DECEMBER 1971

MASTER

MDC G2705

**FIRST INTERIM BRIEFING
REUSABLE NUCLEAR STAGE
SYSTEM DEFINITION STUDY**

PHASE IV

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

T. L. Lennora
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PREPARED BY **NASA-MSFC UNDER CONTRACT NAS8-27951**
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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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FIRST INTERIM BRIEFING REUSABLE NUCLEAR STAGE SYSTEM DEFINITION STUDY PHASE IV

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BRIEFING SCHEDULE

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

BRIEFING SCHEDULE

- INTRODUCTION S. GRONICH
- SELECTION OF ALTERNATE SECOND STAGES R. S. COWLS
- MISSION ANALYSIS AND LOGISTICS R. S. COWLS
- DESIGN ANALYSES K. P. JOHNSON
- CONCEPT EVALUATION AND SELECTION K. P. JOHNSON

PHASE IV RNS STUDY SCOPE

The study is divided into two parts. Part A is concerned with investigation and conceptual definition of modular RNS concepts which are compatible with promising new launch vehicles and launch modes other than those previously studied during the Phase III. Two classes of RNS concepts were investigated during Phase III: Class 1 - Hybrid, which had a single large propellant module launched by the Saturn INT-21, and Class 3, which had 8 propellant modules launched inside the space shuttle orbiter cargo bay.

The prospect of significant improvements of RNS system performance was identified for the new RNS configurations, launch and logistics concepts which are being investigated during Phase IV. The first class entails use of a space shuttle booster together with an alternate second stage to launch RNS propellant modules to orbit. The second class of RNS systems retains the space shuttle orbiter for delivery to orbit, but mounts the modules external to the orbiter. This briefing will report the results of Part A, Task 1, Concept Synthesis and Evaluation, which has been concerned with identification of the most promising RNS concepts within these two classes of launch configurations.

Part B of the Phase IV studies will establish a reference stage engine interface and provide support to the NERVA development program. Also, the Phase III analyses will be extended in selected areas including investigation of the application and benefits of advanced technology. The activities in Part B will be discussed in separate meetings.

PHASE IV RNS STUDY SCOPE

26528

PART A -- ALTERNATE RNS CONCEPTS DEFINITION IS TO INVESTIGATE
MODULAR RNS CONCEPTS COMPATIBLE WITH --

- SPACE SHUTTLE BOOSTER / ALTERNATE SECOND STAGE
- EXTERNAL LAUNCH ON HIGH-PAYLOAD ORBITER

PART B -- INTERFACE DEFINITION AND TRADE STUDIES

- ESTABLISH REFERENCE ENGINE / STAGE INTERFACE
- PROVIDE SUPPORT TO NERVA PROGRAM
- EXTEND PHASE III ANALYSES IN SELECTED AREAS

PHASE IV STUDY FLOW

PART A

The logic diagram for Part A of the study is shown in the adjoining figure. Major study inputs, the task breakdown structure and associated study results, and the study phases are indicated. The initial concept definition phase has been completed and will be reported in this briefing. During the second phase the conceptual design definition and system requirements analyses will be performed for the reference systems selected in Task 1. In the third phase these tasks will be completed and the development and implementation plan will be derived.

PHASE IV STUDY FLOW (PART A)

26529

STUDY SCHEDULE

The schedule for the study is shown in the adjoining figure. The total duration is 14 months including reviews of documentation. The portion of the study which has been completed is shown with the solid bar.

STUDY SCHEDULE

CANDIDATE MODULAR RNS CONFIGURATIONS

Phase III established the advantages of a modular RNS design concept consisting of a propulsion module, a command and control module, and an array of propellant modules. The study has focused on the candidate modular RNS configurations shown in the adjoining chart, ranging from 1 to 8 propellant modules to provide the baseline 300,000 lbs LH₂ capacity. Configurations with 1 to 4 propellant modules have been investigated for launch by the space shuttle booster with an alternate second stage. Configurations with 4 and 8 propellant modules have been investigated for external launch on the space shuttle orbiter.

CANDIDATE MODULAR RNS CONFIGURATIONS

26556

SUMMARY OF CANDIDATE RNS SYSTEM CONCEPTS

An RNS system concept is defined by the following top level features: launch vehicle class and initial deployment mode, RNS configuration, and the logistic system to support its operations. The candidate systems which have been evaluated during Task 1 are indicated in the adjoining chart. Three categories of second stage for the space shuttle booster have been investigated: current hardware derivative, new (reusable) stage, and NERVA suborbit start. The full range of actively considered space shuttle concepts has been considered in conjunction with evaluation of these systems. Additional requirements from alternative mission modes have also been investigated. Propellant module jettisoning is a candidate with launch by a space shuttle booster/new second stage and for launch external to the orbiter. Also, the possibility of a space tug assisting the RNS during the mission has been investigated.

SUMMARY OF CANDIDATE RNS SYSTEM CONCEPTS

26531

DEPLOYMENT LAUNCH VEHICLE	RNS CONFIGURATION (NO. PROP. MODULES)	INITIAL DEPLOYMENT (PROP. MODULES/ LAUNCH)	LOGISTICS SYSTEM
SSB/CURRENT-HARDWARE- DERIVED SECOND STAGE	1, 2, 3, OR 4	1 TO FULL RNS	SPACE SHUTTLE
SSB/NEW SECOND STAGE	1, 2, 3, OR 4	1 TO FULL RNS	SPACE SHUTTLE OR SSB/SECOND STAGE
SSB/NERVA SUBORBIT START	1 OR 2	FULL RNS	SPACE SHUTTLE
SPACE SHUTTLE EXTERNAL	4 OR 8	1 OR 2	SPACE SHUTTLE

REFERENCE LOGISTICS OPERATIONS

NEW SECOND STAGE

An opportunity for major reductions of the RNS system operating cost derives from the possibility of utilizing a space shuttle booster with a new reusable alternate second stage concept for LH_2 resupply. As shown in the figure, two 150 K-lb LH_2 modules would be delivered to orbit and propellant transferred to the RNS. The additional propellant required to top-off the stage would be provided by a space shuttle tanker. However, two space shuttle launches to orbit for LH_2 resupply would be saved. Further cost savings could be obtained if the alternate second stage propellant module were customized for the tanking operation so that the requirement for LH_2 topping by the space shuttle could be eliminated. This would reduce the propellant resupply launch requirement to two alternate second stage launches. Such an approach promises a significant reduction of the RNS transportation cost.

REFERENCE LOGISTICS OPERATIONS

26599

NEW SECOND STAGE

TASK 1 -- CONCEPT SYNTHESIS AND EVALUATION

The objective and approach of the task are indicated in the adjoining chart. Two baseline system concepts will be recommended for further study.

TASK 1 -- CONCEPT SYNTHESIS AND EVALUATION

OBJECTIVE

- **EVALUATE AND SELECT MODULAR RNS SYSTEM CONCEPTS COMPATIBLE WITH**
 - **SSB/ALTERNATE SECOND STAGE**
 - **HIGH-PAYLOAD ORBITER**

APPROACH

- **ANALYZE A RANGE OF MODULAR RNS CONFIGURATIONS**
 - **DETERMINE LAUNCH CONFIGURATION**
 - **OPTIMIZE DESIGN AND PERFORMANCE**
 - **COMPARE LOGISTICS APPROACHES**
 - **INVESTIGATE ALTERNATIVE MISSION MODES**
 - **EVALUATE COMPATIBILITY WITH ALTERNATE SPACE SHUTTLE CONCEPTS**
- **SELECT TWO BASELINE RNS SYSTEM CONCEPTS**
 - **SSB/ALTERNATE SECOND STAGE**
 - **EXTERNAL LAUNCH ON ORBITER**

ESSENTIAL FEATURES OF SPACE SHUTTLE CONCEPTS

Prior to and during the Phase IV RNS study there has been an accelerating rate of change of the space shuttle system concepts under concurrent evaluation. Therefore, it is important to recognize the essential features of the space shuttle concepts under evaluation and to account for the generic features of these concepts which affect the interactions between the space shuttle and the RNS. The designation of the space shuttle systems under investigation at MDAC is shown. These are in general characterized by boosters with high or low staging velocities, with the low staging velocity heat sink boosters currently receiving major emphasis. Another important impact concerns the mounting of the orbiter on the booster. Initially, piggyback mounting was investigated for the fully reusable and tip tank orbiter systems. More recently, when orbiter tankage has been moved totally external to the orbiter, a tandem mounting belly tank on the booster has been considered with piggyback mounting of the orbiter on the belly tank. More recent investigations with that orbiter configuration have also considered twin strap-on booster concepts.

ESSENTIAL FEATURES OF SPACE SHUTTLE CONCEPTS

26533

SYSTEM	STAGING VELOCITY	MOUNTING ON BOOSTER	ORBITER TANKAGE
-20B	HIGH	PIGGYBACK	INTERNAL
PARALLEL BURN	LOW	PIGGYBACK	LH ₂ TIP TANKS
LO ₂ /RP	LOW	TANDEM	BELLY TANK (LO ₂ AND LH ₂)
RATO	LOW	STRAP-ON	BELLY TANK (LO ₂ AND LH ₂)

SENSITIVITY OF RNS SYSTEMS TO SPACE SHUTTLE CONCEPTS

Because of the changing space shuttle parameters, the approach to the RNS configuration assessment has given attention to a series of questions to test the validity of each conclusion reached concerning the RNS system. These are indicated in the adjoining chart. It is expected that the selected RNS system features will remain generally valid in the face of these considerations.

SENSITIVITY OF RNS SYSTEMS TO SPACE SHUTTLE CONCEPTS

26534

- IS PAYLOAD DELIVERY ADEQUATE TO LAUNCH RNS MODULES?
- IS LAUNCH CONFIGURATION CONTROLLABLE?
- ARE RELATIVE COST EFFECTIVENESS COMPARISONS VALID?
- IS RELATIVE LOADING IMPACT VALID?
- IS RNS DESIGN OPTIMIZATION VALID?

PRINCIPLE RESULTS OF TASK 1

The two recommended RNS systems are indicated on the adjoining chart. Selections are based on a preliminary optimization of design features, operations, logistics, and mission modes for these systems. It is proposed to evaluate these two system concepts in depth during the balance of the study. The basis for these selections will be described during the remainder of this briefing.

PRINCIPLE RESULTS OF TASK 1

- RECOMMENDED SYSTEM FOR ALTERNATE SECOND STAGE LAUNCH
 - TWO 150 K-LB LH₂ MODULES
 - ONE MODULE PER LAUNCH WITH COMMON LH₂ SECOND STAGE
 - NON-JETTISON MISSION MODE
 - LH₂ RESUPPLY BY CUSTOMIZED SECOND STAGE/TANKER

- RECOMMENDED SYSTEM FOR EXTERNAL LAUNCH
 - FOUR 75 K-LB LH₂ MODULES
 - TWO MODULES PER LAUNCH MOUNTED PARALLEL TO FUSELAGE
 - NON-JETTISON MISSION MODE
 - LH₂ RESUPPLY BY ORBITER/TANKER

SELECTION OF ALTERNATE SECOND STAGES

Objectives and Approach

The objective of this section is to select baseline current-hardware-derivative and new-stage concepts for RNS deployment, logistics, and related design analyses. Current-hardware-derivative concepts considered include S-II-derived and S-IVB-derived configurations. The previous MDAC and NAR expendable second stage studies (NASA Contracts NAS8-26016 and NAS9-10960) provide a substantial base for this analysis. These studies identify cost requirements, concept performance, and the impact of parameters such as booster mounting alternatives. These were extended and adapted to the subject Phase IV study. The cost of RNS deployment for the various concepts was determined. Further, the sensitivity of the RNS concepts to a variety of space shuttle configurations was assessed.

SELECTION OF ALTERNATE SECOND STAGES

(OBJECTIVES AND APPROACH)

26536

- SELECT BASELINE CURRENT-HARDWARE-DERIVATIVE AND NEW-STAGE CONCEPTS FOR RNS DEPLOYMENT, LOGISTICS, AND RELATED DESIGN ANALYSES
- EXTEND AND ADAPT PREVIOUS SECOND-STAGE-STUDY RESULTS TO EVALUATE--
 - COST
 - CONCEPT PERFORMANCE
 - BOOSTER MOUNTING ALTERNATIVES
- DETERMINE COST OF RNS INITIAL DEPLOYMENT
- ASSESS SENSITIVITY OF CONCEPTS TO SPACE SHUTTLE CONFIGURATION

SUMMARY OF CANDIDATE RNS SYSTEM CONCEPTS

Four launch vehicle configurations are considered for deployment of the RNS concepts (shown), each having its compatible logistics system launch vehicle. Since current-hardware-derivative second stages are launch systems with high recurring cost but low development cost, the appropriate system mix would be to use this configuration for initial RNS deployment only and to provide logistic support with the more economical reusable space shuttle system. Plausible deployment configurations range from single modules through completely assembled multi-module RNS configurations. Conversely, a new second stage concept employing partial reuse possesses relatively low transportation cost characteristics and is therefore a candidate for logistic support as well as for initial deployment, and must be tested against the alternative of the space shuttle. Deployment of the RNS with a NERVA suborbit start as a second stage configuration offers an alternative which would avert the requirement for developing a second stage for application with the shuttle booster. The shuttle is the logical logistics system in this case. Lastly, a space shuttle configured for externally carrying RNS propellant modules on the orbiter (to circumvent the volume-limited condition associated with shuttle performance capabilities in excess of approximately 40,000 lbs), used for initial RNS deployment, is coupled with a space shuttle external carrying logistic system. In this case RNS concepts configured of four or more modules (because of impact on the shuttle flight characteristics) would be required.

SUMMARY OF CANDIDATE RNS SYSTEM CONCEPTS

26531

DEPLOYMENT LAUNCH VEHICLE	RNS CONFIGURATION (NO. PROP. MODULES)	INITIAL DEPLOYMENT (PROP. MODULES/ LAUNCH)	LOGISTICS SYSTEM
SSB/CURRENT-HARDWARE- DERIVED SECOND STAGE	1, 2, 3, OR 4	1 TO FULL RNS	SPACE SHUTTLE
SSB/NEW SECOND STAGE	1, 2, 3, OR 4	1 TO FULL RNS	SPACE SHUTTLE OR SSB/SECOND STAGE
SSB/NERVA SUBORBIT START	1 OR 2	FULL RNS	SPACE SHUTTLE
SPACE SHUTTLE EXTERNAL	4 OR 8	1 OR 2	SPACE SHUTTLE

SPACE SHUTTLE PERFORMANCE

The table summarizes specific operating alternatives leading to varying payload delivery capabilities of the space shuttle configuration. The basis for the sizing of present reusable space shuttle vehicles is the 40 K-lb polar orbit payload requirement. This capability is generally achieved through fully loading the orbit maneuvering system (OMS) and removal of the air breathing engines (ABES). The 65 K-lb payload requirement for the due-east logistics mission is less stringent and not the sizing consideration. Vehicles sized to this 40 K-lb capability typically deliver approximately 51 K-lb to the RNS design orbit of 260-nmi altitude at 31.5° inclination. The volume of the 15 ft x 60 ft cargo bay will hold a maximum of approximately 40 K-lb of LH_2 . Thus greater payload capabilities than approximately 46 K-lb are not to advantage in terms of LH_2 lift capability unless provision is made for externally carrying the payload. This impact is illustrated for the baseline shuttle showing an increase in performance of from 40.3 K-lb, internally carried, to 46.1 K-lb in the external-carried mode. Since the external carry is assumed accompanied by an additional cost of one million dollars for tankage, there is no net improvement in transportation cost (\$/lb). If, however, increased performance is achieved via such techniques as down-range landing for aerial refueling of the booster, the performance is enhanced to the point of not only increasing net LH_2 lift capability but also an improvement in specific transportation cost. The performance picture is further clouded by variations in vehicle performance related to the specifics of the concept in question. In the case of the $\text{LO}_2/\text{RP}/\text{F}-1$ booster concept used in conjunction with the Mark I orbiter, the 25 K-lb design polar mission requirement translates into an LH_2 lift capability of 30 K-lb for the RNS design mission, or a transportation cost of \$167/lb. For this reason, a reference transportation cost of \$100/lb was selected as typical of a low cost reusable system to be applied in comparing various RNS logistics concepts.

