FINAL BRIEFING
NUCLEAR SHUTTLE
DEFINITION STUDY PHASE III

MASTER

PREPARED FOR NASA-MSFC UNDER CONTRACT NAS8-24714
DRL NO. MSFC-DRL-196, LINE ITEM NO. 2
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

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PHASE III FINAL BRIEFING REUSABLE NUCLEAR STAGE CONCEPTS

NUCLEAR SHUTTLE SYSTEM DEFINITION
STUDY CONTRACT NAS 8-24714

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NUCLEAR STAGE STUDY SCOPE

The Nuclear Flight System Definition Studies were initiated in July 1969 to evaluate the nuclear stage as an expendable third stage of the Saturn V. Manned planetary and a lunar shuttle application, with one reuse of the nuclear stage, were considered evolutionary missions for the stage design. Particular attention was paid to an optimum evolutionary development program. Candidates that were considered included use of S-II hardware, an advanced integral tank with compressible high-performance insulation, and advanced propulsion and astrionic subsystems; and an outer load-carrying shell configuration, which supported a monocoque tank with advanced state-of-the-art subsystems.

Later in 1969 a Reusable Nuclear Stage (RNS) was proposed as a part of the integrated space plan by the President's Space Task Group. The studies were then reoriented to an RNS concept definition (Phase II), which considered several launch vehicles. Class 1 RNS was launched by the INT-21 as an unmanned payload, Class 2 systems were modular configurations assembled in orbit and launched by intermediate expendable launch vehicles or space shuttle boosters with expendable second stages, and Class 3 RNS's were also modular assemblies but launched within the cargo bay of the space shuttle orbiter.

RNS system and program definition were then carried out in Phase III study activities for the most attractive concepts defined for Classes 1 and 3. Class 2 was not to be studied until there was greater definition of high-lift space shuttle configurations.

NUCLEAR STAGE STUDY SCOPE

PHASE I -- NFPM

- SATURN - DERIVATIVE
- ADVANCED

PHASE II -- RNS CONCEPT DEFINITION

- CLASS 1 -- INT-21 LAUNCH
- CLASS 2 -- INTERMEDIATE LAUNCH VEHICLES
- CLASS 3 -- SPACE SHUTTLE

PHASE III -- RNS SYSTEM DEFINITION

- INT-21 LAUNCHED CLASS 1 HYBRID
- SPACE SHUTTLE LAUNCHED CLASS 3 MODULAR

STUDY ORGANIZATION

Nuclear Flight System Definition Study organization is shown here. Primary responsibilities for study tasks are noted.

STUDY ORGANIZATION

11635A

DIRECTOR, ADVANCE SYSTEMS AND TECHNOLOGY - A. J. VANDER WEYDEN

BRIEFING SCHEDULE

Organization of briefing and the speakers are shown in the accompanying figure.

BRIEFING SCHEDULE

INTRODUCTION	S. GRONICH
RNS OPERATIONS	K. P. JOHNSON
RNS DESIGN	R. J. HOLL
RNS PROGRAM SUMMARY	R. G. RIEDESEL

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY--SYSTEM

The results of the previous Phase I and II Nuclear Shuttle System Definition Studies provided a sound basis for the Phase III study. The major study ground rules and decisions during the various RNS study phases are summarized on this and the subsequent chart. The concepts that are still viable are indicated by the arrows extending past the applicable study phase.

Although Phase I concerned an expendable nuclear stage (NFPM), an advanced stage concept was selected which included a reusable shuttle mission as a design requirement. Phase II entailed a total reorientation to reusable systems and surveyed a broad spectrum of potential RNS system and subsystem concepts. The mission applications during Phase I considered a Saturn third stage for various injection applications as well as lunar and interorbital shuttles, and a manned Mars mission. During Phase II the reusable mode of operation changed the injection mode to a reusable orbital based approach. During Phase III the manned Mars mission was de-emphasized for design and a eight-burn lunar shuttle mission provided the basis for design requirements.

During Phase I the nuclear stage was considered as a third stage launched on Saturn V, but during subsequent phases it became an unmanned payload for the available launch vehicles. These defined various RNS design concepts. Reusability imposed a requirement for maintenance and refurbishment in orbit, and a variety of orbital support concepts were considered. Provision of separate orbital support facilities was discarded after Phase II, and the basic support systems for the RNS were selected as the space shuttle and the space tug.

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY

SYSTEM

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY DESIGN

During Phase I a major decision was made between a Saturn derivative and advanced stage concept. Reduced development requirements for the reference program model and the ultimate requirement of reusability led to the selection of an advanced stage concept. The launch configuration was also a major concern for the INT-21 launch RNS concept. As the designs evolved it was found that a stiffened tank configuration approached the mission performance efficiency of a design utilizing an ascent shell, but had reduced development requirements. Accordingly, the stiffened tank launch configuration was retained for Phase III.

The NFPM in Phase I was a single module concept. The reusable stage operation mode and the alternate launch vehicle concepts for Phase II resulted in definition of a variety of modular stage concepts, consisting of propulsion, propellant, and command and control modules. The single module concept evolved to the Class 1 Hybrid which included a propulsion module for engine replacement. The Class 2 concept was based on a 22-ft-diameter launch vehicle, and the Class 3 concept was based on the 15-ft-diameter space shuttle cargo bay. Subsystem features were defined and selected according to cost effectiveness during Phases I and II. Shielding requirements were analyzed during Phase II to define optimum stage geometries, such as the 10-degree conical aft bulkhead of the Class 1 RNS. The Phase III study was focused on the Class 1 Hybrid and Class 3 concepts for which the launch vehicles were well defined. The objective was to define RNS operations and the associated design requirements. Investigation of the Class 2 concept was deferred pending further definition of the alternate second stages for the space shuttle, which would make that configuration attractive.

The orbital maintenance level was a crucial issue in the design phases. The NFPM required no maintenance, but the desirability of maintenance in orbit was established for the RNS. Design for maintenance at both the component level and maintenance assemblies proved to be complex and required excessive orbital support. The selected orbital maintenance level consists of RNS assembly modules.

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY DESIGN

PHASE II MODULAR NUCLEAR SHUTTLE CONFIGURATIONS

The accompanying chart shows schematics of the orbital nuclear shuttle configurations and their usable propellant mass fractions which were selected in Phase II as baseline systems. The Class 1 evolved to a hybrid configuration that included a propulsion module. The propellant module of this system is placed in orbit by the INT-21, and the propulsion module consisting of a small run tank and engine is launched separately within the cargo bay of the orbiter. A two-module plus propulsion-module configuration was selected for Class 2. The propellant modules are placed in orbit by a space shuttle booster and expendable second stage. The Class 3 is a multipropellant modular system in which each module is carried to orbit within the cargo bay of the orbiter. A planar array, as shown on the accompanying chart, was selected for the Class 3 on the basis of a compromise between shielding and vehicle stability. The former criteria wanted a tandem configuration and the latter a squatter cluster configuration. The Class 3 deployed a separate command and control module (CCM), but the Class 1 system replaced subsystems and expendable resupplies of the CCM in orbit. A special tug was designed to perform this function. The Class 1 Hybrid had slightly better usable propellant mass fractions but greater transportation costs to Earth orbit. No attempt was made to compare the performance of these systems since Phase II was only to a concept definition level.

PHASE II MODULAR NUCLEAR SHUTTLE CONFIGURATIONS

PHASE III CONCEPTS EVALUATED

In Phase III the Class 1 Hybrid and the Class 3 were selected for further definition, to be completed to Phase A definition. Attention was devoted to particular configurational features. For the Class 1 Hybrid, an alternative approach of a separate command and control module that can be recycled and maintained on the ground was evaluated. For the Class 3 system the impact of orbital assembly operations was assessed on the desired clustered arrangement. The change to the Class 1 Hybrid made the Class 1 and Class 3 systems closer in configuration, where major differences were now relegated to propellant module tankage configuration and packaging.

PHASE III CONCEPTS EVALUATED

RNS STUDY PHASE III TASKS

The major outputs of the study phases indicated on the schedule are shown on the accompanying figure. Mission performance and capability of the RNS were further updated for the specific concepts defined previously for four missions: (1) a lunar orbit-to-orbit shuttle, (2) a geosynchronous orbit-to-orbit shuttle, (3) unmanned planetary probes, and (4) manned planetary missions. Specific preliminary operational requirements, functional analyses, and a reliability improvement plan, which impact the concepts definition and their evaluation, were generated during the first phase. Sub-system analyses and trade studies were also conducted. During the second phase, alternative RNS systems and subsystem designs were updated to reflect the operational requirements, reliability improvements, thermodynamic analyses, new radiation environments, and NERVA/RNS interface definition. The intent of the activity was to present alternative RNS designs for final review at the end of 7 months. During this phase of the study, test, facility and GSE requirements, and manufacturing techniques were identified.

In the last phase, a final RNS system description was prepared, including hardware trees, design details, and system specifications. Complete functional analyses, reliability allocation sheets, safety contingency plans, and interface requirements were identified. Lastly, the integrated program was formulated and an overall program cost was established.

RNS STUDY PHASE III TASKS

CONCEPT DEFINITION AND EVALUATION

- MISSION PERFORMANCE AND TIMELINES
- RELIABILITY IMPROVEMENT PLAN
- OPERATIONS ANALYSIS
- SUBSYSTEM DESIGN REQUIREMENTS

SYSTEM TRADE STUDIES

- SUBSYSTEM DESIGN
- UPDATE FLIGHT SYSTEM DEFINITION
- INITIATE PROGRAM PLANS

PROGRAM AND SYSTEM DEFINITION

- FINALIZE REQUIREMENTS DEFINITION
- DOCUMENT BASELINE SYSTEM DEFINITIONS
- COMPLETE INTEGRATED PROGRAM PLANS
- PREPARE INTERFACE RECOMMENDATIONS

RNS STUDY GUIDELINES AND ASSUMPTIONS

Primary study guidelines and assumptions are shown on the accompanying figure.

RNS STUDY GUIDELINES AND ASSUMPTIONS

- PRIMARY DESIGN MISSION WILL BE AS A LUNAR SHUTTLE
- AN EVOLUTIONARY VERSION WILL BE USED FOR MANNED MARS MISSIONS
- FIRST FLIGHT TEST AND IOC ARE CY 1979 AND 1981 RESPECTIVELY
- PROPELLANT CAPACITY OF RNS WILL BE AS CLOSE TO 300,000 LB AS POSSIBLE WITH AN INTEGRAL NUMBER OF TANKS
- TWO SPACE SHUTTLE PAYLOAD CAPABILITIES TO 260 NMI BY 31.5 DEG INCLINATION ORBIT WILL BE CONSIDERED: 33,000 AND 50,000 LB
- SHUTTLE CARGO BAY WILL SUPPLY A CLEAR VOLUME OF 15-FT DIA BY 60-FT LENGTH
- 3-YEAR LIFETIME OR 10 USES WITH MAINTENANCE
- METEOROID SHIELDING WILL BE DESIGNED FOR A NO-TANK-PENETRATION CRITERIA
- ALL CREDIBLE SINGLE FAILURE MODES WILL BE ELIMINATED
- NERVA RADIATION DOSE TO PASSENGERS AND CREW WILL BE 10 AND 3 REM, RESPECTIVELY
- AN OPERATIONAL COST OF \$5 MILLION FOR THE SPACE SHUTTLE AND \$107 MILLION FOR INT-21 WILL BE USED
- NERVA ENGINE WILL COST \$13 MILLION

LUNAR SHUTTLE DESIGN MISSION PROFILE

While the normal lunar mission operating mode will be based upon coplanar transfer between the Earth and lunar orbits, as constrained by the occurrence of these opportunities, it is necessary to provide the functional capability to efficiently accomplish plane-change maneuvers upon lunar arrival and departure. This will open a finite launch window at the moon, in addition to providing the ability to perform a mission at other than the coplanar mission opportunities. Thus, the eight-burn mission profile represented in the figure constitutes the design condition. The 30-degree lunar plane rotation maneuver (imposed for the purpose of identifying RNS design requirements) is equivalent to a 21-degree node shift when measured in terms of velocity (390 fps). Full-power operation of the NERVA is used for Earth departure and arrival, as well as the perilune orbital maneuvers. Conversely, the plane-change maneuvers are accomplished in the throttle mode, and midcourse correction maneuvers in the idle mode. The figure is based on the first of the two coplanar mission opportunities of the 54.6-day cycle, indicating an 18-day stay in lunar orbit. The total time available for earth-orbit turnaround is 84.2 days, corresponding to a mission model with a six-mission-per-year frequency.

LUNAR SHUTTLE DESIGN MISSION PROFILE

- 1 TRANSLUNAR INJECTION
- 2 LUNAR ORBIT INJECTION
- 3 PLANE CHANGE (30 DEGREES), THROTTLE
- 4 CIRCULARIZATION
- 5 DEPARTURE ORBIT INJECTION
- 6 PLANE CHANGE (30 DEGREES), THROTTLE
- 7 TRANSEARTH INJECTION
- 8 EARTH ORBIT INJECTION

RNS OPERATIONS SUMMARY

A major focus of the Phase III Nuclear Shuttle Definition Study has been definition of RNS operations and the associated design requirements. This portion of the briefing will describe the selected operations concepts. The operations considered include launch, orbital operations, flight operations, maintenance and replenishment, and end-of-life disposal. They will be discussed in the sequence indicated in the adjoining flow diagram. The implications for the RNS design and interface with other systems have been established based on the eight-burn lunar shuttle mission profile. Although the orbital operations, maintenance and replenishment, and NERVA disposal are unique to the reusable operations mode, even the launch and flight operations have evolved considerably for the RNS from the original Phase I operational concept as a Saturn V third stage. This is due largely to the operational features and opportunities introduced by the space shuttle system.

RNS OPERATIONS SUMMARY

LAUNCH MODES—PHASE III CONCEPTS

Each of the RNS modules is launched separately and assembled in the 260 nmi/31.5-degree inclination operational orbit. The RNS does not persist as a single entity but is continuously reassembled for each mission to the extent required by the prescribed lifetime and status of the individual modules. The propulsion module and command and control module are designed for launch inside the 15 ft diameter by 60 ft long space shuttle orbiter cargo bay.

The RNS design concept derives from the method of launching the propellant module(s) to orbit. The two concepts evaluated during the Phase III study are shown in the figure. The Class 1 Hybrid propellant module is launched by the Saturn INT-21 launch vehicle, which has a delivered payload forward of the S-II/RNS interstage of approximately 192,000 lb. The Class 3 propellant module is launched inside the space shuttle, which has a nominal payload capability of 33,000 lb for the study. Thus, both are launched off-loaded and must be topped off in orbit.

The minimum required payload delivery capability for the space shuttle is the inert weight of the RNS propulsion module, which is dominated by the 28,000-lb NERVA weight. The difference between the Class 1 Hybrid and Class 3 propulsion module weights shown is due to the 2,900-lb external disk shield required for the former configuration.

The Class 1 Hybrid CCM requires placement of APS thrusters on outriggers to avoid plume impingement on the propellant module. Consequently, its envelope requires launch on its side within the cargo bay and associated mounting provisions. The Class 3 CCM permits APS operation within the 15-ft-diameter envelope so it is launched in the normal attitude.

LAUNCH MODES -- PHASE III CONCEPTS

PROPULSION MODULE

CLASS 1-H: 33,725 LB

CLASS 3: 30,825 LB

- SPACE SHUTTLE
CARGO BAY

COMMAND AND CONTROL MODULE

CLASS 1-H: 4,225 LB

CLASS 3: 4,185 LB

- SPACE SHUTTLE CARGO BAY

ALTERNATE LAUNCH CONCEPTS

RNS propellant modules larger than the volume of the space shuttle cargo bay result in a superior mass fraction, but these were originally constrained to using expensive expendable launch vehicles (INT-21, Saturn 1-B, etc.). Also, with the movement toward the reusable space shuttle system, the Saturn INT-21 concept may not survive. Alternate RNS module launch concepts were proposed during Phase II. The concepts depicted in this figure use the space shuttle booster together with candidate alternate second stages currently under consideration. Both 260-in. -diameter Class 2 and 396-in. -diameter Class 3 RNS propellant modules are shown. Performance of the S-IVB/SRM configuration is approximately 175,000 lb to the 260 nmi/31.5 degree operational orbit. The other alternatives perform comparably. One of the candidates indicated uses the RNS propellant module as the LH₂ tank for the second stage, and the LO₂ tank and engine are removed after delivery to orbit. Development of one of these concepts can be a significant factor in the economics of the RNS system.

ALTERNATE LAUNCH CONCEPTS

PROPULSION MODULE LAUNCH TO ORBIT

The baseline concept for launching NERVA to orbit consists of launching the propulsion module inside the cargo bay of the space shuttle orbiter. It is launched in a normal vertical attitude as depicted in the figure. It is considered to be installed in the cargo bay in a horizontal attitude and the orbiter is subsequently erected on the booster.

The module is attached to the standard space shuttle payload deployment mechanism, which is used to deploy it in orbit. Lateral ties are indicated to provide restraint and load attenuation during launch. The maximum longitudinal load factor experienced is currently specified as + 3 g steady state at maximum acceleration and ± 3 g dynamic at booster cutoff/separation. Lateral dynamic load factors of ± 2 g are also specified at the latter condition and at launch release.

The module is launched with its propellant tank dry and unpressurized. Umbilical services are provided by the space shuttle. Poison wires are installed in NERVA during core assembly for safety during transportation and launch operations. An automatic removal mechanism is attached to the cargo bay aft bulkhead to withdraw the wires and throat shield prior to deployment of the module in orbit.

PROPULSION MODULE LAUNCH TO ORBIT

INT-21 LAUNCH IMPLICATIONS OF RNS CONFIGURATIONS

The RNS Class 1 Hybrid propellant module is designed to comply with the INT-21 ground launch and ascent design load envelope compatible with current design loads for the S-IC and S-II stages. These are impacted by the large envelope of the RNS, so during the Phase II the possibility of load reduction by utilizing an improved Saturn V autopilot design was investigated and found to be promising.

Subsequently, a comprehensive evaluation of the loading implications for a range of payload envelopes on the INT-21 vehicle was performed by Boeing (Application of Saturn V Intermediate-21 Launch Vehicle to Space Station Missions—Final Report, Boeing Report G5-15804-2, September 1970). The payloads considered included Skylab, space station concepts, and RNS concepts. All are to be launched unmanned and utilizing existing S-IC and S-II structure. The parametric results are summarized in the adjoining figure in terms of launch availability versus payload length using a wind-biased launch trajectory for the worst winter winds. The Class 1 Standard configuration (with NERVA attached) has an availability of 62 percent. The baseline Class 1 Hybrid propellant module has an 84 percent availability. Availability could be increased about 3 percent for the Class 1 Hybrid propellant module by using an inverted launch, but the additional complications of a dual flight vent system and integrating a ground fill and drain system with a conical aft bulkhead are not warranted. For summer winds the Class 1 Hybrid propellant module launch availability is increased to 90 percent without wind biasing.

