MASTER

SECOND INTERIM BRIEFING NUCLEAR SHUTTLE DEFINITION STUDY, PHASE III

PREPARED FOR NASA-MSFC UNDER CONTRACT NAS8-24714
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16 DECEMBER 1970

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

5301 Bolsa Avenue, Huntington Beach, CA 92647

PHASE III SECOND INTERIM BRIEFING REUSABLE NUCLEAR STAGE CONCEPTS

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY

CONTRACT NAS 8-24714

16 DECEMBER 1970

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NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY

During Phase I and Phase II of the nuclear flight system definition study, the contracted effort (1) evaluated three classes of reusable nuclear shuttle concepts that could efficiently perform missions from low earth orbit to either lunar orbit or synchronous earth orbit, and perform planetary missions in the shuttle mode, (2) identified system element characteristics that have major impact on the economics of the nuclear shuttle operations, and (3) defined nuclear stage characteristics. At the conclusion of this phase, it was decided to proceed with a Phase A conceptual definition for two variations of the reusable nuclear shuttle: (1) a 33-ft diameter, load-carrying tank that could be launched to earth orbit by the Intermediate-21 (Int-21) launch vehicle, and (2) propellant modules delivered to low earth orbit within the cargo hold of the Space Shuttle.

The objectives of this study are to define the reusable nuclear stage concepts more completely and establish integrated test, manufacturing, facility and equipment, and supporting research and technology plans in order that a preliminary technical plan, a development schedule, and program costs can be identified for each of these concepts. A comparison between the two classes of RNS vehicles will be made at the conclusion of this study.

NUCLEAR SHUTTLE SYSTEM DEFINITION STUDY

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- OVERALL OBJECTIVE
 - ESTABLISH PHASE A CONCEPTUAL DEFINITION FOR TWO VERSIONS OF REUSABLE NUCLEAR SHUTTLE
 - 33 FT DIAMETER DERIVATIVE
 - EOS COMPATIBLE
- SPECIFIC OBJECTIVES
 - COMPLETE PRELIMINARY TECHNICAL DEFINITION OF THE RNS CONCEPTS
 - ESTABLISH INTEGRATED PROGRAM REQUIREMENTS FOR THE SELECTED RNS CONCEPTS
 - CONDUCT SPECIALIZED ANALYTICAL STUDIES
 - PROVIDE MISSION AND PERFORMANCE ANALYSES DATA
 - IDENTIFY PHYSICAL AND FUNCTIONAL INTERFACES WITH OTHER SYSTEM ELEMENTS

BRIEFING SCHEDULE

The organization of the briefing and the speakers are shown in the accompanying figure.

BRIEFING SCHEDULE

EXECUTIVE SUMMARY

S. GRONICH

MISSION OPERATIONS

R. G. RIEDESEL

RNS DESIGN

K. P. JOHNSON

R. J. HOLL

PROGRAM PLAN

R. G. RIEDESEL

STUDY SCHEDULE

The schedule identifies the tasks to be performed under the nuclear shuttle study and indicates the current status of each of the individual efforts. The study is broken into three phases, which consist of about 3-1/2 months each: (1) concept definition and evaluation, (2) system trade studies, and (3) program and system definition. As indicated on the schedule, the tasks initiated during the first phase were mission capability analysis, operations requirements and systems definition of specific subsystems in order to perform preliminary configuration definition, and engine-stage interface definition. In addition, engineering trade studies such as engine-stage vehicle dynamics and engineering support activities (Task 9) were initiated during this phase of the study.

Trade analyses for structures, propulsion, auxiliary propulsion and astrionic subsystems were conducted during the second portion of the Phase III study. These will be reported on at this briefing. In addition, mission and RNS operations were further updated and integrated-program-plan-related tasks were initiated.

STUDY SCHEDULE

CONCEPTS EVALUATED

The Class 1 and 3 RNS concepts are shown in the accompanying figure. At the conclusion of Phase II, the Class 1 hybrid, which consisted of a small propellant run tank and engine, delivered within the cargo hold of the space shuttle and a 33-ft diameter propellant module delivered by the INT-21 launch vehicle, was adopted as a primary baseline. Specific design analyses of a standard configuration with a 10-degree conical aft dome would also be studied to a depth sufficient to define major technical problems. The aft angle for the Class 1 Hybrid configuration will also be a simulated 10-degree angle in order to optimize the shield and tank configuration of the overall system. The propellant tank for the Class 1 hybrid is fabricated from 2014-T6 aluminum alloy and integrally stiffened cylindrical section. The small propellant run tank is of a monocoque construction, and the total capacity of both tanks is about 300,000 lb of propellant. Fiber-glass heat blocks and high-performance insulation, which can be compressed during launch, are used to thermally protect the propellant tanks. A fiber-glass bumper and foam are used for the basic meteoroid protection system.

RNS equipment was placed in the forward skirt area; a modular configuration of the subsystems was devised to provide maintainability. At the conclusion of a trade study conducted during the first three months of the current study effort, a single command and control module, which would be removed after each mission for replenishment and repair, was selected over the previous design.

The planar configuration of the Class 3 system was selected at the conclusion of Phase II on the basis of a trade analysis between shielding requirements and vehicle stiffness. On further investigation in the first three months of Phase III, which evaluated the impact of assembly operations, a cruciform configuration was selected. At the same time, further definition of fluid line deployment, flexible elements, and docking and clustering mechanisms was made. An integral number of propellant modules was selected with a total capacity slightly greater than 300,000 lb. This represented a configuration with eight modules. The propellant modules would be of aluminum monocoque construction, and all of the other subsystems would be similar to that described for the Class 1 hybrid concept. The Class 3 functional subsystems would be packaged in a command and control module. Scheduled maintenance in this concept would be achieved by removing the entire command control module.

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 would be 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, would be generated during the first phase. Subsystem analyses and trade studies were also conducted in the phase. During the second phase alternative RNS systems and subsystem designs would be updated to reflect the operational requirements, reliability improvements, thermodynamic analyses, new radiation environments, and NERVA/RNS interface definition. The intent of the activity would be 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 would be identified.

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

LUNAR SHUTTLE MISSION TIMELINE-EARTH ORBIT TURNAROUND

The accompanying illustration identifies major activities occurring between orbit insertion (EOI) following a lunar shuttle mission and subsequent departure on another mission. The total time available for earth orbit turnaround of 84.2 days corresponds to a mission model with a six-missions-a-year frequency. For this mission model, two RNS systems alternately perform lunar shuttle missions at a combined rate of once each 54.6 days (every two lunar cycles). Since the missions are performed alternately by the two RNS's, 84.2 days are spent in earth orbit by each RNS between mission applications. In order to minimize, if not eliminate, the requirement to perform recycling operations simultaneously on the two RNS's, only a portion of this time is allocated for the performance of the major operations of propellant refueling and mission payload launch and integration. A space shuttle launch rate of one each three days is required to fulfill this objective. Specific areas investigated included launch and prelaunch operations, lunar shuttle phasing cycles, utilization schedules, logistic turn around cycles, and performance impact of after cooling and APS impulse requirements. Time in the summary permits only a review on the next chart of the performance impact of the trans lunar after cooling. The figure indicates the combined launch of the new command and control module and mission crew. This approach is taken to maximize the use of the space shuttle payload capability. Should future investigations indicate this approach untenable because of the extended crew time required in each orbit (an additional 14 days of on-orbit time), the crew could be launched separately, following launch and integration of the unmanned payload, at the expense of an added space shuttle launch.

LUNAR-SHUTTLE MISSION TIMELINE

EARTH ORBIT TURNAROUND -- SIX MISSIONS PER YEAR

PERFORMANCE IMPACT--TRANSLUNAR COOLDOWN UTILIZATION

Estimates made to date of the baseline RNS performance for the lunar shuttle mission have not credited impulse derived during the NERVA cooldown phase toward the accomplishment of mission velocity maneuvers. Thus, in effect, propellant consumed for the NERVA cooldown function was treated as a nonpropulsive, unusable propellant. The performance implications of this assumption have been evaluated using a two-body patched conic solution for the baseline 108-hour translunar mission leg. The reference condition (zero cooldown used for impulse) was a payload delivery capability to lunar orbit of 112,000 lb (20,000 lb crew module on the return leg), based on a NERVA steady-state run time of 1,800 seconds. The cooldown impulse profile was modeled per Aerojet Report S-130-BP-090290-FL-PREL, "NERVA Reference Data--Full Flow Engine," dated April 1970. The duration of the cooldown phase in this case is actually somewhat in excess of the 108-hr transfer time between the earth and the moon. The total impulse contributed during the cooldown phase for this particular engine run time would be 3.3×10^6 lb-sec, or an equivalent characteristic velocity of 320 ft/sec. Total use of the cooldown impulse for the translunar velocity requirement results in an equivalent reduction in the full-thrust velocity requirement of approximately 130 ft/sec, resulting in a performance improvement of approximately 3,400 lb. This 3,400-lb performance improvement would be increased further by an additional 11,000 lb performance gain if the requirement for engine cooldown could be completely eliminated. That is, the 7,600 lb of propellant presently allocated for cooldown could be reassigned for use during full-thrust operations. This potential performance improvement (11,000 lb) would have to be played against any system weight increases required to effect cooldown elimination (for example radiator systems). The performance impact of increases in RNS system inert weight is 2.7 lb lost in orbital payload per pound increase in inert weight, or approximately a 4,000 lb inert weight increase as the break-even point.

**PERFORMANCE IMPACT OF NERVA
AFTERCOOLING IMPULSE UTILIZATION
TRANSLUNAR MISSION PHASE**

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RNS DESIGN

The context for the current phase of the RNS design activity is given on the facing chart. Phase II resulted in definition of the two basic RNS concepts—the single-module, 33-ft-diameter Class 1 concept and the multiple-module Class 3 configuration. The first period of Phase 3 focused on selection of major characteristics for each concept and the overall configuration of the vehicles. The most significant selection during this period was that of a discrete command and control module for the Class 1 concept to most effectively accomplish orbital maintenance. Another major result of the first period analysis was the selection of the Class 3 vehicle configuration with the modules in the form of a cruciform cluster. Operations were analyzed in support of making the above concept/configuration selections as well as to provide the bases for more detailed definition of the RNS itself.

During the second period major design activities were oriented toward trade studies selecting specific subsystem design features. To accomplish these trade studies, detailed operations analysis, using the scenarios developed during the first period, were performed to establish subsystem requirements. Subsequent charts will show the operations analysis and subsystem definition for the RNS functional subsystems. This section will conclude with a summary of the major features selected during this period and with the current weight statement for both RNS concepts which are summarized on the next two charts.

RNS DESIGN

- FIRST PERIOD RESULTS:
 - RNS CONCEPT/CONFIGURATION
 - CLASS 1 – – CCM FOR MAINTENANCE
 - CLASS 3 – – CRUCIFORM CLUSTER
 - OPERATIONS
 - MISSION TIMELINE
 - ORBITAL ASSEMBLY AND REFURBISHMENT
 - RNS OPERATIONS
- SECOND PERIOD OBJECTIVES:
 - DESIGN FEATURE TRADE STUDIES
 - DETAIL OPERATIONS TO ESTABLISH REQUIREMENTS

RNS CLASS 1 HYBRID

A sketch of the Class 1 Hybrid RNS configuration is shown on the facing chart. It illustrates the current configuration and provides a locator for the specific features selected during the second period of the study which will be discussed 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 which was selected during the Phase II shield optimization. The outriggers containing the auxiliary propulsion engines on the command and control modules are also visible on the picture. Specific details are identified by the callouts.

CLASS 1 HYBRID RNS

RNS CLASS 3

This chart shows the current 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 the design features selected during this period.

CLASS 3 RNS

DESIGN FEATURES SELECTED

This and the next chart summarize some of the major design features which were selected during the second study period. It should be kept in mind that many major design features were selected in both the Phase II study and during the first period of Phase III.

The forward dome shape for the Class 1 propellant module was re-evaluated in terms of the current hybrid launch mode and mission utilization. It was found that approximately a 600-lb reduction in operational weight could be achieved with only a 19-in. increase in the length of the module. An integral waffle pattern was provided for all Class 3 propellant modules to withstand launch loads. This stiffening also allows transmission of RNS operational modes through the inboard modules to the payload without pressure in the propellant module tanks. Optimization of the run tank diameter for the Class 3 propulsion module yielded a 160-in. value. This included consideration of shielding optimization, structural analysis, and operations. No biological shielding is required with this configuration. The fiber glass composite structure which was selected during Phase II for the thrust structures and intermodule structures was reviewed during this period. Utilizing current values for insulation performance and structural weight sensitivity to stage pressure reinforces the selection of fiber glass which was made during Phase II.

As described earlier in the presentation, an autonomous navigation system was selected with the provision of utilizing ground tracking for backup. It was also shown that data processing requirements are consistent with the centralized computer and that this approach could make most effective use of equipment for redundancies. Also as shown earlier stored procedures are utilized for checkout with BITE employed for specific components.

DESIGN FEATURES SELECTED

- HEMI SPHERICAL FORWARD DOME--CLASS 1 PROPELLANT MODULE
- INTEGRAL WAFFLE PATTERN--CLASS 3 PROPELLANT MODULE
- 160 INCH RUN TANK DIAMETER--CLASS 3 PROPULSION MODULE
- FIBERGLASS COMPOSITE STRUCTURE--REVIEWED
- AUTONOMOUS NAVIGATION
- CENTRALIZED DATA PROCESSING
- STORED PROCEDURES FOR ONBOARD CHECKOUT
 - BITE FOR SPECIFIC COMPONENTS

DESIGN FEATURES SELECTED - 2

Additional characteristics for RNS subsystems which were selected during the second period are shown on the facing chart. The integrated chilldown subsystem which combines the NERVA and stage chilldown operations as well as including the operations associated with refill or the run tank following depletion was described earlier. Additionally, a blocking valve was added in the Class 3 feed systems connecting the various propellant module tanks into the run tank. This enhances feed system integrity as well as eliminating excessive liquid residuals following shutdown and excessive thermal leaks.