SPACE SHUTTLE PERFORMANCE

26614

CONDITION	CARGO (KLB)	LH ₂ (KLB)	COST (\$/LB)
POLAR, 100 NMI, DESIGN REQUIREMENT	40	—	—
DUE EAST, 100 NMI	65	—	—
RNS DESIGN MISSION, 260 NMI/31.5°	51	—	—
• INTERNAL CARRY		40.3*	124
• EXTERNAL CARRY		46.1	130
POTENTIAL PERFORMANCE IMPROVEMENTS			
• DOWN-RANGE LANDING	61	54.8	109
• AERIAL REFUELING	71	63.7	94
<u>REFERENCE FOR RNS LOGISTICS TRADES</u>	67	60	<u>100</u>
*VOLUME CONSTRAINT			

PARAMETERS OF ALTERNATE SPACE SHUTTLE CONCEPTS

The chart summarizes space shuttle concepts specifically evaluated during the present study. Whereas, these are limited to MDAC shuttle concepts and data, these systems contain generic features also investigated by other space shuttle contractors, so there is no loss of generality for the purposes of the RNS study. The -20B configuration singularly represents a high staging velocity, active thermal protection system, configuration. All other systems represent relatively low staging velocity and associated passive thermal protection requirements. The $\text{LO}_2/\text{RP}/\text{F-1}$ configuration is the only one configured for tandem mounting. The TPFB configuration is a parallel-burn concept, which depends upon the orbiter for boost thrust vector control (presently). This configuration is presently under study in the MDAC Shuttle Study and has yet to be subjected to evaluation in the context of RNS requirements.

PARAMETERS OF ALTERNATE SPACE SHUTTLE CONCEPTS

DESIGNATION	-20B	PARALLEL BURN*	LO ₂ /RP/F1 + MARK I	LO ₂ /RP/F1 + MARK II	TPFB**
PAYLOAD REQUIREMENT (K-LB) (100-NMI, POLAR)	40	40	26.7	40	40
GLOW (MLB)	4.65	4.12	5.78	5.63	4.87
BOOSTER					
BLOW (MLB)	3.64	2.05	4.85	4.69	3.22
PROPELLANT (MLB)	3.04	1.65	4.06	3.90	2 x 1.35
NO. ENGINES	12	7	5	5	2 x 6
THRUST/ENG. (K-LB, S.L.)	550	550	1,390	1,390	491.5
STAGING VELOCITY (FPS)	10,824	6,290	7,000	7,000	5,000
ORBITER					
GLOW (MLB)	0.86	2.06	0.932	0.940	1.653
PROPELLANT (MLB)	0.53	1.65	0.709	0.709	1.39
NO. ENGINES	2	3	4	4	4
THRUST/ENG. (K-LB, VAC)	632	632	265	306	306
SPECIFIC IMPULSE (SEC, VAC)	459	459	436	450.2	450.2

*TIP TANK ORBITER

**TWIN PRESSURE-FED BOOSTERS, PARALLEL BURN

RESULTS OF PREVIOUS ALTERNATE SECOND STAGE STUDIES

Major conclusions derived from the NAR and MDAC expendable second stage studies included (1) the relatively high payload performance of the S-II configuration when compared to the S-IVB, (2) a relatively low booster impact for the S-IVB, and (3) all concepts studied were shown feasible, providing appropriate constraints upon second stage/payload mounting, launch trajectory shaping, booster engine throttling, and propellant loading. These study results have been extended to reflect the peculiar requirements of the RNS payloads. The application of these second stages was studied in conjunction with alternate booster concepts and associated transportation costs identified. The S-IVB was shown to have lower development cost impact, which is particularly significant where the sole RNS requirement imposed is placement of the hardware into orbit. Propellant topping is provided by the relatively economical reusable space shuttle.

RESULTS OF PREVIOUS ALTERNATE SECOND-STAGE STUDIES

26538

- CONCEPT FEASIBILITY
 - CONCEPTS IDENTIFIED ARE FEASIBLE
- PARAMETRIC PERFORMANCE
 - S-II PAYLOAD CAPABILITY HIGH
- BOOSTER IMPACT --
 - PAYLOAD ENVELOPE VARIATIONS
 - 18 TO 33 FT DIA
 - SECOND STAGE ALTERNATIVES
 - S-IVB LOAD IMPACT LOWER
 - MOUNTING ALTERNATIVES
 - FORWARD MOUNTING DESIRABLE
 - CONTROLLABILITY ASSESSMENT
 - KEEP CG FORWARD AND CLOSE TO BOOSTER
- RANGE OF SPACE SHUTTLE CONCEPTS
 - EMPHASIZED HIGH STAGING VELOCITY
- DEVELOPMENT REQUIREMENTS
 - S-IVB LESS DEMANDING
- ANALYSES EXTENDED FOR RNS STUDY TO INCLUDE:
 - RNS PAYLOAD ENVELOPES
 - ALTERNATE BOOSTER CONCEPTS
 - ALTERNATE SECOND-STAGE CONCEPTS
 - ALTERNATE PAYLOAD CRITERIA, REQUIREMENTS

CANDIDATE CURRENT-HARDWARE-DERIVATIVE SECOND STAGES

The principal current-hardware-derivative second stages evaluated were variations of the S-IVB and S-II stages which were identified as most promising in the previous studies. An S-IVB configuration with space shuttle engine propulsion was introduced to permit a degree of reusability through retrieval of this engine by the orbiter following alternate second stage payload injection. Both S-IVB configurations are augmented by 8 Poseidon solid rocket motors. This provides for more closely approximating shuttle orbiter mass characteristics as well as supplementing second stage performance characteristics. Similarly, the S-II configuration recommended by NAR has one ring removed from the hydrogen tank.

CANDIDATE CURRENT-HARDWARE-DERIVATIVE SECOND STAGES

26539

CONFIGURATION	S-IVB/J-2/8 SRM	S-IVB/SSE/8 SRM	S-II (-1)*/2 SSE
PROPELLANT (K-LB)	230 + 312 (SRM)	230 + 312 (SRM)	750
INERT WEIGHT (K-LB)	37.5 + 33.1 (SRM)	43.9 + 33.1 (SRM)	126.7
NO. ENGINES	1 J-2 + 8 SRM	1 SSE ₀ + 8 SRM	2 SSE ₀
THRUST/ENG (K-LB)	190	632	632
SPECIFIC IMPULSE (SEC, VAC)	429.4	459	459
DIAMETER (FT)	22	22	33
LENGTH (FT)	62.6	66.6	71.3

*LESS ONE LH₂ TANK RING

CURRENT-HARDWARE-DERIVATIVE SECOND STAGE PERFORMANCE

The facing chart provides a device which permits assessing the relative merit of various second stage configurations as influenced by changing space shuttle booster characteristics. The figure of merit in this case is the relative booster burn-out velocity occurring when employing an S-IVB/J-2/SRM second stage. The reference condition occurs for the MDAC -20B booster. Sensitivities about this condition were derived based on impulsive velocity solutions for the S-II and S-IVB/SSE/8SRM configuration. The remaining configuration performance was developed based on trajectory simulations over the range of staging velocities. The altitude and flight path angle associated with a given velocity corresponded to the histories for these parameters as given for the -20B reference configuration. All of the data shown are normalized to the following trajectory groundrules; (1) booster flyback to the KSC launch site, (2) the deorbit of expendable second stages following orbit insertion (260 nmi/31.5°, circular), (3) full rendezvous capability of 1500 ft/sec (above the 50 x 100 nmi injection orbit). The 6,000 ft/sec point noted corresponds to the parallel-burn, heat sink booster, studied by MDAC. The adequacy of S-IVB performance at low staging velocities was confirmed in the present study with trajectory simulations.

CURRENT-HARDWARE-DERIVATIVE, SECOND-STAGE PERFORMANCE

REFERENCE CURRENT-HARDWARE-DERIVATIVE SECOND STAGE PERFORMANCE AND COST

Configuration cost and performance are shown for the candidate current-hardware-derivative second stage applied to three of the space shuttle boosters studied. The staging velocity (V_g) shown is that associated with the subject booster configured with the S-IVB/J-2/8SRM. The cost data are based on 20 units or launches. All costs are expressed in constant 1971 dollars without fee. Maximum use is made of shuttle program launch operations resources. The production rate is optimized and a 90% learning curve applied. The partially reusable system hardware is recovered from earth orbit by the space shuttle at no cost. A difference of groundrules concerning the S-II operational cost under partial reuse is noted. In this case NAR assumed the total cost of avionics on the basis of follow-on buys of equipment used by the space shuttle. The baseline in the current self-consistent comparison assesses costs for this equipment starting at the first unit. Transportation cost effectiveness is shown based on the operational cost data shown.

REFERENCE CURRENT-HARDWARE-DERIVATIVE, SECOND-STAGE PERFORMANCE AND COST

ALTERNATE SECOND STAGE	COST (\$10 ⁶)		-20B (V _S =11,000FPS)		PARALLEL-BURN (V _S =6,000FPS)		LO ₂ /RP/F-1 (V _S =7,900FPS)	
	DDT&E	OPERA- TIONAL	PL (K-LB)	\$/LB	PL (K-LB)	\$/LB	PL (K-LB)	\$/LB
EXPENDABLE								
S-IVB/J-2/8 SRM	114	30.1	156	193	64	470	88	342
S-II (-1 RING)/2 SSE	162	48.5	229	212	112	433	146	332
PARTIALLY REUSABLE								
S-IVB/SSE/8 SRM	149	28.0	178	157	88	318	114	245
S-II (-1 RING)/2 SSE	280 (183)*	35.0 (38.3)*	229	153 (141)	112	312 (288)	146	240 (221)

*ALTERNATE VALUE - NAR ESTIMATE

CURRENT-HARDWARE-DERIVATIVE SECOND STAGE LAUNCH COSTS

Total launch costs for the range of RNS configurations of interest are shown for the three study booster configurations as dependent upon the number of launches required for RNS deployment. The RNS stages are assumed topped with LH_2 at the cost of \$100 per lb via launch of the reusable space shuttle. While the S-II was previously shown relatively more cost effective as a delivery system than the S-IVB, it is nonetheless more expensive when compared to space shuttle transportation cost. Thus, when applying a strategy of initializing RNS hardware with an alternate second stage and topping LH_2 with the space shuttle, it is most economical to maximize the proportion of payload delivered to orbit via the space shuttle. Combining the low unit cost of the S-IVB with the economics of shuttle LH_2 delivery yields a relatively lower cost system. The impact of total second stage expendability (EXP) and partial reuse (PR) are shown. Introduction of partial reuse reduces the price differential between the S-IVB and the S-II systems, although the S-IVB is still the more cost effective system.

**CURRENT-HARDWARE-DERIVATIVE,
SECOND-STAGE LAUNCH COSTS (\$MILLIONS)**

26542

BOOSTER / 2ND STAGE	CAPACITY (K-LB LH ₂)	300	150		100		75	
	NUMBER OF LAUNCHES	1	1	2	1	2	1	2
-20B BOOSTER								
S-IVB/J-2/8 SRM (EXP)		48.9	48.8	63.3	49.0	67.7	49.4	64.0
S-II (-1 RING)/2SSE (EXP)		60.0	59.9	97.0	60.1	97.0	60.5	97.0
S-IVB/SSE/8 SRM (PR)		44.6	44.5	56.0	44.7	61.3	45.1	56.0
S-II (-1 RING)/2SSE (PR)		46.5	46.4	70.0	46.6	70.0	47.0	70.0
PARALLEL BURN HEAT SINK BOOSTER								
S-IVB/J-2/8 SRM (EXP)		58.1	58.0	81.7	58.2	82.0	58.6	82.4
S-II (-1 RING)/2SSE (EXP)		71.7	71.6	108.9	71.8	109.2	72.2	109.6
S-IVB/SSE/8 SRM (PR)		53.6	53.5	72.7	53.7	73.0	54.1	73.4
S-II (-1 RING)/2SSE (PR)		58.2	58.1	81.9	58.3	82.2	58.7	82.6
LOX/RP/F-1 BOOSTER								
S-IVB/J-2/8 SRM (EXP)		55.7	55.6	76.9	55.8	77.2	56.1	77.6
S-II (-1 RING)/2SSE (EXP)		68.3	68.2	102.1	68.4	104.5	68.8	102.8
S-IVB/SSE/8 SRM (PR)		51.0	50.9	67.5	51.1	67.8	51.5	68.2
S-II (-1 RING)/2SSE (PR)		54.8	54.7	75.1	54.9	78.5	55.3	75.8

SELECT S-IVB/J-2/8SRM CURRENT-HARDWARE-DERIVATIVE SECOND STAGE

An S-IVB with a J-2 engine and 8 Poseidon solid rocket motors (SRM) is selected as a baseline for RNS design optimization for the current-hardware-derivative second stage class of launch vehicles based on the following considerations (1) adequate launch vehicle performance to deliver the RNS hardware to orbit for all candidate boosters considered, (2) superior (or at least equal) operating cost effectiveness as compared to S-II derivative systems, (3) availability of 15 J-2 engines (or at least 7 if two Mark I orbiters are produced), (4) minimum development cost compared to S-II derivative systems, and (5) minimum loading impact on the space shuttle booster. This conclusion does not consider additional space program requirements which could warrant a larger second stage.

SELECT S-IVB/J-2/8 SRM CURRENT-HARDWARE-DERIVATIVE SECOND STAGE

26543

- FAVORABLE OPERATING COST EFFECTIVENESS
- ADEQUATE PERFORMANCE TO DELIVER RNS HARDWARE FOR ALL CANDIDATE BOOSTERS CONSIDERED
- MINIMUM DEVELOPMENT COST
- AVAILABILITY OF 15 J-2 ENGINES (OR AT LEAST 7 IF 2 MARK I ORBITERS PRODUCED)
- MINIMUM LOADING IMPACT ON BOOSTER
- S-II-DERIVATIVE ACCEPTABLE FOR RNS IF HIGHER PAYLOAD IS REQUIRED FOR OTHER SPACE PROGRAM ELEMENTS

CANDIDATE NEW SECOND STAGES

Two basic alternatives were considered as candidates for the new second stage: (1) a discrete or integral configuration, (2) a configuration sharing a common LH_2 tank with the RNS. The characteristics of these configurations (shown) reflect utilization of associated space shuttle orbiter propulsion systems. The propellant capacities shown reflect a compatibility either in terms of orbiter mass characteristics or equivalent axial load at the orbiter/booster interface (in the case of the $\text{LO}_2/\text{RP}/\text{F}-1$ configuration). In each case the LO_2 tank capacity is geometrically compatible with space shuttle retrieval.