While the propellant module permits more favorable launch availability, it is probably unwarranted to exclude the standard configuration on this basis alone, considering the use of the system in a shuttle mode with orbital assembly, which provides greater latitude for launch of modules to orbit.

INT-21 LAUNCH IMPLICATIONS OF RNS CONFIGURATIONS

- USE EXISTING S-IC AND S-II STRUCTURE
- USE WIND-BIASED TRAJECTORY

NERVA STRUCTURAL DYNAMICS FOR INT-21 LAUNCH

An evaluation of engine/stage structural dynamics was performed during Phase III to evaluate launch of NERVA in both the Class 1 Standard and integral Class 1 Hybrid configurations on the INT-21 vehicle. A lateral acceleration transient was input to the RNS aft bulkhead at the interstage to excite the dynamic model. The transient was based on Saturn V launch data provided by MSFC. It has a peak lateral acceleration of 2.2 g. NERVA dynamics were simulated by a coupled spring mass with 92 degrees of freedom. The maximum lateral displacement and lateral accelerations are shown in the adjoining table at three locations for both an unrestrained launch and a typical lateral restraint applied at the nozzle throat. Lateral displacements of the cantilevered system are not severe but significant amplification of the lateral acceleration is obtained. The second location indicated is the base of the reactor core. The fuel elements are cantilevered upward from that point. The implications of structural dynamics transients on the core during launch would appear to deserve particular attention.

The first two resonant frequencies for each of the Class 1 configurations are as follows:

	<u>Standard</u>		<u>Hybrid</u>	
	<u>Unrestrained</u>	<u>Lateral Restraint At Throat</u>	<u>Unrestrained</u>	<u>Lateral Restraint At Throat</u>
First Mode Frequency (Hz)	0.97	2.34	0.63	2.01
Second Mode Frequency (Hz)	4.92	4.92	2.28	2.47

The lateral acceleration transient used to excite the dynamic model had appreciable energy at 2.46, 4.50, 5.37, 7.99, 9.30, and 11.2 Hz. For the standard configuration with lateral restraint the first mode frequency increased to a level approaching the first frequency of the input acceleration transient, resulting in the relatively high maximum lateral accelerations for that case.

A space shuttle launch for the propulsion module is required to accomplish NERVA replacement. Therefore, it would be desirable to develop a restraint and load attenuation concept for only a single launch concept. This consideration should preclude any integral launch concept at this time and a single development is recommended for a space shuttle launch.

NERVA STRUCTURAL DYNAMICS FOR INT-21 LAUNCH

<div style="display: flex; align-items: center;"> <div style="flex: 1; text-align: center;">LAUNCH CONCEPT</div> <div style="flex: 1; text-align: center;">LOCATION</div> </div>	CLASS I - STANDARD		CLASS I - HYBRID	
	UNRESTRAINED	LATERAL RESTRAINT AT THROAT	UNRESTRAINED	LATERAL RESTRAINT AT THROAT
STAGE/UPPER THRUST STRUCTURE <ul style="list-style-type: none"> • MAXIMUM LATERAL DISPLACEMENT (IN.) • MAXIMUM LATERAL ACCELERATION (g) 	1.71	1.70	1.95	1.90
PRESSURE VESSEL/NOZZLE/ NUCLEAR SUBSYSTEM <ul style="list-style-type: none"> • MAXIMUM LATERAL DISPLACEMENT (IN.) • MAXIMUM LATERAL ACCELERATION (g) 	4.3	4.4	1.1	0.9
PRESSURE VESSEL/NOZZLE/ NUCLEAR SUBSYSTEM <ul style="list-style-type: none"> • MAXIMUM LATERAL DISPLACEMENT (IN.) • MAXIMUM LATERAL ACCELERATION (g) 	0.54	3.20	0.35	1.75
NOZZLE THROAT <ul style="list-style-type: none"> • MAXIMUM LATERAL DISPLACEMENT (IN.) • MAXIMUM LATERAL ACCELERATION (g) 	2.2	2.00	0.2	0.7
NOZZLE THROAT <ul style="list-style-type: none"> • MAXIMUM LATERAL DISPLACEMENT (IN.) • MAXIMUM LATERAL ACCELERATION (g) 	0.51	3.60	0.61	1.75
	2.1	2.2	0.5	0.7

• RECOMMEND SINGLE DEVELOPMENT FOR SPACE SHUTTLE LAUNCH

CLASS 1 HYBRID ASSEMBLY AND MAINTENANCE CONCEPT

The Class 1 Hybrid vehicle consists of three discrete modules. Maintenance is performed by replacing these modules analogous to initial orbital assembly. The command and control module is recycled to the ground each mission for maintenance and replenishment of the expendables (APS propellants and fuel cell reactants). The space shuttle is the basic orbital support system and no additional facilities or systems are required except for NERVA disposal, which is performed using a space tug for propulsion.

For initial orbital assembly the CCM is launched first, followed by the propellant module. The CCM rendezvous with the propellant module and docks to it. Then the propulsion module is launched by the space shuttle. It is deployed and separates itself from the space shuttle and maintains a stable attitude using its cold gas attitude control system. The RNS assemblage, self-propelled, then docks to the propulsion module. During CCM replacement the old CCM removes itself, leaving the RNS stabilized by gravity gradient.

CLASS 1-HYBRID ASSEMBLY AND MAINTENANCE CONCEPT

APPROACH

- MAINTENANCE AT ASSEMBLY LEVEL
- RECYCLE CCM TO GROUND AFTER EACH MISSION
- SPACE SHUTTLE IS SUPPORT SYSTEM
- SPACE TUG FOR NERVA DISPOSAL

OPERATIONS

- CCM RENDEZVOUS WITH PROPELLANT MODULE
- CCM MANEUVERS ASSEMBLY TO PROPULSION MODULE
- PROPULSION MODULE SELF - STABILIZED

CLASS 3 ASSEMBLY AND MAINTENANCE CONCEPT

The approach for assembly and maintenance in the Class 3 concept is analogous to that for the Class 1 Hybrid with the exception of the additional requirements imposed by the multiple propellant module configuration. The propellant modules are assembled initially in the sequence indicated in the figure employing end to end docking and rotating the out-board modules into the cruciform cluster. The top of the RNS is completed first, the CCM is attached, and then the bottom is assembled with the propulsion module last. Two space tugs are required for the assembly and clustering operations to both stabilize the vehicle and perform the module rotations. A very small propulsion requirement for these operations would permit use of an RNS CCM to perform the role of a tug.

CLASS 3 ASSEMBLY AND MAINTENANCE CONCEPT

APPROACH

- MAINTENANCE AT ASSEMBLY LEVEL
- RECYCLE CCM TO GROUND AFTER EACH MISSION
- 2 SPACE TUGS (OR CCM) FOR ASSEMBLY AND CLUSTERING
- SPACE TUG FOR NERVA DISPOSAL

OPERATIONS

- END-TO-END DOCKING
- ROTATE OUTBOARD MODULES INTO CLUSTER
- COMPLETE TOP OF RNS
- PROPULSION MODULE LAST, SELF-STABILIZED

RENDEZVOUS AND DOCKING

Rendezvous and docking operations are required for the RNS during assembly, payload handling, propellant resupply, and possibly for interfacing with destination space stations. A stable-orbit closure trajectory is utilized, which maintains a target in a vertical attitude and permits terminating the closure maneuver within the shadow cone provided by the NERVA radiation shield. This maneuver is also characterized by a slow rate of change of the line-of-sight which would permit a cooperative orientation of the RNS to extend the range of the shadow cone.

The cold-gas APS concept provides adequate stabilization capability for the propulsion module to overcome a disturbance from a missed docking operation during either assembly to the RNS or during CCM replacement (5 and 3 degree per sec, respectively, or about 5 times the expected disturbance).

Evaluation of sensor and thruster accuracies indicate that these are adequate for an automated rendezvous and docking operation. A laser radar system is utilized for target acquisition and alignment and rate determination during the docking maneuvers. Orientation accuracy could be improved for RNS assembly over the current ITT laser radar concept, which employs a cooperative transponder on the target, by employing multiple laser units on the active vehicle and a pattern of passive corner cube reflectors on the target. The impact of a 10 lb/sec impulse applied by a CCM attached to a 33,000-lb payload module is also indicated. A 3 lb-sec impulse is currently utilized for the APS design.

RENDEZVOUS AND DOCKING

STABLE ORBIT CLOSURE TRAJECTORY

- TARGET IN VERTICAL ATTITUDE
- TERMINATE CLOSURE WITHIN RADIATION SHIELD SHADOW CONE
- LINE OF SIGHT CHANGES < 4 DEG/SEC

PROPULSION MODULE STABILIZED FOR ASSEMBLY

- ACCOMMODATE MISSED DOCKING OPERATION
- MODULE ASSEMBLY OR CCM REPLACEMENT

SENSOR AND THRUSTOR ACCURACIES ADEQUATE FOR AUTOMATED OPERATION

	LASER RADAR	10 LB-SEC IMPULSE TO PAYLOAD/CCM
VELOCITY (FPS)	0.016	0.02
PITCH (DEG/SEC)	0.01	0.04
ROLL (DEG/SEC)	0.01	0.3

ORBITAL ASSEMBLY INTERFACE

The approach to implementing the module docking and functional assembly operations is depicted in the adjoining figure. First, docking is accomplished with a probe and drogue mechanism. A deployable soft probe is utilized so that docking forces are not required to actuate the system. This mechanism is used to draw the modules together over the final 3 in. so that a set of cable actuated latches can be engaged to lock the modules together. After structural latching is completed, fluid line coupling is initiated with a remote coupling mechanism as shown. A screw jack mechanism deploys the line across the interface and a coupling mechanism closes over the flange to complete the mating. A dual-seal flange is provided for leak check of the interface. After fluid line coupling is completed the electrical automatic panel assembly is accomplished utilizing a ball screw jack drive to engage the socket and receptacle. Guide pins are employed for both the fluid line coupling and the electrical panel assembly to ensure alignment.

ORBITAL ASSEMBLY INTERFACE

PROBE AND DROGUE DOCKING MECHANISM

- 12-IN. DEPLOYMENT OF SOFT PROBE
- 4 LOCATIONS

CABLE ACTUATED LATCHES AND SHEAR PINS

- 12 LOCATIONS

FLUID LINE COUPLING

- 3-IN. DEPLOYMENT
- DUAL SEAL FLANGE

ELECTRICAL PANEL ASSEMBLY

- 9 CONNECTORS
- 826 PINS TOTAL

PROPELLANT RESUPPLY

The cost of providing an orbital tank farm is eliminated by providing for direct propellant transfer from the space shuttle to the RNS. The alignment depicted in the figure indicates that space shuttle can interface with the RNS within the protection provided by the shadow cone. Here the dose rate is 0.1 REM/hr at 48 hours after shutdown, and it is further reduced by an order of magnitude after an additional 8 days. The propellant transfer would be performed using linear acceleration provided by the space shuttle. The low (10^{-5} g) acceleration level required for economical propellant transfer would require a lower thrust than provided by the current space shuttle APS.

The cost of delivering LH_2 to the RNS is the dominant factor in its transportation cost. It is recommended that the space shuttle orbiter design include a version configured as a tanker. The launch payload delivered to orbit should be increased for the tanker, considering that it would return to earth with a depleted tank. Efficient propellant transfer is essential to avoid significant residuals in the tanker propellant tank.

PROPELLANT RESUPPLY

DIRECT TRANSFER FROM SPACE SHUTTLE TO RNS

LINEAR ACCELERATION BY SPACE SHUTTLE $\sim 10^{-5} g$

DOMINANT FACTOR IN TRANSPORTATION COST

- DESIGN SPACE SHUTTLE ORBITER VERSION AS TANKER
- INCREASE LAUNCH PAYLOAD FOR TANKER DUE TO RETURN WITH DEPLETED TANK
- EFFICIENT PROPELLANT TRANSFER

ORBITAL CHECKOUT

The requirement for orbital checkout can be satisfied by the use of onboard checkout techniques. Results of the checkout activity are transmitted to ground, and provision is made for the acceptance of ground diagnostic procedures and procedure modification to account for situations that were not anticipated or preprogrammed. All the required procedures for checkout are stored onboard the RNS in the data management subsystem. The procedures are implemented during nonoperational times in the mission profile, hence using processor time that is off the peak requirements of thrusting and after-cooling. The onboard checkout approach will utilize a real or near real time evaluation of all of the data accumulated during the checkout operations and provide for action upon detection of a malfunction. Because of the large size of the replacement module, a minimum of fault isolation is required. A subset of the checkout is performed during peak operations and include data management self-check, certain fault prediction algorithms, and status monitoring for approximately 100 functions.

Component functional checkout was selected over simulated operations based on the minimum operational penalties. This approach avoids specific propellant settling operations, minimizes fluid flow and loss of expendables, and precludes the requirement of NERVA criticality during checkout operations. An evaluation of the propellant management and APS subsystems indicated that no additional components or subsystems would be required to effect the total subsystem checkout. Minor requirements did exist for instrumentation and discrete control of redundant elements, which would be incorporated into component design.

A top-level evaluation of stage checkout operations indicates that a majority (perhaps 70 percent) are concerned with subsystems located on the CCM. Also, there is substantial commonality of the checkout procedures required for orbital and ground operations.

The capability for automatic leak check is provided on the RNS. Dual seal flanges are utilized at static seals and pressure transducers monitor pressure changes between the seals. Also, pressure transducers are used to measure the pressure buildup between series valves.

The orbital checkout of the engine is attributed to NDICE with communication between the RNS processor and the NDICE on the data bus. The stage and engine development should utilize common checkout philosophies and techniques.

ORBITAL CHECKOUT

ONBOARD CHECKOUT -- MINIMAL ASTRIONICS IMPACT

- BULK STORAGE OF PROCEDURES: 25,000 WORDS
- PROCESSOR LOAD OFF PEAK

UTILIZE COMPONENT FUNCTIONAL CHECKOUT

- INCORPORATE POSITION INDICATION IN COMPONENT DESIGN
- NO ADDITIONAL COMPONENTS OR SUBSYSTEMS
- NERVA CRITICALITY NOT REQUIRED

MAJORITY OF CHECKOUT PROCEDURES FOR CCM SUBSYSTEMS

- COMMONALITY WITH GROUND PROCEDURES

AUTOMATIC LEAK CHECK

- DUAL SEAL FLANGES
- SERIES VALVES

NERVA CHECKOUT PERFORMED BY NDICE

MANEUVERS AND THRUST OPERATIONS

TRANSLUNAR INJECTION

The thrust modes and stage operations for translunar injection (TLI) are indicated schematically on the adjoining figure. In the event the RNS is in the vicinity of a manned facility, it is necessary to separate to a safe exclusion distance prior to performing the TLI (or TEI) maneuver. This is accomplished through initial prograde application of the APS in order to achieve a 7-nmi separation behind the facility. The separation rate is increased on the succeeding perigee by operating the NERVA in the idle mode, which alleviates the APS requirement. At apogee the orbit is circularized with a second idle operation. This results in a separation of 160 nmi total in 4 hours. The propulsion module run tank operates autonomously for these maneuvers and is refilled for TLI. Propellant settling is required for the idle mode operation, but prepressurization is not necessary. An orientation parallel to the velocity vector is maintained through the sequence of maneuvers.

Having achieved a satisfactory separation, TLI is accomplished using NERVA in the full-thrust mode. Propellant settling and prepressurization are required during the full thrust startup sequence. About half of the RNS propellant is consumed during this operation and the propellant module(s) is operated to replenish the run tank. Aftercooling and trajectory course correction are conducted concurrently, applying the idle mode for impulsive correction maneuvers, and operating the run tank autonomously. The correction maneuvers are typically performed 15, 37 and 67 hours from TLI. Correction maneuvers requiring impulse levels smaller than the NERVA impulse tolerance ($\pm 20,000$ lb-sec) will be performed by the APS. Cooldown continues for the entire transfer trajectory. The depleted run tank is refilled during the startup operations sequence prior to lunar orbit injection.

MANEUVERS AND THRUST OPERATIONS

TRANSLUNAR INJECTION

SEPARATION MANEUVERS

	FINAL ORBIT (NMI)	ΔV (FPS)	THRUST OPERATION
①	260 x 261.5	2.5	APS
②	260 x 272	17.5	NERVA IDLE/RUN TANK
③	272 x 272	20.0	NERVA IDLE/RUN TANK

MANEUVERS AND THRUST OPERATIONS

LUNAR ORBIT INJECTION

Lunar orbit insertion (LOI) is accomplished with three primary operations of the NERVA: LOI-1, full-thrust operation to achieve a 24-hour period capture orbit (approximate 60-nmi perihune altitude) operating the full RNS; LOI-2, a 30-degree orbital plane rotation (near apoapsis), using the NERVA throttle mode (45,000-lb thrust) and autonomous operation of the run tank; and LOI-3, full thrust for circularization at 60-nmi altitude. Application of the throttle mode is indicated due to the short steady-state operating times (25 sec during LOI and 0 sec during TEI) for the plane change. The run tank is refilled during the startup sequence for LOI-3.

Following completion of cooldown, terminal rendezvous is accomplished by sequential operation of the NERVA in the idle mode with the autonomous run tank (twice) and the APS for terminal braking. Correction maneuvers requiring impulse levels smaller than the NERVA impulse tolerance ($\pm 20,000$ lb-sec) will be performed by the APS. Given a residual range error of completion of cooldown (in the 60-nmi circular orbit), the desired closure rate is achieved by enlarging the RNS orbit as required to close to within 7 nmi in an integral number of orbits. Having achieved this condition, a second idle operation reduces the apoapsis to 61.5 nmi. This results in rendezvous at the next periapsis passage. Terminal braking (circularization) is accomplished with the APS.

After a 16-day lunar orbit coast, the series of maneuvers is reversed to perform injection for a 72-hour transit to Earth. The stage and engine operations are analogous to those for TLI and LOI.

MANEUVERS AND THRUST OPERATIONS

LUNAR ORBIT INJECTION

RENDEZVOUS MANEUVERS ^{*}

	FINAL ORBIT (NMI)	ΔV (FPS)	THRUST OPERATION
⑨	60 x 75	20.0	NERVA IDLE/RUN TANK
⑩	60 x 61.5	18.0	NERVA IDLE/RUN TANK
⑪	60 x 60	2.0	APS

LUNAR ORBIT INJECTION

- ⑥ L01-1: NERVA FULL THRUST/RNS
- ⑦ L01-2 (PLANE CHANGE):
NERVA THROTTLE/RUN TANK
- ⑧ L01-3: NERVA FULL THRUST/RNS

* TYPICAL, 80-NMI INITIAL ERROR

VEHICLE ATTITUDE

The major considerations which establish the RNS attitude throughout the mission profile are: (1) to maximize the performance through utilization of aftercooling propellant, (2) to minimize APS requirements, and (3) to make no special orientation provisions for meteoroid or thermal protection.

During prolonged coast periods in earth or lunar orbit, the vehicle is oriented in a gravity-gradient-stabilized mode which eliminates the requirement for station-keeping with the APS. This orientation is also compatible with the rendezvous and docking maneuvers. The thermal protection requirement is comparable to other orientations in orbit.