The auxiliary propulsion system was sized for both concepts. A engine thrust was selected based upon performing requisite maneuvers, attitude control, and propellant settling. Total propellant capacity was established for the baseline lunar shuttle mission.

The primary power source trade study performed during Phase II was reviewed in terms of current power requirements. The final selection was made between fuel cells and solar cells utilizing state-of-the-art projections for fuel cells which are being employed in the space shuttle, and for solar cells which are to be employed in advanced space programs beyond Skylab. The evaluation favored fuel cells for the RNS. Redundant fuel cells are provided for reliability.

DESIGN FEATURES SELECTED - 2

- INTEGRATED CHILLDOWN SUBSYSTEM
 - COMBINED NERVA/STAGE CHILLDOWN
 - INCLUDES REFILL OF RUN TANK
- BLOCKING VALVE IN FEED SUBSYSTEM--CLASS 3
- AUXILIARY PROPULSION SYSTEM SIZED
 - ENGINE THRUST
 - PROPELLANT CAPACITY
- REDUNDANT FUEL CELLS--PRIMARY POWER--REVIEWED

RNS WEIGHT STATEMENT

The accompanying chart contains current weight statements for both RNS concepts. For nearly identical propellant capacities it can be seen that both the structure, meteroid/thermal, and docking/clustering entries penalize the multiple-module Class 3 concept. The main propulsion entry contains a 2,800-lb biological shield for the Class 1 Hybrid concept which almost offsets the greater plumbing and component weights for the Class 3 concept. The last three entries under the dry weight are nearly the same for both concepts. A net dry weight advantage of nearly 10,000 lb accrues to the Class 1 concept.

It can be seen that the RCS propellant is nearly identical for both concepts, but that the residuals of propellant contained in the stage at burnout are about 75,000 lb heavier for the Class 1 concept than for Class 3. This results in a net difference in operational weight of only about 2,000 lb favoring Class 1. These greater residuals for the Class 1 concept diminish the usable propellant so that the propellant mass fraction, λ' , given as the last entry is identical for both configurations.

RNS WEIGHT STATEMENT

	CLASS 1 HYBRID (LB)	CLASS 3 (LB)
STRUCTURE	24,080	28,750
METEOROID/THERMAL	7,910	8,800
DOCKING/CLUSTERING	760	3,440
MAIN PROPULSION	31,220	31,840
AUXILIARY PROPULSION	1,010	1,010
ASTRIONICS	2,135	2,430
CONTINGENCY	1,840	2,410
TOTAL DRY WEIGHT	68,955	78,680
RCS PROPELLANT	1,130	1,140
PROPELLANT RESIDUALS	9,470	1,920
TOTAL OPERATIONAL WEIGHT	79,555	81,740
VENTED PROPELLANT	—	2,240
FLIGHT PERFORMANCE RESERVE	1,700	1,700
USABLE PROPELLANT	289,830	297,190
PROPELLANT MASS FRACTION, λ'	0.784	0.784

LAUNCH AND PRELAUNCH OPERATIONS—CLASS 1 HYBRID

Operations involving the launch of the RNS will be scheduled to meet the requirements of the Space Shuttle. Also, the configuration demands made on the shuttle will be held to a minimum. These considerations give rise to the establishment, as a baseline, of the receipt of the RNS elements in launch-ready condition. Therefore, the operational profiles presented on this and the next figures are based on these assumptions.

There are several additional, more detailed, assumptions that have shaped the baseline profile presented. Mating with the space shuttle will be in the horizontal position in the shuttle maintenance area. The orbiter cargo compartment will be accessible to a crew member in orbit.

In operations that involve the INT-21 (i. e., Class 1 hybrid operations) it is assumed that MTF will be operational and will have the capabilities needed to perform acceptance testing on both the propellant module and the propulsion module.

The accompanying figure shows the Class 1 baseline operational profile. The assumption that the module will be launch-ready when it is received is reflected in the use of the low bay aisle as the receiving inspection area. Operations here will be limited to removing shipping protection and verifying that the orbiter/propulsion-module and the INT-21/propellant-module interfaces are ready for mating. If receiving operations should require significantly longer time, then receiving operations on the propellant module would be moved to one of the VAB high bays if integrated program considerations permit.

The propellant module and the command and control module will be launched integrally. They will be mated at Michoud and moved to MTF for production acceptance testing. Then they will be shipped to KSC for launch vehicle Integration, C/O, and launch.

In Class 1 hybrid operations (as well as Class 3) the schedule of the propulsion module will be planned to meet the requirements of the Space Shuttle. For safety, the neutron source for NERVA, if required, will not be installed until orbit is reached, and the poison wires will remain in the core until orbit. Both of the operations will require a crew member to enter the cargo compartment of the orbiter in orbit; and that he have the necessary access to accomplish this task.

The propulsion module will have its nuclear and nonnuclear subsystems shipped to NRDS, mated and tested there. They will be flown to the Cape where they will be mated with the propulsion module tankage. One of the low bay cells will be used for this operation. The engine will have been fully safed by poison wires and no special nuclear safety precautions will be required except for controlled access and periodic monitoring of the area and personnel. Additionally, the engine will not have, at this time, the neutron source installed. This source will be installed by a member of the orbiter crew after orbit has been achieved and prior to his removing the poison wires.

LAUNCH AND PRELAUNCH OPERATIONS—CLASS 3

Operations for the Class 3 RNS interface only with the space shuttle. Consequently the command and control module will be launched separately from the other modules.

The prime difference between Class 3 operations and Class 1 hybrid operations is in the use of Sacramento as a site for production acceptance testing. This difference results from the assumption that the INT-21 is not operational and therefore MTF will have been closed down. Another possibility is that the space shuttle program will fully utilize MTF so that it is unavailable for the RNS program.

The propellant modules will be inspected in the VAB low bay area. This receiving inspection will be limited to verification that the modules have not been damaged in shipment, and verification that the space-shuttle-orbiter/propellant-module interfaces are ready for mate.

The propulsion module will be handled similarly to the operations used for the Class 1 hybrid configuration. This includes mating the propulsion module tankage and the NERVA system in the low bay cells of the VAB.

PRELAUNCH AND LAUNCH OPERATIONS

CLASS 3 RNS

LUNAR SHUTTLE MISSION TIMELINE—EARTH ORBIT TURNAROUND

The accompanying illustration identifies major activities occurring between orbit insertion (EOI) following a lunar shuttle mission and subsequent departure on another mission. The total time available for earth orbit turnaround of 84.2 days corresponds to a mission model with a six-missions-a-year frequency. For this mission model, two RNS systems alternately perform lunar shuttle missions at a combined rate of once each 54.6 days (every two lunar cycles). Since the missions are performed alternately by the two RNS, 84.2 days are spent in earth orbit by each RNS between mission applications. In order to minimize, if not eliminate, the requirement to perform recycling operations simultaneously on the two RNS, only a portion of this time is allocated for the performance of the major operations of propellant refueling and mission payload launch and integration. A space shuttle launch rate of one each three days is required to fulfill this objective. Two time blocks are allocated in the profile shown to perform unscheduled maintenance. The first block of time (41 days) immediately follows the completion of cooldown operations and mission crew retrieval. This time block provides for major maintenance such as propellant module replacement. A similar, but smaller, block of time is allocated following exchange of the RNS command and control module and subsystem verification and integrated tests. The extent to which the first unscheduled maintenance period (41 days) is used correspondingly infringes upon the performance of turnaround operations on the alternate RNS, and would impose a greater burden because of increased space shuttle launch frequency and orbital activity. The figure indicates the combined launch of the new command and control module and mission crew. This approach is taken to maximize the use of the space shuttle payload capability. Should future investigations indicate this approach untenable because of the extended crew time required in earth orbit (an additional 14 days of on-orbit time), the crew could be launched separately, following launch and integration of the unmanned payload, at the expense of an added space shuttle launch.

LUNAR-SHUTTLE MISSION TIMELINE

EARTH ORBIT TURNAROUND -- SIX MISSIONS PER YEAR

*3 DAYS BETWEEN SHUTTLE LAUNCHES

COPLANAR LUNAR SHUTTLE PHASING

The spacing of lunar shuttle mission opportunities is shown in this chart. It is based on a target polar lunar orbit of 60 nmi, and a departure from a 260-nmi, 31.5-degree-inclination, earth-operations orbit. During a year, 13 mission opportunities exist, consisting of seven long-stay lunar missions and six short-stay lunar missions. The opportunities repeat every 54.6 days. The lower portion of the chart details the timeline associated with each opportunity. For the longer stay mission, 17.6 days are allowed in lunar orbit, while 4.0 days are allowed for the shorter stay mission. For either mission the outbound trip time is 4.5 days and the return leg is 3.0 days.

COPLANAR LUNAR SHUTTLE PHASING

RNS UTILIZATION SCHEDULE

Typical RNS operating plans were generated for traffic models of two and four missions a year. The schedule at the top of the chart is for two missions a year using one RNS. This low traffic rate allows a minimum of 138.8 days in earth orbit for performing the turnaround operations and any contingency maintenance. The schedule at the lower portion of the chart reflects a traffic model of four missions a year and uses two RNS systems. RNS No. 1 performs short lunar-stay missions while RNS No. 2 performs long lunar-stay missions. The minimum time between successive missions with the same RNS is 84.2 days for RNS No. 2. However, not all of this time is available to perform the turnaround operations. A ground rule was formulated restricting turnaround operations to one RNS at a time. As a result of this noninterference philosophy, only 69 days are available to resupply RNS No. 2 after returning from its first mission. The implications of performing turnaround operations on two RNS systems concurrently are additional requirements for orbital support systems, such as space tugs.

RNS UTILIZATION SCHEDULE

RNS UTILIZATION SCHEDULE—TWO RNS SYSTEMS

This chart presents typical RNS operating plans for six and eight missions a year when using two RNS systems. For the six missions per year, 84.2 days are spent in earth orbit between successive missions with the same RNS. However, it can be seen that both RNS systems are in earth orbit at the same time during certain portions of the schedule. To avoid operational interference, a ground rule was established limiting logistics support operations to one RNS at a time. As a result, only a portion of the time in earth orbit will be available for resupply operations; typically this would be 54.6 days prior to leaving on a mission. The lower schedule reflects an eight-mission-a-year traffic model using two RNS systems. The time between successive use of the same RNS varies with the minimum being 57.7 days. Using the same noninterference-operations philosophy discussed above results in a minimum allotted resupply time of 42.1 days.

RNS UTILIZATION SCHEDULE

TWO RNS

ORBIT GEOMETRY DURING COOLDOWN

The orbital geometry resulting from the cooldown impulse profile following full power engine operation is shown for a case representative of the EOI maneuver. The pulse is specified by its mid-point as each pulse was treated as an impulsive perturbation to the orbit. The cooldown phase is assumed to be accomplished at zero angle-of-attack throughout, that is, the thrust vector is always aligned with the velocity vector.

Two observations that relate to the characteristic early accumulation of the majority of the cooldown impulse are (1) that the desired injection orbit, (the orbit desired at the end of full-power operation) is eccentric, and (2) the orbit becomes near-circular very quickly.

The data show that if insertion occurs in an initial orbit of 437 nmi apogee by 366 nmi perigee (the eccentricity is 0.0093), the RNS will retro down to a 260-nmi circular orbit by the end of the cooldown phase. Specifically, the end of full-thrust shutdown occurs at an altitude of 381 miles at an initial flight path angle of -0.44 degrees. The negative flight path angle, and the closeness of the injection altitude to the perigee altitude noted, indicate that injection occurs prior to perigee passage. The total cooldown phase, in this case, lasts for 52.8 hours following shutdown, or a total of 33.5 orbital revolutions. When considering the accumulated impulse derived from cooldown during this retrograde phase, a correspondence is shown to the reduction in average orbital altitude (the sum of apogee altitude plus perigee altitude divided by 2), as would be expected. For example, four orbits following injection (23,000 seconds), 80 percent of the cooldown impulse to be derived has been delivered and, correspondingly, 80 percent of the average altitude reduction has been accomplished. Similarly, 90 percent of the effective reduction in average altitude is accomplished in less than nine orbits, or 14 hours, following injection. The total ideal velocity contribution during this cooldown phase is approximately 470 ft/sec, delivered at an effective specific impulse of 441 seconds.

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ORBIT GEOMETRY DURING COOLDOWN EARTH ORBIT INSERTION

ORBITAL INSERTION PROFILE OPTIONS

Noting that approximately 53 hours (or 33-1/2 orbital revolutions) are required to complete the cooldown phase for the EOI maneuver, the question is raised as to the possibility of crew deployment prior to the termination of the cooldown phase. Two approaches to accomplishing this were investigated: (1) injecting the RNS at a lower initial orbit to permit spiraling down to 260 miles more quickly, followed by deploying the crew and allowing the RNS to complete the cooldown phase on its own, and (2) intercepting the RNS early in the cooldown phase at a higher orbit with another stage, such as the chemical tug, and returning the crew to 260 nmi. In the latter case, the RNS would continue its downward spiral to 260 miles following deployment of the crew.