CANDIDATE NEW SECOND STAGES

BOOSTER	-20B		PARALLEL BURN		LO ₂ /RP/F-1	
SECOND STAGE CONCEPT	DISCRETE	COMMON LH ₂	DISCRETE	COMMON LH ₂	DISCRETE	COMMON LH ₂
PROPELLANT (K-LB); LO ₂ /LH ₂	480/80		692/115		602/109	
INERT WEIGHT (K-LB)	51.5	38.9	73.1	56.2	65.7	49.5
NO. ENGINES	1 SSE	1 SSE	2 SSE	2 SSE	4 J-2	4 J-2
THRUST/ENG. (K-LB)	632	632	632	632	230	230
SPECIFIC IMPULSE (SEC)	459	459	459	459	425	425

NEW SECOND STAGE PERFORMANCE

Launch vehicle performance for the various booster/new second stage configurations studied is presented parametrically in the form of gross weight injected into the design 260-nmi orbit as a function of propellant consumed by the second stage. The data observe the shuttle booster entry constraint of 3 g's maximum. Main stage injection is accomplished in all cases at 50 x 260 nmi. Booster flyback and no rendezvous capability are assumed. In the cases of the -20B and $\text{LO}_2/\text{RP}/\text{F}-1$ configurations, the terminus of the curves correspond to the orbiter gross weight. In the case of the parallel-burn configuration, the terminus represents the condition where the axial load at the booster/second stage interface is equivalent to the design condition at booster burnout in the parallel-burn/orbiter configuration. When this vehicle is configured with an alternate second stage, however, a series burn mode is applied. Thus, ignition of the second stage does not occur until booster burnout, and the second stage/payload configuration is lighter than the corresponding orbiter.

NEW SECOND STAGE PERFORMANCE

ALTERNATIVE COSTS AND REUSABILITY APPROACHES

Parallel Burn Booster/ CLH_2 Second Stage

The figure summarizes the impact on launch vehicle operating costs, of varying levels of sub-system reusability. The basis of comparison is for a totally expendable second stage. The concept, in this case, is the common- LH_2 -tank concept. The first increment of reusability introduced is to recover from orbit only the astrionics module, consisting of the navigation and guidance, data management, and command and control subsystems. The engine/astrionics level designation includes most of the functional subsystems required to propel and control the stage. The third level of reuse shown introduces the additional element of the LO_2 tank module which contains the oxidizer for the alternate second stage. Thus, in the limiting condition shown, only the LH_2 module (the RNS propellant module) is not recovered. In all reusable-systems cases, it is assumed that three sets of hardware are sufficient. This is compatible with the number of reusable space shuttle boosters currently planned. To achieve an average cost per flight, a 20 mission requirement over ten years was used. The launch costs shown are in 1971 dollars and include space shuttle booster operations in addition to second stage costs. No charge is made for the space shuttle retrieval of components.

ALTERNATIVE COSTS AND REUSABILITY APPROACHES

26615

PARALLEL - BURN BOOSTER/CLH₂ SECOND STAGE

LEVEL OF REUSE	OPERATIONAL COST	
	\$10 ⁶	\$/LB
NONE (EXPENDABLE)	29.6	145
ASTRIONICS	28.1	138
ENGINE/ASTRIONICS	16.3	80
ENGINE/ASTRIONICS, LO ₂ MODULES	13.9	68

NOTES: 20 MISSIONS, 3 SETS OF REUSABLE HARDWARE

REFERENCE NEW SECOND STAGE PERFORMANCE AND COST

The reference new second stage performance data shown correspond to orbiter-equivalent conditions as noted previously. Data are shown for both the common-LH₂-tank and discrete stage concepts. The performance benefit shown with the common-LH₂-tank concept reflects the weight savings of eliminating a discrete LH₂ tank. Observing the orbiter constraints discussed results in a configuration with slightly less than maximum performance. Gross weight injected into orbit could be increased by having a larger second stage propellant capacity and throttling booster engines as maximum acceleration is approached to alleviate booster loads. However, it is not considered promising on the basis that the performance is already near maximum, and if the LO₂ tank size were increased further its recovery would be precluded in the case of the parallel-burn concept. The operational cost data are based on a 20-mission requirement over a ten-year period.

REFERENCE NEW SECOND STAGE PERFORMANCE AND COST

26572

BOOSTER 2ND STAGE CAPACITY (K-LB) 2ND STAGE PROPULSION	-20B 560 1 SSE DISCRETE CLH ₂		PARALLEL BURN 807 2 SSE DISCRETE CLH ₂		LO ₂ /RP/F-1 711 4 J-2 DISCRETE CLH ₂	
PAYLOAD (K-LB)	248.0	260.7	187.0	203.9	173.0	189.2
LH ₂ RESIDUAL** (K-LB)	204.0	216.7	143.0	159.9	129.0	145.2
COSTS (\$10 ⁶)						
DDT&E	340	315	340	315	340	315
OPERATIONAL*						
• RETRIEVE ENTIRE CPM	15.4	12.6	17.3	13.9	17.4	14.1
• JETTISON LO ₂ TANK	17.2	14.4	19.7	16.3	19.4	16.1
PAYLOAD TRANSPORTATION COST (\$/LB)						
• RETRIEVE ENTIRE CPM	62	48	93	68	101	75
• JETTISON LO ₂ TANK	69	55	106	80	112	85

*BASED ON 3 UNITS OVER 20 MISSIONS

**SINGLE, 300 K-LB CAPACITY RNS PROPELLANT MODULE (44 K-LB INERT)

NEW SECOND STAGE LAUNCH COSTS

The data discussed in the preceding chart on performance and cost have been combined with preliminary RNS module launch weights to determine the cost of launching the RNS configuration to orbit. The cost of topping off LH_2 is included at the charge of \$100 per lb, reflecting space shuttle transportation figures. Recovery of the LO_2 tank is assumed for both candidate second stages. The common LH_2 tank concept is shown more cost effective for launch of the full RNS since the cost of LH_2 tank is defrayed. Since the cited costs are based on three reusable units for 20 launches, the relative cost advantage for the common LH_2 tank would increase for a more ambitious program. However, it is noted that when launching only one LH_2 module per launch (at a capacity of less than 300 K-lbs LH_2) the common LH_2 concept can be penalized by limited available LH_2 , which reduces the residual delivered to orbit. Thus, if factors other than cost require launching one small module at a time, a discrete stage could become attractive.

26546

NEW SECOND STAGE LAUNCH COSTS (\$ MILLIONS)
(LH₂ TOPPING BY SPACE SHUTTLE AT \$100/LB)

BOOSTER / 2ND STAGE	CAPACITY (K-LB LH ₂)	300	150		100		75	
	NUMBER OF LAUNCHES	1	1	2	1	2	1	2
-20B BOOSTER								
COMMON LH ₂ TANK / 1 SSE		20.9	20.8	31.2	21.0	31.4	21.2	31.2
DISCRETE STAGE / 1 SSE		25.0	24.9	30.8	25.1	30.8	24.9	30.8
PARALLEL BURN HEAT SINK BOOSTER								
COMMON LH ₂ TANK / 2 SSE		27.9	27.8	39.2	28.0	39.4	24.8	39.4
DISCRETE STAGE / 2 SSE		33.0	32.9	34.6	33.1	39.0	32.9	34.6
LOX / RP / F-1 BOOSTER								
COMMON LH ₂ TANK / 4 J-2		29.6	29.5	41.0	29.7	41.2	30.0	41.0
DISCRETE STAGE / 4 J-2		34.5	34.4	34.8	34.6	40.6	34.4	34.8

COMMON-LH₂ DESIGN IMPACT ON RNS

Space-shuttle-orbiter engine requirements were reviewed and compared to the RNS capabilities to evaluate the impact of imposing shuttle engine requirements on the RNS propellant modules in the common-LH₂ design concept. Introducing parallel LH₂ feed legs permits satisfying the higher flow rate requirements with the existing RNS tank operating pressure of 31 psia. The associated increased pressurant flow rate requirements can be satisfied via engine bleed from the second stage engines.

COMMON LH₂ SECOND STAGE DESIGN IMPACT ON RNS

26547

- RNS TANK DESIGN PRESSURE (31 PSIA) SUFFICIENT TO SATISFY SHUTTLE ENGINE REQUIREMENTS
- PROVIDE ADDITIONAL FEED SYSTEM LEGS TO ACCOMMODATE HIGHER LH₂ FLOW RATES
- HIGHER PRESSURIZATION FLOW RATES ACCOMMODATED BY RNS MULTI-LEVEL PRESSURIZATION SYSTEM --
 - UTILIZE ENGINE BLEED GH₂ FOR EXPULSION PRESSURANT

SELECT COMMON LH₂ TANK NEW SECOND STAGE

A common LH₂ tank concept (in contrast to the discrete stage concept) is selected as a baseline new second stage for RNS design optimization for this class of launch vehicles, based on the following considerations: (1) delivery of greater useful payload (residual LH₂), (2) lower operational cost, (3) lower development cost, (4) minimal performance penalty for RNS missions, (5) reduced length of the second stage/payload launch configuration. As discrete stage performance capabilities are acceptable, this configuration would be sufficient for the RNS if an optimum-stage concept is required based on other space program elements.

SELECT COMMON LH₂ TANK NEW SECOND STAGE

26548

- COMPARABLE PERFORMANCE AND LAUNCH COST
 - LAUNCH OF SMALL SINGLE MODULES COULD FAVOR DISCRETE STAGE
- LOWER DEVELOPMENT COST
- MINIMAL MISSION PERFORMANCE PENALTY
- REDUCED OVERALL PAYLOAD / SECOND STAGE LENGTH
- DISCRETE STAGE ACCEPTABLE FOR RNS IF OPTIMUM STAGE IS REQUIRED
FOR OTHER SPACE PROGRAM ELEMENTS

SUBORBIT START CONCEPT

Employment of the NERVA in suborbit start mode offers an attractive alternative to utilization of an alternate second stage with the space shuttle booster, in that the requirement for second stage development is averted. Problems encountered with this concept focus upon developing configurations which do not substantially violate booster capabilities. This is particularly true in the area of trying to match corresponding orbiter mass characteristics. Introducing thrust augmentation through solid rocket motors, as is done in the case of the S-IVB second stage concept, serve the purposes of (1) thrust augmentation, (2) providing ballast, (3) and introducing a mode for separating the booster from the RNS prior to NERVA startup, thereby minimizing the radiation impact on the booster. A principal safety measure envisioned is that of introducing NERVA idle mode operation during the African overfly, thereby greatly reducing the likelihood of failure during this period. The orbital injection profile envisioned includes injection by the NERVA at full thrust into an 80 nmi x 260 nmi phasing orbit, followed by idle mode circularization at 260 nmi.

SUBORBIT START CONCEPT

- USE 8 POSEIDON SRM TO PROVIDE --
 - THRUST AUGMENTATION
 - BALLAST ! 71 (. , 72 t ')
 - SEPARATION FROM BOOSTER BEFORE NERVA STARTUP
- USE IDLE MODE DURING AFRICAN OVERFLY
- INJECTION TO 80-NMI X 260-NMI ORBIT FOLLOWED BY
CIRCULARIZATION AT 260-NMI USING IDLE MODE

SUBORBIT START PERFORMANCE AND COST

The performance of the RNS used in the NERVA suborbit start mode has been demonstrated as approximately 100,000 lbs of LH_2 residual in the operational earth orbit, when employed with the -20B shuttle booster. Conversely, the feasibility of the concept when employed with low-staging-velocity, heat-sink booster concepts has yet to be demonstrated. Difficulties occur due to the opposing requirements of (1) restraining booster burnout conditions to shuttle design levels and (2) providing sufficient lofting at booster burnout to permit achievement of earth orbit with the low RNS thrust-to-weight ratio. Launch costs are relatively modest as no charge for the launch is accrued for the second stage apart from the solid rocket motors (SRM's) and their associated interstage. The LH_2 topping cost of \$20 million (shown) is a nominal figure reflecting approximately 200,000 lbs of LH_2 provided at the cost of \$100/lb. Development requirements for the configuration would be relatively modest, only requiring integration of the SRM's (in a manner analogous to that defined during the S-IVB expendable second stage studies) and development of a launch restraint for NERVA.

≈ 117 Just to 1-2 ... 200,000 lb H_2
... 6 AHs!

SUBORBIT START PERFORMANCE AND COST

26584

- PERFORMANCE

- -20B: ~100K LB LH₂
- LOW STAGING VELOCITY: QUESTIONABLE

- LAUNCH COST (\$10⁶) \$27.8

- SHUTTLE BOOSTER 3.0
- SRM'S 3.8
- INTERSTAGE 1.0
- LH₂ TOPPING 20.0

- DEVELOPMENT REQUIREMENTS

- SRM INTEGRATION
- NERVA RESTRAINT

SUBORBIT START ASSESSMENT

The feasibility, performance wise, of the suborbit start concept rests heavily upon the specifics of the reusable space shuttle booster employed. The -20B booster configuration performance has been demonstrated, showing the capability of at least delivering 100,000 lbs of LH_2 to the operational orbit, plus the RNS hardware. The capability of this concept has not been demonstrated for the lower-staging-velocity configurations (such as the parallel-burn and LO_2 /RP/F-1 boosters). Introducing solid rocket motor augmentation has been shown essential for reasons of providing ballast, thrust augmentation, and reducing radiation levels at the booster to acceptable values. Techniques to increase the potential of SRM augmentation such as increasing the size of the motors or staggering the ignition sequence to prolong the effective operating period, will have to be investigated to fully understand this mode. In the case of the -20B, the radiation to the space shuttle booster crew is approximately 20 millirems direct and no more than 300 millirems to the entire booster configuration due to plume impingement. Safety requirements dictate leaving poison wires in the core until after separation and removing them via an automatic device prior to ignition. Introducing the idle mode concept during the African overfly, greatly reduces the probability of failure during this period and prior to achieving a long-lived orbit. Further evaluation is required to demonstrate that this reduction in failure probability is sufficient. Dynamic considerations during launch dictate that a lateral restraint be provided for the NERVA.

SUBORBIT START ASSESSMENT

PERFORMANCE

- FEASIBILITY QUESTIONABLE FOR LOW STAGING VELOCITY BOOSTERS

RADIATION TO SPACE SHUTTLE BOOSTER / CREW

- DIRECT ~ 20 M REM
- PLUME IMPINGEMENT < 300 M REM

ANTICRITICALITY PROVISIONS

- LEAVE ALL POISON WIRES IN CORE UNTIL AFTER SEPARATION
- UTILIZE AUTOMATIC REMOVAL DEVICE

FAILURE PRIOR TO ATTAINMENT OF LONG-LIVED ORBIT

- IDLE MODE FAVORABLE
- REQUIRES FURTHER EVALUATION

REQUIRES LATERAL RESTRAINT CONCEPT FOR NERVA

S-IVB/COMMON-LH₂ TANK INITIAL DEPLOYMENT BREAK-EVEN POINT
Parallel-Burn Booster

The figure compares the cost of deploying the RNS using the S-IVB/J-2/SRM configuration and the common-LH₂-tank configuration. In this case initial deployment cost is defined as the cost of the launch vehicles required to place the RNS propellant modules into orbit plus the cost of topping LH₂ via the space shuttle, to provide a full (300 K-lb of LH₂) RNS for its first mission. In addition, the full cost of DDT&E for the second stage was assumed to be charged to the RNS program. The cost data is presented parametrically as a function of the number of RNS systems deployed over the ten-year program life and the number of RNS modules carried to orbit per launch. The examples shown are for a configuration comprised of a single 300 K-lb capacity module and a configuration comprised of two 150 K-lb modules. In the latter case, the 150 K-lb modules are launched separately in two launches. Thus, for example, for four RNS's, 8 launches of the alternate second stage would be required. Only a single line is shown for the common-LH₂-tank concept for both the single 150 K-lb module and single 300 K-lb module cases. This is due to the characteristically low recurring cost of the concept due to the partial reusability feature, when compared to the overall program cost. In general, for low launch requirements, corresponding to either low annual mission rates and/or boosting complete RNS configurations in a single launch, the expendable S-IVB/J-2/8 SRM's is more cost effective due to its low development cost. The impact of a delayed re-opening of the S-IVB manufacturing line is also shown with the dashed line. In the case of a 1979 IOC, 42% of second stage hardware common to the S-IVB is assumed returned to a first-unit basis. If the IOC is delayed to 1981, it is assumed all S-IVB-common hardware is returned to a first-unit basis.