During transit and while aftercooling is taking place the vehicle will be oriented parallel to the velocity vector and NERVA will be trimmed to minimize the attitude errors. In establishing the APS impulse requirements for the mission profile a total of 36 attitude maneuvers were defined.

VEHICLE ATTITUDE

- MAXIMIZE AFTERCOOLING UTILIZATION
- MINIMIZE APS REQUIREMENTS
- NO ORIENTATION FOR METEOROID OR THERMAL PROTECTION

NAVIGATION AND GUIDANCE

The functional requirements for navigation and guidance were established in terms of their sensitivity to midcourse ΔV requirements. Specific sensor candidates were evaluated for both ground assisted and autonomous navigation. An autonomous navigation and guidance scheme was selected with an independent ground backup capability. The sensors required for attitude determination are common to either approach. Dual accelerometer ranges accommodate the high and low impulse requirements of thrusting and aftercooling respectively. In order to achieve autonomous navigation, an unknown landmark tracker was added to determine position in Earth or lunar orbit. This represented about a 37 percent increase in the navigation and guidance processor requirement, but only about a 12 percent increase in the total RNS processing requirement. The ground-assisted system would provide greater accuracy, but the autonomous system exceeds the minimal accuracy requirements for a 50-fps midcourse budget by a factor of about 5. Independent ground backup could be used to provide update capability in trans-lunar and transearth trajectories.

The RNS provides some unique guidance problems not previously encountered because the response time of the vehicle is large compared to the engine burn time for some maneuvers. The three shortest burn times are indicated on the facing page. The performance of a rate feedback guidance system with fixed position and guidance gains was evaluated. It was found that the sensitivity to the initial thrust misalignment was high compared to other parameters. For the TEI-3 burn a lateral velocity of 6 fps resulted for an initial thrust misalignment of 0.5 degree. The lateral velocity is plotted against time for two gain settings on the figure. With an optimal guidance policy, position and guidance gains would be varied between and during each of the burns depending on the mission phase. This could be implemented with the use of the digital flight control system and the procedure modifications accommodated in software.

NAVIGATION AND GUIDANCE

SYSTEM CONCEPT

- AUTONOMOUS CAPABILITY
- INDEPENDENT GROUND BACKUP
- ACCURACY: 0.1 NMI AND 0.2 FPS

OPTIMAL GUIDANCE POLICY

- SHORT BURNS CRITICAL

MANEUVER	BURN TIME (SEC)
TEI-2	42
LOI-1	72
TEI-1	84

- GUIDANCE ERROR MOST SENSITIVE TO INITIAL THRUST MISALIGNMENT
- VARY POSITION AND GUIDANCE GAINS BETWEEN AND DURING BURNS

CLASS 3 STABILITY AND CONTROLLABILITY

Two considerations in the feasibility of the Class 3 multiple propellant module configuration are the structural stability and flight control stability. The structural stability considerations concern the garden hose effect, depicted on the left side of the figure, where the first bending mode frequency for the RNS including its payload is plotted as a function of engine thrust for a range of intermodular structural stiffness. The lower bound is a design for flight loads and the upper bound considers the interstage stiffened to the level of the propellant tankage. The rapid change in the slope of the bending frequency at high thrust is associated with the onset of divergent oscillations. The 8-module tandem configuration has ample margin against garden hose instability.

The right-hand side of the figure is a plot of the first bending mode frequency versus the total number of propellant modules for the same design range of the tandem configuration. The minimum acceptable first mode bending frequency criterion was set at 0.1 Hz based on control studies. These indicated that a rigid-body control frequency of 0.01 Hz would be high enough to prevent interaction between the control and guidance systems and would achieve satisfactory attitude transient response, while still remaining sufficiently below the first mode bending frequency to avoid interaction with it. It is seen that the 8-module tandem would be marginal and has limited growth potential. However, the baseline cruciform cluster, shown by a single point on the figure has ample margin. Since no external radiation shield was required for the cruciform cluster configuration, it was selected based on these considerations.

CLASS 3 STABILITY AND CONTROLLABILITY

- 8 - MODULE TANDEM MARGINAL FOR CONTROL
- CRUCIFORM CLUSTER PROVIDES AMPLE MARGIN

INFORMATION MANAGEMENT

The processor requirements established for the data management function are presented in the facing table. The associated data rates and data compression requirements were based on 732 channels of instrumentation which includes the NERVA data. The selected data bus rate of 0.5×10^6 bits/sec allows for development flight requirements of 1,152 channels of instrumentation. Based on the processing requirements of 241,000 operations/sec, which can easily be satisfied with a single state-of-the-art computer, a centralized approach to the data management function was selected. To achieve reliability compatible with the mission objectives a redundant processor configuration was selected. Using a redundant processor configuration a MTBF of about 38,500 hours would be required for each processor. The primary interface between the RNS and external system elements is the RF data transmission to ground. Status and performance data are transmitted to ground for performance monitoring and subsequent trend analysis between missions. Using a data compression algorithm which provides a 100:1 compression ratio based on Gemini simulations, 8.3×10^3 bits would be transmitted over each ground station from earth orbit. Five ground stations and a viewing time 160 minutes per 24 hour period was assumed. This relatively low data transmission rate can be achieved without the use of relay satellites. The corresponding rate from lunar distances would be approximately 900 bits/sec, assuming full view capability from the DSIF. During launch and prior to system assembly the space shuttle will interface directly (hardwire) with the RNS module data bus to provide control and obtain status information.

INFORMATION MANAGEMENT

INTERNAL ARCHITECTURE

- 732 INSTRUMENTATION CHANNELS
- DATA BUS: 0.5×10^6 BITS/SEC
- CENTRALIZED --
1 + 1 PROCESSOR CONFIGURATION
- ONBOARD DATA EVALUATION

EXTERNAL INTERFACES

- TRANSMISSION TO GROUND USING DATA COMPRESSION
 8.3×10^3 BITS/SEC FROM EARTH ORBIT WITHOUT RELAY SATELLITE
 9×10^2 BITS/SEC FROM LUNAR DISTANCES

PROCESSOR REQUIREMENTS

FUNCTION	PEAK OPS/SEC	STORAGE (WORDS)
NAVIGATION AND GUIDANCE	83,200	16,000
CHECKOUT	8,200	1,200
COMMAND AND CONTROL	4,800	2,500
DATA MANAGEMENT	40,000	4,750
DATA COMPRESSION	105,000	2,000
TOTAL	241,000	27,650

PROPELLANT MANAGEMENT OPERATIONS

The RNS propellant management operations will be described with reference to the propulsion module shown in the adjoining figure, since the propulsion module participates in all operations and contains all of the propellant management functions required for the stage.

Beginning with propellant loading in orbit, a low-g propellant transfer operation is accommodated without venting using a spray nozzle for ullage collapse. A check valve and flow meter are provided to alleviate pressure surges when filling a warm tank. The feed system for both the stage and engine are conditioned during the startup operation employing an integrated stage/NERVA chilldown system. A separate pump is also located in the feed system to refill the run tank, if required, before startup.

During the autogenous startup operations, the small volume of the propulsion module run tank reduces the pressurant demand on NERVA. The 10,800-lb LH₂ capacity of the run tank is sufficient to permit autonomous operation during startup, aftercooling, and short burns. Its limited volume reduces LH₂ settling requirements for short burns. The autonomous operation of the run tank permits bootstrapping the propellant tank pressurization during NERVA full thrust operation. Propellant level control is utilized in the run tank and its depletion during startup is limited (~ 5,000 lb LH₂ minimum) to retain its benefit for reducing the radiation dose to equipment located at the top of the run tank.

Propellant acquisition for aftercooling is provided with a surface tension device. This operation is also simplified by the reduced run tank volume. Propulsive venting is provided, but the vent system would typically be employed during orbit coast periods without specific propellant settling operations.

PROPELLANT MANAGEMENT OPERATIONS

BOOTSTRAP PROPELLANT TANK PRESSURIZATION DURING FULL THRUST OPERATION

STARTUP OPERATIONS PHASING

The sequencing and interrelation of the operations which have been defined for propellant settling, propellant feed system conditioning, NERVA thrust buildup, and prepressurization of propellant tankage are delineated in this schematic. Propellant settling consists of two phases. The initial phase of inviscid orientation precedes the NERVA thrust ramp and utilizes a low acceleration provided by the APS. Settling is completed during the thrust buildup portion indicated in the figure. The operations for preconditioning the feed system include chilldown and prestart refilling of the run tank. These are accomplished during the inviscid orientation phase after initial settling period.

Pressurant is fed to the run tank for expulsion makeup during the beginning of the startup ramp. However, efficient prepressurization cannot be insured until completion of the dissipated phase of propellant settling. Also, NERVA cannot operate above the throttle point without tankage prepressurization, so a thrust hold period at the throttle point is incorporated into the thrust buildup ramp. After prepressurization of the run tank NERVA thrust can be increased to full power, although for some cases with large pressurized volumes indicated by the dashed thrust buildup curve, it could be desirable to maintain the thrust hold until completion of the prepressurization of the propellant module. When the propellant module is pressurized it can be brought on-line to refill the run tank under full power. Note that propellant module prepressurization creates the greatest pressurant demand on NERVA, and this operation is deferred with the concept described here until full I_{sp} (engine temperature) has been achieved. Also, it is stretched within the time constraints of run tank depletion.

STARTUP OPERATIONS PHASING

PROPELLANT SETTLING

The RNS mission profile entails eight mainstage burns and multiple idle mode operations, all of which require propellant settling. Although propellant orientation can be provided with surface tension screens, the most flexible and economical approach for multiple missions is to employ linear acceleration for propellant settling.

The propellant settling operations are divided into two phases. Initially, there is an inviscid orientation phase to locate the propellant at the bottom of the tanks while imparting a minimum amount of kinetic energy to it. The criterion determined for the design is to provide an initial run tank Bond number = 10 at TLI. This is provided by 3 lb of axial settling thrust from the APS corresponding to an initial acceleration of 6.7×10^6 g. Anti-geysering baffles are provided for orientation control. The second phase of settling requires high thrust to dissipate the kinetic energy of the fluid, damp out slosh, and eliminate bubbles. Slosh baffles are incorporated to assist energy dissipation. The objective for this phase is to achieve a quiescent liquid to permit efficient prepressurization with a hot gas. The most efficient design concept is to utilize the NERVA thrust ramp and to hold the thrust at the throttle point until adequate settling for prepressurization has been achieved. Using existing criteria this requires 10 to 60 sec for the range of startup conditions in the mission. A thrust hold at the throttle point provides full I_{sp} , and consequently, negligible payload loss.

For cases where the run tank operates autonomously only the run tank is settled prior to operation.

PROPELLANT SETTLING

LINEAR ACCELERATION

- FLEXIBLE FOR MULTIPLE RESTARTS
- APS -- 3-LB THRUST
- 120-LB PROPELLANT TOTAL

UTILIZE NERVA THRUST RAMP FOR
HIGH THRUST DISSIPATIVE PHASE

- THRUSHOLD AT THROTTLE POINT

SETTLE ONLY RUN TANK FOR AUTONOMOUS
OPERATION

INTEGRATED NERVA/STAGE CHILLDOWN

This chart depicts the schematic of the integrated NERVA/stage pump driven chilldown system for prestart chilldown of the propellant feed system. It is located in the run tank and provides conditioning for both the NERVA and stage interfaces. It is operated during the low-g inviscid orientation phase of settling to avoid separate chilldown operations. Forced convection is required for the low-g chilldown. The indicated schematic is compatible with the current NERVA interface. Check valving is located at all injection points to prevent surges and disturbances from being transmitted to the adjoining systems. The concept and its operation is a variation on the chilldown system which has been proven in flights on the S-IVB.

INTEGRATED NERVA / STAGE CHILLDOWN

- FORCED CONVECTION REQUIRED
- OPERATE DURING LOW-G SETTLING
- CONCEPT MINIMIZES PRESSURE SURGES -- PROVEN ON S-IVB
- CONDITION STAGE AND NERVA INTERFACES AS INTEGRATED OPERATION:

2 LB/SEC

TANK PRESSURE AND LIQUID LEVEL CONTROL

A representative schematic of the tank pressure and liquid level control between the run tank and the active propellant module is shown in the adjoining figure. The concept employs independent control of the tank pressures, utilizing accurate strain gage pressure transducers and bang-bang pressure control valves in a quad-redundant configuration for both pressurization and vent functions. The run tank liquid level is also controlled using point level sensors and servo-control feed valves. Simulations of the dynamic behavior of the run tank pressure and liquid level during startup, run tank refill, and transistion to the NERVA malfunction mode have been performed. These simulations established that the liquid level overshoot during run tank refill at full thrust could be controlled and that only a small liquid level rise would be incurred if NERVA flow rate demand was suddenly reduced by a malfunction. Control requirements established the pressure schedule indicated, based on a NERVA pump performance map (ANSC letter 7410:1075, July 1970) including 26 psia and 0 NPSP at full thrust. No increase of total pressure is provided for NERVA malfunction mode operation.

The approach for providing the various flow rate requirements during various stage operating modes using the selected pressurization functions is indicated in the table, assuming a pressurant inlet temperature of 230 °R. Except for prepressurization of the Class 1 Hybrid propellant module, all required operations are provided by two pressurization functions: (1) expulsion, 0.6 lb/sec, and (2) pressure control, 0.4 lb/sec. The Class 1-H propellant module prepressurization function was sized at 4 lb/sec, based on limiting run tank depletion during startup.

TANK PRESSURE AND LIQUID LEVEL CONTROL

INDEPENDENT CONTROL OF MODULE PRESSURES

- BANG-BANG CONTROL VALVES

RUN TANK LIQUID LEVEL CONTROL

- SERVO-CONTROL FEED VALVES

PRESSURE SCHEDULE:

- NERVA 26 PSIA
- CLASS 1-H 29 PSIA
- CLASS 3 30 PSIA

MULTIMODE PRESSURIZATION OPERATIONS:

OPERATION	FLOW RATE (LB/SEC)	FUNCTION UTILIZED
• EXPULSION	0.58	1
• CONTROL	0.06	2
• PREPRESSURIZATION		
I-H PROPELLANT	5.0	1 + 2 + 3
OTHER	0.58	1
• RUN TANK REFILL	0.81	1 + 2
• MALFUNCTION	0.35	2

PROPELLANT THERMODYNAMICS IMPLICATIONS

Propellant heating from the space environment occurs both prior to and during the mission. The RNS is refilled with LH₂ in orbit with a series of space shuttle flights during the 54.6-day period between missions. For the case considered here, propellant is delivered in 30,000-lb increments at 4-day intervals. The amount of propellant heating is indexed in terms of the equivalent time as a full tank, which accounts for the reduced heat capacity of the system during periods when the tank is offloaded. It is evident from the table that the propellant heating sustained prior to the mission exceeds that incurred during the operational portion of the mission after TLI. In addition, the heat capacity of the propellant is reduced further by providing for chilldown of a warm tank, which increases the saturation pressure of the propellant by ~5 psia. In view of these considerations an optimization was conducted which led to the operational concept of venting prior to the mission to reject the chilldown heating and premission orbital heating. The tankage would then be topped off prior to departure. In the case of the Class 3 inboard propellant modules it was found desirable to vent to the extent of subcooling in orbit below the 16 psia delivered condition. With this approach the RNS operates during the mission without venting.

A significant consideration in the propellant heating during the mission is the impact of stratification. During the orbital coast phases the RNS modules are oriented in a gravity gradient stabilized configuration which provides sufficient local acceleration to orient the liquid at the end of the tank. The coast periods are sufficiently long to permit development of significant stratified layers within the liquid, which can result in saturation pressure rises varying between 3 and 6 psia for the various conditions encountered. Consequently, active stratification is required during the mission operations. Pump mixers have been considered and would be feasible. However, the current concept is to utilize the APS to induce a breaking slosh wave. This approach would mix both the liquid and gas, thereby reducing concern about nonequilibrium ullage heating experienced on Saturn flights. Also, it does not require additional hardware and imposes a negligible operational penalty on the system. During transit the propellant would be oriented in a minimum energy configuration which would be periodically disturbed by aftercooling pulses. The effect of stratification for that case is considered negligible.

Nuclear heating of propellant has been evaluated. The run tank configuration isolates the nuclear heating and permits a design with complete mixing of the incoming propellant. The total energy deposition rate at full power corresponds to 13 kw and results in a saturation pressure rise for a complete mixing model of less than 0.2 psia. This design approach therefore results in a minimal impact from nuclear heating. If stratification of the heated propellant occurred, a severe pressure penalty would be incurred and venting would be required.

PROPELLANT THERMODYNAMICS IMPLICATIONS

20633

THERMAL HEATING

EQUIVALENT TIME (HR):	PROPELLANT MODULE		
	1-H	3- INBOARD	3- OUTBOARD
BEFORE MISSION	2,000	1,090	1,090
DURING MISSION	1,190	695	1

- VENT PRIOR TO MISSION
- TOP OFF PROPELLANT
- NONVENTED MISSION

TANK CHILLDOWN $\Delta P \approx 5$ PSIA

STRATIFICATION

PROPELLANT
ORIENTATION

ORBIT COAST

TRANSIT

- DESTRATIFICATION REQUIRED
- INDUCE BREAKING SLOSH WAVE
- MIXES BOTH LIQUID AND GAS

STRATIFIED LAYER
PRESSURE RISE (PSIA)

3 TO 6

~0

NUCLEAR HEATING

- HEATING ISOLATED IN RUN TANK
- COMPLETE MIXING WITH INCOMING PROPELLANT
- PRESSURE RISE < 0.2 PSIA

AFTERCOOLING SYSTEM

The baseline aftercooling concept is depicted in this schematic. It employs a surface tension pulse basket to provide liquid to the NERVA aftercooling bypass system. There are no operations imposed on the RNS for either propellant settling or pressurization with this concept. Only the run tank is employed for aftercooling pulse operations.

The stage performance can be improved considerably if the NERVA specifications are modified to permit the use of a mixed phase or gas for aftercooling. This would permit the utilization of residual gas, thereby reducing the inert weight penalty of the stage. The minimum savings would be obtained for the Class 1 Hybrid RNS: 2,800 lb for EOI cooldown. Greater savings could be obtained for the multiple module concepts by permitting the venting of depleted tanks for aftercooling.

AFTERCOOLING SYSTEM

CURRENT CONCEPT

SURFACE TENSION PULSE BASKET

- LIQUID FEED
- NO PROPELLANT SETTLING
- NO PRESSURIZATION

USE ONLY RUN TANK

RECOMMENDED CONCEPT

NERVA ACCOMMODATE

MIXED PHASE OR GAS

UTILIZE RESIDUAL GAS

AFTERCOOLING UTILIZATION

The two major features of the nuclear engine which distinguish its integration into a stage are its radiation environment and the requirement to provide coolant for the fission product afterheat. Operationally, the integration and utilization of aftercooling propellant has a major impact on stage performance. Accurate n-body trajectory simulations were performed using the ANSC NERVA cooldown data to evaluate the performance implications of aftercooling. Whereas early RNS performance calculations neglected any potential payload gain from utilization of aftercoolant, the benefits have now been established. This amounts to a credit to the mission velocity resulting in 8,400 lb of payload delivered to lunar orbit, increasing the total to 105,000 lb (20,000-lb return payload, 8-burn) for the Class 1 Hybrid RNS. If thrust nulling were employed, this bonus would need to be subtracted from the stage performance. The amount of aftercoolant required represents a degradation of the total Isp for the stage. It was established that there would be a potential additional payload gain of 23,500 lb if aftercooling with propellant could be eliminated entirely.