In the former of the two alternates, if 260 nmi insertion were desired at the end of two orbital revolutions (following 40 cooldown pulses), injection must occur in an orbit with a 394-nmi apogee and a 320-nmi perigee. This compares with the 437 by 365 nmi initial injection orbit, which would use all of the cooldown prior to circularization at 260 nmi, as was previously discussed. Adopting this approach in effect results in depriving the RNS of the useful impulse occurring following circularization at 260 nmi. The effect is to increase the full -thrust injection velocity required by virtue of injecting into a lower earth orbit. The payload impact of this higher energy requirement in this example is 950 lb. This payload penalty is compared with an equivalent cost for the second of the two alternatives mentioned, where a tug is assumed to intercept the RNS during its downward spiral in the cooldown phase. These data are based on the retrieval of a 20,000-lb crew module with a tug weighing 12,000 lb (inert weight, as specified in the NASA Guidelines) at a specific impulse of 460 seconds. Thus, the profile entails transfer of the tug from the 260-nmi orbit up to the intercept orbit, acquisition of the crew module, followed by return to the 260-nmi orbit. No velocity penalties were assigned beyond the ideal Hohmann transfer requirement. The tug propellant requirement to accomplish this sequence of events (10.2 lb per nautical mile between 260 nmi and the intercept orbit) was converted to equivalent payload delivered to lunar orbit at the rate of 112,000-lb of payload per 300,000 lbs of propellant, or 0.373 lb per lb. As can be seen, the second of the two alternatives is superior.

ORBITAL INSERTION PROFILE OPTIONS

TOTAL UTILIZATION
OF COOLDOWN IMPULSE

EARLY CREW DEPLOYMENT

EARLY CIRCULARIZATION

TUG INTERCEPT

OPTION

1

2

3

TIME TO CREW
DEPLOYMENT (HR)

52.8

3.2

3.2

PAYLOAD LOSS (LB)

0

950

200

—— RNS + CREW - - - - RNS ONLY

COMMAND AND CONTROL MODULE TURNAROUND CYCLE

The current RNS operating plan calls for the return of the command and control module (CCM) to the ground for maintenance and refurbishment subsequent to the completion of every RNS mission. The objectives are:

- A. Replenish CCM consumables.
- B. Verify CCM functionality.
- C. Verify CCM redundancies.
- D. Calibrate and adjust components.
- E. Replace limited-life hardware.

The CCM turnaround cycle is illustrated in the chart. Transportation to and from orbit is by the space shuttle, which provides a protective environment during boost and entry. The ground maintenance could be performed at KSC or at the manufacturing site. The latter was selected as the most cost-effective. The total turnaround time takes about 28.5 days, of which 14 days are spent at the manufacturing site and ten days at KSC for prelaunch and launch operations. The turnaround cycle of 28.5 days presents no hardship on performing the candidate RNS traffic models of two to eight missions per year.

COMMAND AND CONTROL MODULE TURNAROUND CYCLE

COMMAND AND CONTROL MODULE MAINTENANCE REQUIREMENTS

To establish the terrestrial maintenance requirements of the CCM, End Item Maintenance Sheets were prepared as illustrated in the chart. The CCM was broken down to the major assembly levels, e.g., star tracker assembly. The installation status, maintenance function required, maintenance frequency and maintenance location were established for each of these major assemblies. Brief task descriptions were then generated for each of the identified maintenance functions defining what is to be done. These task descriptions were used by the maintenance support engineering staff and RNS study personnel for estimates of the task-hours and personnel required.

COMMAND AND CONTROL MODULE MAINTENANCE REQUIREMENTS

SYSTEM/SUBSYSTEM/ ASSEMBLY/PRIME EQUIPMENT	INSTALLATION STATUS			MAINTENANCE				FUNCTIONS				SHELF LIFE	MAINTENANCE LOCATION
	SUBSYSTEM INSTALLED	SUBSYSTEM ASSEMBLED	SUBSYSTEM DISASSEMBLED	TEST OR CHECK	CALIBRATE & ADJUST	REMOVE/INSTALL	REPLACE	DECONTAMINATE/PURGE	COMPOSITE TEST	MONITOR-OPERATE	VISUAL CHECK/INSPECT	MAINTENANCE FREQUENCY	
C&C MODULE	X							X	X	X	AEM*	MFG	
ASTRIONICS S/S	X									X	AEM		
GUIDANCE, NAVIGATION & CONTROL	X								X		AEM		
STAR TRACKER ASSY	X		X	X						X	AEM		
IMU	X		X	X						X	AEM		

*AEM – AFTER EVERY MISSION

COMMAND AND CONTROL MODULE MAINTENANCE SUMMARY TIMELINE

This chart presents a summary CCM maintenance timeline. It is the result of summations of man-hours required for individual maintenance functions performed on each major CCM assembly. A major consideration in establishing the man-hours required for maintenance is that a high degree of automation would be used in checkout. An additional prerequisite is that maintainability be designed into the CCM. The unscheduled maintenance requirement is based on aircraft historical data necessitating 1 to 1.5 man-hours of unscheduled maintenance for every hour of scheduled maintenance. Major candidates for unscheduled maintenance are elements of the data management subsystems, e.g., the computer, auxiliary memory unit, etc.

COMMAND AND CONTROL MODULE MAINTENANCE SUMMARY TIMELINE

SPACE SHUTTLE REQUIREMENTS FOR RNS TURNAROUND

The figure identifies the number of space shuttle vehicles required for mission accomplishment as influenced by the annual mission rate and shuttle turnaround time. The turnaround times reflect the total time from launch to launch, including contingencies, for a given vehicle. In establishing the space shuttle requirements, the following ground rules were enforced:

- A. RNS requires 300,000 lb of LH₂.
- B. RNS lunar payload is 112,000 lb, assuming a 20,000-lb return payload.
- C. The CCM weighs 6,290 lb.
- D. Two candidate space shuttles were considered:
 - 1. 25K S/S—33,000 lb delivered into a 260-nmi by 31.5-degree earth orbit. For propellant delivery a 30,000-lb capability was assumed, allowing 3,000 lb for structure (the orbiter configured as an integral tanker).
 - 2. 40K S/S—50,000 lb delivered into a 260-nmi by 31.5-degree earth orbit. For propellant delivery, a 40,000-lb capability was assumed (the orbiter configured as an integral tanker and volume limited).
- E. No propellant or payload storage facility in earth or lunar orbits.

The required launch rates, which established the number of vehicles required, are based on 14 and 11 space shuttle launches required for turnaround for the 33,000 and 50,000-lb-capability vehicles, respectively. The breakdown of this requirement is as follows:

Space Shuttle Capability to 260 nmi ($i = 31.5$ degrees)	33,000 lb	50,000 lb
LH ₂ Refueling	10	8
Payload (112,000 lb) and CCM	4	3
	<hr/> 14	<hr/> 11

A single RNS is assigned to accomplishing the two-missions-a-year case, while two RNS are assigned for the higher rates. In all cases, the uninterrupted available time between missions is used to complete turnaround activities, which are scheduled in such a manner as to not interfere with turnaround of the other RNS. Except for the eight-missions-a-year annual rate, the turnaround sequence is scheduled for completion as close as possible to the translunar injection opportunity to minimize the hold time in a ready condition. This was not convenient in the eight-missions-a-year case, and resulted in the RNS being turned around immediately following return from the mission in some cases to prevent interference with turnaround of the alternate RNS. Current space shuttle definition studies are based on an eventual total program capability of 75 flights a year with a turnaround capability of 14 days for each space shuttle.

SPACE SHUTTLE REQUIREMENTS FOR RNS TURNAROUND

	SPACE SHUTTLE TURNAROUND TIMES		
	15 DAYS	10 DAYS	5 DAYS
RNS MISSIONS/YEAR	2 4 6 8	2 4 6 8	2 4 6 8
NUMBER OF 25/33K SPACE SHUTTLES REQUIRED	2 4 5 8	1 3 4 5	1 2 2 3
NUMBER OF 40/50K SPACE SHUTTLES REQUIRED	2 3 4 5	1 2 3 4	1 1 2 2

SPACE TUG UTILIZATION

The figure identifies the required availability and number of tugs required to perform requisite RNS operations. The extent of tug utilization is indicated by the number of operations per cycle as well as an associated estimate of hours of active operation per cycle. Operations are defined as an activity related to the handling of an individual module, whether it be payload or RNS. For example, ten operations are required per cycle in module deployment during RNS assembly to handle eight propellant modules, one command and control module, and one propulsion module. The requirement for four operations for payload deployment and assembly is predicated on a 33,000-lb capability space shuttle to the 260-nmi, 31.5 degree inclination operational orbit (25,000 lb to 55 degree inclination). Two tugs are required to perform module assembly, as well as command and control module replacement, as the stabilization function is provided the RNS by the command and control module.

SPACE TUG UTILIZATION

FUNCTIONS	NO. REQUIRED	OPERATIONS PER CYCLE	HOURS PER CYCLE	CYCLES* PER YEAR	HOURS PER YEAR
ASSEMBLY					
● MODULE DEPLOYMENT	1	10	10	<1	<10
● MODULE ASSEMBLY	2	10	12	<1	<12
● PAYLOAD DEPLOYMENT & ASSEMBLY	1	4**	8	<1	< 8
EARTH ORBIT TURNAROUND					
● COMMAND & CONTROL MODULE REPLACEMENT	2	1	4	6	24
● CREW MODULE RETRIEVAL	1	1	8	6	48
● PAYLOAD DEPLOYMENT & ASSEMBLY	1	4**	8	6	48
LUNAR ORBIT OPERATIONS					
● PAYLOAD DEPLOYMENT & ASSEMBLY	1	1	11.5	6	69

* BASED ON 6 RNS MISSIONS PER YEAR & A 3-YEAR OR 10-MISSION RNS DESIGN LIFE

** 25/33K LB CAPABILITY SPACE SHUTTLE

PERFORMANCE IMPACT--TRANSLUNAR COOLDOWN UTILIZATION

Estimates made to date of the baseline RNS performance for the lunar shuttle mission have not credited impulse derived during the NERVA cooldown phase toward the accomplishment of mission velocity maneuvers. Thus, in effect, propellant consumed for the NERVA cooldown function was treated as a nonpropulsive, unusable propellant. The performance implications of this assumption have been evaluated using a two-body patched conic solution for the baseline 108-hour translunar mission leg. The reference condition (zero cooldown used for impulse) was a payload delivery capability to lunar orbit of 112,000 lb (20,000 lb crew module on the return leg), based on a NERVA steady-state run time of 1,800 seconds. The cooldown impulse profile was modeled per Aerojet Report S-130-BP-090290-FL-PREL, "NERVA Reference Data--Full Flow Engine," dated April 1970. The duration of the cooldown phase in this case is actually somewhat in excess of the 108-hr transfer time between the earth and the moon. The total impulse contributed during the cooldown phase for this particular engine run time would be 3.3×10^6 lb-sec, or an equivalent characteristic velocity of 320 ft/sec. Total use of the cooldown impulse for the translunar velocity requirement results in an equivalent reduction in the full-thrust velocity requirement of approximately 130 ft/sec, resulting in a performance improvement of approximately 3,400 lb. This 3,400-lb performance improvement would be increased further by an additional 11,000 lb performance gain if the requirement for engine cooldown could be completely eliminated. That is, the 7,600 lb of propellant presently allocated for cooldown could be reassigned for use during full-thrust operations. This potential performance improvement (11,000 lb) would have to be played against any system weight increases required to effect cooldown elimination (for example radiator systems). The performance impact of increases in RNS system inert weight is 2.7 lb lost in orbital payload per pound increase in inert weight, or approximately a 4,000 lb inert weight increase as the break-even point.

**PERFORMANCE IMPACT OF NERVA
AFTERCOOLING IMPULSE UTILIZATION
TRANSLUNAR MISSION PHASE**

18078

APS IMPULSE REQUIREMENTS

Impulse and thrust level requirements for the APS have been established. These requirements are displayed graphically here. The total impulse for the Class 1 hybrid configuration of approximately 453,000 lb-sec translates into 1,132 lb of propellant, and the Class 3 configuration requires 1,138 lb of propellant to provide the 455,000-lb-sec impulse requirement ($I_{sp} = 400$ sec). A thrust-level requirement of 100 lb has been selected to provide reasonable maneuver rate capability for attitude maneuvers. Axial thrust-level requirements of 3 lb (positive) and 200 lb (negative) for preignition separation and rendezvous maneuvers have been identified.

There are seven distinct functions performed by the APS during the lunar mission. These are (1) attitude control during coast phases, (2) attitude maneuvers, (3) attitude control during cooldown thrusting, (4) separation maneuvers prior to main stage ignition, (5) roll control during main engine burns, (6) supplemental thrust during rendezvous maneuvers, and (7) acceleration for propellant settling.

Limit cycle requirements are shown to be one to two orders of magnitude below other functional requirements. Limit cycling was assumed to be accomplished within a plus or minus one-degree deadband, using a minimum impulse bit of 3 lb-sec. Attitude maneuvers were performed at a rate of 0.1 deg/sec and include vehicle orientation for various NERVA operations, coast, separation, and gravity gradient storage in earth and lunar orbits. Contrary to engine operation at full thrust and in the idle mode, where vehicle attitude is provided by gimbaling the NERVA to counteract overturning moments, the APS is required to stabilize the vehicle during cooldown operations. The requirements shown for this function are based on an assumed 0.1 degree misalignment between the cooldown thrust vector and the vehicle center of gravity. A velocity provision of 2.5 ft/sec each for separation from manned-lunar and earth-orbit facilities prior to NERVA operations was budgeted. Roll control requirements evolve during the start transient and steady-state engine operations. Steady-state impulse requirements were scaled at the rate of 500 lb-sec plus 0.1 lb-sec per second of steady-state operation, based on experience with the J-2 engine (scaled appropriately). A velocity allocation for rendezvous maneuvers of 10 ft/sec each for lunar orbit and earth orbit rendezvous was made.