S-IVB/CLH₂ INITIAL DEPLOYMENT BREAK-EVEN POINT PARALLEL - BURN BOOSTER

SELECTION OF SECOND STAGE FOR RNS DEPLOYMENT
IN COMBINATION WITH SPACE SHUTTLE LOGISTICS

The S-IVB/J-2/8SRM configuration is selected as the baseline for RNS design optimization, to be used in combination with the space shuttle for logistic support. This selection is consistent with a modest lunar program and high cost effectiveness. It averts high development expenditures for an alternate second stage and has minimum impact on the shuttle. Further, the configuration is compatible with the entire range of RNS concepts, capable of delivering the entire stage to the operational 260-nmi orbit for each of the space shuttle boosters considered. Consideration of the impact on S-IVB development costs caused by a late startup and reopening of the S-IVB manufacturing line, tends to soften this conclusion, reducing the number of RNS deployments required before the common LH₂ tank configuration becomes more cost effective. However, if the program is so ambitious that development of a new second stage is warranted, its economic advantage should also be used for the logistics system.

SELECTION OF SECOND STAGE FOR RNS DEPLOYMENT IN COMBINATION WITH SPACE SHUTTLE LOGISTICS

- **SELECT S-IVB FOR LIMITED PROGRAM**
 - **COMPATIBLE WITH ENTIRE RANGE OF RNS CONCEPTS**
 - **MINIMUM SHUTTLE IMPACT**
 - **MINIMUM DEVELOPMENT COST**
- **NEW STAGE MORE COST EFFECTIVE FOR AMBITIOUS PROGRAM MODEL**

MISSION ANALYSIS AND LOGISTICS

Objectives and Approach

The mission analysis and logistics tasks embrace evaluation of the capability of the various RNS concepts identified to deliver payload to lunar orbit. The capability of these concepts, as applicable, is evaluated for the alternative mission modes identified. These include independent modes (non-jettison, jettison, and aerobraking), operating apart from any external assistance during the entire mission, and the assisted modes which depend upon external systems for mission completion. Logistics concepts are identified which are compatible with the mentioned candidate mission modes. These concepts include employment of the space shuttle and/or space shuttle booster/alternate second stage vehicles. RNS mission performance comparisons in this section are based upon preliminary RNS concept mass characteristics.

MISSION ANALYSIS AND LOGISTICS

(OBJECTIVES AND APPROACH)

26551

- EVALUATE LUNAR MISSION PERFORMANCE OF RNS CONCEPTS
(1, 2, 3, 4, 8 MODULES)
- EVALUATE ALTERNATIVE MISSION MODES
 - INDEPENDENT
 - NON-JETTISON
 - JETTISON
 - AEROBRAKING
 - ASSISTED
 - TUG RETRIEVAL IN EARTH ORBIT
 - REFUELING IN EARTH OR LUNAR ORBIT
- IDENTIFY LOGISTICS CONCEPTS COMPATIBLE WITH CANDIDATE MISSION MODES --
 - SPACE SHUTTLE
 - SPACE SHUTTLE BOOSTER/ALTERNATE SECOND STAGE

LUNAR SHUTTLE DESIGN MISSION PROFILE

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

1 - Mission profile for the 11.2 day cycle

LUNAR SHUTTLE DESIGN MISSION PROFILE

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

RNS PROPELLANT UTILIZATION

The figure illustrates the propellant-consumption distribution for the RNS when used on the four-burn lunar shuttle mission. The distribution provides insight to the performance incentive of jettisoning tankage following translunar injection (TLI) when employing multi-module RNS concepts. While the schematic illustrates the three-module configuration (100 K-lb of LH_2 per module), it is representative of the other concepts studied. Since lunar payload increases accompany the jettisoning of modules at TLI, the proportion of propellant consumed for this maneuver is slightly increased. Thus, two 100 K-lb modules would be depleted, permitting efficient staging for the concept represented.

RNS PROPELLANT UTILIZATION

26586

REFERENCE LOGISTICS OPERATIONS

New Second Stage

The illustration schematically represents operations required to recycle the RNS prior to departure on the lunar shuttle mission. The sequence is initiated with the supply of the required LH_2 via the space shuttle booster/common- LH_2 -tank second stage, supplying approximately 90 K-lb of usable LH_2 per launch. The RNS would be subsequently topped-off with LH_2 by two space shuttle launches. Three space shuttle launches are required following RNS fueling to deliver the lunar payload, command and control module, and retrieve the common- LH_2 -tank second stage propulsion modules injected during the LH_2 resupply operation. The alternative of payload delivery with a space shuttle booster/alternate second stage configuration, rather than the space shuttle, has not been investigated and could provide potential benefits. The requirement for launching two space shuttles to provide LH_2 topping is predicated on the assumption that RNS propellant modules are used with the alternate second stage configuration in the role of a propellant tanker. This configuration (in the case of the 150 K-lb LH_2 module capacity) presents a volume-limited condition. For this reason, introduction of a customized LH_2 tanker module would permit greater lift efficiency and potentially eliminate the requirement of space shuttle launches for topping. Thus, employing the new common- LH_2 -tank second stage concept has the potential of reducing the total number of launches for propellant supply from six (with the all-space-shuttle approach) to two.

REFERENCE LOGISTICS OPERATIONS

NEW SECOND STAGE

COMPARISON OF JETTISON AND NON-JETTISON MISSION MODES FOR ALTERNATE LOGISTICS SYSTEMS

The figure illustrates lunar mission transportation costs for a 10-year lunar program over a varying range of mission requirements (expressed in number of missions per year). Both the jettison and non-jettison mission modes are contrasted, employing S-IVB and common-LH₂-tank second stage concepts for jettisoned module replacement. In deriving the costs of logistics, full charge was made for development of the alternate second stage hardware. The data illustrates the potential benefit of jettisoning propellant modules during the mission when employed in conjunction with a logistics scheme using the common-LH₂-tank second stage concept. Conversely, the S-IVB second stage is only competitive for low mission rates used in conjunction with a non-jettison lunar mission profile. The cost effectiveness of the common-LH₂-tank second stage concept used with the jettison mission mode rests upon the economies of providing LH₂ delivery to earth orbit at no charge for the LH₂ module as it is common to the RNS. Thus, the concept serves a dual purpose of providing a propellant container for launch to orbit as well as replacement of the expended RNS modules. While the transportation cost comparison for the common-LH₂-tank concept between the jettison and non-jettison mission modes shows a substantial benefit from the jettison case, this is to a large degree dependent upon the specific RNS concept in question. For example, when considering an RNS configured of two 150 K-lb propellant modules, the comparison is not nearly so dramatic, indicating the non-jettison mode to be slightly superior in cost. In all cases, however, the common-LH₂-tank new second stage concept is economically more cost effective for the annual mission rates greater than four missions per year, for RNS concepts of three 100 K-lb modules to a single 300 K-lb module.

COMPARISON OF JETTISON AND NON-JETTISON MISSION MODES FOR ALTERNATE LOGISTICS SYSTEMS

TUG-ASSISTED MISSION PROFILES

Mission performance can be enhanced through employment of the tug in either a RNS retrieval mode or to provide refueling in earth orbit prior to final circularization at earth orbit injection (EOI). In the former mode the RNS injects into an eccentric earth orbit, followed by tug intercept and subsequent return by the tug to the 260-nmi circular earth orbit. In the refueling mode, the RNS similarly injects into an eccentric orbit at EOI. A tug subsequently rendezvous with the RNS in this orbit and provides for transfer of propellants to the RNS to permit makeup of the deficit at EOI ΔV . The tug nominally is assumed to return to the circular earth orbit independently. However, performance advantages would be attendant if it were practical for the tug to be returned by the RNS due to the relatively high NERVA performance. Both of these modes entail operation in the high intensity regions of the Van Allen radiation belts. In the tug refueling case, assuming a cost-optimum tug size of 19,000 lbs and a propellant transfer of 24,000 lbs, the eccentric orbit would have a perigee of 260 nmi and an apogee of approximately 8,000 nmi. This orbit has a period of approximately 4.5 hours and an attendant dose rate of about 5 rads per orbit, assuming an equivalent aluminum shield thickness of 5 gm/cm². Correspondingly, a tug-retrieval concept employing a tug of capacity 57,300 lbs (corresponding to the maximum space shuttle capability) would require operation in an orbit with apogee of approximately 6,000 nmi. This orbit possesses a period of approximately 3.7 hours and an attendant radiation dose rate of approximately 6 rads per orbit. Clearly for both modes greater shielding levels would be required. Even allowing 40 gm/cm² equivalent aluminum shield thickness, a dose rate of approximately one rad per orbit would be accumulated. Thus, considering the requirement of at least 2 to 4 orbital revolutions to accomplish requisite operations, this would result in radiation dose levels to the crew comparable to that induced from NERVA operations.

TUG-ASSISTED MISSION PROFILES

RNS RETRIEVAL:

- ① RNS INJECTION INTO ECCENTRIC ORBIT (EOI),
APOGEE ALTITUDE $\sim 6,000$ NMI PERIOD ~ 3.7 HR
- ② RNS/TUG RENDEZVOUS (TWO ORBITS MINIMUM)
- ③ RNS/TUG CIRCULARIZATION BY TUG

ORBITAL REFUELING:

- ① RNS INJECTION INTO ECCENTRIC ORBIT (EOI),
APOGEE ALTITUDE $\sim 8,000$ NMI PERIOD ~ 4.5 HR
- ② RNS/TUG RENDEZVOUS (TWO ORBITS MINIMUM),
 LH_2 TRANSFER (~ 0.5 HR)
- ③ RNS CIRCULARIZATION

RNS PERFORMANCE - TUG-ASSISTED MISSION MODES

The figure summarizes the performance impact of the tug-assisted mission modes as dependent upon tug propellant capacity. The data are based upon an inert weight scaling law of the tug of $2800 + 0.08028W_{p_c}$ and a specific impulse of 469.5 seconds, obtained from concurrent space tug studies. In the case of the propellant transfer mode, the propellant tanker has a mass fraction of 0.9. Equal velocities are assumed for the up and down legs of the tug in both mission modes. No velocity allowance is made for requirements to perform the macro and micro-eccentric orbit by the tug and subsequent return to the circular orbit. These rendezvous ΔV requirements, in any case, are considered to be relatively small when compared to the total round trip impulsive requirement of 9,000 to 18,000 ft/sec over the range of interest. Geometry limitations are noted for the propellant transfer mode, based on a combined tug/tanker length of 60 ft. This limitation is distributed as follows:

Mode	Tug		Tanker	
	Propellant (K-LB)	Length (ft)	LH ₂	Length (ft)
No Jettison	19	22.8	24	37.2
Jettison	25	24.6	23	35.4

The tug length alone doesn't approach 60 ft over the propellant range of interest.

RNS PERFORMANCE - TUG-ASSISTED MISSION MODES

COMPARISON OF TUG-ASSISTED AND INDEPENDENT MISSION MODES

The table compares the mission performance and specific transportation costs of the independent mission modes to the tug-assisted modes, relating specific costs of the assisted modes to an equivalent-performance integral RNS concept. In the case of the tug-assisted mission modes, the tug capacity and LH_2 transfer requirement, as applicable, are compatible with the space shuttle cargo bay geometry of 15 ft x 60 ft. In the case of RNS retrieval, the 57.3 K-lb tug capacity is assumed to relate to the maximum space shuttle orbital capability. The transportation costs noted reflect a nominal \$30 million for RNS refueling (transportation specific cost of \$100 per lb) and a tug launch cost of 5.9 million dollars, including propellants and LH_2 for transfer. In the case of the jettison mode, a charge of five million dollars is assessed for RNS propellant module replacement. The comparison indicates the assisted mission modes provide somewhat more economical transportation for equivalent payload values. It is felt, however, that this difference is sufficiently small to raise the question as to the desirability of the modes considering their relative operational complexity.

COMPARISON OF TUG-ASSISTED AND INDEPENDENT MISSION MODES

26553

MISSION MODE	RNS: 3 @ 100K				EQUIVALENT INTEGRAL RNS	
	TUG CAPACITY (K LB)	LH ₂ TRANS- FERRED (K LB)	PAYLOAD (K LB)	TRANSPOR- TATION COST (\$ / LB)	W _P (K LB)	TRANSPOR- TATION COST (\$ / LB)
INDEPENDENT - NON-JETTISON	--	--	155.1	193.5	300	193.5
INDEPENDENT - JETTISON 2 IN LUNAR ORBIT	--	--	189.6	184.5	336.0	177.5
TUG-ASSIST VIA PROPELLANT TRANSFER	19.0	24.0	224.0	160.5	371.8	166.0
TUG ASSIST VIA RNS RETRIEVAL	57.3	--	216.5	165.8	364.0	168.2

LUNAR ORBIT PROPELLANT DEPOT IMPLICATIONS

Propellant transfer in lunar orbit is based upon depletion of the RNS propellant load on arrival in the 60-nmi operational lunar orbit. The RNS is subsequently refueled from a propellant store for the earth-return leg of the mission. This mode of operation requires a typical propellant storage capability of approximately $7\frac{1}{2}$ K-lb, assuming a 20 K-lb earth-return payload. This mode is accompanied by a performance benefit of approximately twice the comparable performance for the same capacity RNS using the independent mission mode. This mode would require the development of active refrigeration for long-term storage of LH_2 in the lunar orbit in order to allow for contingencies in mission rate. Associated transportation costs would account for the transportation of the LH_2 and its container to lunar orbit at the cost of \$193/lb, transportation of the RNS propellant to earth orbit at \$100/lb, and an assessment for amortizing development costs of the propellant depot itself. Based on the 310K-lb lunar orbit delivery capability, this would result in a transportation cost of \$285 per lb. If the propellant depot cost of development is not charged to the mission this would be reduced to a figure of \$172/lb. In this latter case, this would be competitive with the tug-assisted mission modes. The mode offers the ability to provide for exceptionally large payloads in relatively rare circumstances or conversely provides a means for effectively modularizing the RNS with a resultant increase in performance delivery efficiency (in terms of pounds of propellant required per pound of delivered payload). It is significantly less complex, operationally, than the other assisted mission modes studied.

LUNAR ORBIT PROPELLANT DEPOT IMPLICATIONS

- STORAGE REQUIREMENT (20 K-LB EARTH-RETURN PL) 74 K-LB
- PERFORMANCE BENEFIT (CF. 155 K-LB INDEPENDENT) 310 K-LB
- REQUIRES DEVELOPMENT OF ACTIVE REFRIGERATION FOR LONG-TERM STORAGE OF LH₂
- TRANSPORTATION COST \$285 /LB*

TRANSPORT LH ₂ TO LUNAR ORBIT @ \$193.5 /LB	\$15.9M
PROPELLANT DEPOT**	\$35.0M
RNS PROPELLANT @ \$100/LB	\$37.4M
	<u>\$88.3M</u>

*\$172/LB, IF PROPELLANT DEPOT NOT CHARGED TO RNS

**\$700M, AMORTIZED OVER 20 MISSIONS

~ 4 M \$ / year to mission!