The current NERVA specifications contain an impulse tolerance of $\pm 20,000$ lb-sec. The impact of this tolerance on the translunar trajectory was determined for the trajectory simulations as corresponding to 0.6 percent of TLI impulse or less than 12-nmi lunar miss distance. Consequently it is considered that the tolerance could be relaxed and should be related to the operating time and total impulse for the burn.

Evaluation of midcourse correction concepts indicated that multiple impulsive midcourse maneuvers or a single impulsive correction early in the trajectory are preferable to a single impulsive maneuver at the end of the cooldown phase. A simulation indicated that manipulating the vehicle attitude and cooldown impulse during the cooldown thrusting is competitive with an impulsive midcourse correction.

It is desirable to develop a method for predicting error early in the cooldown phase. This would permit implementation of a guidance policy to maximize the cooldown utilization as indicated in the controller schematic.

AFTERCOOLING UTILIZATION

PERFORMANCE IMPACT ON PAYLOAD TO LUNAR ORBIT

- CREDIT MISSION VELOCITY = 8,400 LB
- POTENTIAL ADDITIONAL GAIN BY
AFTERCOOLING ELIMINATION = 23,500 LB

IMPULSE TOLERANCE

- $\pm 20,000$ LB-SEC ON TLI <12 - NMI LUNAR MISS

VECTORED COOLDOWN COMPETITIVE WITH IMPULSIVE MIDCOURSE

DEVELOP IMPULSE PREDICTION AND GUIDANCE ALGORITHM

35 2 650 $\frac{t}{Isp}$
 2.5

AFTERHEAT REJECTION IMPLICATIONS

Whereas the nominal NERVA Isp is 825 sec, the actual Isp obtained for the mission operations, exclusive of idle mode burn, is 790 sec. This imposes a substantial performance penalty (23,500 lb) on the system. Therefore, it is desirable to reduce the amount of aftercoolant required by increasing the radiated power level from NERVA. As shown in the adjoining figure, increasing the radiated power level from the current level of 5 kw could substantially reduce the total cooldown time, which continues throughout the entire translunar trajectory. Most of the afterheat energy is released while the decay power is relatively high. For example, only 31 percent of the afterheat energy is incurred at a power level below 100 kw, although this portion consumes 90 percent of the cooldown time.

If the reactor materials cannot be conveniently changed to permit passive heat rejection, alternative heat rejection systems should be considered to increase the performance. The breakeven heat rejection system specific power is shown in the figure based on the n-body trajectory simulations. For example, if it were desired to radiate 200 kw, the breakeven specific power for the heat rejection system would be 18 lb/kwt. Therefore, if the heat rejection system weighed less than 3,600 lb a performance gain could be achieved. Attainment of the full potential of passive heat rejection would require systems with specific powers in the range of 1 to 5 lb/kwt.

AFTERHEAT REJECTION IMPLICATIONS

LUNAR SHUTTLE MISSION N-BODY TRAJECTORY SIMULATION

TLI ABORT—EARTH IMPACT CONSIDERATIONS

Evaluation of the TLI trajectories with n-body trajectory simulations indicated that when using the aftercooling propellant for mission velocity there is a critical period between 0.8 and 3.2 hours from ignition during which a vehicle abort could result in an earth impact trajectory, as indicated by the dashed line in the figure. This trajectory results from deflection of the vehicle by the lunar gravitational field. Failures which could lead to such a condition include loss of NERVA operation, loss of attitude control, and destruction of the RNS. The maximum velocity requirement to miss the earth during this critical period is 110 fps. Contingency operations have been evaluated for these failure modes. The baseline APS would only provide about 40 fps of the requirement so a contingency operation is considered for which main tank hydrogen would be heated by gas generators in the APS and dumped at a lower I_{sp} . Depending on the cause of loss of attitude control, a variety of contingency operations would be available.

could
be supplied
by APS →

TLI ABORT-- EARTH IMPACT CONSIDERATIONS

MAINTENANCE

An extensive evaluation of orbital maintenance has been performed including identification of multiple replacement modules, application of a single command and control module for functional subsystems, and in-situ maintenance at the component level using the capabilities of man in orbit. It was found that design for maintenance at both the component level and maintenance assemblies proved to be complex and required excessive orbital support. The selected orbital maintenance level consists of RNS assembly modules: the command and control module, propulsion module, and propellant module. Consequently, the operations required for orbital maintenance are analogous to those for initial assembly. The orbital support systems are the space shuttle and space tug used as for assembly operations. In addition, the space tug is used to support a specific propulsion module disposal operation. With this approach there are no manned operations or remote manipulators required for orbital maintenance of the RNS.

The CCM is recycled to the ground after each round trip mission for maintenance and replenishment. This includes a complete checkout and calibration, verification of all redundancies, scheduled and unscheduled replacements, and replenishment of the LH_2 and LO_2 reactants of the APS and fuel cells. Reliability analyses indicate that 90 percent of the anticipated RNS component failures which would require replacement are contained in the CCM. Thus, designing for ground operations enhances the simplicity of maintenance. The replacement operation of the CCM requires that no fluid connections be made or broken during its replacement in orbit.

For space resident modules such as the propellant and propulsion modules a fault prediction capability should be included by providing specific sensors measuring the characteristic performance parameters of the RNS. Methods which have been considered include trend analysis, mechanical signature analysis, acoustic emission, and ultrasonic crack detection. It is anticipated that implementation of fault prediction techniques would require processing of RNS performance data on the ground.

MAINTENANCE

POLICY

- REPLACE RNS MODULES (CCM, PROPULSION, PROPELLANT)
- OPERATIONS ANALOGOUS TO INITIAL ASSEMBLY
- SUPPORT BY SPACE SHUTTLE AND SPACE TUG
- NO MANNED OPERATIONS OR REMOTE MANIPULATORS

CCM RECYCLED TO GROUND AFTER EACH MISSION

- CONTAINS 90% OF POTENTIAL FAILURES
- NO FLUID CONNECTIONS

UTILIZE FAULT PREDICTION FOR SPACE RESIDENT MODULES

- PROCESS DATA ON GROUND

NERVA END-OF-LIFE DISPOSAL

The relatively inexpensive space shuttle launch (\$5 million) and simplified propulsion module replacement concepts have minimized the cost of engine replacement in orbit. NERVA I_{sp} and lifetime are intimately related and it is considered that the I_{sp} is more valuable than the lifetime for stage performance and transportation economics. Consequently, it is expected that relatively frequent engine replacement would be employed. Also, NERVA replacement would be required in the event of a failure. In either case it is necessary to dispose of NERVA as the propulsion module to avoid earth impact or hazards to space operations.

To initiate disposal the propulsion module is disassembled and jettisoned from the propellant module, and it remains self-stabilized while the RNS assembly separates to a safe distance. The selected approach utilizes a space tug, which rendezvous and docks to the propulsion module and then operates in a reusable mode to inject it into a heliocentric orbit. A tug propellant capacity of 63,000 lb would be required for this operation. The same operating mode could be utilized in either earth orbit or lunar orbit. Actually the propulsion module propellant capacity is sufficient to permit self-disposal from lunar orbit if a sufficient guidance package were provided. Self-disposal could also be considered from earth orbit if a single Class 3 propellant module were added to the propulsion module.

Since the command and control module is recycled to the ground after each mission, it does not have a space disposal problem. Inoperative propellant modules can be jettisoned from the operational area and permitted to re-enter the atmosphere.

NERVA END-OF-LIFE DISPOSAL

- BASELINE CONCEPT -- REUSABLE SPACE TUG
- ALTERNATE CONCEPT -- SELF DISPOSAL

RNS INTERFACE WITH OTHER PLANNED SYSTEMS

The evaluation of RNS operations and interfaces with other systems has indicated that the space shuttle and space tug are the major support systems for the RNS. The space shuttle provides delivery of RNS modules to orbit. A version of the space shuttle also provides propellant resupply as a tanker. The space tug provides payload handling. It is not required for assembly of the Class 1 Hybrid or other tandem RNS configurations, but is required for assembly of the Class 3 vehicle to stabilize it and perform clustering operations. However, a RNS CCM is sufficient to provide these tug functions. NERVA disposal would be provided by a space tug using a lunar lander sized tug system. The evaluation has indicated that many candidate future space systems are not required to support the RNS. These include an orbital propellant depot, an orbital maintenance facility, communications satellites and remote manipulator units. Major orbital facilities can impose a major operating cost burden on the RNS system which can be avoided with the availability of the space shuttle.

RNS INTERFACE WITH OTHER PLANNED SYSTEMS

SPACE SHUTTLE

- MODULE DELIVERY TO ORBIT
- PROPELLANT RESUPPLY AS TANKER

SPACE TUG

- PAYLOAD HANDLING
- NOT REQUIRED FOR CLASS I-H ASSEMBLY
- USE TUG OR CCM FOR CLASS 3 ASSEMBLY
- NERVA DISPOSAL

CANDIDATE ORBITAL SYSTEMS NOT REQUIRED TO SUPPORT RNS:

- PROPELLANT DEPOT
- MAINTENANCE FACILITY
- COMMUNICATIONS SATELLITES
- REMOTE MANIPULATOR UNITS

RNS DEFINITION

This section summarizes the designs resulting from the Phase III study for the two RNS concepts. As described earlier, the Class 1 Hybrid configuration is configured to be launched by the Saturn V INT-21 launch vehicle while Class 3 is configured to be launched within the cargo hold of the space shuttle. Both concepts employ a propulsion module, consisting of NERVA and a run tank, and a command and control module containing the RNS control equipment and all expendables. They differ primarily in the configuration of the propellant modules with the Class 1 Hybrid employing a single module while Class 3 employs eight separate modules.

The study activities in Phases I and II provided baseline designs for both concepts. This included both vehicle configurations and subsystem characteristics. Phase III design activity was based primarily upon meeting the design requirements established in the operations analysis described in the last section and accommodating the reliability and safety specifications generated during this phase.

Subsequent charts contain a brief summary of the major design features for both concepts. The same ground rules and design approaches were employed for the two concepts including extensive use of the same subsystems where appropriate. This provides a meaningful comparison between the two concepts with differences truly representing concept characteristics.

RNS DEFINITION

- TWO CLASSES OF CONCEPTS
 - CLASS 1 HYBRID--INT-21 LAUNCH
 - CLASS 3--SPACE SHUTTLE LAUNCH
 - BOTH EMPLOY THREE TYPES OF MODULES
- CONTINUITY FROM PHASES I AND II
 - VEHICLE CONFIGURATIONS
 - SUBSYSTEM CHARACTERISTICS
- PHASE III DESIGN FEATURE SELECTIONS
 - BASED ON OPERATIONS ANALYSES--REQUIREMENTS
 - MEET RELIABILITY AND SAFETY SPECIFICATIONS
- CONCEPT COMPARISONS
 - SAME SUBSYSTEMS EMPLOYED EXTENSIVELY
 - DIFFERENCES REFLECT CONCEPT CHARACTERISTICS

CLASS 1 HYBRID RNS

A sketch of the Class 1 Hybrid RNS configuration is shown on the facing chart. It illustrates the final configuration for Phase III and provides a locator for design features which will be described on subsequent charts.

The three distinct modules are visible as well as their containment within the 10-degree half-angle cone measured from the NERVA engine. Outriggers containing the auxiliary propulsion engines on the command and control module are also visible in the picture.

CLASS 1 SINGLE-MODULE HYBRID RNS

RNS WEIGHT STATEMENT

A weight summary for the two RNS classes is shown on the facing chart. It can be seen that a significant weight advantage accrues to the Class 1 Hybrid concept in structures, meteoroid/thermal, docking/clustering, and the main propulsion subsystems. This is because of the more efficient structural configuration of the single module, its lower surface area, and less redundant equipment required for assembly and hookup. On the other hand, the Class 3 concept has no biological shield requirement and has significantly lower residual propellant penalties. The net weight advantage to Class 1 Hybrid is seen to be slightly more than 10,000 lb.

RNS WEIGHT STATEMENT

ITEM	WEIGHT (LB)	
	CLASS 1-H	CLASS 3
STRUCTURE	23,130	30,470
METEOROID/THERMAL	7,070	10,750
DOCKING/CLUSTERING	640	3,320
MAIN PROPULSION-STAGE	1,010	4,550
NERVA	27,800	27,800
DISK SHIELD	2,900	0
AUXILIARY PROPULSION (WET)	2,360	2,360
ASTRIONICS	2,505	3,170
CONTINGENCY	1,830	2,590
RESIDUAL PROPELLANT	9,470	4,160
TOTAL OPERATIONAL WEIGHT	78,715	89,170
PROPELLANT MASS FRACTION	0.788	0.771

STRUCTURAL FEATURES

Some of the major structural characteristics of the RNS Class 1 Hybrid design are shown on the accompanying chart. The propellant module configuration was selected in Phase II with the design trade studies reverified during Phase III. The propellant module was configured to be launched on the Saturn V INT-21 launch vehicle in an upright position without modifications to the launch vehicle. It is launched separate from the other two modules. The aft dome was configured to be contained within a 10-degree half-angle cone measured from the PVARA source of radiation. This combined structural/shielding optimization was reaffirmed in Phase III. Use of the propulsion module allows the propellant tank to utilize a 140-in. cap radius which provides the configuration shown on the earlier chart. A hemispherical forward dome resulted from a trade study considering the RNS weight and the interface with the command and control module.

Fiber glass honeycomb heat blocks are employed fore and aft of the cylindrical portion of the propellant module tank to limit thermal input to the propellant tank and still provide structural integrity for the launch configuration. Their length was selected for compatibility with the layup requirements of the high-performance insulation. The intermodule structure connecting the propulsion module with the run tank was selected as fiber glass tubular struts in a truss configuration as a result of the combined optimization of structural and thermal performance. This configuration also provides access to the intermodule region.

STRUCTURAL FEATURES

RNS CLASS 1-H

FEATURE	SELECTION	BASES
PROPELLANT MODULE TANK:		
DIMENSIONS	101 FT LONG, 33 FT DIA	PHASE II, LAUNCH CONFIGURATION
AFT DOME	10 DEG CONE, 140 IN. CAP RADIUS	PHASE II, STRUCTURAL/ SHIELDING OPTIMUM
FORWARD DOME	HEMISPHERICAL	WEIGHT, LAYOUT
HEAT BLOCKS:		
CONSTRUCTION	FIBER GLASS HONEYCOMB	STRUCTURAL/THERMAL OPTIMUM
LENGTH	3 FT	HPI LAYUP
INTERMODULE STRUCTURE	FIBER GLASS TUBULAR STRUTS, TRUSS	STRUCTURAL/THERMAL OPTIMUM, ACCESS

STRUCTURAL FEATURES-2

Structural characteristics of the RNS Class 1 Hybrid design are continued on this chart. The payload adapter, which is a truncated conical component extending from the forward dome of the propellant module tank to the docking ring that interfaces with the command and control module, is fabricated from a fiber glass honeycomb structure on the basis of the combined structural-thermal optimization.

The run tank is configured to be contained within the 10-degree cone which resulted from the combined structural/shielding optimization. Autonomous operation with the run tank desires maximum propellant loading. Thus, a trade study was conducted in Phase III comparing variations in the run tank dimensions. No further shielding advantage was found for smaller run tank diameters because of scattering from the aft dome of the propellant module tank. At a maximum diameter of 174 in., shielding performance was degraded and no further operational advantage was obtained. Thus, the nominal dimensions shown were selected.

The command and control module was sized to accommodate the equipment required within the module. A trade study was conducted considering the performance loss by canting the aft-facing APS engines outward to avoid plume impingement on the propellant tank versus the weight of providing outriggers; the 3-ft outrigger was selected as optimum. The command and control module is constructed of isogrid which provides for equipment mounting from any of the nodes.

The probe and drogue docking subsystem selected during Phase II was carried forward. Final subsystem definition will be dependent upon the selection for other system elements.

STRUCTURAL FEATURES-2

RNS CLASS 1-H

FEATURE	SELECTION	BASES
PAYLOAD ADAPTER	FIBER GLASS HONEYCOMB	STRUCTURAL/THERMAL OPTIMUM
RUN TANK DIMENSIONS	23 FT LONG, 160 IN. DIA	SHIELDING/OPERATIONS OPTIMUM
COMMAND AND CONTROL MODULE:		
DIMENSIONS - CORE	6 FT LONG, 165 IN. DIA	EQUIPMENT PACKAGING
OUTRIGGERS	3 FT EXTENSION	APS ENGINE PLUME IMPINGEMENT, SPACE SHUTTLE LAUNCH
CONSTRUCTION	ISOGRID	EQUIPMENT MOUNTING
DOCKING SYSTEM	PROBE AND DROGUES	PHASE II

THERMAL/METEOROID PROTECTION

The facing chart contains major features of the thermal/meteoroid protection subsystem selected for the RNS Class I Hybrid. The insulation material selected during Phase II was doubly aluminized Mylar with dacron net spacers. The thermal/structural optimization conducted during Phase III resulted in selection of 51 layers or 0.52 in. of insulation. The design layout employed 3 blankets each containing 17 layers of insulation. Fiber glass straps and nylon studs were used to attach insulation to the tank. Ground purge was accomplished by a recirculating helium system contained within a Mylar shroud.

The meteoroid protection system employed the HPI adjacent to the tank covered by a 2-in. -thick layer of flexible foam having a density of 1.2 lb/cu ft and contained within a shroud of 0.020 in. of fiber glass laminate. The configuration was selected on the basis of Phase II hypervelocity test results which compared alternative configurations. The system provides for a survival probability of 0.9974 for the baseline lunar shuttle mission. In addition to providing meteoroid protection, the fiber glass shroud also functions as an aerodynamic shroud during launch.

THERMAL/METEOROID PROTECTION

RNS CLASS 1-H

FEATURE	SELECTION	BASES
INSULATION:		
MATERIAL	DAM/NET	PHASE II
THICKNESS	0.52 IN., 51 LAYERS, 3 BLANKETS	THERMAL/STRUCTURAL OPTIM
ATTACHMENTS	FIBER GLASS STRAPS, NYLON STUDS	THERMAL PERFORMANCE
GROUND PURGE	RECIRCULATING He, MYLAR SHROUD	PREVENT CRYOPUMPING
METEOROID PROTECTION:		
FLEXIBLE FOAM	2 IN. THICK, 1.2 LB/CU FT	CONFIGURATION -- PHASE II TESTS, PROTECTION -- SURVIVAL = 0.9974 SHROUD -- AERO LOADS DURING LAUNCH
SHROUD	0.020 IN. FIBERGLASS LAMINATE	

MAIN PROPULSION

Design features for the propellant feed system are shown on the facing chart. Propellant feed from the propellant module tank to the run tank is accomplished through 12-in. ducting employing dual 8-in. valves in each module. These effectively provide quad redundancy for reliability. Following startup on propellant from the run tank only, resupply to the run tank is accomplished by the analog control valves in the run tank which maintain a constant propellant level using three arrays of discrete-type liquid-level sensors. A sump fitting is used in the propellant module to minimize liquid residuals. Anti-vortex filtration screens are employed to maximize propellant usage and limit contaminants. Separate dome penetrations are used in the run tank to match the NERVA interface. No penalty accrues to propellant usage since terminal propellant drain uses an aftercooling bypass system located at the bottom of the aft dome. A remote motor-driven duct deployment is utilized to connect the propellant module tank and the run tank. A V-coupling clamp is employed to complete the feedline seal. Linear compensators and gimbals are used to accommodate motion requirements.