APS IMPULSE REQUIREMENTS

RNS DESIGN

The context for the current phase of the RNS design activity is given on the facing chart. Phase II resulted in definition of the two basic RNS concepts—the single-module, 33-ft-diameter Class 1 concept and the multiple-module Class 3 configuration. The first period of Phase 3 focused on selection of major characteristics for each concept and the overall configuration of the vehicles. The most significant selection during this period was that of a discrete command and control module for the Class 1 concept to most effectively accomplish orbital maintenance. Another major result of the first period analysis was the selection of the Class 3 vehicle configuration with the modules in the form of a cruciform cluster. Operations were analyzed in support of making the above concept/configuration selections as well as to provide the bases for more detailed definition of the RNS itself.

During the second period major design activities were oriented toward trade studies selecting specific subsystem design features. To accomplish these trade studies, detailed operations analysis, using the scenarios developed during the first period, were performed to establish subsystem requirements. Subsequent charts will show the operations analysis and subsystem definition for the RNS functional subsystems. This section will conclude with a summary of the major features selected during this period and with the current weight statement for both RNS concepts.

RNS DESIGN

- FIRST PERIOD RESULTS:
 - RNS CONCEPT/CONFIGURATION
 - CLASS 1 – – CCM FOR MAINTENANCE
 - CLASS 3 – – CRUCIFORM CLUSTER
 - OPERATIONS
 - MISSION TIMELINE
 - ORBITAL ASSEMBLY AND REFURBISHMENT
 - RNS OPERATIONS
- SECOND PERIOD OBJECTIVES:
 - DESIGN FEATURE TRADE STUDIES
 - DETAIL OPERATIONS TO ESTABLISH REQUIREMENTS

RNS PROPELLANT MANAGEMENT APPROACH

This portion of the briefing will develop the design concept and operations for the propellant management functions of the RNS. Functional schematics will be developed, beginning with the most basic functions required for a stage and adding subsystem design concepts specifically required for RNS orbital and mission operations. The approach will be to identify design requirements and implications of the various operational phases. Prior to commencing the mission there are orbital operations, including propellant resupply and checkout, required for reusability of the system. The mission operations for the reference lunar shuttle profile encompass multiple burns in various NERVA thrust modes. The associated operations and sequencing of the stage functional subsystems will be defined for these requirements.

RNS PROPELLANT MANAGEMENT APPROACH

DEVELOP RNS PROPELLANT MANAGEMENT SCHEMATIC

- BASIC FUNCTIONS
- ADD DESIGN CONCEPTS FOR RNS ORBITAL & MISSION OPERATIONS

IDENTIFY DESIGN REQUIREMENTS AND IMPLICATIONS OF RNS OPERATIONS
PHASES

- ORBITAL - PROPELLANT RESUPPLY, CHECKOUT
- MISSION - LUNAR SHUTTLE PROFILE

DEFINE FUNCTIONAL SUBSYSTEMS OPERATIONS & SEQUENCING

- STARTUP
- CONTROL
- SHUTDOWN & AFTERCOOLING

BASIC PROPELLANT MANAGEMENT SCHEMATIC

The basic propellant management schematic shows the propulsion module and a single propellant module. Functions are provided for ground, launch, and minimum mission operations. The stage intermodule interfaces are flight remote couplings.

Ground fill and drain for the Class 3 modules uses the existing propellant feed system for propellant loading inside the space shuttle. The propulsion module is launched dry, however. The Class 1-H propellant module incorporates a separate fill-and-drain riser duct, a pneumatically actuated, normally closed fill-and-drain valve, and an umbilical disconnect.

The ground vent and relief system provides for venting of the fuel tank during filling and safety relief capability in the event of inadvertent pressure buildup. The system contains a vent valve and a vent-and-relief valve. The vent valve is pneumatically actuated for ground operation only. Ground vent functions for the propulsion module are provided by field connections to the flight vent system.

The flight vent system utilizes quad-redundant pilot-operated solenoid valves, which are pressure sensor controlled. Nonpropulsive vent nozzles are incorporated.

The pressurization system operates with NERVA bleed gas. It utilizes a set of quad-redundant, direct-acting solenoid valves, which are pressure sensor controlled. Separate functions of prepressurization, expulsion, and pressure control are provided. The parallel redundant check valves are engine supplied. A diffuser inlet is incorporated.

The propellant feed system permits independent access to each propellant module and independent operation of the propulsion module. It consists of two parallel 8.00-in. -diameter motor-driven shutoff valves and a 12.00-in. -diameter blocking valve located in the feedthrough riser. Antivortexing and filtration is accomplished with tank bottom screening.

BASIC PROPELLANT MANAGEMENT SCHEMATIC

GROUND FILL AND DRAIN

- CLASS 1-H: PROVIDE DISCRETE SYSTEM
- CLASS 3: USE FEED SYSTEM
- PROPULSION: LAUNCH DRY

GROUND VENT AND RELIEF

- PROPELLANT: DISCRETE
- PROPULSION: USE FLIGHT VENT

FLIGHT VENT

- NON-PROPULSIVE

PRESSURIZATION

- CONFIGURED FOR NERVA BLEED
- PROVIDE SEPARATE REPRESSURIZATION, EXPLUSION, AND CONTROL
- DIFFUSER INLET

PROPELLANT FEED

- INDEPENDENT ACCESS TO MODULES

PROPELLANT RESUPPLY CONCEPT

A schematic of the design concept for orbital propellant resupply is depicted in this chart. It is used for orbital fill on both propellant and propulsion modules. An objective of the design is to fill a propellant tank in orbit without venting or an excessive pressure rise. This is accomplished by using spray-nozzle injection to accomplish ullage collapse, maintaining propellant orientation during the propellant transfer operation with axial acceleration provided by the tanker vehicle. Also, the orbital fill system includes a check valve and a flow meter in the fill line to control the propellant in-flow rate and minimize pressure surges during chilldown of a warm tank. This requirement is imposed on modules which have been depleted early in the mission or have sustained a long coast in orbit before refill. The main LH_2 feed duct is blocked near the top of the tank to limit penetration of cold fluid into the warm feed duct inside the tank during chilldown and inhibit geysering. The delivered propellant conditions at startup of the RNS mission depend on the propellant resupply logistics model. The variations introduced by such models will not be considered here. For the simplest case, the difference between delivering the propellant to a warm and a cold tank is indicated.

PROPELLANT RESUPPLY CONCEPT

TANK FILLED WITHOUT VENTING

- SPRAY NOZZLE INJECTION
- ACCELERATION BY TANKER

PROVIDE CHILLDOWN OF WARM TANK

- CHECK VALVE & FLOW METER CONTROL
- MINIMIZE PRESSURE SURGES
- FEED LINE BLOCKED

DELIVERED PROPELLANT CONDITIONS

- COLD TANK - 16 PSIA
- WARM TANK - 21 PSIA

PROPELLANT MANAGEMENT CHECKOUT

The requirements for RNS propellant management checkout in orbit before starting the mission consist of functional check of subsystems and components and leakage check at interfaces, which also includes initial verification of orbital assembly. Candidate functional check approaches are delineated here as either component functional checkout or actual simulated operations of the system. A component functional checkout strategy could minimize fluid flow and expendables compared to simulated operations, while the latter could even require NERVA criticality to accomplish pressurization. In utilizing either approach it is desired to impose minimal additional components or operations on the baseline design.

PROPELLANT MANAGEMENT CHECKOUT

REQUIREMENTS

- **FUNCTIONAL CHECK -- ALL SUBSYSTEMS AND COMPONENTS**
 - **VERIFY OPERATION AND REDUNDANCIES**
- **LEAKAGE CHECK AT INTERFACES**
 - **STATIC SEALS**
 - **DYNAMIC SEALS (VALVES)**
 - **REMOTE FLUID COUPLINGS (ORBITAL ASSEMBLY)**

CANDIDATE FUNCTIONAL CHECK APPROACHES

- **COMPONENT FUNCTIONAL CHECKOUT**
 - **OPERATE COMPONENTS SEQUENTIALLY -- VERIFY TALKBACKS**
 - **MINIMIZE FLUID FLOW AND EXPENDABLES**
- **SIMULATED OPERATIONS**
 - **PROPELLANT SETTLING, CHILLDOWN, PRESSURIZATION, RUN TANK REFILL, AFTERCOOLING**
 - **NERVA CRITICALITY REQUIRED**

COMPONENT FUNCTIONAL CHECKOUT

Approaches to component functional checkout are defined here for three general classes of propellant management subsystem configurations. For the first class, quad-redundant valve configurations, it is evident that redundancy has been imposed on most flight systems for reliability. Thus, no additional checkout valves are required. The checkout approach consists of sequencing valve actuation to minimize fluid losses, verifying talkbacks from the controls. The approach requires independent control of the valves.

The second class of propellant management subsystems is represented by the LH₂ feed system. For this system, blocking valves isolate each module interface, permitting actuation of the dual feed valves. Similarly, the chilldown and refill pumps could be run with the discharge valves closed. These checkout operations could be performed at convenient times in the operations profile, which include the propellant resupply period and the normal feed system chilldown during the startup ramp to minimize the impact of these operations.

The third class of checkout items consists of ground-only functions such as the fill-and-drain and ground vent systems. These are locked for flight, and orbital checkout is not required.

COMPONENT FUNCTIONAL CHECKOUT

CLASS 1: QUAD-REDUNDANT VALVE CONFIGURATIONS

- REDUNDANCY IMPOSED ON MOST FLIGHT SYSTEMS FOR RELIABILITY--ORBITAL FILL, PRESSURIZATION, FLIGHT VENT, CHILLDOWN, AFTERCOOLING, APS
- NO ADDITIONAL C/O VALVES REQUIRED
- SEQUENCE ACTUATION TO MINIMIZE LOSSES
 - VERIFY TALKBACKS
 - REQUIRES INDEPENDENT CONTROL

CLASS 2: LH₂ FEED SYSTEM

- BLOCKING VALVES ISOLATE EACH MODULE INTERFACE
- ACTUATE DUAL FEED VALVES
- RUN CHILLDOWN AND REFILL PUMPS WITH DISCHARGE VALVES CLOSED
- PERFORM AT CONVENIENT TIMES
 - PROPELLANT RESUPPLY
 - FEED SYSTEM CHILLDOWN (STARTUP RAMP)

CLASS 3: GROUND-ONLY FUNCTIONS (FILL AND DRAIN, GROUND VENT)

- LOCKED FOR FLIGHT -- ORBITAL C/O NOT REQUIRED

PROPELLANT MANAGEMENT CHECKOUT APPROACH

Component functional checkout is favored over simulated operations on the basis of minimizing operational penalties. Furthermore, it is evident that there are no major additional design requirements: specifically, no checkout valving. The additional requirements for operational instrumentation and stimuli are considered to be small and the only variation imposed on the design is the requirement for providing independent valve control in quad-redundant systems.

Leakage check at interfaces can be accommodated by a number of approaches, with the consideration that the design should provide insensitivity to small leaks. Several practical candidates are available for leakage check of seals. Dual seal flanges and leak detection ports have already been demonstrated for static seals on S-IVB. Acoustic emission sensors are presently being developed for dynamic seals. Furthermore, it is considered that orbital assembly verification is feasible for the baseline remote, automated assembly operations. Torque control can be employed for screw drives and position or torque talkbacks can be employed.

PROPELLANT MANAGEMENT CHECKOUT APPROACH

COMPONENT FUNCTIONAL C/O FAVORED OVER SIMULATED OPERATIONS

- MINIMIZES OPERATIONAL PENALTIES
- MINIMAL DESIGN REQUIREMENTS
 - NO C/O VALVING
 - SMALL Δ STIMULI AND INSTRUMENTATION
 - INDEPENDENT VALVE CONTROL

LEAKAGE CHECK AT INTERFACES CAN BE ACCOMMODATED

- DESIGN FOR INSENSITIVITY TO SMALL LEAKS
- SEVERAL PRACTICAL CANDIDATES AVAILABLE
 - STATIC: DUAL SEAL FLANGES AND LEAK DETECTION PORTS
 - DYNAMIC: ACOUSTIC EMISSION SENSORS
- ORBITAL ASSEMBLY VERIFICATION FEASIBLE
 - TORQUE CONTROL FOR SCREW DRIVES
 - POSITION OR TORQUE TALKBACKS

RNS OPERATIONS FOR MISSION PHASES - I

The propellant utilization and NERVA thrust modes during the lunar shuttle mission profile, which generate the stage propellant management design requirements, are depicted in the next two charts for the Class 3 RNS. These show the propellant loadings in the propellant modules and the propulsion module after completion of mainstage burns. Also, the aftercoolant required after completion of the burns is shown separately. In these figures the propulsion module is blown up in scale to provide greater definition of the propellant loadings in that module. The capacity of a Class 3 propellant module is 36,400 lb LH₂ (8 are utilized) and the propulsion module capacity is 9,700 lb LH₂.

The NERVA thrust modes for the various mission maneuvers are indicated. The first burn, translunar injection (TLI), is performed at full thrust. The required propellant for pulsed aftercooling is contained in the propulsion module run tank. The mid-course correction is performed using the NERVA idle mode. Only the propulsion module is operated for that maneuver, so only that module is depicted. The initial elliptical lunar orbit injection maneuver (LOI-1) is also performed at full thrust. Since the run tank was depleted for TLI aftercooling and the mid-course maneuver, it must be refilled before LOI-1. The subsequent plane change maneuver at the moon (LOI-2) is performed with the NERVA throttle mode, and all of the required propellant for that maneuver and LOI-1 aftercooling is contained in the run tank. Completion of lunar orbit injection (LOI-3) is performed as a full thrust operation, requiring a refill of the run tank before startup. All aftercooling operations and the small maneuvers which are performed at less than full thrust are performed using only the propulsion module run tank.