AEROBRAKING CONCEPT

The aerobraking mission mode entails injection, via NERVA propulsion, into an eccentric earth orbit on return from the lunar mission, followed by aerodynamic decay to near-circular conditions. The orbit would be subsequently circularized via application of the NERVA idle mode. Control of perigee conditions during the decay process would be achieved through trimming with the RNS APS near apogee.

AEROBRAKING CONCEPT

- ① EOI VIA NERVA INTO ECCENTRIC ORBIT ($h_p \sim \underline{50 \text{ NMI}}$, TYPICAL)
- ② ORBIT DECAY (10 TO 50 DAYS), PERIGEE TRIM VIA RNS APS
- ③ ORBIT CIRCULARIZATION VIA NERVA IDLE MODE; RAISE PERIGEE TO 260 NMI

AEROBRAKING ASSESSMENT

The chart provides a parametric representation of mission payload impact of the aerobraking mode as a function of the resultant reduction in earth orbital injection (EOI) velocity requirement. The reference configuration is an RNS composed of three 100,000 lb-capacity propellant modules, two of which are jettisoned in lunar orbit prior to transearth injection. Decay time is related to the reduction of EOI ΔV , based on a ballistic parameter of 20 psf and a perigee altitude of the injection orbit of 50 nmi. The performance impact is correspondingly related to transportation cost. In order to be competitive with an assisted mission mode, such as a propellant transfer in earth orbit, it would be necessary to achieve a specific transportation cost on the order of \$160/lb, or a payload increase of approximately 30,000 lbs. To accomplish this, in the limiting case, with no increase in RNS inert weight a reduction in EOI ΔV of approximately 2700 ft/sec would be required. This would result in an increase in mission time on the order of 5 days. Should this be accomplished at the expense of a 10,000 lb increase in EOI inert weight, a reduction in EOI ΔV of approximately 4800 ft/sec would be required, or a corresponding increase in mission time of approximately 30 days. It is therefore concluded that, to realize the potential of this mode of operating, a significant increase in mission time would be required. Additionally, this mode entails multiple orbital passes through the high intensity regions of the Van Allen radiation belt, occurring in the vicinity of 5,000 to 1,000 nmi in altitude, incurring dose rates as high as approximately 15 rads per orbit at the maximum (assuming an equivalent aluminum shield thickness of 5 gr/cm²), or at the other extreme with a 40 gr/cm² shield thickness, of approximately 2 rads per orbit. Should this mode be undertaken, a significant development requirement would be needed to provide proper capability in the RNS insulation and an aerobraking system. Operationally, should a failure of the reaction control system occur during the decay process, the earth's propulsion would be jeopardized.

AEROBRAKING ASSESSMENT

- SIGNIFICANT INCREASE IN MISSION TIME REQUIRED TO REALIZE MODE'S POTENTIAL
- ENCOUNTERS SIGNIFICANT VAN ALLEN RADIATION ENVIRONMENT
- REQUIRES SIGNIFICANT DEVELOPMENT EFFORT (INSULATION, AEROBRAKING SYSTEMS)
- REACTION CONTROL FAILURE DURING DECAY COULD RESULT IN HAZARD TO EARTH'S POPULATION

SELECT INDEPENDENT MISSION MODE

The independent mission mode was found to compare favorably with the assisted mission modes when identifying equal payload requirements. While the tug-assisted modes were shown to be slightly more cost effective, the associated operational complexities and van Allen radiation hazard do not justify their selection. In cases of unusual, high payload delivery requirements, jettisoning of propellant modules is shown favorable as a method of achieving higher payload requirements with limited propellant capacity. This conclusion is based upon utilization of a new logistics system.

SELECT INDEPENDENT MISSION MODE

- INDEPENDENT MISSION MODES COMPARE FAVORABLY WITH ASSISTED MODES FOR COMPARABLE PAYLOAD REQUIREMENTS
- OPERATIONAL COMPLEXITIES AND VAN ALLEN RADIATION ASSOCIATED WITH TUG-ASSISTED MODES DON'T JUSTIFY MODEST IMPROVEMENT IN TRANSPORTATION COST
- IN CASES OF UNUSUAL PAYLOAD DELIVERY REQUIREMENTS, JETTISONING OF PROPELLANT MODULES SHOWN FAVORABLE WHEN USED WITH NEW LOGISTICS CONCEPTS

DESIGN ANALYSES

The objectives and approach of the design analyses which will be discussed in this portion of the briefing are shown in the adjoining chart. It is desired to evaluate the impact of candidate single and multiple module launch configurations on the RNS and space shuttle for the purpose of identifying the most promising configurations for evaluation in subsequent study phases. In addition, it is intended to synthesize optimum designs for the various multiple module RNS configurations utilizing preliminary design analyses performed to a sufficient depth to differentiate these configurations on a meaningful common basis. These analyses will be performed taking into account range of space shuttle configurations currently under consideration.

DESIGN ANALYSIS

(OBJECTIVES AND APPROACH)

26555

- EVALUATE IMPACT OF CANDIDATE SINGLE AND MULTIPLE MODULE LAUNCH CONFIGURATIONS ON RNS AND SPACE SHUTTLE
 - ALTERNATE SECOND STAGE
 - EXTERNAL MOUNTING ON ORBITER
- SYNTHESIZE OPTIMUM DESIGNS TO DIFFERENTIATE MULTIPLE MODULE RNS CONFIGURATIONS ON A COMMON BASIS
- ACCOUNT FOR RANGE OF SPACE SHUTTLE CONFIGURATIONS

CANDIDATE MODULAR RNS CONFIGURATIONS

The candidate modular RNS configurations which were proposed for the Phase IV RNS study are shown in the adjoining chart. These configurations consist of a propulsion module, a command and control module, and an array of propellant modules. During Phase III the advantages of such a modular RNS design concept were established. However, the Phase III investigation was limited to the Class 1 - Hybrid configuration, in which a 300 K-lb LH_2 module was launched to orbit by the Saturn INT-21 launch vehicle, and the Class 3 configuration, which consisted of 8 propellant modules launched inside the cargo bay of the space shuttle orbiter. The geometry constraints of the latter configuration required the use of a clustered propellant module configuration and imposed a structural weight penalty. The range of geometries which are attractive for the Phase IV study permits the use of a tandem configuration of propellant modules in all cases. This reduces the complexity of orbital assembly operations and permits uniform intermodule assembly interfaces. Partitioning the RNS into multiple modules both permits more favorable configurations for launch and reduces the penalty from cold gaseous residuals in multiple burn operations. The Phase IV candidate configurations are potentially more attractive for the alternate space shuttle launch concepts. Configurations consisting of 1 to 4 propellant modules have been proposed for launch by the space shuttle booster with an alternate second stage. Configurations with 4 and 8 propellant modules have been proposed for external launch on the space shuttle orbiter.

CANDIDATE MODULAR RNS CONFIGURATIONS

LAUNCH ASSESSMENT APPROACH

This portion of the briefing will be concerned with selection of reference launch configurations in terms of the number of propellant modules and their diameter. The launch configuration concept with alternate second stages on the space shuttle booster consists of locating the RNS modules as a free body on the second stage ahead of the forward attach point of the shuttle booster. Launch vehicle controllability and reaction loads on the booster have been investigated for a range of RNS configurations. The approach is parametric as a function of RNS module diameter. Representative dynamic response simulations have been utilized to bracket the range of attractive configurations and the data has been interpolated from these. In the case of a piggyback mounting of the second stage and RNS payload on the space shuttle booster, interference effects from shock impingement have been accounted for in evaluating the impact of reaction loads on the booster.

External launch configurations will also be discussed. The approach entails identification of alternative external mounting locations which are compatible with attachment to the primary frames of the orbiter fuselage, or in the case of external hydrogen tip tanks, primary frames on the tip tanks would be utilized. The controllability and reaction loads on the orbiter have been investigated for these configurations and a preliminary identification of orbital operations concepts has been made.

LAUNCH ASSESSMENT APPROACH

- **OBJECTIVE: SELECT REFERENCE LAUNCH CONFIGURATIONS**
- **ALTERNATE SECOND STAGES --**
 - **CONFIGURE RNS MODULES AS FREE BODY**
 - **INVESTIGATE CONTROLLABILITY AND REACTION LOADS**
 - **PARAMETRIC ANALYSIS VS. DIAMETER -- UTILIZE REPRESENTATIVE DYNAMIC RESPONSE SIMULATIONS AND INTERPOLATE DATA**
 - **ACCOUNT FOR INTERFERENCE EFFECTS**
- **EXTERNAL LAUNCH**
 - **IDENTIFY ALTERNATIVE EXTERNAL MOUNTING LOCATIONS -- ATTACH TO PRIMARY FRAMES**
 - **INVESTIGATE CONTROLLABILITY AND REACTION LOADS**
 - **IDENTIFY ORBITAL OPERATIONS CONCEPTS**

CANDIDATE ALTERNATE SECOND STAGE LAUNCH CONFIGURATIONS

As shown in the sketch, the launch configurations on the space shuttle booster/alternate second stage vehicle range from a single RNS module to the full RNS mission configuration. It is desirable to establish the controllability of these configurations, some of which are more severe than have been previously investigated, and to assess the loads impact of the launch vehicle. Trajectory simulations have been performed for this purpose and loading analyses have been performed based on the reference trajectories.

CANDIDATE ALTERNATE SECOND STAGE LAUNCH CONFIGURATIONS

- OBJECTIVE: SELECT REFERENCE LAUNCH CONFIGURATION FOR EACH MULTIPLE MODULE RNS --
 - NUMBER OF MODULES PER LAUNCH
 - DIAMETER SENSITIVITY
- ESTABLISH CONTROLLABILITY
- ASSESS LOADS IMPACT

REFERENCE TRAJECTORY ANALYSES

Trajectory simulations have been performed for alternate second stage launch of RNS propellant modules by a range of space shuttle boosters to establish booster controllability and determine the dynamic pressure and angle of attack for critical loading conditions. The launch configurations shown in the chart were investigated to bracket the range of geometries of interest. Dynamic response simulations were performed for both -20B and parallel burn boosters to establish the response to head winds, tail winds, and side winds. In addition, still air simulations were performed for the LO_2/RP booster. Dynamic response simulations were computed utilizing drift minimum gains, which result in zero drift in the case of a steady state wind. This constraint is in general incompatible with achieving minimal loads. However, it provides a common basis for comparing the various boosters and second stage/payload combinations. Control gains were set to provide for stability margins in the presence of flexible body dynamics effects. Synthetic wind profiles employing the 95% wind speed envelope and the 99% wind shear envelope multiplied by 0.85 (and a superimposed 25 ft. per second gust) were utilized. This is consistent with wind profiles being used in the mainline space shuttle study. The impact of gusts at various altitudes was investigated. The simulations were performed based on a common LH_2 tank launch configuration. Additional trajectory data from the previous expendable second stage studies were also utilized. It was found that the still air angle of attack fell in a narrow range for each of the boosters and second stage/payload configurations evaluated. The shifts in angle-of-attack due to head wind, tail wind, or side wind was also found to fall in the narrow ranges. The consistency of the dynamic response simulation behavior provided a basis for interpolation and a more complete parametric analysis for the range of configurations.

REFERENCE TRAJECTORY ANALYSES

(TRAJECTORY SIMULATIONS PERFORMED)

26559

RNS MODULES \ BOOSTER			
	-20B	PARALLEL BURN	LO ₂ /RP
2 @ 150 K - 33 FEET	DYNAMIC	DYNAMIC	STILL AIR
2 @ 150 K - 22 FEET	DYNAMIC	DYNAMIC	STILL AIR
2 @ 100K - 33 FEET	--	--	STILL AIR
2 @ 100K - 22 FEET	DYNAMIC	DYNAMIC	STILL AIR

● BASIS --

- DRIFT MINIMUM GAINS
- STABLE FOR FLEXIBLE BODY DYNAMICS
- SYNTHETIC WIND PROFILE
- GUSTS AT VARIOUS ALTITUDES -- 30 TO 45 K-FT
- COMMON LH₂ TANK CONFIGURATION

● PARAMETRIC ANALYSIS BY INFERENCE FROM SIMULATIONS

BOOSTER ATTACHMENT LOCATIONS

Loading analyses have been performed for two reference booster configurations with a piggy-back mounting of the orbiter or second stage. The attachment locations are shown in the associated figure which indicates the stations and the types of loads which can be reacted. For the -20B booster it was found desirable in the previous alternate second stage studies to utilize a stirrup mounting concept to carry the axial forces from the aft end of the S-IVB to the forward attach point of the booster. This has the advantage of the loading the second stage in compression. In the parallel burn booster configuration the axial loads are reacted at the aft stations. Retaining a forward mounted payload configuration requires the construction of a truss extending forward from the aft reaction points so that the second stage and truss act as a single beam.

BOOSTER ATTACHMENT LOCATIONS

PARALLEL BURN SHUTTLE BOOSTER

-20B SHUTTLE BOOSTER

BOOSTER INTERFACE LOADS

PARALLEL BURN BOOSTER: S-IVB/J-2/8 SRM

The booster interface loads are indicated here for two candidate RNS launch configurations, a single 300 K-lb LH_2 module with a 33 ft diameter and a single 150 K-lb LH_2 module with a 28 ft diameter. Ultimate loads based on free body aerodynamics and the reference trajectory parameters defined from the simulations performed are indicated in the table. On this basis the 300 K-lb LH_2 module slightly exceeds the orbiter flight envelope for the forward radial reaction, but the 150 K-lb LH_2 module is within the bounds of the orbiter flight envelope. An additional factor which is not accounted for in these results is the interference from impingement of the shock wave from the booster nose impacting the side of the RNS module. This term would have the effect of increasing the magnitude of the radial reactions at both the forward and aft attach points. Preliminary calculations of this effect based on wind tunnel data obtained in the MDAC alternate second stage study indicate that the increase in radial reactions would be significant and would cause the 300 K-lb LH_2 module to exceed the orbiter flight envelope by a wide margin. However, the interference effect is still receiving further evaluation to assure the validity of conclusions which are reached concerning the magnitude of its effect.

BOOSTER INTERFACE LOADS

PARALLEL BURN BOOSTER: S-1VB/J-2/8 SRM

CONFIGURATION	CONDITION	ULTIMATE LOAD (K-LB)*		
		R ₁	R ₂	R ₃
300 K-LB LH ₂ MODULE – 33 FT DIA	HEADWIND**	3,850	594	-792
	TAILWIND**	3,340	122	-244
	MAX ACCEL	2,960	-195	-664
150 K-LB LH ₂ MODULE – 28 FT DIA	HEADWIND**	3,500	400	-637
	TAILWIND**	3,090	230	-321
	MAX ACCEL	2,970	-171	-692
ORBITER	FLIGHT ENVELOPE	5,790	+440 -280	+590 -1,950

* INCLUDES DMF; NO INTERFERENCE; ** AT MAX (α_q)

INTERFACE LOAD SENSITIVITY

LO₂/RP BOOSTER -- TANDEM MOUNTING

The adjoining figure shows the sensitivity of combined ultimate load intensity at the RNS aft interface for a range of RNS module propellant capacities and diameters. This is for the 33 ft. diameter aft interstage/LO₂ tank interface of a common LH₂ tank RNS/second stage configuration. Both the axial component and the total loads including bending are shown. Dynamic magnification was not included for this tandem configuration. Since drift minimum trajectories were utilized, there is some margin between these for load reduction during launch, although compatible relief of ground wind criteria would also be necessary to achieve overall system weight reductions. It is evident that the 300 K-lb LH₂ module imposes much more severe integration problems than the smaller capacity module. A configuration in the vicinity of the 150 K-lb LH₂ module would be analogous to the orbiter belly tank. However, the impact would tend to be less severe for the RNS since the winged orbiter would not be mounted on it. Similar analyses have been performed for launch by an S-IVB second stage which is limited to a 22 ft diameter interface. Load relief would be required for most candidate RNS configurations in this case and some increased structural strength would be required for the S-IVB.