MAIN PROPULSION

RNS CLASS 1-H

FEATURE	SELECTION	BASES
PROPELLANT FEED:		
PROPELLANT TANK	DUAL 8-IN. SHUTOFF VALVES	FLOW REQUIREMENTS, RELIABILITY
RUN TANK CONTROL	DUAL 8-IN. ANALOG CONTROL VALVES, SERVOMOTOR	OPERATIONS, RELIABILITY
PROPELLANT LEVEL — RUN TANK	THREE DISCRETE TYPE LIQUID - LEVEL SENSORS CONTROL ANALOG VALVES	OPERATIONS, RELIABILITY
PROPELLANT TANK EXIT	SUMP FITTING, ANTI-VORTEX FILTRATION SCREENS	MAXIMUM PROPELLANT USAGE, CONTAMINANT LIMITS
RUN TANK EXIT	SEPARATE DOME PENETRATIONS, ANTIVORTEX FILTRATION SCREENS	NERVA INTERFACE
PROPELLANT TANK — RUN TANK COUPLING	REMOTE MOTOR DRIVEN DUCT DEPLOYMENT, V-COUPLING DUAL STATIC SEALS, LINEAR COMPENSATOR, GIMBALS, 12-IN. LINES	DESIGN AND OPERATIONS TRADE STUDIES

MAIN PROPULSION-2

Characteristics of the pressurization and orbital fill subsystems for the RNS Class 1 Hybrid are shown in this chart. As described earlier in the operations analysis, a bootstrap startup is employed. Initial startup on propellant from the run tank is used until sufficient pressurization is obtained in the propellant module tank. At this time a pressure-fed transfer of propellant from the propellant module to the run tank is initiated. Pressure control on both tanks is located forward of the propellant tank with high pressure GH_2 from NERVA carried to the control location. This resulted in significant weight savings for the pressurant lines and reduction in envelope requirements. Strain gage sensors were used for pressure control to provide the accuracy desired for the propellant feed system. On-off control was selected for reliability purposes. Separate flowrates are provided for the startup and steady state operations. During the bootstrap operation 4 lb/sec are used while 0.6 lb/sec are required during full-power operation. The control level was selected as 0.4 lb/sec.

The orbital flow operations were described earlier with a low-g transfer mode selected. Injection into the propellant tank is by a spray nozzle which condenses the ullage and provides an adequate transfer rate for a non-vented transfer. A feedthrough is provided in the command and control module to allow direct docking between the RNS vehicle and the tanker without disassembly of the CCM. This simplifies the operations required for tanking and allows use of the CCM control functions during and between tanking operations.

MAIN PROPULSION -2 **CLASS 1-H RNS**

20664

FEATURE	SELECTION	BASES
PRESSURIZATION:		
START MODE	BOOTSTRAP -- START ON RUN TANK	OPERATIONS ANALYSES
CONTROL LOCATION	FORWARD ON TANKS, HIGH- PRESSURE TRANSFER	WEIGHT, ENVELOPE, PERFORMANCE
CONTROL	STRAIN GAGE SENSORS, ON-OFF CONTROL	ACCURACY, RELIABILITY
FLOW RATES	STARTUP -- 4 LB/SEC EXPULSION -- 0.6 LB/SEC CONTROL -- 0.4 LB/SEC	OPERATIONS ANALYSES
ORBITAL FILL:		
MODE	LOW g TRANSFER	OPTIMIZATION
INJECTION	SPRAY NOZZLE	CONDENSE ULLAGE
TANKER INTERFACE	CCM FEED THROUGH	SIMPLIFY OPERATIONS

MAIN PROPULSION-3

This chart contains additional propulsion system features for the RNS Class 1 Hybrid configuration. A pump-fed system is provided to refill the run tank before each major operation. This provides startup flexibility and optimum performance, but is not a flight critical system since a pressure fed refill could be accomplished. A transfer rate of 5 lb of LH₂ per second at a head of 3.5 psi was selected from combined system and operations analysis. Spray nozzle injection is provided to allow this transfer rate without a pressure buildup in the run tank.

A pump-fed recirculating chilldown system is provided for NERVA chilldown as well as for the main propellant feed system of the stage. This system significantly improves performance over that utilizing open loop chilldown. A bypass system is provided for aftercooling which utilizes a surface tension screen to collect liquid in the run tank.

A 2,900-lb disk shield resulted from the combined configuration/shield optimization study.

MAIN PROPULSION-3**RNS CLASS 1-H**

FEATURE	SELECTION	BASES
RUN TANK REFILL		
MODE	PUMP FED, SETTLED TRANSFER	FLEXIBILITY, PERFORMANCE
RATE	5 LB LH ₂ /SEC	OPERATIONS REQUIREMENTS
INJECTION	SPRAY NOZZLE	TRANSFER RATE, PERFORMANCE
NERVA/STAGE CHILLDOWN		
MODE	PUMP FED, RECIRCULATION, SETTLED	PERFORMANCE
RATE	2 LB LH ₂ /SEC	TIME
AFTERCOOLING		
MODE	BYPASS	CONTROL, RELIABILITY, RESIDUALS
COLLECTION	SURFACE TENSION SCREEN	PERFORMANCE
DISK SHIELD	2,900 LB	CONFIGURATION/SHIELD OPTIMIZATION

AUXILIARY PROPULSION

Features of the auxiliary propulsion subsystems for the RNS Class 1 Hybrid configuration are shown on this chart. The reaction control system is located on the command and control module to facilitate refurbishment and maintenance through ground recycle between all RNS missions. A cryogenic system was selected on the basis of performance. Propellant storage is integrated with that of the fuel cells to optimize combined weights. Propellant conditioning and thrusters were selected to be consistent with those proposed for the space shuttle which is a leading program. Thus, their development can be used for the RNS. Engine sizes were selected based upon performance and reliability. A total propellant requirement of 1,250 lb was found based upon mission requirements.

Propulsion module stabilization, employed during assembly and disassembly operations, is provided by a stored ambient gaseous hydrogen system utilizing NERVA recharge.

AUXILIARY PROPULSION

RNS CLASS 1-H

FEATURE	SELECTION	BASES
REACTION CONTROL SYSTEM:		
LOCATION	CCM	REFURBISHMENT, MAINTENANCE
TYPE	H ₂ /O ₂	PERFORMANCE
PROPELLANT STORAGE	LIQUID, INTEGRATED WITH FUEL CELL REACTANTS	WEIGHT
CONDITIONING	GAS GENERATOR DRIVEN TURBOPUMP, HEAT EXCHANGER, ACCUMULATORS	CONSISTENT WITH SELECTION FOR SPACE SHUTTLE
THRUSTERS	HIGH PRESSURE, RADIATION COOLED, TWENTY 50-LB THRUST TWO 1.3-LB THRUST	PERFORMANCE, RELIABILITY
PROPELLANT CAPACITY	1, 250 LB	MISSION REQUIREMENTS
PROPULSION MODULE STABILIZATION	STORED GH ₂ , NERVA RECHARGE	SIMPLICITY

ASTRIONICS

An autonomous guidance, navigation and control capability was selected with a ground-tracking backup capability for navigation. This selection will provide accuracies of approximately 0.1 nmi in position and 0.2 fps in velocity. The sensors for attitude include two star trackers, an IMU which consists of 6 redundant gyros in a strapped-down configuration and 12 accelerometers covering the 2 indicated ranges, and a horizon sensor for initial or coarse orientation. The star trackers have the capability of 4-arc-sec pointing accuracy and a field of view of about 1 degree on a gimbal platform that covers a ± 60 degree angle of view. Horizon sensor has a pointing accuracy of 0.1 degree and a conical field of view of 160 degrees using a gimbaled mount. These sensors are required whether ground assisted or autonomous navigation is selected. To implement autonomous navigation, an unknown landmark tracker was added. The landmark tracker is similar to the star tracker with a 4-arc-sec pointing accuracy and 120 degree field of view using gimbaled mounts. This sensor adds about 37 percent to the processing requirement of the guidance and navigation processing requirement but only about 12 percent to the total RNS processing requirement. The processing of all sensor data is accomplished in the data management subsystem. Each of the RNS modules contains optical corner cubes to allow for rendezvous and docking operations with a laser scanning radar. Redundant radar units are provided in the command and control module for rendezvous operations when the RNS is the active element.

ASTRIONICS

RNS CLASS 1-H

20660

FEATURE	SELECTION	BASES
GUIDANCE, NAVIGATION AND CONTROL:		
CAPABILITY	AUTONOMOUS WITH GROUND TRACKING BACKUP	STUDY GUIDELINES, MISSION FLEXIBILITY
OPTICAL SENSORS	LANDMARK TRACKER, HORIZON SENSOR, TWO STAR TRACKERS	PERFORMANCE
IMPULSE MANAGEMENT	12 ACCELEROMETERS – 6 WITH 1 TO 10^{-3} g RANGE, 6 WITH 10^{-3} TO 10^{-6} RANGE	MISSION REQUIREMENTS, AFTERCOOLING UTILIZATION
SHORT TERM ATTITUDE	6 GYROS IN REDUNDANT DODECAHEDRON STRAPDOWN CONFIGURATION	RELIABILITY
RENDEZVOUS	2 SCANNING LASER RADARS, OPTICAL CORNER CUBES	ACCURACY

ASTRIONICS-2

Astrionics system selections were made to satisfy the functional requirements of the RNS. Wherever practical these subsystems were located in the command and control module to minimize the radiation environment and to provide for a recycle capability each round trip so that redundancy, checkout, and maintenance operations would occur on the ground.

The command and control subsystem contains the communication equipment between the RNS and external system elements. Redundant S-band transmitters are provided to communicate vehicle status and performance information to the ground in a format compatible with DSIF/MSFN. Incoming data are received by one of the redundant receivers and decoded by the command decoders. Procedure modification, ground tracking update information, and emergency commands would be received via this link. The antenna complement would include two omni antennas for near Earth communications and one steerable, directional antenna for communications at lunar distance. All RNS data will be encoded in PCM format by encoders which format and address data for subsequent transmission.

Electrical power is supplied by redundant 2-kw fuel cells similar to those under development for the space shuttle. Each fuel cell will be capable of supplying the aftercooling power of 1.2 kw plus some nominal amount of battery recharge current for the secondary AgZn batteries which supply emergency and peaking power in the CCM and on the propulsion module.

The total power requirement for one lunar roundtrip is 317 kwh, corresponding to 250 lb of reactants and 100 lb of associated tankage for the fuel cells. The reactant storage is integrated with the APS tankage and is delivered at 100 psi and 300°R from the accumulator. DC to AC inverters are provided for the motor-driven valves in the RNS. Copper conductors were selected over aluminum because of the termination difficulties presently encountered with aluminum conductors. Polyimide insulation was selected for power wiring in the high-radiation environment of the propulsion module and kapton for the balance of the RNS. Intermodule connections are made using a motor-driven panel that contains the electrical connectors that must be made during assembly operations.

ASTRIONICS-2

RNS CLASS 1-H

FEATURE	SELECTION	BASES
COMMAND AND CONTROL	TRANSMITTERS RECEIVERS AND UPLINK COMMAND DECODER, PCM ENCODER, LOGIC DECODERS, CONTROLLERS	COMPATIBLE WITH DS IF/ MSFN AND DATA BUS
POWER:		
PRIMARY SUPPLY	TWO 2 KW FUEL CELLS, REGULATED CAPILLARY MATRIX TYPE, ALKALINE ELECTROLYTE	PHASE II, SYSTEM TRADE
SECONDARY	TWO Ag Zn RECHARGEABLE BATTERIES	EMERGENCY AND PEAKING POWER
CONDITIONING	INVERTERS - 400 Hz, 120V	VALVE OPERATION
CONDUCTORS	COPPER WITH KAPTON OR POLYIMIDE INSULATION	TERMINATION RELIABILITY, RADIATION EFFECTS
INTERMODULE CONNECTION	MOTOR-DRIVEN DEPLOYABLE PANEL	REMOTE ASSEMBLY

ASTRIONICS-3

The onboard checkout trade studies selected functional component checkout over the alternative of simulated operations. The onboard checkout procedures will be stored in the bulk storage of the data management subsystem and will be performed in the off-peak periods of the data management function. Components will be stimulated using the normal operational control channels and the normal data acquisition channels will be used for data. Capability for fault prediction is provided for 100 functions onboard with ground processing of trend data transmitted during the previous mission. The emergency detection concept provides hardware signals to the command and control module where an independent emergency detection processor is located. The emergency detection system is capable of detecting and removing a fault independent of the primary data management subsystem and associated data bus.

Requirements for the data management subsystem, excluding NDICE, total 241,000 operations per second with a storage requirement of 27,650 words of high-speed storage. This relatively modest computing requirement can be satisfied by one processor with an add time of approximately 4 microseconds. Based on these requirements, a centralized approach to data management was selected. To achieve the reliability requirements of 0.9976 for the data management subsystem, a second redundant computer is incorporated in the baseline design. Each computer must have an MTBF of 38,500 hours. Bulk storage of approximately 10^6 bits is provided to accommodate the checkout and operational procedures.

The information distribution between modules and between subsystems uses a data bus concept. The requirement of 0.5-MHz data rate for the data bus has been established based on the development vehicle instrumentation list of 1,152 parameters. To satisfy the RNS requirements, eight data bus terminals are incorporated: two on the propulsion module, two on the propellant module, and four in the command and control module. One data bus terminal on each of the propulsion module and the command and control module are dedicated to the NDICE. The baseline design of the data management subsystem allows for an autonomous processor associated with the NDICE for control of the engine functions. The use of the data bus concept minimizes the interconnections between modules to redundant coaxial connections and the related emergency detection functions.

ASTRIONICS-3**RNS CLASS1-H**

FEATURE	SELECTION	BASES
ONBOARD CHECKOUT	FUNCTIONAL COMPONENT CHECK- OUT, STORED PROCEDURES, USE OF NORMAL DATA AND CONTROL CHANNELS, FAULT PREDICTION	TRADE STUDY
EMERGENCY DETECTION	DISCRETE, REDUNDANT HARDWIRE	SAFETY
DATA MANAGEMENT:		
PROCESSOR	CENTRALIZED, REDUNDANT, 4- μ SEC ADD TIME	TRADE STUDY, COMPUTING REQUIREMENTS
BULK STORAGE	10 ⁶ BIT CAPACITY	STORAGE REQUIREMENTS
DISTRIBUTION	DATA BUS -- 0.5 MHz RATE, 8 TERMINALS	INSTRUMENTATION REQUIREMENTS
NDICE INTERFACE	DEDICATED DATA BUS TERMINALS, AUTONOMOUS PROCESSOR	NERVA REQUIREMENTS
INTERMODULE CONNECTION	DEPLOYED PANEL, TWO REDUNDANT CONNECTORS	REMOTE ASSEMBLY

CLASS 3 RNS

This chart shows the final baseline configuration for the Class 3 RNS concept. Clustering of outboard propellant modules into a cruciform configuration at the second propellant module level is illustrated. Comparison with the previous sketch shows how both RNS concepts have converged in their characteristics by definition of the functional modules. It can be seen that the only basic difference between the two concepts is the manner in which propellant is stored—within the multiple modules in this case and in the single propellant module for the Class 1 Hybrid.

The main feed system, providing communication from any propellant module to the run tank on the propulsion module, is shown in this figure. Other details are noted by the callouts. Again, this sketch should be used as a locator for the discussion of design features.

CLASS 3 MULTI-MODULE RNS

STRUCTURAL FEATURES

Some of the unique structural features of the RNS Class 3 configuration are shown on this chart. The selection of a central column containing the propulsion module, four propellant modules, and a command and control module was made during Phase II on the basis of shielding optimization and vehicle stability. This selection was verified during Phase III. Selection of a cruciform cluster at the second tier of propellant modules for the outboard modules was made during Phase III as a result of trade studies conducted on vehicle assembly. The same run tank dimensions were selected for this concept as for the Class 1 Hybrid based upon the same tradeoffs between shielding and operations analysis.

The propellant tank employed an isotropic waffle pattern as stiffening to accommodate the launch loads within the space shuttle. Single-piece hemispherical domes are used to minimize weight and manufacturing costs.

Other structural subsystems are of the same type as those selected for the Class 1 Hybrid with the exceptions of no requirements for heat blocks or outriggers for the APS engines.

STRUCTURAL FEATURES

RNS CLASS 3

FEATURE	SELECTION	BASES
CONFIGURATION:		
CENTRAL COLUMN	PROPULSION MODULE, FOUR PROPELLANT MODULES, CCM	PHASE II, SHIELDING, STABILITY
OUTBOARD MODULES	CRUCIFORM CLUSTER	ASSEMBLY OPERATIONS
RUN TANK DIMENSIONS	23 FT LONG, 160 IN. DIA	SHIELDING/OPERATIONS OPTIMUM
PROPELLANT TANK CONSTRUCTION:		
CYLINDERS	ISOTROPIC WAFFLE PATTERN	LAUNCH LOADS, DESIGN OPTIMUM
DOMES	SINGLE PIECE, HEMISPHERICAL	MANUFACTURING ECONOMY, WEIGHT OPTIMUM
OTHER STRUCTURAL SUBSYSTEMS:	SAME AS CLASS 1-H WITH DELETION OF HEAT BLOCKS AND APS OUTRIGGERS	

THERMAL/METEOROID PROTECTION

Features for the thermal/meteoroid protection subsystem of the RNS Class 3 are shown in this chart. The same basic configuration is used for this concept as for the Class 1 Hybrid. The different thicknesses are also shown in the chart. The inboard modules employ 48 layers of insulation while the outboard modules only require 30 layers. The meteoroid protection subsystem is designed to a survival probability of 0.995. The fiber glass outer shroud is only required for meteoroid protection since the module is protected within the cargo bay of the space shuttle during launch.