RNS OPERATIONS FOR MISSION PHASES-I

RNS OPERATIONS FOR MISSION PHASES-II

The remaining phases of the lunar shuttle mission profile are depicted in this chart, including the trans-earth injection (TEI) and earth orbit injection (EOI) maneuvers. The same general modes of operation are applied: throttle mode for the plane change at the moon and idle mode for mid-course, with full-thrust operation in the main burns. Again the propulsion module run tank supplies all of the aftercoolant and the propellant required for small maneuvers. It is refilled before each full-thrust burn.

RNS OPERATIONS FOR MISSION PHASES-II

REQUIREMENTS FOR NERVA OPERATING MODES

The NERVA thrust modes described on the preceding charts generate requirements for different stage propellant management functions, including propellant settling, feed system chilldown, prepressurization, and prestart run tank refill. The various NERVA thrust operating modes are defined according to their respective parameters and required RNS functions in this chart. These are used as a basis for defining the RNS propellant management design concepts and operations.

REQUIREMENTS FOR NERVA OPERATING MODES

NERVA OPERATING MODE	NERVA PARAMETERS			RNS FUNCTIONS			
	THRUST (LB)	FLOW RATE (LB/ SEC)	I _{SP} (SEC)	PROPELLANT SETTLING	FEED SYSTEM CHILLDOWN	PREPRESS- URIZATION	PRESTART RUN TANK REFILL
FULL POWER	75,000	91.9	825	✓	✓	✓	✓
THROTTLE MODE	45,000	55.1	825	✓	✓		
IDLE MODE	1,000	2	500				
AFTERCOOLING	300	0.7	430				

✓ = REQUIRED

STARTUP OPERATION PHASING SCHEMATIC

The sequencing and interrelation of the operations of 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 requires a low acceleration provided by the APS. This is followed by a high-thrust, dissipative settling phase for which the necessary acceleration is provided by NERVA during its startup ramp. The operations for preconditioning the feed system include chillover and prestart refilling of the run tank. These are accomplished during the inviscid orientation phase after an initial settling period. Prepressurization cannot be initiated until completion of the dissipative phase of settling and 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 the NERVA thrust can be increased to full power, although for some cases it could be desirable to maintain the thrust hold until completion of 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. The design concepts for each of these operations will be defined in subsequent charts.

STARTUP OPERATIONS PHASING SCHEMATIC

PROPELLANT SETTLING

The propellant settling operations are defined here, 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 $6.7 \times 10^{-6} \text{ g}$. Antigeysering baffles are provided for orientation control. Providing settling for each of the burns in the lunar shuttle mission profile results in a total inviscid phase settling propellant consumption of 120 lb with a cryogenic APS. Definition of the system has indicated no interference of the settling times with limit cycling or aftercooling, even though the required inviscid settling times are long, ranging from 3,200 sec at TLI to 1,700 sec for EOI with the Class 3 RNS.

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.

PROPELLANT SETTLING

INVISCID ORIENTATION PHASE

- CRITERION: INITIAL RUN TANK
BOND NO. = 10
- UTILIZE APS: 3 LB THRUST,
120 LB PROPELLANT TOTAL
- NO INTERFERENCE OF SETTLING TIMES WITH
LIMIT CYCLING OR AFTERCOOLING:
TLI 3, 200 SEC, EOI 1, 700 SEC

DISSIPATIVE PHASE

- CRITERION: ELIMINATE SLOSH & BUBBLES
FOR PREPRESSURIZATION
- UTILIZE NERVA THRUST RAMP - POSSIBLE HOLD
AT THROTTLE POINT
- REQUIRES 10 TO 60 SECONDS

NERVA STARTUP THRUST RAMP

NERVA operating conditions, acceleration level, and the required saturation pressure for 0 NPSP at the existing flow rate are indicated at various times through the NERVA thrust buildup ramp. After the first 30 sec of bootstrap operation, the acceleration level becomes adequate for the dissipative requirements of settling. It is seen that the engine can operate up to the throttle point without prepressurization for the anticipated propellant histories, since tank chill-down results in a 21-psia initial condition.

NERVA STARTUP THRUST RAMP

PHASE	TIME (SEC)	FLOW RATE (LB/SEC)	THRUST (LB)	I _{SP} (SEC)	ACCELERATION (g) *	PSAT FOR O NPSP (PSIA)
BOOTSTRAP	0	1.2	295	253	6.3×10^{-4}	~ 12
	25	1.2	383	331	8.1×10^{-4}	~ 12
	30	1.8	691	375	1.5×10^{-3}	~ 12
RAMP UP	39	29.8	17,090	572	3.6×10^{-2}	16.2
	52	55.1	44,990	816	9.6×10^{-2}	20.3 ← THROTTLE POINT
	56	91.9	75,000	816	0.16	26.0 ← FULL THRUST

* FULL RNS AT TLI

CHILLDOWN REQUIREMENTS

Prior to startup it is necessary to chilldown the active portion of the RNS feed system to assure propellant conditions for NERVA and to accomplish a predictable startup operation. The feed system interfaces that require conditioning include the two legs of the NERVA feed system between the turbopump and the run tank and the interfaces between the various RNS modules. These are summarized in the facing chart. All the stage feed ducting uses two basic types of flexible elements, gimbal joints and linear pressure volume compensators, which account for the masses shown for those systems. Chilledown time requirements were based on the minimal permissible time for chilledown of each interface considering film boiling heat transfer for a duct initially at ambient temperature and providing a margin of safety for flow surges.

CHILLDOWN REQUIREMENTS

INTERFACE	COMPONENTS	MASS (LB)	LENGTH (FT)	EQUIVALENT BOILOFF (LB-LH ₂)	CHILL TIME (SEC)
NERVA (EACH SIDE)	PSOV-VALVE 9 IN. FEED DUCT * TURBOPUMP PDKVA-VALVE	973	8.9	92	43
RUN TANK/ PROPELLANT MODULE	12 IN. FEED DUCT*	263	11	28	34
PROPELLANT MODULE/ PROPELLANT MODULE	12 IN. FEED DUCT*	217	10.2	23	24
OUTBOARD/ INBOARD PROPELLANT MODULES	8 IN. FEED DUCT*	116	11.5	13	17

* INCLUDES GIMBAL JOINTS

INTEGRATED NERVA/STAGE CHILLDOWN SYSTEM

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 operations. Forced convection is required for the low-g chilldown. The indicated schematic is compatible with the current NERVA interface. The propulsion module run tank contains redundant, submerged, ac-motor-driven centrifugal pumps. An inverter is provided for each motor to utilize the dc power bus. Each pump is sized for full chilldown system capacity, amounting to 2 lb LH₂ per second. The dominant pressure drop is in the NERVA turbopump (about 3.5 psi). This results in a pump power of about 1 HP. Fluid return for stage feed duct chilldown is accomplished with the refueling spray nozzle bypass system on the run tank. Fluid return for the NERVA feed chilldown is provided by a separate gimbaled return line and shutoff valves. Check valving is located at all injection points to prevent surges and disturbances from being transmitted to the adjoining systems. The indicated design is a variation on the chilldown system concept which has been proven in flights on the S-IVB.

INTEGRATED NERVA / STAGE CHILLDOWN SYSTEM

SYSTEM LOCATED IN RUN TANK

CONDITIONS NERVA & STAGE INTERFACES

OPERATE DURING LOW-G SETTTLING

- FORCED CONVECTION REQUIRED

UTILIZE REDUNDANT AC SUBMERGED PUMPS

- 2 LB-LH₂/SEC
- 1 HP

DESIGN MINIMIZES PRESSURE SURGES

- CONCEPT PROVEN ON S-IVB

PRESTART RUN TANK REFILL SYSTEM

It was explained in the definition of the mission operations profile that it is necessary to refill the run tank before startup for all full power burns. The system for accomplishing refill is described here. The objectives in the design of the system are to avoid venting, to accommodate a higher pressure in run tank than in the propellant module supply, to integrate the refill operation with the normal sequence of startup operations (avoiding separate operational requirements), and to provide for delivery of up to 8,500 lb of LH₂ during the refill operation. As depicted in the startup operation phasing schematic, the refill operation will be phased subsequent to the feed system chilldown. The system concept defined in this schematic uses redundant, ac submerged pumps located in the run tank with a capacity of 5 lb LH₂ per second and a power of 1 HP. The base sump for the pumps is located in the main feed duct and the pumps discharge through the conventional orbital fill system. The design approach would integrate the refill system with the chilldown system by utilizing single-motor, double-ended pumps.

PRESTART RUN TANK REFILL SYSTEM

DESIGN OBJECTIVES

- NO VENTING
- ACCOMMODATE HIGHER PRESSURE IN RUN TANK
- INTEGRATE REFILL WITH STARTUP
- UP TO 8,500 LB-LH₂ REQUIRED

PHASE WITH FEED SYSTEM CHILLDOWN

UTILIZE REDUNDANT AC SUBMERGED PUMPS

- 5 LB-LH₂/SEC
- 1 HP

INTEGRATE HARDWARE WITH RUN TANK SYSTEMS

- CHILLDOWN
- ORBITAL FILL

SUMMARY OF RUN TANK DEPLETION DURING STARTUP

Although the run tank operates independently during the startup operation, it is desirable to avoid depleting its propellant level too greatly because of increased radiation dosage to equipment located at the top of the propulsion module. The nominal run tank capacity is 9,500 lb of LH_2 and typically it is desirable to keep the run tank level above 5,000 lb of LH_2 , where the dose rate is a factor of 2 higher than for the full tank. The minimum run tank level (or depletion) during the startup operations is summarized in this figure for the mission profile. The duration of the NERVA thrust hold to complete propellant settling and tankage prepressurization operations is also indicated in the figure. The resulting mission performance penalties are negligible. To avoid excessive depletion of the run tank for the two initial burns, it proved desirable to hold the thrust at the throttle point until completion of prepressurization. The resulting reduced flow rate before the propellant module could be brought on-line avoids excessive run tank depletion. After the propellant module is brought on-line, the run tank will be refilled during full power with the pressure head differential between the tanks by reducing the impedance of the flow control valve from its steady-state setting.

SUMMARY OF RUN TANK DEPLETION DURING STARTUP

CLASS 3 RNS

BURN	NERVA THRUST HOLD (SEC)	PROPELLANT TANK PREPRESSURIZATION TIME (SEC)	RUN TANK DEPLETION (LB-LH ₂)	MINIMUM TANK LEVEL (LB-LH ₂)
TLI	67 *	23	4, 430 *	5, 260 *
LOI-1	59 *	31	3, 990 *	5, 700 *
LOI-3	27	26	4, 620	5, 070
TEI-1	18	7	2, 380	7, 310
TEI-3	16	30	4, 390	5, 300
EOI	14	28	4, 090	5, 600

* THRUST HOLD THRU PROPELLANT TANK PREPRESSURIZATION

CONCLUSION: SUFFICIENT PROPELLANT FOR SHIELDING CAN BE MAINTAINED

TANK PRESSURE AND LIQUID LEVEL CONTROL SCHEMATIC

The pressurization control system schematic shown uses independent pressure and flow control for the propulsion and propellant modules. The bang-bang pressure control system consists of parallel redundant, normally closed shutoff valving that are controlled by strain gage pressure transducers located in the tank ullages. A separate steady-state expulsion pressurization leg is provided. The propellant module system requires a third operating range for the large prepresurization flow requirement and the full power run tank refill operation. The flow control system consists of two 8-in.-diameter throttle valves. These motor-driven throttle valves are controlled by sensing liquid level in the run tank. Three discrete liquid-level sensors provide the control signal based on a voting circuit. Overpressurization is prevented by the baseline quad-redundant flight vent system.

TANK PRESSURE AND LIQUID LEVEL CONTROL SCHEMATIC

INDEPENDENT CONTROL OF MODULE PRESSURES

- STRAIN-GAGE PRESSURE TRANSDUCERS
- BANG-BANG PRESSURE CONTROL VALVES
- PRESSURIZATION, VENT
- SEPARATE EXPULSION PRESSURIZATION
- PREPRESSURIZATION

CLASS 3: USE EXPULSION

CLASS 1-H: REQUIRE DISCRETE SYSTEM

RUN TANK LIQUID LEVEL CONTROL

- OPTICAL POINT LEVEL SENSORS
- SERVO-CONTROL FEED VALVES

TANK PRESSURE AND LIQUID LEVEL CONTROL SIMULATION

The dynamics of the baseline control system have been investigated to establish system responses and controller characteristics. The simulation shown here evaluated the operation of the LH₂ feed valve controller as it responded only to liquid-level height without additional information as to the rate or direction of level change. The following transient operations are presented: (1) the propellant loading in the run tank was increased from 6,000 to 9,000 lb while supplying full flow to the engine, (2) a step increase of 0.2 psi was imposed in the propellant module pressure to simulate pressurant changes or acceleration head changes within the propellant module, and (3) a drop in the demand of the flow rate to the engine to respond to the emergency mode condition.

The run tank refill case shows an immediate requirement to vent the run tank after the LH₂ feed valve is opened. The pressure adjustment reduced the flow rate from its initial refill value. Upon reaching 9,000 lb, the command was given to increase the control valve impedance to its steady-state value. The pressures within the propellant module and propulsion run tank show the anticipated self-regulating characteristics.

Next, a 0.2-psia pressure perturbation was introduced in the propellant mode. For the other functions this is comparable to a head change upon switching propellant modules. The resulting increase in the pressure of the run tank quickly damped out the perturbation.

Finally, the NERVA emergency mode was applied. The feed valve controller responded and achieved the new 60-lb flow rate after the propellant in the run tank had increased an additional 150 lb. Oscillations were obtained around the 9,200-lb level because the feed valve controller was responding to the liquid level sensor before the self-regulating characteristics of the pressures in the run tank and the propellant tank could damp out these oscillations. This effect is only caused by the simplified control model used for the simulation.

