similar to the one used for propellant modules, would be utilized. Various payload mixes such as Space Tug Fuel Modules and Crew Modules launched by the Space Shuttle can be carried in this configuration.

TYPICAL PAYLOADS

- INT-21 LAUNCH
- 33 FT DIA.

INTERFACE
PLANE

- EOS LAUNCH
- 15 FT DIA.

RNS PAYLOAD INTEGRATION

Optimum propellant drain on the modular RNS must be balanced against penalties associated with vehicle control. A preferred drainage scheme is, of course, to drain tanks sequentially whenever less than one tank load is required per burn. The impact on controllability for a nominal mission profile indicates that a 2-deg., 40-min. gimbal is required when 5 of the 6 tanks are empty during the return flight.

RNS/PAYLOAD INTEGRATION

ALTERNATE PAYLOAD

- TRANS LUNAR/COAST
- LUNAR INSERTION
- LEAVE MOON BURN 1/COAST
- LEAVE MOON BURN 2/COAST
- LEAVE MOON BURN 3/COAST
- ARRIVE EARTH

NERVA TURBOPUMP NSP REQUIREMENTS

The objective of the first part of the tank pressurization analysis was to obtain estimates of pressurant gas flow-rate requirements for representative RNS configurations; the resulting flowrate estimates can then be used in defining tank operating pressure levels. Preliminary net suction pressure (NSP) requirements were obtained as a function of LH_2 outflow saturation pressure and engine thrust level. Operation in the malfunction (single pump) mode demands higher pump inlet NSP values, and correspondingly higher pressurant flowrates, than normal mode operation. During a typical mission the saturation temperature and pressure of the propellant increases with time, so that pump NSP requirements decrease. However, for a fixed operating pressure level, available outflow NSP also decreases with time. If the operating pressure level is not sufficiently high, the available NSP can drop below that required by the turbopump.

NERVA TURBOPUMP NSP REQUIREMENTS

MALFUNCTION MODE

NET SUCTION PRESSURE AT TANK EXIT - ARRIVE MOON BURN

Values of tank outflow NSP were computed for the single RNS tank having a propellant capacity of 300,000 lb_m and a propellant module tank from the baseline RNS. Tank operating pressure was 30 psia for each burn. NERVA startup and shutdown transients were simulated for each drain, assuming that pressurant bleed gas is made available from the engine at 88 seconds from flow initiation, when the engine is at 13.4% of rated thrust (i.e., beginning of startup ramp). Steady-state operation was assumed to be in the malfunction mode: thus, during steady-state operation, the thrust level was 60,000 lb_f and the propellant flowrate 72.3 lb_m/sec. Upon reaching steady operating conditions the outflow NSP attains its maximum value. During steady-state operation the NSP drops slightly as the propellant is heated. During the shutdown transient the NSP remains constant while the thrust is reduced to the 60% level (the throttling plateau). During throttling a slight decrease in NSP is observed due to additional heating of the propellant. At the end of the throttling period addition of pressurant to the tank ceases and the outflow NSP drops to zero at the end of the pulse cooling period.

NET SUCTION PRESSURE AT TANK EXIT

BURN 2, SINGLE 300K TANK, MALFUNCTION MODE

PRESSURANT FLOWRATE REQUIREMENTS

Required values of pressurant flowrate were computed for the single and multiple tank configurations using a 30 psia operating pressure. It was assumed that, for all runs, the ullage pressure increased linearly from the initial tank pressure at 88 seconds to the specified operating pressure at 116 seconds (the beginning of full thrust operation). Thus, during the start period, initial high pressurant flowrates were required for initial pressurization. During steady-state operation relatively small flowrates were required to maintain the required ullage pressure. The arrive moon burn requires the largest pressurant flowrate because of the large ullage volume and large difference between operating pressure and initial propellant saturation pressure.

PRESSURANT FLOWRATE REQUIREMENTS

SINGLE 300K TANK, BURN 2, MALFUNCTION MODE

MAXIMUM PRESSURANT FLOWRATES DURING STARTUP

A simplified energy balance on the ullage vapor in the tank yields an approximate relation for the mass required to effect initial pressurization. Assuming that the maximum pressurant flowrate, $\dot{m}_{p_{\max}}$, is proportional to the mass of pressurant required for initial pressurization, this relation can be written

$$\dot{m}_{p_{\max}} = K_1 \Delta p V_{u_i} + K_2$$

Where Δp is the difference between the initial propellant saturation pressure and the operating pressure, V_{u_i} is the initial ullage volume, and K_1 and K_2 are constants. Using the maximum pressurant flowrates predicted by the propellant heating computer program, and fitting the computed points with a straight line, the relation

$$\dot{m}_{p_{\max}} = \frac{\Delta p V_{u_i}}{68667} + 0.35$$

is obtained for both the single tank and the baseline propellant module.

MAXIMUM PRESSURANT FLOWRATES

DURING STARTUP

NERVA TURBOPUMP NSP / PERCENT VAPOR REQUIREMENTS

Normal and malfunction mode NSP requirements have been developed for the turbopump. The normal mode design goal is operation with 26 psia saturated liquid and zero NSP. The malfunction mode design specification is 28 psia saturated liquid and 2 NSP.

The pump is capable of operating with a broad range of saturation pressures and is capable of ingesting considerable amounts of vapor at low flowrates.

NERVA TURBOPUMP NSP/% VAPOR REQMTS

NERVA TURBOPUMP OPERATING REQUIREMENTS

The normal mode NSP requirements were developed as a function of saturation pressure of the outflow propellant at full thrust. For malfunction mode operation, the minimum thrust level for negligible performance degradation is 65 percent. Using the malfunction mode NSP requirements for operation at a thrust level of 65 percent of rated thrust produces malfunction mode NSP requirements which are nearly identical with the normal mode requirements. This allows the engine user considerable flexibility in vehicle design and operation.

NERVA TURBOPUMP OPERATING RQMTS