THERMAL/METEOROID PROTECTION

RNS CLASS 3

FEATURE	SELECTION	BASES
INSULATION:		
MATERIAL	DAM/NET	PHASE II
THICKNESSES:		
INBOARD MODULES	0.50 IN., 48 LAYERS, 3 BLANKETS	THERMAL/STRUCTURAL OPTIMUM
OUTBOARD MODULES	0.31 IN., 30 LAYERS, 3 BLANKETS	THERMAL/STRUCTURAL OPTIMUM
ATTACHMENT AND PURGE	SAME AS CLASS 1-H	
METEOROID PROTECTION:		
FLEXIBLE FOAM	2-IN. THICK, 1.2 LB/ CU FT	CONFIGURATION-- PHASE II TESTS, SURVIVAL PROBABILITY-- 0.995
SHROUD	0.010 IN. FIBERGLASS LAMINATE	

OTHER DESIGN FEATURES

Other RNS subsystem design features for the RNS Class 3 are similar to those selected for the Class 1 Hybrid. The main propulsion system provides individual access to each propellant module for pressurization and propellant feed. No disk shield is required for this configuration and a maximum pressurant flow rate is the same during startup and operation at 0.6 lb of LH_2 per sec.

With this configuration no outriggers are required for the APS engines and 14 data bus terminals are provided for communication between all modules.

OTHER DESIGN FEATURES

RNS CLASS 3

FEATURE	SELECTION	BASES
MAIN PROPULSION	SAME EQUIPMENT AS CLASS 1-H INDIVIDUAL ACCESS TO EACH PROPELLANT MODULE NO DISK SHIELD MAXIMUM PRESSURANT FLOW RATE - - 0.6 LB LH ₂ /SEC	OPERATIONS ANALYSES PHASE II, CONFIGURATION OPTIMIZATION OPERATIONS ANALYSES
AUXILIARY PROPULSION	SAME AS CLASS 1-H NO OUTRIGGERS	
ASTRIONICS	SAME AS CLASS 1-H 14 DATA BUS TERMINALS	

RNS DESIGN SUMMARY

The configurations selected for both concepts in Phase II were confirmed during the Phase III design activities. The importance of including shielding within the basic vehicle configuration optimization was established. Launch of the Class 1 Hybrid propellant module does not require any structural modifications for the Saturn V INT-21 launch vehicle. The minimum launch availability of 0.84 during winter wind conditions is considered adequate for the RNS system.

The orbital operations required for remote assembly and refurbishment of the RNS vehicle are considered feasible and within the projected state of the art for the RNS program. Maximum use has been made of developments from leading programs such as Saturn and the Space Shuttle. Redundancy has been employed extensively in the design and wherever possible a fail operational—fail safe criterion has been applied.

The 10,000-lb weight advantage of the Class 1 Hybrid configuration compared with Class 3 is considered to represent the inherent difference between the concepts since the same ground rules and design approaches were used for both concepts.

RNS DESIGN SUMMARY

- PHASE II CONFIGURATION SELECTIONS CONFIRMED
SHIELDING INCLUDED IN OPTIMIZATION
- NO STRUCTURAL MODIFICATIONS REQUIRED FOR INT-21
MINIMUM LAUNCH AVAILABILITY--0.84
- REMOTE ASSEMBLY AND REFURBISHMENT
WITHIN PROJECTED STATE OF THE ART
- MAXIMUM USE OF LEADING PROGRAMS
SATURN--SPACE SHUTTLE
- EXTENSIVE USE OF REDUNDANCY
FAIL OPER - FAIL OPER - FAIL SAFE
- 10,000-LB WEIGHT ADVANTAGE FOR CLASS 1-H
SAME GROUND RULES FOR BOTH CONCEPTS

PROGRAM SUMMARY

The subjects discussed during the Program Summary portion of the briefing are listed in the order of presentation. The information presented in these areas was generated as a result of performing Tasks 2, 4, 5, 6, 7, and 8 of the Phase III Study effort. The level of effort applied to each task was consistent with the study objective of completing a Phase A conceptual definition of two RNS concepts, which MDAC has identified as the Class 1 Hybrid and the Class 3. Programmatic requirements and characteristics have been treated as common to both concepts where feasible, with unique considerations for each concept handled as required.

PROGRAM SUMMARY

- TEST REQUIREMENTS
- MANUFACTURING REQUIREMENTS
- PRELAUNCH AND SUPPORT OPERATIONS
- FACILITIES DEFINITION
- SUPPORTING RESEARCH AND TECHNOLOGY REQUIREMENTS
- PROGRAM MILESTONES AND SCHEDULES
- PROGRAM COSTS

TEST REQUIREMENTS

The test requirements effort was initiated with Subtask 4.1, Test Definition, which was performed with a bottom-up approach utilizing two types of work sheets. The test item work sheet considered each test item (a group of identical components utilized on the RNS) and discussed the specific testing that would be performed on the component. Research and technology, development, qualification, and reliability testing were discussed at the component, subsystem, and system level.

The system test candidate work sheets investigated the individual subsystem and system tests that could be considered in this type of program. Each test was discussed to delineate the reason for the test, the expected results, the worth of the test, and alternatives to the test.

The results of the test definition subtask were used to develop an Integrated Test Plan which delineates the ground test and the flight test plans. Development, qualification, and acceptance testing were discussed.

A reliability test plan has been included in the Integrated Test Plan. This reliability plan was developed from the reliability allocations for each test item and the confidence level determined by the location on the RNS and the degree of difficulty of maintenance.

Test hardware requirements and ground support equipment requirements were also defined for the Integrated Test Plan.

TEST REQUIREMENTS

- TEST DEFINITION EFFORT

- INTEGRATED TEST PLAN (GROUND AND FLIGHT)

DEVELOPMENT

QUALIFICATION

ACCEPTANCE

- RELIABILITY TEST PROGRAM DEFINITION

- TEST HARDWARE REQUIREMENTS

- GSE REQUIREMENTS

COMPONENT AND SUBSYSTEM TESTING

Component tests were defined in the Integrated Test Plan in narrative form and on test matrix sheets which delineate the test item, the type of test (qualification, development, etc.), the number of test items and the imposed environment for structural, functional and repeated cycle testing. These data also appear in the test item work sheets.

Subsystem testing will be conducted in three test facilities which MDAC has identified as required. A Systems Integration Laboratory (SIL) will consist of an active mockup of the electrical and electrical/mechanical components. This mockup will be used to investigate the electrical interface between components, subsystems, systems, modules, and between the stage systems and the NDICE under normal and abnormal conditions. The interface and operation of the ground support electronics will be developed and qualified in this facility.

A Propulsion Integration Laboratory (PIL) will be constructed at MDAC Sacramento based upon the use of an existing facility to investigate the mechanical and fluid interfaces and the operation of the stage propulsion systems. The various propulsion system components will be placed in a mockup which simulates the physical arrangement in the RNS. Actual and simulated tanks will be employed. The systems will then be subjected to normal and extended parameter testing under ambient and cryogenic conditions. Liquid hydrogen will be employed to investigate chilldown and propellant transfer operations.

The special docking simulator will be capable of simulating the various docking maneuvers to investigate and qualify the docking and mating hardware. Full-size and mass simulated modules will be employed.

COMPONENT AND SUBSYSTEM TESTING

COMPONENT TESTS

- STRUCTURAL
- FUNCTIONAL
- RELIABILITY

SUBSYSTEM TESTS

- SYSTEMS INTEGRATION LABORATORY
ELECTRICAL/MECHANICAL INTERFACE DEVELOPMENT AND QUALIFICATION
- PROPULSION INTEGRATION LABORATORY
MECHANICAL/FLUID FUNCTIONAL TESTING
- SPECIAL DOCKING SIMULATOR
DOCKING AND MATING OPERATIONS DEVELOPMENT

SYSTEM LEVEL TESTING

A battleship test program will be conducted in E/STS-2 at NRDS. The test article will consist of development level hardware which has successfully completed the component and subsystem (SIL, PIL) testing. Heavy-wall tankage will be used to allow extended parameter testing. Safety systems will be incorporated to allow malfunction simulation.

The Battleship Test Program will be conducted in two phases, a facility (E/STS-2) activation and cold flow phase with a NERVA simulator and a hot firing phase with a prequalification NERVA.

The test program will investigate and demonstrate normal integrated engine/stage operation and extended parameter (high pressure, low pressure, high temperature, low NPSH, etc.) operation. Abnormal operations (emergency mode, malfunction mode, etc.) will be demonstrated in conjunction with specific induced malfunctions.

The All Systems Test Program will be the final qualification of the RNS before flight. The test program will have a cold-flow phase with a NERVA simulator and a hot firing phase with a qualification level NERVA. Normal operation will be demonstrated and the engine/stage interface will be verified. A lunar shuttle mission will be simulated to an extent dictated by the facility limitations. Extended parameter and induced malfunctions will be limited by the flight-weight tanks and the limited safety systems, but safety and abort systems will be demonstrated.

SYSTEM LEVEL TESTING

BATTLESHIP TEST PROGRAM - DEVELOPMENT

PHASES

- COLD FLOW (NEVRA SIMULATOR)
- HOT FIRING (NERVA - PREQUALIFICATION ENGINE)

TYPE OF TESTS

- NORMAL INTEGRATED ENGINE/STAGE OPERATIONS
- NOMINAL VERIFICATION OF NERVA/STAGE INTERFACE
- EXTENDED PARAMETER TESTING
- ABNORMAL OPERATIONS (SAFETY/ABORT CONSIDERATIONS)

ALL SYSTEMS TEST PROGRAM - QUALIFICATION

PHASES

- COLD FLOW (NERVA SIMULATOR)
- HOT FIRING (NERVA - QUALIFICATION ENGINE)

TYPES OF TESTS

- NORMAL INTEGRATED ENGINE/STAGE OPERATIONS
- FINAL VERIFICATION OF NERVA/STAGE INTERFACE
- MISSION SIMULATION
- ABNORMAL OPERATIONS (SAFETY/ABORT CONSIDERATIONS)

FLIGHT TEST PROGRAM

The Flight Test Program has been designed to complete the qualification program by an operational demonstration of the component, subsystem, and systems that cannot be qualified in the ground test program due to lack of zero-gravity, lack of other space environmental conditions, and facility limitations. This includes the NERVA Category III testing and demonstrations of mission performance capability and abort/safety systems.

The Flight Test Program procedures were evolved to provide as safe a flight test as possible. The recommended philosophy is to evolve from the simple operation to the more complex operations. For example, the tank pressure idle mode is recommended to raise the RNS to a "safe" orbit prior to attempting turbopump or high-power NERVA operations. The subsequent operations evolve from this idle mode operation to full-power operation with induced malfunctions in a series of steps which allow data reduction and evaluation before a more complex (and less safe) operation is attempted.

Emergency and malfunction modes and other abort operations will be demonstrated. All RNS requirements except the 10-hour NERVA lifetime and the space storage times will be demonstrated during the flight test program.

A second flight test will perform essentially the same procedures as the first flight to demonstrate repeatability. This could be performed with the same RNS after a resupply phase or preferably with a second RNS.

move to
500 n mil
for 2 steps
to the use
roll mode
- unmanned
earth orbit
18 mps

FLIGHT TEST PROGRAM

TEST OBJECTIVES

- COMPLETION OF QUALIFICATION PROGRAM
- NERVA CATEGORY III TESTING
- DEMONSTRATION OF MISSION PERFORMANCE CAPABILITY
- DEMONSTRATION OF SYSTEM SAFETY

TEST PROCEDURES

- SEQUENCE DICTATED BY SAFETY CONSIDERATIONS
- PROGRESSION FROM SIMPLE TO COMPLEX OPERATIONS
IDLE MODE, NORMAL STARTUP, FULL POWER, AFTERCOOLING
INDUCED MALFUNCTIONS - EMERGENCY MODE, ABORT OPERATIONS
- DEMONSTRATION OF ALL RNS REQUIREMENTS EXCEPT LIFETIME
- DEMONSTRATION OF REPEATABILITY WITH SECOND FLIGHT

TIME SPAN - APPROXIMATELY 18 MONTHS

TEST HARDWARE - 2 RNS SYSTEMS (1 EQUIVALENT MISSION EACH)

EXPLODED VIEW—CLASS 1 HYBRID RNS PROPELLANT MODULE

An exploded view of the Class 1 Hybrid propellant module is shown here, including the launch interstage. The propellant tank is fabricated from 2014-T6 aluminum alloy, and features the use of integrally machined isogrid patterns on the inner walls of the cylindrical sections and the truncated conical section to provide sufficient stiffness for unpressurized handling of the tank and to withstand the launch loads. Forged Y-rings are used to provide the transition between domes and tank sections and facilitate the assembly operation. The cylindrical and conical tank sections are each fabricated from five longitudinal segments, which are welded together in a horizontal position using a Pandjiris welder. The hemispherical domes are welded up from gore segments which have been formed to the desired radius of curvature using a drape-forming technique.

All heatblocks depicted here are fabricated from fiber glass honeycomb material, and are designed as load-carrying structural members. The intermodule thrust structure and payload adapter are also fabricated from fiber glass material, with the thrust structure utilizing a fiber glass epoxy composite material. Fiber glass is also employed, in combination with flexible foam, for the thermal/meteoroid protection system shroud.

The launch interstage is fabricated from 7075-T73 aluminum alloy, and features longitudinal segments, integrally machined on the exterior, and mechanically fastened to internal stiffener rings.

*Tooling cost \$2.2M
Mfg site Michoud*

EXPLODED VIEW -- CLASS 1 HYBRID RNS PROPELLANT MODULE

EXPLODED VIEW-PROPULSION MODULE

The structural assembly of the propulsion module is shown here in exploded form. The propellant tank is fabricated from 2014-T6 aluminum alloy, and it features an integrally machined isogrid pattern on the inner surface of the cylindrical section, which is comprised of two longitudinal segments that are drape-formed and welded in a horizontal position. Single-piece hemispherical forgings are used to machine the forward and aft domes, and attach points for the thrust structure are an integral part of the domes.

Fiber glass epoxy is used to fabricate the engine upper thrust structure and forward interstage, and fiber glass, in combination with flexible foam, is used for the thermal/meteoroid protection system shroud.

MF8 Huntington Beach

EXPLODED VIEW -- PROPULSION MODULE CLASS 1 HYBRID AND CLASS 3 RNS

EXPLODED VIEW—COMMAND AND CONTROL MODULE STRUCTURE

The command and control module structure consists basically of a hollow cylinder, some internally mounted equipment racks around the perimeter, and outriggers for the attitude control nozzles (Class 1 Hybrid only). The cylindrical section is fabricated from 2014-T6 aluminum alloy, and is made up of two longitudinal segments which are integrally machined with an isogrid pattern for stiffening and welded while in a horizontal position. A forward and aft frame are also used to provide additional stiffening to the structure.

EXPLODED VIEW -- COMMAND AND CONTROL MODULE STRUCTURE

CLASS 1 HYBRID AND CLASS 3 RNS

MANUFACTURING SITE COMPARISON

Five options for the fabrication and final assembly of the Class 1 hybrid RNS were examined as part of the manufacturing requirements effort (Task 5), with the objective of choosing a combination of manufacturing methods and manufacturing locations which was the most cost effective and the most technically sound. Facilities and tooling considerations proved to be the most crucial factors affecting the program cost, with the manufacturing methods being constant for all locations. The alternative manufacturing plans considered for the Class 1 hybrid were:

Option 1—Fabricate and assemble the complete vehicle at the NASA-Michoud Facility.

Option 2—Fabricate details at Huntington Beach, assemble the propellant module at Michoud, assemble the Propulsion module and the Command and Control Module at Huntington Beach.

Option 3—Fabricate and assemble the complete vehicle at the NASA-Seal Beach Facility.

Option 4—Fabricate all details at Huntington Beach, assemble the propellant module at Seal Beach, assemble the propulsion module and the command and control module at Huntington Beach.

Option 5—Fabricate and assemble the complete vehicle at Huntington Beach.

The propellant module tooling estimate for the complete initial tooling effort is approximately \$16 million for options 1 and 2—both of which involve final assembly at the NASA Michoud Facility. The comparable estimate for the necessary tooling for options 3 and 4 in which Seal Beach Facilities are used comes to approximately \$19.3 million, with the estimated increase over Michoud being attributable in part to the expensive weld fixtures required for joining the forward dome to the forward Y-ring and the fixtures for trimming the welded dome. In contrast, the Huntington Beach option requires a complete set of new tooling for all assembly operations, with a total estimated cost of \$25. million. The differences between these tooling cost and those tabulated in the figure account for the propulsion module and command and control module tooling cost estimates, which are carried at a constant \$6 million for all options.

MANUFACTURING SITE COMPARISON

CLASS 1 HYBRID RNS

CATEGORY	MICHOUD OR HB/MICHOUD \$ M	SEAL BEACH OR HB/SEAL BEACH \$ M	ALL HB \$ M
TOOLING	22.0	25.3	31.0
NONSEVERABLE FACILITIES (BUILDING AND STRUCTURES)	1.8	5.1	6.5
SEVERABLE FACILITIES (MACHINERY AND EQUIPMENT)	2.8	3.5	3.5
TOTAL COST (MILLIONS OF 1971 DOLLARS)	26.6	33.9	41.0

The Huntington Beach/Michoud and all Michoud options feature the lowest costs for buildings and structure, since the only modifications required are to modify existing final assembly towers to provide an environmentally controlled atmosphere and to increase the height of the hydrostatic test facility to accommodate the length of the propellant module.

The Huntington Beach/Michoud option is recommended for manufacturing the Class 1 Hybrid RNS, based on the comparative economics discussed above, as well as the desire to locate production activities near engineering as much as practically possible. Also, this approach will minimize the potential impact of a joint utilization of the Michoud Facility by the RNS and Space Shuttle.

BLANK

CLASS 1 HYBRID RNS PROPELLANT MODULE ASSEMBLY-1

The assembly of the Class 1 Hybrid propellant module involves operations at MDAC Huntington Beach and NASA-Michoud. The forward dome is welded up at Michoud utilizing appropriate S-IC tooling available there. The construction is complicated by the requirement to provide a structural attachment for the payload adapter directly in the dome itself. The sequence of operations required is depicted in the flow diagrams.

The tank segments for both cylindrical and truncated tank sections are machined and formed at Huntington Beach after which the cylindrical section is welded in a Pandjiris at Michoud, trimmed, and welded to the forward dome. The truncated section is welded in a Pandjiris at Huntington Beach, mated with a Y-ring, shipped to Michoud, and mated with the cylindrical section. The welding is done in a horizontal position as much as possible to allow downhand welding and the associated benefits, e. g., high quality welds, accruing from this technique; however, welding in a vertical position is still required for final assembly.

CLASS 1 HYBRID RNS PROPELLANT MODULE ASSEMBLY-1

HUNTINGTON BEACH - MICHLOUD OPTION

CLASS 1 HYBRID RNS PROPELLANT MODULE ASSEMBLY-2

The continuation of the Class 1 Hybrid propellant module manufacturing operations features the fabrication of the aft dome and the closeout welding of the dome to the inverted propellant module, followed by tank cleaning, leak test, and hydrostatic test.

Subsequent to hydrostatic testing of the tank, the remaining operations are all performed in a clean room type, controlled environment with the module in a vertical position. The controlled environment is required to prevent contamination of the sensitive aluminized Mylar used for insulation.