TANK PRESSURE AND LIQUID LEVEL CONTROL SIMULATION

PRESSURE CONTROL SETTINGS (PSIA):

	PRESSURANT	VENT
PROPULSION	26.2	26.5
PROPELLANT	27.7	28.0

LIQUID LEVEL CONTROL SETTINGS:

- 9,000 LB-LH₂ NORMAL SETTING
- Δ IMPEDANCE = 10% PER 50 LB-LH₂

SHUTDOWN OPERATIONS PHASING SCHEMATIC

The relationship of the shutdown operations for NERVA and the propellant and propulsion module propellant management systems is shown in this schematic. The thrust level is reduced from full power to the throttle point maintaining all systems in operation. At this point, typically, the propellant module is isolated, terminating the requirement for pressurization and feed system operation for the propellant module. During the temperature retreat phase of NERVA, propellant feed is maintained through the normal NERVA feed system. Run tank pressurization can be terminated at the throttle point or continued through the temperature retreat if desired. After pump tailoff, the separate aftercooling bypass system is actuated to provide aftercooling pulses.

SHUTDOWN OPERATIONS PHASING SCHEMATIC

AFTERCOOLING SYSTEM

The baseline aftercooling system concept is depicted in this schematic. It employs a surface tension pulse basket to provide liquid to the NERVA after-cooling 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.

AFTERCOOLING SYSTEM

SURFACE TENSION PULSE BASKET

- LIQUID FEED
- NO PROPELLANT SETTLING
- NO PRESSURIZATION

USE ONLY RUN TANK

RNS PROPELLANT MANAGEMENT

SUMMARY AND CONCLUSIONS

To review the portion of the briefing just completed, the operations and design requirements for the RNS propellant management systems have been established for the lunar shuttle mission profile. System design concepts, operations, and sequencing have been defined for each of the required operations, including those in orbit prior to operation of the RNS and those required during normal mission operations. The subsystem design concepts which have been identified are feasible and supported by proven S-IVB design approaches. A question remains concerning component lifetimes for the long duration, high life cycle mission requirements. It should be emphasized that orbital experiments will be required early in the program to refine the design criteria imposed on the operations of the identified systems. Included among the issues addressed here are criteria for propellant settling, chilldown heat transfer, pressurization requirements, and aftercooling system operations.

RNS PROPELLANT MANAGEMENT SUMMARY AND CONCLUSIONS

OPERATIONS AND DESIGN REQUIREMENTS ESTABLISHED FOR LUNAR SHUTTLE MISSION

SYSTEM DESIGN CONCEPTS, OPERATIONS, & SEQUENCING DEFINED

- PROPELLANT RESUPPLY
- CHECKOUT
- STARTUP: PROPELLANT SETTLING, CHILLDOWN, RUN TANK REFILL
- PRESSURE & RUN TANK LH₂ LEVEL CONTROL
- SHUTDOWN & AFTERCOOLING

SELECTED DESIGN CONCEPTS FEASIBLE

- COMPONENT LIFETIMES TO BE ESTABLISHED
- RNS DESIGN BASIS SUPPORTED BY S-IVB

ORBITAL EXPERIMENTS WILL BE REQUIRED TO REFINE DESIGN CRITERIA

ASTRIONICS APPROACH

The system requirements for astrionics were established. The baseline RNS mission requirements were utilized together with RNS operations incurred during all mission phases. Several candidate approaches were established for each subsystem. These approaches were evaluated and the subsystem characteristics determined. Special attention was paid to the onboard checkout function, including the relationship of checkout and the maintenance strategy. Additionally, the sequence of checkout operations was established. The characteristics of relative degrees of autonomy for the guidance and navigation subsystem were established. The data management function was evaluated in the context of three separate types of requirements. The requirements for communication between the RNS and ground were established. Additionally the processing and storage requirements for the onboard processor were quantified. This included a review of all subsystem and RNS requirements. Alternate data buses were considered and the traffic on the RNS data bus determined. An architecture for the RNS data bus was established.

ASTRIONICS APPROACH

- **ESTABLISH SYSTEM REQUIREMENTS**

MISSION

RNS OPERATION

- **IDENTIFY CANDIDATE APPROACHES**

- **EVALUATE AND SELECT SYSTEM CHARACTERISTICS**

ONBOARD CHECKOUT

GUIDANCE AND NAVIGATION

DATA MANAGEMENT

- **PROCESSING**
- **COMMUNICATION**
- **DATA BUS**

RNS MODULE DEFINITION

Three distinct modules have been identified. The Command and Control Module contains the entire navigation, guidance and control function including the sensors and processing capability required to implement autonomous navigation. The primary power source is also included in the Command and Control Module as well as the auxiliary propulsion system. The major components of NDICE are physically contained in the Command and Control Module communicating to the propulsion module via the data bus.

The propellant module contains a minimum amount of hardware and capability. The function is limited to hydrogen storage and only that hardware needed to implement this function is included.

The propulsion module includes the run tank and a minimum of astrionics equipment which is effectively shielded from the radiation environment by the run tank. Multiplexing and signal conditioning of instrumentation and command decode is included on this module.

RNS MODULE DEFINITION

COMMAND AND CONTROL MODULE

- NAVIGATION, GUIDANCE AND CONTROL
- DATA PROCESSING
- POWER
- AUXILIARY PROPULSION
- NDICE

PROPELLANT MODULE(S)

- PROPELLANT STORAGE ONLY
- MINIMUM CAPABILITY

PROPULSION MODULE

- NERVA RELATED FUNCTIONS ONLY
- RUN TANK FOR OPERATION

RNS ONBOARD CHECKOUT

The maintenance strategy defines ground recycle for the Command and Control Module after each mission. Space shuttle transportation is postulated. Replenishment of expendables for the fuel cells and the auxiliary propulsion system are accomplished on the ground. Scheduled maintenance operations will be programmed as required. The primary checkout functions, including calibration, will be accomplished using the onboard checkout capability aided by ground support equipment. The Command and Control Module includes hardware required to perform onboard checkout. The onboard checkout system will be designed to accomplish orbital checkout. All other functions required during the recycle operation will be supplied by ground support equipment. All procedures are stored and processing is accomplished by the centralized processor in the data management subsystem. The NDICE included in the Command and Control Module will effect checkout of the NERVA. The propellant module will utilize the capability of the onboard checkout system in the Command and Control Module to verify its flight readiness. Since the propellant module is a space resident element, all fault prediction capability is included. The propulsion module also being space resident will have the same characteristic requirements for checkout as the propellant modules. Additionally, the NERVA engine checkout will be performed by NDICE.

RNS ONBOARD CHECKOUT

- **COMMAND AND CONTROL MODULE**

GROUND REFURBISHMENT EACH MISSION

- REPLENISHMENT OF EXPENDABLES
- SCHEDULED MAINTENANCE
- CHECKOUT AND CALIBRATION -- GSE SUPPORT

CHECKOUT CONTROL FOR ALL MODULES

- PROCESSING AND PROCEDURES
- NDICE FOR NERVA

- **PROPELLANT MODULE(S)**

- FLIGHT READINESS
- FAULT PREDICTION

- **PROPULSION MODULE**

- STAGE SUBSYSTEMS -- SAME AS PROPELLANT MODULE
- NERVA -- NDICE

ONBOARD CHECKOUT SEQUENCE

Four discrete phases of checkout can be identified: (1) during orbital assembly (prior to the first mission) or refurbishment (after subsequent missions). Assembly verification of those modules that are involved in assembly (including pay load) will be made. Rechecks on all broken fluid connections and on the dynamic seals of all critical valves will be made. The interface between modules and specific subsystems which are best checked during this phase of the operation will be verified. (2) During the orbital countdown all subsystem and component checkout will occur, including the verification of all redundancies for space resident modules. This will be accomplished by the systematic performance of a series of procedures stored in the data management subsystem. The combination of this series of procedures will verify the vehicle is ready for flight. (3) during the operational phase of the mission continuous status, monitoring of a limited set of functions will occur. The status of these functions will be compared to some predetermined standard to ensure that the vehicle health is as expected. During the operational phase, data must be collected to accomplish fault prediction and a limited amount of trend analysis will be performed on line. (4) Following the mission the fault prediction data will be utilized to determine the potential of impending failures on space resident hardware and the ground will process the mission data to determine unforeseeable anomalies.

ONBOARD CHECKOUT SEQUENCE

DURING ASSEMBLY/REFURBISHMENT

- ASSEMBLY VERIFICATION
- LEAK CHECKS
- MODULE INTERFACE CHECKS
- SPECIFIC SUBSYSTEMS

ORBITAL COUNTDOWN

- SUBSYSTEM AND COMPONENT CHECKOUT
- VERIFY ALL REDUNDANCIES
- VEHICLE FLIGHT READINESS

OPERATIONAL PHASE

- STATUS MONITORING
- FAULT PREDICTION DATA COLLECTION

FOLLOWING MISSION

- FAULT PREDICTION
- GROUND PROCESSING OF MISSION DATA

ONBOARD CHECKOUT REQUIREMENTS

Reviewing the various subsystems, orbital checkout, and utilizing S-IVB test data, it is estimated that 25,000-word storage will be required for the checkout procedures. This includes both subsystem and emergency procedures. Although the bulk of the procedures are performed off of peak data processing load time (orbital operations or coast modes), there is a requirement to perform specific operations during peak which is anticipated to be during engine burn. Reviewing those functions that must be performed during peak, a total of 8,200 equivalent adds per second (ops) have been identified. These include primarily the data management selfcheck procedures that is guaranteeing the health of the processor and the trend analysis to detect impending failures which potentially preclude an emergency situation. Additionally, a small amount of processing will be utilized for the general health monitor or status monitoring capability included in the data management functions. A review of specific subsystems indicates that with rare exception the existing vehicle operational data acquisition capability can be used as a primary data source to evaluate the performance of each subsystem during the checkout phase. Additionally, the control to stimulate these subsystems/components can be effected by the nominal control lines of the RNS. A minimum of additional instrumentation and control will be required. Exceptions to this are the requirement that position indications be supplied for all components to verify the performance of the component upon stimulation and discrete instrumentation and control be provided for all redundancies. Because CCM checkout is assisted by ground support equipment, the addition of test connectors will be required for access to critical test points for the verification of this subsystem and the associated redundancies.

ONBOARD CHECKOUT REQUIREMENTS

- PROCEDURES STORAGE -- 25,000 WORDS
- PROCESSING REQUIREMENTS

VEHICLE CHECKOUT OFF PEAK

8,200 OPERATIONS/SEC AT PEAK

- DATA MANAGEMENT SELF CHECK
 - FAULT PREDICTION
 - STATUS MONITORING
-
- PRIMARY DATA AND CONTROL VIA RNS OPERATIONAL CHANNELS
 - ADD POSITION INDICATION TO COMPONENTS
 - DISCRETE INSTRUMENTATION AND CONTROL FOR REDUNDANCIES
 - TEST CONNECTORS ON CCM

GUIDANCE AND NAVIGATION CANDIDATES

Three concepts were developed. Each of which represents a different degree of autonomy for the guidance and navigation subsystem. The first concept, autonomous guidance and navigation, is characterized by a landmark tracker in addition to the star trackers, an IMU, and a horizon sensor which are required for all candidates. In the case of the autonomous concept, the capability for ground tracking as a backup was included. The use of navigation satellites or ground beacons is considered attractive for the space shuttle. Because of the likely existence of this capability during RNS operations, it was included as a candidate in the guidance and navigation study. This candidate is characterized by the absence of the landmark tracker and substitution of a ranging radar. The difficulty with this concept lies in the requirements for a navigation aid in lunar orbit. The third candidate is characteristic of the Apollo approach of ground tracking and is characterized by the use of the Manned Space Flight Network (MSFN) on the ground and a transponder and receiver on the RNS.

Plant a beacon
on Back Side
of moon
powered by
a nuclear
source

GUIDANCE AND NAVIGATION CANDIDATES

		CONCEPT	UNIQUE FEATURES
1		<ul style="list-style-type: none"> • AUTONOMOUS 	<ul style="list-style-type: none"> • LANDMARK TRACKER AND PROCESSING
2		<ul style="list-style-type: none"> • NAV SATELLITES OR GROUND BEACONS 	<ul style="list-style-type: none"> • RANGING RADAR • LUNAR ORBIT NAVIGATION AID
3		<ul style="list-style-type: none"> • GROUND TRACKING 	<ul style="list-style-type: none"> • TRANSPONDER • MSFN

GUIDANCE AND NAVIGATION CHARACTERISTICS

The characteristics of the three candidates are shown. Generally, the systems are comparable because of the large number of common items required to determine attitude and satisfy other mission requirements. The weights of the three systems are comparable as are the power requirements. The fundamental differences are in the accuracy potential of a ground tracking system and the processing requirements to provide for autonomous navigation.

The inability to determine the availability of the DSIF and the modest increase in requirements to provide totally autonomous navigation suggests the selection of an autonomous system as baseline with a ground tracking backup. Should the DSIF be available, it would be desirable to provide for an accuracy update of the autonomous system within the program plan to take advantage of the high-accuracy capability of the ground tracking system.

GUIDANCE AND NAVIGATION CHARACTERISTICS

CONCEPT	WEIGHT (LB)	POWER (W)	PROCESSING		ACCURACY (FT) (EARTH ORBIT)
			RATE	MEMORY	
• AUTONOMOUS	310	110	59.5K	13.7K	2,000
• NAVIGATION ✓ SATELLITES OR GROUND BEACONS	380 + ANTENNA	185	50K	11.4K	1,000
• GROUND TRACKING	295	100	30K	4.4K	600

SELECTION -- AUTONOMOUS WITH GROUND TRACKING BACKUP

GROUND COMMUNICATION

Although numerous data interfaces can be established between the RNS and other space program elements, the primary recurring communication exists between the RNS command and control module and the ground. The baseline system is represented by using a direct link to ground stations located on Earth, with an alternate of communicating through a communications satellite. With relatively low data rates, a dump of data over each ground station can be effected. With very high data rates, communication satellites must be used to establish continual data flow to earth.