INTERFACE LOAD SENSITIVITY LO₂/RP BOOSTER--TANDEM MOUNTING

- MULTIPLE LAUNCHES OF SMALL MODULES MOST FAVORABLE
- RNS TANK ANALOGOUS TO ORBITER BELLY TANK
- INCREASED STRUCTURAL STRENGTH WOULD BE REQUIRED FOR S-IVB

ALTERNATE SECOND STAGE LAUNCH CONFIGURATION ASSESSMENT

Based on the preceding considerations the recommended launch envelopes are indicated in the chart. The 300 K-lb LH_2 module can only be launched one module per launch and amounts to launching the full RNS in a single launch. This represents the most difficult RNS configuration to integrate with the launch vehicle and depending on the space shuttle configuration selected could conceivably be precluded on this basis. It appears quite adequate to launch the 150 K-lb module at a rate of one module per launch and this should not pose a major integration problem, particularly since a significant reduction of diameter can be achieved compared to the 300 K-lb LH_2 module without imposing a performance penalty on the RNS mission. The 100 K-lb LH_2 modules can be launched at a rate of one or two modules per launch and it does not appear necessary to launch them in their full flight configuration. Similarly, the 75 K-lb LH_2 modules can be launched at a rate of two modules per launch and would approximate the impact of the 150 K-lb LH_2 module. In attempting to assess the range of space shuttle concepts it has not been possible to go into depth on a single concept. However, it is anticipated that there will be a requirement to investigate load relief for the launch of the RNS/second stage configuration for the selected space shuttle booster concept. The approaches of adaptive flight control systems or of changing the launch trajectory by booster throttling and/or propellant offloading would warrant investigation.

ALTERNATE SECOND STAGE LAUNCH CONFIGURATION ASSESSMENT

26591

- RECOMMENDED LAUNCH ENVELOPES

<u>CAPACITY (K-LB)</u>	<u>MODULES/LAUNCH</u>
300	1
150	1
100	1 OR 2
75	2

- ANTICIPATE REQUIREMENT TO INVESTIGATE LOAD RELIEF FOR SELECTED SPACE SHUTTLE CONCEPT
 - ADAPTIVE FLIGHT CONTROL
 - BOOSTER THROTTLING AND/OR PROPELLANT OFF-LOADING

CANDIDATE EXTERNAL LAUNCH CONFIGURATIONS

External launch on the space shuttle orbiter is proposed for 37.5 or 75 K-lb LH_2 modules. Three classes of orbiter configurations are shown on the adjoining figure: fully reusable, tip tank, and belly tank. Alternative RNS module mounting locations are indicated. These can have the module located on the top over the cargo bay door or on the side of the orbiter over the wings and adjacent to the fuselage. In the case of the tip tank orbiter the modules can be located parallel to the tip tanks or above the tip tanks. Configurations with the propellant modules located aft of the tip tanks were also investigated. However, these are subject to constrained geometry to avoid protruding aft into the plume of the orbiter engines. One configuration which may be desirable with a belly tank orbiter is shown with the RNS modules mounted external to the belly tank and parallel to it.

CANDIDATE EXTERNAL LAUNCH CONFIGURATIONS

26578

FULLY REUSABLE ORBITER	TIP TANK ORBITER	BELLY TANK ORBITER
<p>TOP</p>	<p>TOP</p>	<p>SAME AS FULLY REUSABLE ORBITER</p>
<p>WINGS</p>	<p>ABOVE OR PARALLEL TO TIP TANKS</p>

<p>AFT OF TIP TANKS</p>	<p>PARALLEL TO BELLY TANK</p>

ORBITER EXTERNAL ATTACHMENT LOCATIONS

The basic principle involved in definition of external mounting concepts is to utilize the frames of the orbiter fuselage. The frames located at the forward and aft bulkhead for the payload cargo bay have been used in previous space shuttle design studies to define tip tank configurations or for mounting of the orbiter on a belly tank. External mounting concepts for RNS modules would be derivative from the structural attach concepts for tip tank orbiter configurations.

ORBITER EXTERNAL ATTACHMENT LOCATIONS

26580

EXTERNAL LAUNCH CONTROLLABILITY ASSESSMENT

Consideration was given to the controllability of the shuttle booster with externally mounted modules on the orbiter and to controllability of the orbiter during separation and during orbiter flight. The latter was the dominant consideration and most amenable to analysis, since mass data were available so that thrust vector deflections could be analyzed and control margins could be determined. Determination of booster controllability would require wind tunnel data which are not available at this time. However, the candidate RNS configurations do not appear to be more severe than other space shuttle configurations which have been identified such as tip tank orbiters. The assessment shown in the adjoining table is principally related to the orbiter controllability. Top mounting is severe for each of the configurations and would be excluded on the basis of orbiter controllability, although it is evident that this would also present the most severe aerodynamic impact for launch of booster. In the case of the orbiters with a clean fuselage, the mounting over the wings and parallel to the fuselage appears most favorable. In the case of the tip tank orbiter a similar mounting parallel to the tip tanks is presently considered most favorable.

EXTERNAL LAUNCH CONTROLLABILITY ASSESSMENT

MODULE LOCATION (NO.)	ORBITER		
	REUSABLE	TIP-TANK	BELLY-TANK
● TOP (1)	NO	NO	NO
● TOP (1) + INTERNAL (1)	NO	MARGINAL	NO
● WINGS (2)	YES	--	YES
● PARALLEL TIP TANKS (2)	--	YES	--
● ABOVE TIP TANKS (2)	--	NO	--
● AFT OF TIP TANKS (2)	--	ACCEPTABLE	--
● PARALLEL BELLY TANK (2)	--	--	MARGINAL

BASELINE EXTERNAL LAUNCH MOUNTING CONCEPT

Considering the implications of launch controllability and the compatibility of external attachment locations, the external launch mounting concept shown in the adjoining figure is recommended as a baseline for both the 37.5 and 75 K-lb LH_2 modules. It is proposed to launch the modules two at a time mounted parallel to the fuselage of the orbiter. The forward attach point would be located at the frame associated with the forward bulkhead of the cargo bay. Radial and lateral loads would be picked up at that point and distributed by a frame in the jettisoned forward skirt of the propellant module. The aft attach point would be located at the frame which forms the aft bulkhead of the cargo bay. Radial and lateral loads would be picked up by a central attach point at this location. Rotational stability would be provided by an additional pair of struts attached to the frame of the jettisonable aft skirt of the propellant module. Axial loads would be picked up by a shelf arrangement attached to the aft skirt frame. In this configuration the tank would be loaded in compression during launch and bending from inertial loads would not be imposed on the tank. The module diameter would be constrained to be compatible with distributing the radial loads in jettisoned skirts without increasing the weight of flight structure.

It is currently envisioned that module deployment and assembly in orbit should employ a 180° rotation of the modules to a forward orientation. Design of the forward attachments would need to provide for this operation.

BASELINE EXTERNAL LAUNCH MOUNTING CONCEPT

26581

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STA. 1077

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ORBITER INTERFACE LOADS -- EXTERNAL MOUNTING

The orbiter interface loads for a 75-K-lb LH_2 tank 20 ft in diameter mounted parallel to the fuselage of the orbiter as shown in the preceding figure are indicated here. Module weight is 32,500 lbs including the propellant loading. Two modules would be launched simultaneously in this configuration, one on each side of the orbiter. The ultimate loads indicated are imposed on the frames of the orbiter fuselage. Interference loads are not accounted for and would require wind tunnel data.

75 K-LB LH₂ TANK, 20 FT DIA
WEIGHT = 32,500 LB INCLUDING LH₂

DESIGN CONDITION MAX (α q)	ULTIMATE LOAD (K-LB)*						
	R_{F1}	R_{F2}	R_{A1}	R_{A2}	$R_{A3} = R_{A4}$	$R_{A5} = R_{A6}$	$R_{A7} = R_{A8}$
HEADWIND	0	- 80	-296	304	4	300	392
TAILWIND	0	-111	-233	237	7	230	300
SIDEWIND	-70	0	-257	-257	0	264	344

* INCLUDES DMF; NO INTERFERENCE

RNS DESIGN OPTIMIZATION FACTORS

It is desired to optimize the design of each of the multiple module RNS configurations to a sufficient level to distinguish their essential features and select the most promising configuration. Phase III established the advantages of a modular RNS design concept incorporating a command and control module and a propulsion module (consisting of NERVA and a mini-tank). These have been retained as baseline features for Task 1 so candidate RNS configurations are distinguished primarily by the number of propellant modules, their size, and arrangement. Accordingly, a common CCM and propulsion module will be used for each of the multiple module configurations. In addition, the propellant modules will be arranged in a tandem array, since the range of module diameters under consideration would not be expected to incur controllability or structural stability problems and a tandem array simplifies the design and operational requirements. The approaches utilize the Phase III results for subsystems configured to achieve a no-single-failure criterion. An important factor in comparison of the configurations is to customize the propellant utilization and residuals for each configuration operating on the reference lunar shuttle mission profile providing for venting of depleted tanks after completion of each maneuver. The design approaches entail a combined optimization of the factors sensitive to propellant module diameter, including structure (the mission configuration after jettison of launch structure), meteoroid/thermal protection, and the NERVA external shield. The requirements of the alternative jettison and non-jettison mission modes have been included in this optimization procedure.

RNS DESIGN OPTIMIZATION FACTORS

- UTILIZE COMMON CCM AND PROPULSION MODULE
- UTILIZE TANDEM ARRAY OF PROPELLANT MODULES
- UTILIZE PHASE III DERIVED SUBSYSTEMS
- CUSTOMIZE PROPELLANT UTILIZATION AND RESIDUALS --
 - LUNAR SHUTTLE MISSION PROFILE
 - VENTING AFTER MANEUVER
- PERFORM COMBINED OPTIMIZATION OF MODULE DIAMETER INCLUDING --
 - STRUCTURE -- MISSION CONFIGURATION
 - METEOROID / THERMAL PROTECTION
 - NERVA EXTERNAL SHIELD
- DISTINGUISH JETTISON AND NON-JETTISON MISSION MODES

RNS PROPELLANT MODULE SUBSYSTEMS

A schematic of a Phase III derivative propellant module is shown identifying the propellant management functions. These include isolation of the tanks with discrete feed-thru ducting for orbital fill operations and propellant feed to the propulsion module. The pressurization system accommodates variable pressurant flow rates for RNS mission operations or to accommodate expulsion pressurization during launch operations as a common LH₂ tank second stage. Separate ground and flight vent systems are provided. The astrionics functions on each propellant module are based on use of data bus terminals to link each module into the system, and the necessary associated multiplexing, encoding and decoding equipment is provided on each module. Inverters are provided for valve actuation. Each propellant module is configured for remote assembly/disassembly in orbit with mechanisms which were defined during Phase III. The subsystem configuration is for a no-single-failure criterion as specified in the current guidelines. The desirability and economic advantages of more stringent failure criteria are currently under investigation. However, the no-single-failure criterion provides a reasonable and consistent basis for comparing multiple module configurations.

RNS PROPELLANT MODULE SUBSYSTEMS

- PROPELLANT MANAGEMENT FUNCTIONS --
 - TANK ISOLATION -- DISCRETE FEED THROUGH DUCTING
 - VARIABLE PRESSURANT FLOW RATES
 - SEPARATE GROUND AND FLIGHT VENT SYSTEMS
- ASTRIONICS FUNCTIONS --
 - DATA BUS TERMINALS
 - INVERTERS FOR VALVE ACTUATION
- REMOTE ASSEMBLY/DISASSEMBLY
- CONFIGURED FOR NO-SINGLE-FAILURE

METEOROID/THERMAL PROTECTION

The meteoroid/thermal protection system requirements were assessed for the indicated survival criteria and utilizing Phase III results. It was desired to customize the thermal and meteoroid protection systems to differentiate the active lifetimes of RNS propellant modules during the lunar shuttle mission, and thereby to improve or optimize system weight. However, it was found that there is a minimum practical design value for the combined thermal and meteoroid protection systems as indicated in the adjoining chart. This minimum system exceeds the MSFC survival criterion guideline so that module armor weights can be differentiated only by the differences in surface areas.

METEOROID/THERMAL PROTECTION

- SURVIVAL PROBABILITY: 0.995 FOR LUNAR SHUTTLE MISSION --
 - MSFC GUIDELINE -- 45 DAYS
 - ALTERNATIVE -- MODULE ACTIVE LIFETIME
- MINIMUM PRACTICAL INSTALLED SYSTEM EXCEEDS MSFC GUIDELINE

COMPONENT	MATERIAL	DENSITY (LB/FT ²)
HPI	DAM/DACRON NET	0.14 TO 0.19
SPACER	POLYURETHANE FOAM -- 2 IN.	0.20
EXTERNAL SHROUD	FIBERGLASS	0.20
MINIMUM EFFECTIVE METEOROID PROTECTION		0.54 TO 0.59

NERVA EXTERNAL SHIELD

The NERVA external shield requirements have been estimated for the candidate multiple module RNS configurations based on a parametric formulation of the Phase III shielding results. These are obtained for a criterion of 10 rem to the payload per mission unattenuated, with a 3,500 lb liquid residual remaining in the run tank upon completion of full thrust on the last burn. The data shown are constrained to a 10° half-angle cone which is consistent with a 160 in. diameter run tank on the propulsion module and a 140 inch cap radius on the propellant tank aft bulkhead. The lower dashed curve represents the reduced shielding requirement which can be achieved for a sharper cone angle with smaller tank diameters. The shield requirement is dependent on the overall length of propellant modules in the RNS configuration. The requirements of jettison and non-jettison configurations are distinguished in the parametric analyses.

NERVA EXTERNAL SHIELD

- PARAMETRIC ANALYSIS OF RNS CONFIGURATIONS NORMALIZED TO --
 - 10 REM TO PAYLOAD PER MISSION, UNATTENUATED
 - 3,500 LB LIQUID RESIDUAL IN RUN TANK AFTER LAST BURN
- CONSTRAIN RNS ENVELOPE TO 10 DEGREES HALF-ANGLE CONE
- PERMIT SHARPER CONE ANGLE FOR SMALL DIAMETERS
- DISTINGUISH JETTISON AND NON-JETTISON CONFIGURATIONS

STRUCTURAL DESIGN OPTIMIZATION ELEMENTS

The RNS structural design features have been analyzed to determine their sensitivity to **module** diameter. The three elements involved in the flight configuration are the tankage, heat blocks, and intermodule structure. The characteristics of these systems and constraints or criteria applied for the analyses are shown in the adjoining figure.