CLASS 1 HYBRID RNS PROPELLANT MODULE ASSEMBLY-2

20647

HUNTINGTON BEACH - MICHLOUD OPTION

EXPLODED VIEW—CLASS 3 RNS PROPELLANT MODULE

The exploded view of the propellant module shown here depicts the major structural elements that are in the current definition of the module. The propellant tank is fabricated from 2014-T6 aluminum alloy, and features the use of integrally machined isogrid patterns on the inner walls of the cylindrical section to provide sufficient stiffness for handling the tank in an unpressurized condition and for withstanding design loads during launch. The cylindrical section of the tank is fabricated from three longitudinal segments which are drape formed and welded in a horizontal position using a Pandjiris welder. Single-piece forgings are used for the domes, with machining as required to form interstage attach points as integral parts of the domes. Chem milling is used to reach the desired skin gages for the domes.

Fiber glass epoxy is used for the forward and aft interstage structure, and fiber glass, in conjunction with flexible foam, is employed for the thermal/meteoroid protection system shroud.

EXPLODED VIEW -- CLASS 3 RNS PROPELLANT MODULE

RNS MODULE FABRICATION SEQUENCE

The fabrication sequence for the propulsion module of both RNS concepts and the Class 3 propellant module is the same, the only difference being in the size of the modules. The process for converting the single-piece forgings from the 2014-T3 aluminum alloy as-received condition to finished domes involves several machining steps because of the thin gage required in the finished product. The chem-milling process is used to remove the last material.

For the tank segments, the material is received in the age hardened (T6) condition, and the isogrid pattern is machined into the skins before drape-forming, trimming, and welding up the cylindrical section.

The hydrostatic test operation illustrated here can be performed in the existing hydrostatic test tank at Huntington Beach. The welding operations are all performed in a horizontal, down hand position.

RNS MODULE FABRICATION SEQUENCE

CLASS 3 PROPELLANT MODULE AND PROPULSION MODULES

FWD & AFT DOMES

TANK SEGMENTS

RNS MODULE FINAL ASSEMBLY SEQUENCE

The continuation of the manufacturing process for the propulsion module tankage and the Class 3 propellant module features the installation of the thermal protection system on the tank exterior while in a vertical position. A clean room environment is required for this operation to prevent contamination of the layers of doubly aluminized Mylar used in the insulation system. Installation with the tank in a vertical position has been chosen to facilitate handling of the fragile insulation blankets, which will have a tendency to sag during an attempt to install the insulation with the module in a horizontal position. Subsequent to the shroud installation, other structural elements and functional hardware are installed prior to a dry systems checkout and shipment for cold flow production acceptance testing.

RNS MODULE FINAL ASSEMBLY SEQUENCE

CLASS 3 PROPELLANT MODULE AND PROPULSION MODULES

MANUFACTURING PROGRAM SUMMARY

The manufacturing conclusions and recommendations for the two RNS concepts are tabulated here, in addition to the estimated tooling, facilities, and equipment costs. The recommended philosophy for both concepts is to utilize large sheet sizes (210 by 1,440 inches) where possible to reduce the number of parts, and to utilize advanced concepts, such as machining single-piece domes from forgings where feasible, to decrease the number of parts, reduce the amount of welding, and consequently increase the quality of the finished product.

The rationale for choosing the Huntington Beach/Michoud option for manufacturing the Class 1 Hybrid RNS was explained on the previous chart and will not be repeated here. For the Class 3 RNS, it appears that all of the fabrication and final assembly operations can be performed within existing manufacturing facilities at Huntington Beach. The combination of this factor with the desire to collocate engineering and production activities makes the Huntington Beach location very attractive for the Class 3 RNS.

The estimated costs for machinery and equipment (severable facilities) are the same for both concepts, with the new numerically controlled skin mill (\$2 million) accounting for the majority of the total estimate.

MANUFACTURING PROGRAM SUMMARY

ITEM	CLASS 1 HYBRID	CLASS 3
RECOMMENDED MFG PHILOSOPHY	UTILIZE LARGE SHEET SIZES AND SINGLE-PIECE DOMES, WHERE FEASIBLE	UTILIZE LARGE SHEET SIZES AND SINGLE- PIECE DOMES
RECOMMENDED MFG SITE	HUNTINGTON BEACH/MICHOUD	HUNTINGTON BEACH
ESTIMATED TOOLING COSTS	\$22.0 MILLION	\$17.6 MILLION
ESTIMATED MFG FACILITIES COSTS	\$1.8 MILLION	
ESTIMATED MFG MACHINERY AND EQUIPMENT COSTS	\$2.8 MILLION	\$2.8 MILLION

PRELAUNCH OPERATIONS SUMMARY

The prelaunch operations task of the Phase III study was performed with the objectives of recommending acceptance test sites, a reactor criticality test site, engine/stage mating site, transportation modes, and storage sites for the RNS modules between completion of manufacture and operational use. The results of the study effort are tabulated for each concept on the opposite page.

L+1₂ test

MDAC is recommending a dry functional subsystems checkout of the Class 1 Hybrid propellant module at Michoud following final assembly, as well as a cold flow test at MTF. The recommended approach to testing at MTF is to perform tanking, detanking, vent system operation, etc., in a simplified tower structure, constructed adjacent to one of the existing S-II test stands which utilizes the cryogenic storage and supply system, as well as instrumentation and control systems presently in existence, as much as practical. This appears to be a viable approach in light of the uncertainty of projected shuttle program utilization of the MTF test stands. The use of the same facility for performing cold flow tests of the propulsion module run tank is recommended following dry functional subsystems checkout at Huntington Beach. For the Class 3 configuration, a dry functional subsystems checkout of the propellant and propulsion module tankage at Huntington Beach following final assembly is recommended, followed by cold flow tests at Sacramento in a modified Beta test stand complex. Only a dry functional subsystem checkout at MDAC-HB is required for the command and control module.

Reactor criticality testing is not recommended after engine/stage mating for either concept. Engine/stage mating operations are recommended to be performed at KSC in a VAB low bay checkout cell. This approach is consistent with minimizing the movement of NERVA after assembly at NRDS.

Transportation modes recommended for the Class 1 Hybrid include the use of barges for moving the propellant module between Michoud, MTF, and KSC, using aircraft for transporting the propulsion module run tank to MTF, a barge for moving propulsion modules between MTF and KSC, and aircraft for moving the command and control module. A helicopter is recommended for transporting the all system test vehicle propellant module to NRDS from southern California after moving by barge from Michoud. Aircraft are recommended for transporting single Class 3 propellant and propulsion modules from Huntington Beach to Sacramento, followed by barge transportation of multiple modules from Sacramento to KSC. Either the pregnant Guppy or Super Guppy aircraft can be utilized.

PRELAUNCH OPERATIONS SUMMARY

PROGRAM ITEM	CLASS 1 HYBRID	CLASS 3
<ul style="list-style-type: none"> • ACCEPTANCE TEST SITE <ul style="list-style-type: none"> PROPELLANT MODULE PROPULSION MODULE (RUN TANK ONLY) COMMAND AND CONTROL MODULE • REACTOR CRITICALITY TESTING ENGINE/STAGE MATING SITE • TRANSPORTATION <ul style="list-style-type: none"> PROPELLANT MODULE PROPULSION MODULE (RUN TANK ONLY) COMMAND AND CONTROL MODULE • STORAGE SITE <ul style="list-style-type: none"> PROPELLANT MODULE PROPULSION MODULE (RUN TANK ONLY) COMMAND AND CONTROL MODULE 	<ul style="list-style-type: none"> MICHOUD/MTF HB/MTF HB NONE RECOMMENDED AFTER ENGINE/ STAGE MATING KSC BARGE, HELICOPTER AIRCRAFT, BARGE AIRCRAFT MICHOUD MICHOUD HB 	<ul style="list-style-type: none"> HB/SACTO HB/SACTO HB NONE RECOMMENDED AFTER ENGINE/ STAGE MATING KSC AIRCRAFT, BARGE AIRCRAFT, BARGE AIRCRAFT SACTO HB HB

SPACE SHUTTLE REQUIREMENTS

The number of space shuttle flights required to support the four mission rates have been determined for each RNS concept. The impact of increased shuttle payload capability has also been assessed. The total flights required for RNS deployment include consideration of module delivery to orbit, as well as propellant topping required before the initial mission of an RNS. The number of RNS systems deployed for the four mission rates are determined by a 10-mission lifetime for each RNS and a 10-year operational program. This results in 2, 4, 6, and 8 RNS systems being required. The operational support category includes propellant resupply, command and control module recycle operations, and payload support. For the purposes of this study, a full space shuttle flight is charged for each CCM delivery or recycle operation. Future mission planning may enable a reduction in these requirements through a possible sharing of Space Shuttle Flights, since the CCM does not require the total space shuttle capability.

A utilization schedule for the RNS was identified for the candidate traffic models of 2, 4, 6, and 8 missions per year during the study. The resulting time in Earth orbit in which the turnaround activity can be performed on a noninterference basis is given below. The required space shuttle launch rates for 33K and 50K versions are also shown.

RNS Mission Rate (Flights/year)	Available Turnaround Time (days)	Required Space Shuttle Launch Rate (days between launches)	
		<u>33K</u>	<u>50K</u>
2	138.7	9.9	12.6
4	81.9	5.8	7.4
6	54.6	3.9	5.0
8	41.3 (min.)	2.9	3.8

The RNS turnaround operations require the following number of space shuttle launches per mission:

33K Shuttle — 14 Flights (10 for propellant, 3 for payload, and 1 for CCM)

50K Shuttle — 11 Flights (8 for propellant, 2 for payload, and 1 for CCM)

SPACE SHUTTLE REQUIREMENTS

MISSION RATE (FLIGHTS PER YEAR)	2		4		6		8	
SPACE SHUTTLE CAPABILITY (1,000 LB)	33	50	33	50	33	50	33	50
RNS DEPLOYMENT								
CLASS 1 HYBRID	18	14	36	28	54	42	72	56
CLASS 3	24	22	48	44	72	66	96	88
RNS OPERATIONAL SUPPORT								
CLASS 1 HYBRID OR CLASS 3	258	202	516	404	774	606	1,032	808
TOTAL SHUTTLE FLIGHTS FOR 10-YEAR PROGRAM								
CLASS 1 HYBRID	276	216	552	432	828	648	1,104	864
CLASS 3	282	224	564	448	846	672	1,128	896

TEST FACILITY SUMMARY

The test facility requirements resulting from the testing task performed during the study were examined to determine the recommended approach to fulfilling the requirements for each RNS concept. The majority of test facility requirements are common to both systems, with some slight differences reflecting the specific system characteristics.

The Systems Integration Laboratory was identified as a necessary test facility for use as an active mockup of the electrical and electrical/mechanical components of the RNS. Existing floor space within Building 22 will accommodate these requirements. The use of an existing test stand, with modifications, is recommended to fulfill the Propulsion Integration Laboratory requirements. The Special Docking Simulator identified for performing tests to verify docking procedures, systems, and interfaces will require a tower or towers to permit suspension of modules or mass simulators. This facility is recommended for location at Huntington Beach. Systems development and qualification tests with NERVA are recommended at NRDS in E/STS-2. Production acceptance tests for the Class 3 propellant and propulsion modules are recommended at Sacramento in the PIL following component and subsystem test programs, while construction of a separate test structure on-site at MTF is recommended for use in production acceptance testing of the Class 1 Hybrid modules.

TEST FACILITY SUMMARY

CLASS 1 HYBRID AND CLASS 3 RNS

REQUIREMENT	RECOMMENDATION
• SYSTEMS INTEGRATION LABORATORY (SIL)	USE EXISTING FACILITIES (BLDG 22) AT HB
• PROPULSION INTEGRATION LABORATORY (PIL)	USE EXISTING TEST FACILITY (BETA COMPLEX) AT MDAC-SACTO AND MODIFY AS REQUIRED
• SPECIAL DOCKING SIMULATOR (SDS)	CONSTRUCT FACILITY AT HB
• SYSTEM DEVELOPMENT AND QUALIFICATION SITE	USE E/STS-2 AT NRDS
• PRODUCTION ACCEPTANCE TEST FACILITY	CLASS 1 HYBRID - CONSTRUCT TEST STRUCTURE AT MTF ADJACENT TO ONE OF S-II TEST STANDS CLASS 3 - USE PIL AT SACTO

MANUFACTURING FACILITY SUMMARY

The recommendations on manufacturing facility utilization and post-manufacturing storage sites are listed on the opposite page. The rationale for the detail fabrication and final assembly sites has been treated previously in the manufacturing discussion and will not be repeated here. Similarly, recommendations on post-manufacturing storage have been listed under the prelaunch operations summary. One comment of clarification on the storage flow space requirements is that the Class 1 Hybrid number is based on horizontal storage of the propellant module, while the Class 3 number is based upon storage in a vertical position, that is, 400 sq ft is required per module.

MANUFACTURING FACILITY SUMMARY

REQUIREMENT		RECOMMENDATION
<ul style="list-style-type: none"> • DETAIL FABRICATION AND FINAL ASSEMBLY 		CLASS 1 HYBRID PROPELLANT MODULE - USE MICHOD PROPULSION/C&C MODULES - USE HB
TOTAL FLOOR SPACE	{ CLASS 1 HYBRID - 145,000 SQ FT CLASS 3 - 92,000 SQ FT	CLASS 3 ALL MODULES - USE HB
HYDROSTATIC TEST CAPABILITY		
<ul style="list-style-type: none"> • POST-MANUFACTURING STORAGE 		CLASS 1 HYBRID - USE MICHOD/HB
TOTAL FLOOR SPACE	{ CLASS 1 HYBRID - 9,600 SQ FT CLASS 3 - 8,100 SQ FT	CLASS 3 - USE SACTO/HB

KSC FACILITY SUMMARY

Recommendations on facility utilization for engine/run tank mating operation, receiving inspection, and launch operations are listed on the opposite chart.

The NERVA/run tank mating operation to form the propulsion module is envisioned as taking place in one of the VAB low bay checkout cells, with both the NERVA and the run tank assembly suggested in a vertical position to facilitate the operation.

Class 1 Hybrid propellant module receiving inspection is recommended in the transfer aisle of the VAB low bay with the module in a horizontal position on its transporter. Since the propulsion module and CCM will be launched by the space shuttle, only a small portion of the service area in the proposed shuttle maintenance control facility is required to inspect the module before installation in the orbiter. The propulsion module checkout will basically be accomplished in the low bay checkout cell prior to being transported to the MCF. Recommendations for the Class 3 modules includes use of another low bay checkout cell for receiving inspection of the propellant module, plus use of service area for the other modules as described previously.

One VAB high bay will be required for starting the Class 1 Hybrid propellant module on the INT-21 launch vehicle prior to leaving on the module launcher. Minor expenditures for relocating work platforms and module launcher service orbits will be required. Launching the Class 3 modules will require no additional provisions beyond those required for receiving inspection.

KSC FACILITY SUMMARY

REQUIREMENT	RECOMMENDATION
• ENGINE/RUN TANK MATING FACILITY	USE A VAB LOW-BAY CHECKOUT CELL (BOTH CONCEPTS)
• RECEIVING INSPECTION FACILITY	CLASS 1 HYBRID- USE VAB LOW-BAY TRANSFER AISLE, PLUS SERVICE AREA IN SHUTTLE MCF CLASS 3 - USE A VAB LOW-BAY CHECKOUT CELL, PLUS SERVICE AREA IN SHUTTLE MCF
• LAUNCH FACILITY	CLASS 1 HYBRID - USE A VAB HIGH-BAY, RELOCATE WORK PLATFORMS, MODIFY MOBILE LAUNCHER SERVICE ARMS CLASS 3 - USE SERVICE AREA IN SHUTTLE MCF FOR LAUNCH PREPARATION

MAJOR SRT REQUIREMENTS

SRT requirements identified during the Phase II study were reviewed during Phase III, considering the current design requirements and design concepts to quantify the magnitude of their potential impacts on the design. Also, additional significant items have been added to the list as a result of the evaluation of RNS operations during the current study. Three of the major SRT items are highlighted here.

No feasibility problems have been found which would prevent a commitment to development of the RNS. However, there are SRT questions concerning some baseline subsystem features. Most of the SRT which has been identified can be classified as uncertainties in the design criteria which are applied. Although best judgments of these have been applied conservatively for the RNS, experimental data are required to verify and refine the applicable criteria.

The items under orbital experiments are important from the point of view of design confidence and system performance. The efficiency of orbital propellant transfer operations has a major impact on the cost of propellant delivered to the RNS, which is the dominant factor in the economics of the transportation system.

A study of the irradiation effects on the stage component materials indicated that many of them appeared to be suitable for their designed environment. However, some of the materials appeared questionable for consideration of their respective functions. These materials consist of such items as valve seals, semiconductors, batteries, fuel cells, wire insulation, transducers, fiber glass composites, aluminized Mylar, and polyurethane foam. Transferring many of the stage components from the mid or aft section of the RNS to the forward location will reduce the incident radiation levels on these components and may eliminate the necessity of redesign for radiation hardening, while many of the component materials which are sensitive to radiation and which have unknown behavior in the anticipated environments will require experimental testing.

Because of its superior strength-to-weight characteristics, titanium has been considered as a growth candidate for the nuclear stage propellant tank. However, there are still many characteristics of the material which prevent its utilization for large cryogenic tankage. The rewards for SRT efforts in this area could be quite handsome, however, since this is one item that does offer the promise of substantial system weight reduction.

MAJOR SRT REQUIREMENTS

- ORBITAL PROPELLANT MANAGEMENT EXPERIMENTS
 - INSULATION PERFORMANCE CHARACTERISTICS
 - PROPELLANT DYNAMICS
 - CHILLDOWN AND BOILING HEAT TRANSFER
 - PROPELLANT STRATIFICATION/DESTRATIFICATION
- RADIATION EFFECTS TESTING PROGRAM
 - FIBERGLASS-EPOXY STRUCTURAL MEMBERS
 - THERMAL INSULATION MATERIALS
 - VALVE SEAL MATERIALS
 - ASTRIONICS COMPONENTS
- ADVANCED MATERIALS DEVELOPMENT
 - TITANIUM TANKAGE -- FRACTURE TOUGHNESS, MFG TECHNIQUES

RNS PROGRAM SCHEDULE

An abbreviated version of the RNS program schedule is shown here, with activities time phased relative to the IOC date. Separate program schedules were formulated for the Class 1 Hybrid and Class 3 RNS during the Phase III effort, but they are almost identical except for slight differences in production acceptance testing activities, etc. The schedule shown here is applicable to either RNS concept. A period of 5 years from Phase D ATP to first flight has been identified, as well as another period of 1-1/2 years between first flight and the IOC date.

Milestones for availability of important test, manufacturing, and launch facilities are shown, and are compatible with entries on the major milestone chart. The test program schedules are predicated upon the availability of the required facilities. The battleship and all-systems test programs at NRDS are comprised of an initial cold flow checkout phase with a NERVA simulator, followed by full-power tests using NERVA.

The manufacturing activities feature the field fabrication of battleship test hardware for the Class 1 Hybrid, with field fabrication being optional for Class 3. In either case, the schedule is the same. The all-systems test hardware production and the flight test article production activities overlap by approximately 9 months, implying a higher production rate to satisfy both requirements. For the Class 3, this would not require two complete vehicles, since the all systems test vehicle uses only one propellant module. The production rate shown is one RNS per year, and the total number of RNS systems produced reflects a program with a mission rate of six per year.