There is a strong desire to reduce the total quantity of data transmitted to earth without reducing the informational content of this data. Techniques of data compression are well known to achieve this objective. Taking the total RNS data requirement, it can be determined that there is an expected 8,800 samples per second. For approximately ten bits per sample, 90,000 bits per second of data would be generated. Based on Gemini data compression simulations, compression ratios of about 100 to 1 can be realized on the type of data anticipated for the RNS. This would reduce the total data transmitted from orbit from 5×10^8 bits per orbit to 5×10^6 bits per orbit. Assuming five ground stations would be available and the total transmission time over these ground stations were 160 minutes per day, a transmission rate to ground using data compression would be 8.5×10^3 bits per second. This low transmission rate indicates that there is no requirement for communication satellite relay to transmit full information content to ground. Data compression requirements on the data management function represent one of the largest processing requirements. However, it is considered totally within the capability of a conventional processor.

GROUND COMMUNICATION

REQUIREMENTS

- 732 MEASUREMENTS
- 8800 SAMPLES/SEC
- 90,000 BITS/SEC

GROUND COMMUNICATION WITH DATA COMPRESSION

- 5.1×10^6 BITS/ORBIT
- 8.5×10^3 TRANSMISSION RATE

DATA COMPRESSION PROCESSING REQUIREMENTS

- 105,000 OPS/SEC

DATA MANAGEMENT

PROCESSING AND STORAGE REQUIREMENTS

The total processing and storage requirements for the data management function are summarized in the facing chart. For the data management subsystem, the bulk of the processing requirements are derived from the executive routine. Additionally, the processing required to effect the procedures stored on board are included. The guidance, navigation, and control processing requirement includes capability for totally autonomous navigation in addition to the normal guidance and attitude control functions. Provision is made for processing of ground uplink data that represents a backup to the nominal autonomous navigation scheme. The instrumentation command and control requirements has the data compression requirement of 106,000 operations per second as its largest element. The onboard checkout processing requirement is for peak operations only because most of the checkout procedures are performed off peak.

DATA MANAGEMENT PROCESSING AND STORAGE REQUIREMENTS

	PROCESSING EQUIV ADD/SEC AT PEAK	STORAGE	
		HIGH SPEED (WORDS)	BULK (WORDS)
DATA MANAGEMENT	40,000	3,700	25,000
GUIDANCE, NAVIGATION AND CONTROL (AUTONOMOUS)	83,200	16,000	15,400
INSTRUMENTATION, COMMAND AND CONTROL (INCLUDES DATA COMPRESSION)	109,800	6,750	6,000
ONBOARD CHECKOUT	8,200	1,200	24,350
	<u>241,200</u>	<u>27,650</u>	<u>70,750</u>

DATA BUS CANDIDATES

Four representative concepts are indicated in the facing chart. The four concepts presently under development by various contractors are time-shared systems using serial transmission on a coaxial or twisted shielded pair line and all use transformer coupling of data bus terminals to the data bus lines. The TRW concept presently being developed (MDAC space shuttle) is characterized by two lines—one for address and data and the other a clock. Horizontal and vertical parity (word and block) are included. The nature of the TRW concept is that only a device-to-controller transfer is used. The IBM concept (MDAC space station) is similar but allows for device-to-device transfers, however there is no apparent RNS requirement for this capability. Current mode transformer coupling and a polling clock are used, representing a difference from the other three concepts. The concept presently under development at NASA/MSFC includes a two-line approach—one with data and the other with address, command, and the clock integrated. Word parity is used with one bit for each polarity on filtered bipolar data. The radiation concept uses a single line with total information content. Triple line redundancy is used and credibility testing done at each data bus terminal.

DATA BUS CANDIDATES

CONCEPT	LINE FUNCTION	BIT RATE CODING	SELF CHECK
TRW	1 DATA/ADDRESS 1 CLOCK	1 MHZ MANCHESTER	WORD + BLOCK PARITY
IBM	1 DATA 1 POLLING CLOCK	2 MHz BIPOLAR	ADDRESS + WORD PARITY
NASA/MSFC	1 DATA 1 ADDRESS/ COMMAND/CLOCK	2 MHz BIPOLAR	WORD PARITY FOR EACH POLARITY
RADIATION	1 FULL SERVICE TRIPLY REDUNDANT	5 MHz MANCHESTER	WORD PARITY

DATA BUS ARCHITECTURE

The data bus architecture for the Class 1 H and Class 3 RNS is indicated. The maximum traffic rate anticipated for an operational vehicle is about $1/4 \times 10^6$ bits per second. The maximum load is derived primarily from the transmission of data from all modules to the data bus controller before the compression operation. The number of data bus terminals includes one data bus in each propellant module for the Class 3 and one data bus terminal fore and aft of the Class 1 Hybrid tankage. The processing requirements for the data bus are quantified and assumes the controller function is performed by the data management subsystem. Alternatively, a processing capability can be provided within the data bus controller. An independent NDICE is assumed that will use the RNS data bus. Typical supporting hardware used in each module for the generation of commands and the collection and digitizing of module data are shown.

DATA BUS ARCHITECTURE

MAX TRAFFIC RATE ON BUS

- DEVELOPMENT-- 0.5×10^6 BITS/SEC
- OPERATIONAL-- 0.23×10^6 BITS/SEC

NO. OF DATA BUS TERMINALS

- CLASS 1-- 8 REQUIRED
- CLASS 3 - - 14 REQUIRED

PROCESSING REQUIREMENT

- 9,000 OPS/SEC
- 500 WORDS STORAGE

RNS DESIGN SUMMARY

Current RNS designs will be briefly summarized in this section starting with sketches of the two concepts, the Class 1 Hybrid and Class 3. The major design features which were selected during the second period will be identified on subsequent charts. Finally, the weights for both concepts will be given.

RNS DESIGN SUMMARY

- **RNS SCHEMATICS**

- CLASS 1 HYBRID

- CLASS 3

- **DESIGN FEATURES SELECTED DURING SECOND PERIOD**

- **CURRENT WEIGHT STATEMENTS**

RNS CLASS 1 HYBRID

A sketch of the Class 1 Hybrid RNS configuration is shown on the facing chart. It illustrates the current configuration and provides a locator for the specific features selected during the second period of the study which will be discussed 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 which was selected during the Phase II shield optimization. The outriggers containing the auxiliary propulsion engines on the command and control modules are also visible on the picture. Specific details are identified by the callouts.

CLASS 1 HYBRID RNS

RNS CLASS 3

This chart shows the current 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 the design features selected during this period.

No Page 129 located in original document.

No Page 130 located in original document.

DESIGN FEATURES SELECTED

- HEMI SPHERICAL FORWARD DOME--CLASS 1 PROPELLANT MODULE
- INTEGRAL WAFFLE PATTERN--CLASS 3 PROPELLANT MODULE
- 160 INCH RUN TANK DIAMETER--CLASS 3 PROPULSION MODULE
- FIBERGLASS COMPOSITE STRUCTURE--REVIEWED
- AUTONOMOUS NAVIGATION
- CENTRALIZED DATA PROCESSING
- STORED PROCEDURES FOR ONBOARD CHECKOUT
 - BITE FOR SPECIFIC COMPONENTS

DESIGN FEATURES SELECTED - 2

Additional characteristics for RNS subsystems which were selected during the second period are shown on the facing chart. The integrated chilldown subsystem which combines the NERVA and stage chilldown operations as well as including the operations associated with refill or the run tank following depletion was described earlier. Additionally, a blocking valve was added in the Class 3 feed systems connecting the various propellant module tanks into the run tank. This enhances feed system integrity as well as eliminating excessive liquid residuals following shutdown and excessive thermal leaks.

The auxiliary propulsion system was sized for both concepts. A engine thrust was selected based upon performing requisite maneuvers, attitude control, and propellant settling. Total propellant capacity was established for the baseline lunar shuttle mission.

The primary power source trade study performed during Phase II was reviewed in terms of current power requirements. The final selection was made between fuel cells and solar cells utilizing state-of-the-art projections for fuel cells which are being employed in the space shuttle, and for solar cells which are to be employed in advanced space programs beyond Skylab. The evaluation favored fuel cells for the RNS. Redundant fuel cells are provided for reliability.

DESIGN FEATURES SELECTED - 2

- INTEGRATED CHILLDOWN SUBSYSTEM
 - COMBINED NERVA/STAGE CHILLDOWN
 - INCLUDES REFILL OF RUN TANK
- BLOCKING VALVE IN FEED SUBSYSTEM--CLASS 3
- AUXILIARY PROPULSION SYSTEM SIZED
 - ENGINE THRUST
 - PROPELLANT CAPACITY
- REDUNDANT FUEL CELLS--PRIMARY POWER--REVIEWED

RNS WEIGHT STATEMENT

The accompanying chart contains current weight statements for both RNS concepts. For nearly identical propellant capacities it can be seen that both the structure, meteroid/thermal, and docking/clustering entries penalize the multiple-module Class 3 concept. The main propulsion entry contains a 2,800-lb biological shield for the Class 1 Hybrid concept which almost offsets the greater plumbing and component weights for the Class 3 concept. The last three entries under the dry weight are nearly the same for both concepts. A net dry weight advantage of nearly 10,000 lb accrues to the Class 1 concept.

It can be seen that the RCS propellant is nearly identical for both concepts, but that the residuals of propellant contained in the stage at burnout are about 75,000 lb heavier for the Class 1 concept than for Class 3. This results in a net difference in operational weight of only about 2,000 lb favoring Class 1. These greater residuals for the Class 1 concept diminish the usable propellant so that the propellant mass fraction, λ' , given as the last entry is identical for both configurations.

RNS WEIGHT STATEMENT

	CLASS 1 HYBRID (LB)	CLASS 3 (LB)
STRUCTURE	24,080	28,750
METEOROID/THERMAL	7,910	8,800
DOCKING/CLUSTERING	760	3,440
MAIN PROPULSION	31,220	31,840
AUXILIARY PROPULSION	1,010	1,010
ASTRIONICS	2,135	2,430
CONTINGENCY	1,840	2,410
TOTAL DRY WEIGHT	68,955	78,680
RCS PROPELLANT	1,130	1,140
PROPELLANT RESIDUALS	9,470	1,920
TOTAL OPERATIONAL WEIGHT	79,555	81,740
VENTED PROPELLANT	—	2,240
FLIGHT PERFORMANCE RESERVE	1,700	1,700
USABLE PROPELLANT	289,830	297,190
PROPELLANT MASS FRACTION, λ'	0.784	0.784

TEST DEFINITION APPROACH

The test requirements task is in progress with a bottom-up approach employing test item and system test candidate worksheets. Each test item is examined in the test item worksheet to determine the amount and type of tests that should be performed to provide the necessary design data, to verify the design approach, and to qualify the item for use in the RNS. Data are presented on the test item worksheet on the specific components on the RNS included in the test item, the maintenance category of the component, the reliability allocation, the confidence level, and the lifetime requirements. These data are used to determine the amount of testing to be accomplished. The type of testing is determined by examining the function of the component and the operational environment. This leads to a listing of the specific tests that are required in the research and development, development, qualification, and acceptance testing areas. Tests in the component, subsystem, and system levels are delineated along with alternatives for the specified tests.

The data from the test item worksheet are used in the System Test Worksheets where all candidate tests above the component level are examined to determine the optimum test strategy. Specific topics covered are a description of the proposed test, why it is required, the worth of the test, the alternatives, and the hardware and facility requirements along with the cost and schedule implications.

The results of these analyses are then fused into an overall integrated test plan, which will provide the basis for test hardware and ground support equipment definition. The integrated test plan formulation, as well as definition of the test hardware and ground support equipment, will be accomplished during January and early February.

TEST DEFINITION APPROACH

TEST ITEM WORK SHEETS

- COMPONENT IDENTIFICATION & CHARACTERISTICS (NO. COMPONENTS, MAINT CATEGORY, REL ALLOC, ETC)
- TEST REQUIREMENTS (RES & TECHNOL, DEV, QUAL, & REL TESTING)

SYSTEM TEST WORK SHEETS

- CANDIDATE SYSTEM TESTS ARE SUBJECTED TO THE FOLLOWING QUESTIONS:
 - WHAT DOES THE TEST DO?
 - WHY IS THE TEST REQUIRED?
 - WHAT ARE THE FACILITY/HARDWARE REQUIREMENTS?
 - WHAT IS THE ESTIMATED WORTH OF THE TEST?
 - WHAT ARE THE ALTERNATIVES TO BE CONSIDERED?
 - WHAT IS THE IMPACT OF ALTERNATIVES ON COST & SCHEDULES?
 - WHAT IS THE FINAL DECISION REGARDING THIS SYSTEM TEST?

SYSTEMS INTEGRATION LABORATORY (SIL)

The Systems Integration Laboratory, which was successfully employed on the S-IVB program, is required to provide the opportunity to verify that the electrical interfaces between the components, subsystems, modules, NDICE, and the ground/aerospace support equipment is adequate to meet the system requirements or to determine that interface problems exist; it is also required to provide the design information required for component, subsystem, module, NDICE, or support equipment redesign. This test is also necessary to develop the onboard and ground automatic checkout system software procedures.

The SIL tests will investigate the electrical interfaces under normal and extended parameter operation. The hardware to be involved should include all electrical components ranging from the primary electrical source (fuel cells and batteries) through the interconnections (cables and disconnects) to the final component (valves, motors, etc.), and including the control system (computers, multiplexers, etc.).

The data from this test should provide accurate information on the electrical interfaces under ambient environmental conditions and normal and abnormal operations. These data should reveal any problem areas or verify conformity with RNS requirements. The data should also provide design information useful or required in the redesign of the components or subsystem. Additionally, the test should provide information useful or required in the design of the onboard and ground support checkout systems.