STRUCTURAL DESIGN OPTIMIZATION ELEMENTS

26565

- ANALYZE SENSITIVITY TO MODULE DIAMETER
- TANKAGE -- 2014-T6 ALUMINUM --
 - HEMISPHERICAL BULKHEADS
 - CONSTRAIN AFT MODULE TO 10 DEGREES HALF-ANGLE CONE WITH 140-IN. CAP RADIUS
 - DESIGN PRESSURE = 31 PSIA
 - INTEGRAL STIFFENING OF CYLINDER -- ISOTROPIC GRID
 - DESIGN FOR REFERENCE DRIFT-MINIMUM TRAJECTORIES
- HEAT BLOCKS -- FIBERGLASS HONEYCOMB, 3 FT LENGTH --
 - JETTISON SKIRTS AND LAUNCH INTERSTAGE
- INTERMODULE STRUCTURE -- FIBERGLASS STRUTS --
 - DESIGNED FOR GIMBAL HARD-OVER DURING MISSION
 - NOMINAL 48-STRUT CYLINDRICAL TRUSS
 - CONICAL CONFIGURATION TO CCM AND PROPULSION MODULE
 - PROVISIONS FOR DOCKING STRUCTURE

RNS DESIGN OPTIMIZATION - 150 K-LB LH_2 MODULES

This figure shows the approach which has been used to optimize the RNS system weight for the three principle components which are sensitive to the RNS diameter. These are the structure, the meteoroid thermal protection, and the NERVA external shield. It is evident that it is important to select an optimum diameter for each system in order to fairly compare the concepts to each other. The data shown here is for the LO_2 /RP booster and a common LH_2 tank second stage concept with one module per launch and a drift-minimum trajectory. The difference between structural weights using monocoque tankage and designing for the launch conditions is shown in the figure. The difference between the solid line for the structure and the dashed line for the monocoque case is the potential margin for weight reduction using the load relief launch trajectories. However, only a fraction of the difference could be realized in practice. The system weight shows a rather broad minimum at the larger diameters, and in view of the data shown earlier concerning the sensitivity of interface loads to diameter, it is desirable to choose a module diameter which is near minimum weight but at the smallest possible diameter. The 28 ft diameter selected for the 150 K-lb modules shows the degree of compromise which must be provided. Here the actual weight difference amounted to 250 lbs between a 28 ft and 33 ft configuration, which would appear to be acceptable considering the larger loading impact of the larger diameter. Similar optimizations for the jettison mode of operation indicate no significant difference in the diameter bias for this mode.

**RNS DESIGN
OPTIMIZATION -
150K - LB LH₂
MODULES**

RNS DESIGN OPTIMIZATION -- 75 K-LB LH_2 MODULES

This figure shows the optimization of the RNS system weight for the case of externally launched propellant modules. The jettison and non-jettison modes of operation are distinguished. A 20 ft. diameter is selected as near-optimum and consistent with the recommended external mounting concepts which utilize the bulkhead frames at the forward and aft end of the cargo bay.

26000

**RNS DESIGN
OPTIMIZATION-
75 K-LB LH₂ MODULES
EXTERNAL LAUNCH**

RNS WEIGHT SUMMARY

BOOSTER: LO_2/RP -- COMMON LH_2 TANK

MISSION MODE: NON-JETTISON

A summary weight statement for the various candidate external launch configurations is shown in the adjoining table. The structures, meteoroid/thermal protection, functional subsystems, and residuals conform to the criteria and bases described in the preceding charts. The module diameters represent the optimum selected according to the procedure described above for combined optimization of the structural, meteoroid/thermal, and external shield weights. The intermodule docking structure is included on the propellant modules. The miscellaneous inert weight category includes the external tunnel and fairings, exterior finish and sealer, baffles, equipment support structure, and access provisions based on Phase III RNS design approaches. The CCM and propulsion module weights are based on the latest design weights for the NERVA 400E engine. This includes a flight weight of 26,014 lbs on the propulsion module and an additional 600 lbs provided for NDICE components located on the CCM. The residuals and usable propellant fraction indicated are for the baseline lunar shuttle mission. The configurations shown provide the following payload capability to lunar orbit based on return of a 20,000 lb payload: (1) one at 300 K -- 116.6 K-lb, (2) two at 150 K-lb LH_2 -- 134.8 K-lb, (3) three at 100 K-lb LH_2 -- 122.6 K-lb, and (4) four at 75 K-lb LH_2 -- 118.9 K-lb.

RNS WEIGHT SUMMARY

BOOSTER: LO₂/RP - COMMON LH₂ TANK
MISSION MODE: NON-JETTISON

PROPELLANT MODULES	1 AT 300K	2 AT 150K	3 AT 100K	4 AT 75K
MODULE DIAMETER (FT)	33	28	28	26
WEIGHT (LB)				
PROPELLANT MODULES:				
STRUCTURE	22,598	23,881	24,733	26,093
METEOROID THERMAL	6,440	7,040	7,530	8,180
DOCKING	280	560	840	1,120
PROPELLANT MANAGEMENT	636	1,272	1,908	2,544
ASTRIONICS	480	960	1,314	1,660
MISCELLANEOUS INERT	1,145	1,700	2,175	3,720
CONTINGENCY	1,580	1,770	1,930	2,160
RESIDUALS	9,630	4,400	3,170	1,960
TOTAL INERT	42,789	41,583	43,600	47,437
CCM	6,555	6,555	6,555	6,555
PROPULSION MODULE				
DRY	29,509	29,509	29,509	29,509
RESIDUALS	1,810	1,810	1,810	1,810
EXTERNAL SHIELD	5,550	4,180	3,900	3,280
TOTAL INERT WEIGHT	86,213	83,637	85,374	88,591
VENTED H ₂	0	1,000	3,540	2,560
USABLE LH ₂	299,410	303,640	302,330	304,520
USABLE LH ₂ FRACTION	0.776	0.781	0.774	0.770

RNS WEIGHT SUMMARY

EXTERNAL LAUNCH

A similar weight breakdown is provided here for the two candidate external launch configurations showing both a non-jettison and a jettison mission mode. It is evident that the four 75,000 lb LH_2 module configuration is much more efficient than the eight module configuration. The eight module configuration shown here incurs significant weight penalties compared to the internally carried Class 3 configuration studied in Phase III. This is because the externally launched configuration must include 3 ft long fiber glass honeycomb heat blocks at the forward and aft end of each tank (from which the launch skirts are jettisoned), external tunnels and fairings for routing cables and pressurization lines, and an increased external shroud thickness to accommodate aerodynamic loads. In addition, the astrionics weight has increased by about 1,800 lbs to reflect an upgrading of the reliability criteria. Thus, the eight module external launch configuration has suffered about an 8,000 lb penalty compared to internal launch. The implication is that external launch tends to be desirable if the modules can be made large enough but external launch of small modules would be unfavorable compared to use of the cargo bay. The configurations shown provide the following payload capability to lunar orbit based on return of a 20,000 lb payload: (1) four at 75 K-lb, non-jettison -- 124.5 K-lb, (2) four at 75 K-lb, jettison -- 186.2 K-lb (3) eight at 37.5 K-lb, non-jettison -- 87.0 K-lb, and eight at 37.5 K-lb, jettison -- 150.4 K-lb.

26597

RNS WEIGHT SUMMARY

EXTERNAL LAUNCH

MISSION MODE PROPELLANT MODULES	NON-JETTISON		JETTISON	
	4 AT 75 K	8 AT 37.5 K	4 AT 75 K	8 AT 37.5 K
MODULE DIAMETER (FT)	20	20	20	20
WEIGHT (LB)				
PROPELLANT MODULES:				
STRUCTURE	24,721	29,601	24,721	29,601
METEOROID/THERMAL	9,480	10,480	9,480	10,480
DOCKING	1,120	2,240	1,120	2,240
PROPELLANT MANAGEMENT	2,544	5,088	2,544	5,088
ASTRIONICS	1,660	3,080	1,660	3,080
MISCELLANEOUS INERT	3,720	6,960	3,720	6,960
CONTINGENCY	2,160	2,880	2,160	2,880
RESIDUALS	1,960	2,210	2,140	2,460
TOTAL INERT	47,365	62,539	47,545	62,789
CCM	6,555	6,555	6,555	6,555
PROPULSION MODULE				
DRY	29,509	29,509	29,509	29,509
RESIDUALS	1,810	1,810	1,810	1,810
EXTERNAL SHIELD	900	0	5,800	5,550
TOTAL INERT WEIGHT	86,139	100,413	91,219	106,213
VENTED H ₂	2,560	3,540	3,010	2,340
USABLE LH ₂	304,520	303,290	303,890	304,240
USABLE LH ₂ FRACTION	0.775	0.745	(0.763)	(0.738)

CONCEPT EVALUATION AND SELECTION

The objectives and approach for this portion of the briefing are indicated on the adjoining chart. This portion of the briefing will be concerned with selection of two reference RNS systems for evaluation during the balance of the study: (1) launch by any alternate second stage, and (2) external launch on the orbiter.

CONCEPT EVALUATION AND SELECTION

(OBJECTIVES AND APPROACH)

26566

- DETERMINE MOST FAVORABLE RNS CONCEPT FOR EACH LAUNCH AND LOGISTICS CONCEPT --
 - C-H-D 2ND STAGE/ SHUTTLE LOGISTICS
 - NEW 2ND STAGE/ NEW 2ND STAGE LOGISTICS
 - EXTERNAL LAUNCH/ SHUTTLE LOGISTICS
- IDENTIFY AND COMPARE ALTERNATIVE SYSTEM CONCEPTS
- RECOMMEND RNS SYSTEMS RESPONSIVE TO PROGRAM LEVELS
- REVIEW SENSITIVITY OF SELECTIONS TO SPACE SHUTTLE CONCEPTS
- IDENTIFY ISSUES FOR FURTHER EVALUATION
- ASSESS IMPACT OF RECOMMENDED RNS SYSTEMS ON SPACE SHUTTLE AND NERVA

RNS OPTIMIZATION -- ALTERNATE SECOND STAGE LAUNCH/SPACE SHUTTLE LOGISTICS

The first step will be to determine the most favorable RNS concept for each launch and logistics concept. The adjoining figure addresses this question for the case of launch by an alternate second stage but using the space shuttle for propellant logistics. The data shown are for the LO_2/RP booster using the S-IVB/J-2/8 SRM second stage. The transportation cost consists of the combination of initial deployment costs and resupply cost averaged over ten missions for an RNS operating in a program model with six missions per year. The costs of propulsion module launch, CCM replacement, payload delivery to orbit, initial RNS hardware procurement are not included. These are comparable for all systems considered.

It is evident that the superior performance of the RNS configuration with two 150 K-lb LH_2 modules results in the most favorable transportation costs. The number of launches required for initial deployment of the RNS is distinguished in the figure. It is evident that this is not a large factor in the overall transportation cost and in no way changes the economic advantage of the two module RNS configuration as compared to the large single module RNS. Accordingly, the configuration with the two 150 K propellant modules launched one at a time is recommended for use with an alternate second stage launch vehicle and space shuttle orbiter logistics.

It is significant to compare these systems to the Class 1-H RNS from Phase III. This system required launch by the Saturn INT-21 and was limited to orbiter internal LH_2 resupply by a 33 K-lb payload capability orbiter. The resulting transportation cost for the single module RNS would be 508 \$/lb, which is not convenient to show on the scale of the figure. Thus, the new systems yield significant improvements.

RNS OPTIMIZATION - ALTERNATE SECOND STAGE LAUNCH/SPACE SHUTTLE LOGISTICS

266.7

RNS OPTIMIZATION -- NEW SECOND STAGE LAUNCH AND LOGISTICS

The RNS transportation cost to lunar orbit is shown as a function of the number of propellant modules for the case of launch by a new common LH₂ tank second stage and using a common LH₂ tank second stage or a customized tanker configuration for propellant resupply. A mission rate of six per year is employed. Two launches are assumed for initial deployment of the multiple module RNS concepts. When the non-jettison mission mode is utilized, the configuration consisting of two 150 K-lb LH₂ modules is seen to be most favorable. A reduction of operating cost can be obtained with the jettison mode of operation where the three module RNS configuration would be most favorable. The three module configuration with a jettison mission mode would have about a 10% margin compared to the two module configuration operating in a non-jettison mode. However, two considerations offset this apparent advantage for the three-module jettison concept. In the mission analyses discussion it was shown that increasing the RNS propellant capacity would result in an equal or more favorable operating cost than that configuration. In addition, the jettison operation introduces operational complexity and a potential reduction of the likelihood of mission success. Considering these factors the two-module non-jettison approach would remain competitive. In addition, the two-module configuration would have about 3,200 lbs less dry weight in the propellant modules and an additional 2,900 lbs less external shield weight or a total of about 6,100 lbs less dry weight. Therefore, for other mission modes such as transplanetary injection to high escape velocities, the two-module RNS would be far superior. Accordingly, the two 150 K-lb LH₂ module RNS configuration is recommended for all of the alternate second stage launch/logistics system alternatives.

RNS OPTIMIZATION - NEW SECOND STAGE LAUNCH AND LOGISTICS

LAUNCH/LOGISTICS SYSTEM COMPARISONS

This figure shows the sensitivity of the logistics contribution to lunar orbit transportation cost to the program level for various systems utilizing the space shuttle booster with an alternate second stage launch. Both the S-IVB and new second stage are shown together with space shuttle logistics systems. The common LH_2 launch system is shown with the same launch vehicle for logistics and with a customized common LH_2 tanker. The latter system has the feature of delivering the RNS propellant in two launches without requiring additional topping by the space shuttle. It is evident that the S-IVB launch system with space shuttle logistics works and is adequate for a very limited program model. However, for traffic rates exceeding three missions per year over ten years it appears that development of a new second stage launch system with a customized LH_2 tanker would be warranted.

LAUNCH/LOGISTICS SYSTEM COMPARISONS

COMMON LH₂/LOGISTICS COMPARISON

This figure shows a breakdown of the total launch and logistics cost for the common LH₂ launch and logistics systems to separate out the recurring operational cost and the increment charged for writing off the development of the system. The separate cost element assessed for development of the tanker (about \$40 million) is also broken out. This indicates that a customized tanker is warranted and would save money compared to launching only RNS modules.

COMMON LH₂ LAUNCH/LOGISTICS COMPARISON

ALTERNATE SECOND STAGE LAUNCH/LOGISTICS COMPARISON

This chart provides further insight into the logistics system comparison for alternate second stage launch concepts. The configuration with an S-IVB launch and space shuttle logistics is shown separating the total and operational costs for the nominal \$100 per lb propellant delivery used throughout the comparisons and also for \$167 per lb which would be characteristic of a Mark I orbiter which could deliver 33,000 lbs of payload to the RNS operational orbit. The latter would also be representative of the approximate operating costs which would be achieved by a volume limited logistic system constrained to the cargo bay of the space shuttle. It is evident that the common LH₂ launch and tanker logistic system is superior, particularly if any degradation of space shuttle orbiter logistics capability were to result from the potentially optimistic values which are quoted here. Furthermore, it is apparent that if the full cost of developing the alternate second stage is not charged to the RNS program, the alternate second stage logistics system is far superior. This is true even if the cost of tanker development must be charged to the RNS program. These results are not really suprising considering that the many operational features of the orbiter, including return of modules from orbit to the ground, are not necessary for propellant resupply, and the resulting high mass fraction of the orbiter is a severe penalty on its operation as a propellant delivery system. Thus, it is most desirable to optimize the launch system used for propellant delivery to orbit.

ALTERNATE SECOND STAGE LAUNCH/LOGISTICS COMPARISON

ORBITER EXTERNAL LAUNCH/LOGISTICS

This figure shows the logistics portion of the lunar orbit transportation costs for the two external launch configurations. The jettison and non-jettison modes are compared. The four 75 K-lb LH_2 module RNS configuration is clearly superior. The jettison mode indicates the potential of a performance advantage. However, this is illusory because equal payload capability and cost effectiveness could be achieved by sizing the RNS larger in the first place (about 364 K-lb LH_2 capacity). Therefore, the four 75 K-lb LH_2 module configuration is recommended for use in the external launch mode and a non-jettison mission mode is recommended. These systems are to be contrasted with the Class 3 RNS from the Phase III study, which had a comparable transportation cost of about 460 \$/lb.