The flight test activities include a 6-month period for launching the RNS to orbit, assembling the mission vehicle, checking it out, etc. This is more important for a Class 3 system. After the first launch, a year is provided to perform a series of test objectives, evaluate the test data, perform an Earth orbit turnaround of the RNS, and perform a repeat series of tests prior to committing the RNS to its first operational mission.

RNS PROGRAM SCHEDULE

RNS PROGRAM MILESTONES

Major program milestones have been defined and are presented here relative to the IOC date. A Phase D ATP was determined to be required 6-1/2 years before IOC on the basis of the design, test, facilities, and manufacturing activities that must be accomplished before an operational program can be started. A 2-year basic design effort has been defined following ATP, with the first production drawing release scheduled for the mid-point of the design activity. The tooling design, fabrication, and checkout activities are envisioned as being conducted in parallel with, and slightly lagging, the design activities, with tool fabrication and checkout scheduled for completion six months following the basic design activity. This tooling checkout operation will be conducted using raw material, with the result being the fabrication of structural elements to be used in the structural test program.

The facility milestones indicated on the figure are based upon an assumption that facility construction money will not be available until Phase D ATP (E/STS-2 is one notable exception to this), and another assumption that test programs will be conducted in the facilities to provide meaningful and timely data for use in the design effort. Hence, the majority of the facilities treated here are required early in the development period.

The NRDS test programs are scheduled to be completed prior to launching the modules to orbit for the flight test program. Also, the availability of the production acceptance test facility and NERVA/run tank mating facility is scheduled to be coincident with completion of the first production RNS (Flight Test Article). The major milestone chart has been designed to be applicable to either RNS concept.

RNS PROGRAM MILESTONES

CLASS 1 HYBRID RNS PROGRAM COST SUMMARY

The cost breakdown for the Class 1 Hybrid RNS Program is shown here at the project level. The total nonrecurring (DDT&E) portion is \$965 million. The RNS project requires \$729 million for design and development. The project cost breakdown is detailed in the following pages. The remaining nonrecurring project cost estimates (launch vehicle—\$109 million; launch operations—\$58 million; mission operations—\$69 million) reflect the support required to launch the flight test article and perform two simulated lunar missions. The launch vehicle for the propellant module is the INT-21, which is priced at \$95 million per unit for hardware and \$12 million per unit for launch operations. The program nonrecurring total does not include NERVA development and any required launch vehicle modifications.

The recurring program total (production and operations) for the baseline 6 mission per year rate is \$4,440 million. The expenditure for the mission operations project is by far the largest at \$3,031 million (\$34 million of which is for production, LH₂ and spares procurement). Logistic support provided by the space shuttle is the major cost element within mission operations and reflects the need for 11 space shuttle flights to turn around an RNS. The launch operations (\$346 million), launch vehicle (\$577 million), and RNS (\$486 million), correspond to the purchase and launch of six RNS systems. The recurring RNS project costs are detailed in the following pages. The total program cost varies from \$2.5 to \$6.85 billion as program activity levels vary from 2 to 8 missions per year. The nonrecurring portion is constant at \$965 million.

CLASS 1 HYBRID RNS PROGRAM COST SUMMARY

PROJECT LEVEL -- 6 MISSIONS PER YEAR

- COSTS IN MILLIONS OF 1971 DOLLARS
- COSTS REFLECT A 10 - YEAR OPERATIONAL PROGRAM

CLASS 1 HYBRID RNS PROJECT COST SUMMARY

The total RNS project cost is \$1,215 million, which is made up of \$729 million for non-recurring DDT&E, \$224 million for recurring production, and \$262 million for recurring operations. The recurring portion is based on a rate of 6 missions per year, 10 year program requiring 6 flight articles. The distribution of costs to the subsystem level is shown below for the flight hardware. It includes all labor and material required to design, develop, produce and operate the Class 1 Hybrid RNS. The costs shown are in millions of 1971 dollars.

RNS Module	Structure	Pro- pulsion	Astri- onics	APS	Tooling & STE	Environment Protection	Subsystem Instl & C/O	Total
Propulsion	9.5	12.2	4.2	9.8	5.0	1.8	-	42.5 (1)
	1.9	78.8	2.4	0.6	-	0.4	1.7	85.8 (2)
	3.3	1.4	4.2	1.0	1.7	0.7	2.9	15.2 (3)
Propellant	46.9	17.7	3.2	N/R	16.2	7.1	-	91.1
	14.4	1.3	1.5	N/R	-	2.9	5.7	25.8
	17.9	1.6	1.8	N/R	5.6	3.6	7.1	37.6
CCM	4.6	5.8	47.6	89.4	1.0	0.8	-	149.2
	1.0	0.3	35.8	12.3	-	0.1	14.1	63.6
	1.5	0.5	55.1	18.9	0.3	0.2	21.7	98.2

(1) DDT&E, (2) Production, (3) Operations

Additionally, \$109 and \$49 million are required in the DDT&E phase for test hardware and operations in support of a battleship, all systems, systems integration, propulsion integration, and flight test programs. The facilities nonrecurring cost is \$64 million, made up of \$54.1 million for test (primarily NRDS), \$4.6 million for manufacturing, and \$5.4 million for launch.

CLASS 1 HYBRID RNS PROJECT COST SUMMARY

SYSTEM LEVEL -- 6 MISSIONS PER YEAR

- COSTS IN MILLIONS OF 1971 DOLLARS
- COSTS REFLECT A 10 - YEAR OPERATIONAL PROGRAM

The nonrecurring GSE cost is \$145 million with \$56.7 million for manufacturing, \$73.0 million for test, and \$15.3 million for launch. The recurring GSE cost (\$31 million) is for maintenance during the production and operations phases. The nonrecurring and recurring SE&I cost is \$52 and \$106 million, respectively, and accounts for systems analysis, test and checkout definition, interface design, system effectiveness, and trade studies. Project management during the DDT&E phase is estimated to cost \$27 million while \$19 million are required during production and operations. These estimates account for program control, configuration management and data management.

The total recurring Class 1 Hybrid project cost varies between \$221 and \$619 million reflecting a 2 and 8 mission per year rate. The corresponding average recurring unit costs are \$110 and \$77 million, respectively, based on a production rate of one per year.

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CLASS 1 HYBRID RNS COST EFFECTIVENESS

The cost effectiveness of the Class 1 Hybrid RNS configuration was measured in terms of dollar per pound of payload delivered to lunar orbit. Assuming a 20,000-lb return payload and a minimum-energy lunar mission, the RNS has a delivered payload capability of 132,000 lb. The average recurring cost per flight and resulting transportation cost per pound of payload delivered are shown below as a function of traffic rate. Two sets of data are presented reflecting the baseline space shuttle (33,000 lb into 260 nmi by 31.5 deg Earth orbit) and an alternate space shuttle (50,000 lb into the same orbit). The degree of improvement is limited by the fact that the larger space shuttle has the same cargo volume as the baseline space shuttle. The costs are presented in 1971 dollars.

Mission Rate (No. /yr)	Average Recurring Cost/Flight (\$ million)		Transportation Cost (\$/lb)	
	33K S/S	50K S/S	33K S/S	50K S/S
2	76.4	66.4	578	502
4	74.2	64.2	562	487
6	73.4	63.4	557	481
8	73.0	63.0	553	477

CLASS 1 HYBRID RNS COST-EFFECTIVENESS

CLASS 3 RNS PROGRAM COST SUMMARY

The cost breakdown for the Class 3 RNS Program is shown here at the project level. The total nonrecurring (DDT&E) portion is \$843 million. The Class 3 RNS project requires \$707 million and is detailed in the following pages. The nonrecurring project estimate for mission operations is \$74 million and includes the ground and orbital operations as well as logistics support required to perform two simulated missions during the flight test program. Correspondingly the nonrecurring launch operations project estimate (\$62 million) reflects the space shuttle services required to place the modules of the flight test article into Earth orbit and topping them off with LH₂.

The recurring program total (production and operations) for the baseline 6 missions per year rate is \$3,926 million. The expenditure for the mission operations project is by far the largest at \$3,045 million (\$36 million of the total is for production, LH₂ and spares procurement). Logistics support provided by the space shuttle is the major cost element within mission operations and reflects the need for 11 space shuttle flights to turn around an RNS. The launch operations project cost is \$365 million, corresponding to the placement of six RNS systems into the Earth operations orbit. The recurring RNS project total is \$516 million and is detailed at the system level in the following pages. The total program cost varies from \$2.2 to \$6.0 billion as program activity levels vary from 2 to 8 per year. The nonrecurring portion is constant at \$843 million.

CLASS 3 RNS PROGRAM COST SUMMARY

PROJECT LEVEL -- 6 MISSIONS PER YEAR

NONRECURRING TOTAL -- 843

RECURRING TOTAL -- 3,926

PROGRAM GRAND TOTAL -- 4,769

- COSTS IN MILLIONS OF 1971 DOLLARS
- COSTS REFLECT A 10-YEAR OPERATIONAL PROGRAM

CLASS 3 RNS PROJECT COST SUMMARY

The total RNS project cost is \$1,223 million, which is made up of \$707 million for non-recurring DDT&E, \$262 million for recurring production, and \$254 million for recurring operations. The recurring portion is based on a 6 mission per year, 10 year program requiring 6 flight articles. The distribution of costs to the subsystem level is shown below for the flight hardware. It includes all labor and material required to design, develop, produce and operate the Class 3 RNS. The costs are shown in millions of 1971 dollars.

RNS Module	Structure	Pro- pulsion	Astri- onics	APS	Tooling & STE	Environment Protection	Subsystem Instl & C/O	Total
Propulsion	9.5	12.2	4.2	9.8	5.0	1.8	-	42.5 (1)
	1.9	78.8	2.4	0.6	-	0.4	1.7	85.8 (2)
	3.3	1.4	4.2	1.0	1.7	0.7	2.9	15.2 (3)
Propellant	14.8	16.7	1.2	N/R	10.7	2.2	-	45.6
	23.1	8.3	5.9	N/R	-	3.2	11.5	52.0
	12.0	4.3	3.1	N/R	3.7	1.6	6.0	30.7
CCM	4.6	5.8	47.6	89.4	1.0	0.8	-	149.2
	1.0	0.3	35.8	12.3	-	0.1	14.1	63.6
	1.5	0.5	55.1	18.9	0.3	0.2	21.7	98.2

(1) DDT&E, (2) Production, (3) Operations

Additionally, \$129 and \$64 million are required in the DDT&E phase for test hardware and operations in support of a battleship, all systems, systems integration, propulsion integration, and flight test programs. The facilities nonrecurring cost is \$56 million, made up of \$53.0 million for test (primarily NRDS), \$2.8 million for manufacturing, and \$0.6 million for launch.

The nonrecurring GSE cost is \$142 million with \$55.6 million for manufacturing, \$72.2 million for test, and \$14.6 million for launch. The recurring GSE cost (\$30 million) is for maintenance during the production and operations phases. The nonrecurring and

CLASS 3 RNS PROJECT COST SUMMARY

SYSTEM LEVEL -- 6 MISSIONS PER YEAR

PROJECT GRAND TOTAL -- 1,223

- COSTS IN MILLIONS OF 1971 DOLLARS
- COSTS REFLECT A 10 - YEAR OPERATIONAL PROGRAM

recurring SE&I cost is \$52 and \$106 million, respectively, and accounts for systems analysis, test and checkout definition, interface design, system effectiveness, and trade studies. Project management during the DDT&E phase is estimated to cost \$26 million, while \$20 million are required during production and operations. These estimates account for program control, configuration management, and data management.

The total recurring Class 3 project cost varies between \$230 and \$658 million, reflecting a two and eight mission per year rate. The corresponding average recurring unit costs is \$115 and \$82 million, respectively, these costs based on a production rate of one per year.

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CLASS 3 RNS COST EFFECTIVENESS

The cost effectiveness of the Class 3 RNS configuration was measured in terms of dollar per pound of payload delivered to lunar orbit. Assuming a 20,000-lb return payload and a minimum-energy lunar mission, the RNS has a delivered payload capability of 123,000 lb. The average recurring cost per flight and resulting transportation cost per pound of payload delivered are shown below as a function of traffic rate. Two sets of data are presented reflecting the baseline space shuttle (33,000 lb into 260 nmi by 31.5 deg Earth orbit) and an alternate space shuttle (50,000 lb into the same orbit). The degree of improvement is limited by the fact that the larger space shuttle has the same cargo volume as the baseline space shuttle. The costs are presented in 1971 dollars.

Mission Rate (No. /yr)	Average Recurring Cost/Flight (\$ million)		Transportation Cost (\$/lb)	
	33K S/S	50K S/S	33K S/S	50K S/S
2	68.4	58.9	534	460
4	66.2	56.7	518	443
6	65.4	55.9	511	437
8	65.0	55.5	508	434

CLASS 3 RNS COST-EFFECTIVENESS

RNS PROGRAM FUNDING SUMMARY

The funding schedule associated with the two candidate RNS configurations is illustrated here for the baseline 6 missions per year, 10 year operational program. Funding requirements are initiated approximately 8 years before IOC with expenditures for facilities, primarily E/STS-2 at NRDS. An annual peak of \$532 million and \$438 million is reached one year after IOC for the Class 1 Hybrid and Class 3, respectively. The difference in funding requirement between the two concepts is accounted for by the purchase of INT-21 launch vehicles. It was assumed that the seven INT-21 vehicles required (one for flight test and six for the operational programs) would be bought on a lot basis starting about 4 years prior to IOC. The major funding requirement during the operational years is for logistic support by the space shuttle. Varying the mission rate results in a corresponding change in funding requirement, i.e., about \$60 million for each additional mission per year. The shaded portion of the funding schedule reflects the RNS project funding. It can be seen that it represents a small portion of the total funding requirement. A single schedule is shown for both concepts, since their requirements are virtually identical. The peak annual funding required for the RNS project is about \$200 million, occurring during the DDT&E phase about 4 years prior to IOC.

RNS TOTAL PROGRAM FUNDING SUMMARY

6 MISSIONS PER YEAR

CONCLUSIONS

All of the operations or design features identified in the study appear to be feasible within 1974 state of the art. Automatic rendezvous and docking, onboard checkout, propellant management, orbital assembly support systems and component reliability do not appear to be limiting problems. Using load minimum flight-control techniques to launch the Class 1H propellant module minimizes any requirement for structural modifications to the Intermediate 21 launch vehicle.

The Hybrid concept for the Class 1 has a number of major advantages over the standard configuration. The module docking interface facilitates NERVA replacement. As mentioned above, it imposes reduced design requirements upon the Intermediate-21. Although additional structure weight is required, lower shielding and improved propellant management result in an overall performance advantage for the hybrid configuration. The top of the propulsion module run tank represents a relatively low radiation environment location for engine astrionic subsystems.

Based upon orbital assembly operations, which permit use of a space tug as a support system without incurring additional tolerance buildup factors between adjacent parallel modules, a cruciform Class 3 configuration was selected.

The maintenance concept employed on the Class 3 has been adopted for the Class 1H. Command and control module is recycled to the ground after each mission. Where possible, all subsystems are placed in the CCM to minimize the number of unreliable elements that must be maintained in orbit. No operational fluid connections have to be made between the CCM and propellant modules; only a flow-through connection, used for orbital tanking, has to be made. Electrical connections, primarily associated with the Emergency Detection System, have to be made.

The RNS system tends to be independent for most of its required operations. Orbital assembly is accomplished without direct manned support with automated rendezvous and docking, remote fluid and electrical couplings are provided between modules, and an automatic leak check is provided to verify assembly interfaces. On board checkout capability is provided for orbital checkout operations. Additional processor rate requirements are minimal. Autonomous navigation and guidance capability and onboard data evaluation are provided by the RNS.

CONCLUSIONS

- ALL DESIGN FEATURES AND OPERATIONS SELECTED APPEAR FEASIBLE WITHIN 1974 STATE OF THE ART
- HYBRID CONCEPT ATTRACTIVE
 - FACILITATES NERVA REPLACEMENT
 - REDUCED DESIGN CONDITIONS FOR INT-21 LAUNCH
 - ADVANTAGES ACCRUED FOR PROPELLANT MANAGEMENT
 - INTERMEDIATE SHIELDED LOCATION FOR ENGINE ASTRIONICS
- CRUCIFORM CLASS 3 SYSTEM SELECTED
- MAINTENANCE ON MODULAR LEVEL ATTRACTIVE
 - COMMAND AND CONTROL MODULE MAINTAINED ON THE GROUND
 - NUMBER OF UNRELIABLE ELEMENTS ON PROPELLANT MODULES MINIMIZED
- RELATIVE AUTONOMOUS STAGE OPERATIONS APPEAR FEASIBLE
 - PERMANENT ORBITAL SUPPORT FACILITY NOT REQUIRED
 - REMOTE ORBITAL ASSEMBLY
 - AUTONOMOUS NAVIGATION AND GUIDANCE
 - ONBOARD CHECKOUT AND DATA EVALUATION

Phase III shielding results verified the use of a 10-degree half-angle aft conical dome. This resulted in a 2900-lb additional disc shield weight for the study guidelines. If the factor of 3 attenuation accrued for the crew module were deleted this weight would increase to 5700 lb and perhaps require a new optimization. No disc shield was required for the Class 3 system. A 1,700-lb penalty is accrued for a change in the same guideline stated above.

The Class 1H has about a 10,000-lb weight advantage over Class 3. Because the Class 1H has greater transportation costs to orbit, however, the cost effectiveness considerations between the systems are comparable.

CONCLUSIONS (CONT)

- CONICAL AFT DOME WITH RUN TANK REDUCES DISC SHIELD REQUIREMENTS FOR CLASS 1-H
- FOUR-TIER CONFIGURATION WITH CENTRAL COLUMN OF PROPELLANT ELIMINATES DISC SHIELD REQUIREMENTS FOR CLASS 3
- CLASS 1-H HAS ABOUT A 10,000-LB WEIGHT ADVANTAGE OVER CLASS 3
- COST EFFECTIVENESS IS COMPARABLE BETWEEN CLASSES 1-H AND 3

RECOMMENDATIONS

Phase II identified attractive RNS concepts based on alternate launch vehicles that combine advantages of both concepts. They require less modularity than Class 3 and, therefore, possibly less system weight; they can also use less expensive launch vehicles than the Intermediate-21. These concepts were not evaluated in this Phase because of the lack of definition of candidate launch vehicles. These studies are now being conducted, and it is possible to evaluate these configurations.

Phase III further defined stage operational requirements that impact reference engine/stage functional, fluid, electrical, and structural interfaces. Trade studies associated with further engine/stage definition and with supporting the NERVA development program and facility selection should be performed.

RECOMMENDATIONS

- PERFORM RNS PHASE A DEFINITION STUDY FOR CONFIGURATIONS BASED ON ALTERNATE LAUNCH VEHICLES
- ESTABLISH STAGE OPERATIONS IMPACT ON NERVA REQUIREMENTS