SYSTEMS INTEGRATION LABORATORY

PURPOSE

- INVESTIGATE, VERIFY, PROVIDE DESIGN INFORMATION FOR ELECTRICAL/MECHANICAL INTERFACE & SYSTEM OPERATION
- DEVELOP CHECKOUT OPERATIONS & SOFTWARE

TESTS

- MECHANICAL - CONNECTOR COMPATIBILITY
- ELECTRICAL - VOLTAGE, CURRENT, ETC
- OPERATIONAL - TIMING, RESPONSE, ETC
- ABNORMAL OPERATIONS - LOW VOLTAGE, HIGH IMPEDANCE, ETC
- CHECKOUT DEVELOPMENT - FAILURE ISOLATION, TREND DATA, ETC

HARDWARE

- ALL ELECTRICAL COMPONENTS

TEST LEVEL

- SUBSYSTEM, SYSTEM, MODULE, RNS

PROPULSION INTEGRATION LABORATORY (PIL)

The Propulsion Integration Laboratory (PIL) is an active electrical, mechanical, and fluid mockup of the propulsion subsystems. The test will investigate and develop the mechanical and fluid interfaces between propulsion system components, between modules of the RNS and between the RNS and the NERVA. The tests will investigate the fluid conditions and performance of the propulsion system under normal and abnormal conditions. The mechanical and fluid interfaces must be verified and design information obtained for use in the redesign effort. The performance of the propulsion system as a unit must be verified prior to the time that the system is subjected to higher level testing or the design is considered to be adequate and further design is terminated.

The data from this test should provide accurate information on the mechanical interfaces under ambient and cryogenic conditions and normal and abnormal operations. The data on the performance of the system—flow dynamics, chilldown, etc. must be adjusted to account for the lack of space conditions—zero gravity, space temperatures, vacuum, etc. However, the data will be invaluable in the design and analysis process as an experimental verification of the analytical techniques used in the performance analysis and design.

The level of the test chosen will be the subject of an economics/test result trade-off. The level could consist of a collection of subsystems (vent, pressurization, etc.), the entire propulsion system of a single module, the propulsion system of several modules, or the propulsion system of one or several modules with a NERVA simulator.

PROPULSION INTEGRATION LABORATORY

PURPOSE

- INVESTIGATE, VERIFY, PROVIDE DESIGN INFORMATION FOR MECHANICAL & FLUID INTERFACE & SYSTEM OPERATION

TESTS

- MECHANICAL INTERFACE
 - DIMENSIONAL
 - AMBIENT
 - CRYOGENIC
- SYSTEM OPERATION
 - CHILLDOWN, PRE-PRESS, VENTING, COOLDOWN
 - LH₂ TRANSFER -- BETWEEN MODULES & INFLIGHT
 - CHECKOUT OPERATIONS -- LEAK DETECTION

HARDWARE

- ALL PROPULSION SYSTEM COMPONENTS

TEST LEVEL

- SUBSYSTEM, SYSTEM, SINGLE MODULE, MULTIPLE MODULE

SPECIAL DOCKING SIMULATOR

This test is an active mockup of the docking and disconnect components of the RNS. It will investigate and develop the static and dynamic mechanical, electrical, and optical/laser operation and interfaces of the various docking mechanisms and disconnects between the modules of the RNS, between the RNS and the payload, and between the RNS and other space facilities under normal and abnormal conditions.

The test is required to verify and provide redesign information on the ability of the docking mechanisms and the disconnects to withstand the static and dynamic loadings during the docking operation and the remainder of the RNS operating cycle under normal and abnormal conditions. In addition, simple dimensional compatibility verification is required.

The level of testing could vary from a simple test rig that would simulate the docking operations and loadings on single pairs of docking and disconnect mechanisms to a test rig that would simulate the modules with mass and envelope mockups, in addition to complete sets of docking and disconnect mechanisms. The level of test could also be an actual docking operation between actual modules. The latter test level would provide information on the effects of the docking operation on all module components, in addition to the actual docking and disconnect mechanisms.

SPECIAL DOCKING SIMULATOR

PURPOSE

- INVESTIGATE, VERIFY, PROVIDE DESIGN INFORMATION FOR MECHANICAL & ELECTRONIC DOCKING SYSTEM

TESTS

- MECHANICAL INTERFACE
 - DIMENSIONAL -- STATIC TESTS
- DYNAMIC INTERFACE
 - DOCKING SIMULATIONS
 - DISCONNECT OPERATION
- OPERATIONAL
 - AXIAL LOAD, SHEAR, BENDING MOMENT, ETC

HARDWARE

- ALL DOCKING MECHANISMS, DISCONNECTS

TEST LEVEL

- SUBSYSTEM, SUBSYSTEM WITH MASS SIMULATOR, MODULE

BATTLESHIP TEST PROGRAM

The battleship test is required to provide timely data on the adequacy of the design and timely redesign information. These data cannot be obtained at the component or subsystem level due to the absence of the many interfaces. For example, the testing of a valve does not test the ducting that connects the valves or the connections themselves—the entire subsystem or system must be tested as a unit to investigate the ability of the system (valves, ducting and connections) to withstand the required pressure and pressure transients, temperature and temperature transients, flow rate and flow rate transients, and the effect that each of the individual components (valves, ducting, and connections) has on the pressure, pressure transients, temperature, temperature transients, flow rate and flow rate transients of all of the other components. A subsystem-level test (Propulsion Integration Laboratory) will provide a great deal of this information and is a necessary step in the evolution of the test sequence, but a subsystem test will not provide all of the required information. For example, testing the propulsion module feed system in the PIL will test the feed valves and ducting but will not test the propulsion module tank, the connections between the fill system and the propulsion module tank, or the effect of the pressurization and vent system on the operation of the fill system. Also, it will test the effect of the propellant module propellant tank, the propellant module feed system, vent system and pressurization system on the operation of the propulsion module fill system; the effect of the NERVA and the environment it creates on the propulsion module fill system; and the theory that the propulsion module fill system is independent of the operation of these systems. All of these effects must be analyzed under normal and abnormal conditions.

The battleship tank and specific safety/emergency systems will be required to allow extended parameter testing (high and low pressure, high and low pressure rates, high and low temperature, etc.). This condition would be difficult if not impossible without a special (nonflight) tank with thicker walls and extra penetrations. Therefore, the required information that could not be obtained on an all-systems test article could be obtained at an early date (1 to 2 years before flight) sufficient to allow component, subsystem, or system redesign prior to first flight.

BATTLESHIP TEST PROGRAM

PURPOSE

- INVESTIGATE, VERIFY, PROVIDE DESIGN INFORMATION ON
ENTIRE SYSTEM INTERFACES & OPERATION
- VERIFY CHECKOUT OPERATION
- PROVIDE GTM FOR NERVA

TESTS

- INTEGRATION OF ALL SYSTEMS
- OPERATION OF SYSTEMS WITH PROPELLANT TANKS
FILL, PRESSURIZATION, FEED, VENT, CHILLDOWN
- OPERATION OF SYSTEM WITH NERVA
PRESSURIZATION, PREPRESSURIZATION, FEED, CHILLDOWN
- AB NORMAL OPERATIONS
HIGH PRESSURE, HIGH FLOW RATE, HIGH IMPEDANCE

MANUFACTURING PROGRAM

The manufacturing efforts for the Phase III study involve the formulation of manufacturing plans for both Class 1 hybrid and Class 3 RNS concepts, with each manufacturing plan to include the definition of manufacturing and assembly techniques, as well as estimates of tooling and facilities requirements. The use of advanced manufacturing concepts, such as large sheet sizes to minimize numbers of parts and operations, single piece domes, and electron beam welding are being considered, where practical, for each RNS concept.

Large sheet stock (210 in. wide by 1,440 in. long) is currently projected for 1971 availability. These sizes permit the manufacture of tanks with considerably fewer elements than would be required using conventional material sizes (120 in. wide by approximately 1,000 in. long). The cylindrical and truncated sections of the Class 1 hybrid propellant module could be made from six longitudinal segments each, whereas conventional techniques (cylindrical courses) and sheet sizes would require at least ten elements for the cylinder and approximately eight elements for the truncated sections. Large sheet utilization, combined with single piece domes, provides a technique for making Class 3 propellant module tankage with only five structural elements, thus reducing the amount of weld lengths and operations, such as fit-up, as well as the software, e.g., planning paper, that is associated with the production program.

Electron beam welding is currently considered as a strong candidate for the manufacture of the Class 3 propellant modules, as well as the propulsion module and command and control module for both concepts, since the 15-ft diameter is much more compatible with the close tolerance fit-up requirements associated with electron beam welding than the 33-ft diameter. Techniques such as pulsed arc MIG or TIG are the current primary contenders for welding the 33-ft diameter propellant module.

A total of eight candidate manufacturing program scenarios are being evaluated as part of this task. For the Class 1 hybrid, five programs are as follows: (1) propellant module at Michoud, propulsion module and command and control module at Huntington Beach, (2) all modules at Michoud, (3) propellant module at Seal Beach, propulsion module and command and control module at Huntington Beach, (4) all modules at Seal Beach, and (5) all modules at Huntington Beach. For the Class 3 RNS, the three candidate programs are: (1) all modules at Michoud, (2) all modules at Seal Beach, and (3) all modules at Huntington Beach. The current baseline programs selected from these candidates are shown here.

MANUFACTURING PROGRAM

APPROACH

- INTRODUCE ADVANCED CONCEPTS WHERE APPLICABLE TO REDUCE NUMBER OF OPERATIONS AND IMPROVE QUALITY OF FINISHED PRODUCT
 - LARGE SHEET SIZES
 - UNIQUE FORMING METHODS
 - ADVANCED WELDING TECHNIQUES
- FORMULATE MANUFACTURING PLANS BASED ON MAXIMUM USE OF EXISTING FACILITIES

SIGNIFICANT RESULTS

- LARGE SHEET STOCK USED FOR CLASS-1 HYBRID PROPELLANT-MODULE CYLINDER (6 SEGMENTS) AND CLASS-3 PROPELLANT-MODULE CYLINDER (3 SEGMENTS)
- SINGLE PIECE FORGED DOMES USED EXCLUSIVELY FOR CLASS-3, AND FOR AFT DOME OF CLASS-1 HYBRID PROPELLANT-MODULE
- ELECTRON BEAM WELDING OF CLASS-3 MODULES CONSIDERED AS STRONG CANDIDATE
- CURRENT CLASS-1 HYBRID MANUFACTURING PROGRAM BASELINE FEATURES PROPELLANT MODULE FINAL ASSEMBLY AT MICHoud, PROPULSION MODULE AND COMMAND AND CONTROL MODULE AT MDAC-HUNTINGTON BEACH
- CURRENT CLASS-3 MANUFACTURING PROGRAM BASELINE FEATURES MANUFACTURE OF ALL MODULES AT MDAC-HUNTINGTON BEACH

FACILITIES DEFINITION

The facilities activity is being conducted in three subtasks: namely, facilities requirements, facilities utilization study, and facilities plan. Current efforts have focused on the definition of manufacturing, testing, and launch facility requirements, and the investigation of the compatibility of currently existing facilities with the requirements defined. The facilities plan will be formulated during the third phase of the study.

For both concepts existing facilities can be utilized with no major modifications. The Class 1 hybrid propellant module can be manufactured at either Michoud or Seal Beach without costly modifications to nonseverable facilities. At Michoud, which is the baseline final assembly location for the Class 1 propellant module, approximately 123,000 square feet of floor space will be required in Building 103 (horizontal position work) and Building 110 (vertical assembly and hydrostatic testing). The Class 3 RNS can be manufactured in total at MDAC-Huntington Beach facilities with no major modifications or additions required. The detail fabrication and final assembly would be accomplished in Building 49, with hydrostatic testing in Building 42.

The impact of either RNS concept on KSC facilities will be minimal, as noted. The low bay areas required would not have to be checkout cells except for the NERVA/propulsion module tankage mating operation, which would probably be accomplished most easily with both elements in a vertical position in a low bay checkout cell.

FACILITIES DEFINITION

PRIMARY FACILITY REQUIREMENTS

- **MANUFACTURING FLOOR SPACE**

- CLASS 1 HYBRID — APPROX 145,000 FT²

- CLASS 3 — APPROX 92,000 FT²

- **KSC FACILITIES**

- CLASS 1 HYBRID — 2 VAB LOW-BAY AREAS, 1 HIGH-BAY CELL

- MOBILE LAUNCHER SWING-ARM MODIFICATION

- MINIMAL LAUNCH CONTROL CENTER MODIFICATIONS

- CLASS 3 — 3 VAB LOW-BAY AREAS

FACILITY UTILIZATION STATUS

- **MICHOUD — CLASS 1 HYBRID PROPELLANT MODULE FINAL ASSEMBLY**

- NO MAJOR FACILITY MODIFICATIONS REQUIRED

- PORTIONS OF BUILDINGS 103 AND 110 WOULD BE UTILIZED

- SHUTTLE MANUFACTURING AT MICHOUD IS POTENTIAL PROBLEM ON JOINT UTILIZATION OF BUILDING 110

- **MDAC-HB — CLASS 1 HYBRID PROPULSION MODULE AND COMMAND CONTROL MODULE MANUFACTURING**

- NO MAJOR FACILITY MODIFICATIONS REQUIRED

- CLASS 3 MANUFACTURING (ALL MODULES)

- NO MAJOR FACILITY MODIFICATIONS REQUIRED

- **MTF — PRODUCTION ACCEPTANCE TESTING OF CLASS 1 HYBRID PROPELLANT MODULES**

- FACILITY MODIFICATIONS DEPENDENT UPON NATURE OF SPACE SHUTTLE TEST PROGRAM AT MTF