ORBITER EXTERNAL LAUNCH/LOGISTICS

ALTERNATE RNS DESIGN CONCEPTS

This figure identifies two classes of RNS concepts which have been identified and deserve mention in relation to the baseline concepts for the study. The first type of concept would utilize orbiter external hydrogen tankage for the RNS propellant modules. Two options are available, depending on the type of orbiter. The belly tanks currently under consideration have LH_2 capacities in the range of 100 to 200 K-lb LH_2 . The external tip tank concepts which were previously investigated had LH_2 capacities in the range of 75 to 100 K-lb LH_2 . Thus, the tank sizes are of a range which might be suitable for matching the RNS capacity, although this is hypothetical at the present time. The potential attractiveness of these concepts would be in the realization of a small development cost savings. However, this goal may be elusive, since the tankage is designed specifically for the space shuttle functions and has areas of incompatibility with the RNS design requirements. The tankage is insulated with external foam and covered by external ablators. The diameter may not be compatible with optimizing the RNS mission performance. Some belly tank configurations utilize a common bulkhead in the LH_2 tank, and some of the tip tank concepts have a banana shape, so adaptation for the RNS is not straightforward.

The second type of RNS concept which has been proposed consists of utilizing two sizes of RNS tanks instead of the single module size used in the concepts which have been discussed. This approach would require development of two RNS tanks and two launch systems and an optimum orbiter propellant delivery system would still probably be warranted. The analyses performed to date do not indicate any areas where such a concept would offer any improvement in operational cost compared to the single module system.

ALTERNATE RNS DESIGN CONCEPTS

26589

CONCEPT	ASSESSMENT
<ul style="list-style-type: none">• UTILIZE ORBITER EXTERNAL HYDROGEN TANKAGE FOR RNS<ul style="list-style-type: none">• BELLY TANKS: 100 TO 200K - LB LH₂• TIP TANKS: 75 TO 100K - LB LH₂	<ul style="list-style-type: none">• MATCH RNS CAPACITY?• SMALL DEVELOPMENT SAVINGS• FOAM-INSULATED TANKS• DIAMETER SENSITIVE• COMMON BULKHEAD• BANANA SHAPE
<ul style="list-style-type: none">• USE TWO SIZES OF RNS TANKS<ul style="list-style-type: none">• AFT MODULE: 150K - LB LAUNCHED BY SECOND STAGE• JETTISONED FORWARD MODULES: 75K - LB LAUNCHED EXTERNAL TO ORBITER	<ul style="list-style-type: none">• REQUIRES DEVELOPMENT OF TWO RNS TANKS AND TWO LAUNCH SYSTEMS

RECOMMENDED RNS SYSTEMS

The RNS configuration and mission mode, launch configuration and initial topping approach, and propellant logistics concepts for the two recommended RNS systems are shown in the adjoining chart. These systems appear attractive over the full range of program models which have been considered. The selected systems have indicated the importance of breaking the RNS free from the constraints of either module delivery or propellant resupply with cargo bay volume limitations of the space shuttle orbiter. A non-jettison mission mode is recommended for both systems, with the consideration that the RNS would be sized for its nominal mission requirement. However, jettison could be utilized to increase payload delivery for exceptional missions and the RNS would operate independently for that purpose, not requiring assist by other systems.

RECOMMENDED RNS SYSTEMS

26590

ITEM	ALTERNATE SECOND STAGE	EXTERNAL LAUNCH
<ul style="list-style-type: none"> • RNS CONFIGURATION • MISSION MODE 	<p>TWO 150K - LB</p> <p>NON-JETTISON INDEPENDENT</p>	<p>FOUR 75K - LB</p> <p>NON-JETTISON INDEPENDENT</p>
<ul style="list-style-type: none"> • LAUNCH CONFIGURATION • INITIAL TOPPING 	<p>ONE</p> <p>SPACE SHUTTLE</p>	<p>TWO</p> <p>SPACE SHUTTLE</p>
<ul style="list-style-type: none"> • LH₂ LOGISTICS 	<p>CUSTOMIZED COMMON-LH₂ TANKER</p>	<p>SPACE SHUTTLE (EXTERNAL)</p>

RNS SYSTEM COMPARISON

This figure shows the comparison of the two recommended RNS configurations for a range of program models. The external launch and logistics concept appears attractive for a limited program model but apparently significant cost savings could be realized using the new alternate second stage launch and logistics approach. The factors which will distinguish these two system concepts will receive further in-depth evaluation during the balance of the study.

The logistics costs have been reduced to about 40% of the Phase III concepts. The key factor has been identification of optimum modes of propellant resupply.

56596

RNS SYSTEM COMPARISON

ISSUES FOR FURTHER EVALUATION

Whereas the preceding evaluation has identified attractive RNS system concepts, there are significant issues which require further evaluation during the remaining phases of the study. For the case of alternate second stage launch, it is desirable to investigate the various concepts for load reduction and to establish associated practical constraints for the RNS launch envelope. Since the new second stage concept has been selected and its operation requires engine retrieval, feasibility of multiple engine retrieval should be investigated further. The alternative of using a single engine on the second stage with degraded performance should be investigated for the logistics system. Further consideration should be given to integration of the propellant feed system and pressurization system for the common LH₂ tank operational requirement.

The external launch systems warrant an investigation of the propellant resupply operations to determine the tankage configurations, operations profiles, and interfaces with the RNS, and possibly other supporting elements such as the space tug. Also, the concepts for tank deployment require definition, and it would be desirable to determine practical limits to the size of module which could be carried external to the orbiter.

The potential desirability of suborbit start has been identified in the study, but it is apparent that only a relatively high staging velocity booster would permit its use. Further evaluation of RNS design features is warranted. The external shield and RNS geometry interfaces need further refinement, possibly modified by launch constraints. In addition, it is desirable to optimize the reliability and maintenance criteria on an economic and operational flexibility basis.

ISSUES FOR FURTHER EVALUATION

- ALTERNATE SECOND STAGE LAUNCH --
 - INVESTIGATE LOAD REDUCTION
 - ESTABLISH PRACTICAL CONSTRAINTS FOR LAUNCH ENVELOPE
 - ASSESS FEASIBILITY OF MULTIPLE ENGINE RETRIEVAL
 - REVIEW PROPELLANT SYSTEMS INTEGRATION
- EXTERNAL LAUNCH --
 - ANALYZE PROPELLANT RESUPPLY OPERATIONS
 - DEFINE TANK DEPLOYMENT
 - DETERMINE PRACTICAL LIMITS TO MODULE SIZE
- SUBORBIT START --
 - DETERMINE FEASIBILITY REGIME
 - ANALYZE SAFETY IMPLICATIONS
- RNS DESIGN FEATURES --
 - REFINE EXTERNAL SHIELD/RNS GEOMETRY
 - OPTIMIZE RELIABILITY AND MAINTENANCE CRITERIA

SENSITIVITY OF RNS SYSTEM SELECTIONS TO SPACE SHUTTLE CONCEPTS

We return to the questions which were raised at the beginning of the briefing concerning the sensitivity of the RNS systems which have been evaluated to the continuing changes of the space shuttle concepts. It appears that the current space shuttle performance parameters are compatible with RNS launch and logistics, although a severe degrading of the Mark I shuttle performance could be undesirable. The recommended launch configurations are controllable for the range of space shuttles which have been investigated. Whereas, the system costs will change for the range of shuttle concepts, it is apparent that the principles which produce the relative cost effectiveness of the different launch and logistics concepts apply for the concepts considered. Also, the relative loading impact of the RNS module capacity and diameter appears to be consistent for the alternative booster concepts with either piggyback or tandem mounting. The design optimization of the RNS diameter is on a conservative basis which is consistent for the range of configurations investigated. There remains a margin of improvement by load reduction during launch which could permit further diameter reduction.

Therefore, the general conclusions concerning the desirability of freeing the RNS from the constraints of space shuttle cargo bay and utilizing new multiple module configurations and improved LH_2 delivery systems are expected to remain valid. The implications of the recommended RNS configurations can be utilized with confidence to investigate their impact on the space shuttle configuration and to avoid design compromises which would constrain the ultimate flexibility and effectiveness of that system.

SENSITIVITY OF RNS SYSTEM SELECTIONS TO SPACE SHUTTLE CONCEPTS

26592

- CURRENT SPACE SHUTTLE PERFORMANCE PARAMETERS
COMPATIBLE WITH RNS LAUNCH AND LOGISTICS
- RNS LAUNCH CONFIGURATIONS CONTROLLABLE
- RELATIVE COST EFFECTIVENESS OF LAUNCH AND LOGISTICS
CONCEPTS APPLIES FOR RANGE OF SHUTTLE CONCEPTS
- RELATIVE LOADING IMPACT CONSISTENT FOR ALTERNATIVE
BOOSTER MOUNTING CONCEPTS
- DESIGN OPTIMIZATION CONSISTENT WITH MARGIN FOR
IMPROVEMENT BY LOAD REDUCTION

IMPACT OF RNS CONCEPTS ON SPACE SHUTTLE

ALTERNATE SECOND STAGE

The adjoining chart summarizes the major points which have been identified concerning the impact of the RNS concepts on a space shuttle when using an alternate second stage concept. It has been found that a low staging velocity for the space shuttle booster penalizes the logistics system cost. When used in this operational mode, the space shuttle booster launch trajectory will differ from the shuttle baseline. This is particularly evident when a parallel burn booster configuration is operated in a series burn mode. For some second stage/payload configurations a reduced thrust vector control margin can be imposed on the booster so that it would be desirable to consider a possible change of engine precant for such missions. In addition, increased structural strength may be warranted. The launch operations for the RNS will differ from the conventional shuttle procedures and the launch facilities must be compatible with the additional requirements for handling of the RNS modules, mounting the RNS modules and second stage on the booster, and for providing the necessary umbilical interfaces to the RNS and second stage systems. When used in the alternate second stage launch mode, if that stage utilizes space shuttle engines, the RNS LH_2 tank would require bleed gas from the shuttle engines, so this would be a desirable feature for such engines.

IMPACT OF RNS CONCEPTS ON SPACE SHUTTLE

(ALTERNATE SECOND STAGE)

26569

- LOW STAGING VELOCITY PENALIZES LOGISTICS COSTS
- LAUNCH TRAJECTORY DIFFERS FROM SHUTTLE BASELINE
- REDUCED THRUST VECTOR CONTROL MARGIN -- CONSIDER POSSIBLE CHANGE OF PRE-CANT
- INCREASED STRUCTURAL STRENGTH MAY BE WARRANTED
- LAUNCH FACILITIES MUST BE COMPATIBLE WITH ALTERNATE RNS HANDLING, MOUNTING, AND UMBILICAL INTERFACES
- RNS LH₂ TANK REQUIRES BLEED GAS FROM SHUTTLE ENGINE(S)

IMPACT OF RNS CONCEPTS ON SPACE SHUTTLE
EXTERNAL LAUNCH

TA? wt: 23500
incl. 4000 lbs
DOLLE
4/3007

En 27
27
100 200 300
ADICE

This chart reviews the impact of the RNS concepts on the space shuttle if the external launch mode is utilized. The Mark I orbiter payload capability could be marginal for the RNS application in two aspects. The minimum requirement for the RNS is delivery of the propulsion module to orbit inside the space shuttle cargo bay, the current propulsion module dry weight is 29,509 lbs exclusive of the external shield, which can add up to 5,000 lbs additional weight. A destruct system and mounting provisions must also be provided. Therefore, a limitation to the order of 33,000 lbs delivery to the RNS operational orbit would appear to be marginal without additional orbital support by a space tug. Also as noted in the previous tradeoffs the low payload capability of the orbiter would have a serious impact on the propellant logistics cost. There are a variety of design impacts of external mounting on the orbiter which include interference heating effects, possibly reduced thrust vector control margins, potential requirements for increased structural strength at the attachment locations, the requirement to incorporate jettisonable attachment and deployment mechanisms. In addition, the orbiter would have command and control functions imposed on it for orbital operations which would include module deployment, rendezvous and docking, and perhaps assembly of the RNS. The launch facilities would need to be compatible with the alternate requirements for handling RNS modules, mounting them on the orbiter, and providing the necessary umbilical interfaces for the launch operations. It will be most desirable to optimize the propellant resupply concept for the externally mounted system in terms of the tankage configuration, the means of providing propellant settling thrust for performing the transfer operation, and defining the alternate docking provision for the propellant transfer interface.

IMPACT OF RNS CONCEPTS ON SPACE SHUTTLE

(EXTERNAL LAUNCH)

26570

- MARK I ORBITER PAYLOAD COULD BE MARGINAL -- *~ 25000 LB !*
 - DELIVERY OF PROPULSION MODULE TO ORBIT ~~▲~~
 - DEGRADED LOGISTICS COSTS
- INTERFERENCE HEATING EFFECTS ON ORBITER
- POSSIBLE REDUCED THRUST VECTOR CONTROL MARGIN
- INCREASED STRUCTURAL STRENGTH MAY BE NECESSARY
- INCORPORATE JETTISONABLE ATTACHMENT AND DEPLOYMENT MECHANISMS
- COMMAND AND CONTROL OF ORBITAL OPERATIONS: MODULE DEPLOYMENT RENDEZVOUS AND DOCKING, AND ASSEMBLY
- LAUNCH FACILITIES MUST BE COMPATIBLE WITH ALTERNATE RNS HANDLING, MOUNTING, AND UMBILICAL INTERFACES
- OPTIMIZE PROPELLANT RESUPPLY: TANKAGE CONFIGURATION, SETTLING THRUST, ALTERNATE DOCKING PROVISIONS

IMPACT OF RNS CONCEPTS ON NERVA REQUIREMENTS

The final chart reviews the impact of the new RNS concepts on NERVA requirements on the basis of the preliminary studies which have been done during this phase. First, the propulsion module features remain attractive in the sense that no alternative concepts for the RNS configuration have been identified in this phase which would be potentially more attractive than the modular design approach. Accordingly, it is recommended to retain the launch concept which was proposed by all contractors during Phase III, which provided for launch of NERVA (as part of a propulsion module) inside the cargo bay of the space shuttle orbiter. Based on the results to date suborbit start is not a likely operational requirement for NERVA. The NERVA external shield requirement is minimal, probably no more than 5,000 lbs, and different shield configurations are warranted for the different RNS concepts and for the different jettison and non-jettison operational modes.

Since the advantages of a modular RNS concept are becoming increasingly evident with the Phase IV study, it would appear desirable to consider revising the NERVA maintenance criteria to be consistent with the modular RNS system concept. In previous studies MDAC has emphasized the importance of improving the NERVA specifications in terms of aftercoolant utilization, the tradeoff between engine lifetime, reduction of engine weight on the basis that these improvements will be important for improving the competitive status of NERVA with respect to chemical propulsion systems. The RNS design and operations concepts which have been identified and evaluated during this study offer the prospect of significant improvements in RNS operating costs. However, the advantages of these alternate launch concepts can be shared by chemical systems to some extent, so that these improved RNS concepts do not diminish the importance of improved NERVA specifications. Serious attention should be given to these in future studies.

IMPACT OF RNS CONCEPTS ON NERVA REQUIREMENTS

26571

- PROPULSION MODULE FEATURES REMAIN ATTRACTIVE
- RETAIN PHASE III LAUNCH CONCEPT -- INSIDE CARGO BAY
- SUBORBIT START IS NOT A LIKELY OPERATIONAL REQUIREMENT
- NERVA EXTERNAL SHIELD REQUIREMENT IS MINIMAL
- ADVANTAGES OF MODULAR RNS WARRANT REVISED NERVA MAINTENANCE CRITERIA TO BE CONSISTENT WITH RNS
- IMPROVED RNS OPERATIONS AND LOGISTICS CONCEPTS DO NOT DIMINISH THE IMPORTANCE OF IMPROVED NERVA SPECIFICATIONS