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# NASA SPACE SHUTTLE SUMMARY REPORT



Prepared by:

NASA SPACE SHUTTLE TASK GROUP

JULY 31, 1969

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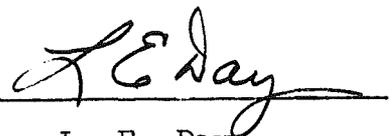
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NASA SPACE SHUTTLE SUMMARY REPORT

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Approved by: \_\_\_\_\_

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L. E. Day  
Manager  
Space Shuttle Task Group

# NASA SPACE SHUTTLE SUMMARY REPORT

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## SUMMARY

To support future space operations there is a critical need to reduce significantly the annual cost of routine round-trip space transportation operations, while greatly increasing the number of space flights.

A versatile space shuttle system that can transport effectively, a varying mix of personnel and cargo to low earth orbits and return, could be the keystone to the success and growth of future space flight developments for the exploration and beneficial uses of near and far space. The use of the space shuttle will provide a broad range of capability in space operations --- capability that would be directly applicable to almost anything the United States may want to do in space.

The space shuttle will accomplish and support the following basic types of missions which are of major interest in NASA's future space program planning.

- o Space Station/Base logistics support
- o Placement and retrieval of satellites
- o Delivery of propulsive stages and payloads for high energy missions
- o Delivery of propellants
- o Satellite servicing and maintenance
- o Short duration orbital missions

The desired system characteristics of the space shuttle are:

- o Lowest Possible Operating Costs

Minimum expendables, high reuse rate for primary systems, onboard checkout, monitoring, fault isolation, and simplified central display systems, minimum or no systems refurbishment, minimum ground support operations.

- o System Development

Aircraft design and systems development approach, incremental flight test approach.

- o Operational Performance

Airline type operations, large and flexible payload capability, autonomous flight system with minimal ground turn-around operations, passenger/cargo mix flexibility.

- o Versatility

Alternate missions, multi-Agency space applications, growth capability, integral cargo area with various interior/modules adaptability.

Fully reusable or near fully reusable systems offer the maximum potential for an economic and versatile space shuttle system that could readily satisfy a vast majority of future space transportation requirements.

This document summarized the information contained in the following NASA Space Shuttle Task Group Reports:

- Vol. I - Missions, June 12, 1969 (Revised)
- Vol. II - Desired Systems Characteristics  
June 12, 1969 (Revised)
- Vol. III - Vehicle Configurations  
June 12, 1969 (Revised)
- Vol. IV - Program Plans, June 12, 1969 (Revised)

## I. BACKGROUND

The first decade in space has seen a tremendous expansion of our capability as a space-faring nation. After demonstrating the technological excellence of the nation in highly successful space exploration, applications, and associated systems developments, the national space program is confronted now by (1) a mix of promising and important mission opportunities for the mid-1970's and beyond, and (2) the high cost of current flight hardware and ground support operations for the recurring orbital transportation operations. The reliability of these flight operations is high, but so is the cost. The time has come to apply innovative techniques to reduce significantly the space transportation costs.

## II. NASA NEEDS

### A. TRANSPORTATION MODES

Based on (1) our total experience to date in space systems development and mission operations and (2) foreseeable space flight programs and their related requirements, the space transportation modes of interest for the next decade or so, fall logically into the following grouping:

1. Earth surface base to low earth orbital base and return (round-trip, manned space shuttle).

2. On-orbit space tug for placement, assembly, and retrieval operations in near earth orbits (manned and unmanned modes).

3. On-orbit space shuttle for transfer to and return from higher energy synchronous or lunar orbits; support of escape missions (manned or unmanned modes).

4. Lunar orbit shuttle for descent to and return from lunar surface (manned).

The first of these is basic to all the others as it provides the transportation link from the orbital facility to the earth surface facility and its resources. Routine delivery operations to replenish expended on-orbit supplies/propellants and equipment; non-routine delivery of experimental equipment/supplies; return from orbit of equipment, data records and flight personnel rotation are examples of some of the extensive, varying logistics missions to be performed. Recurring flight costs for these transportation missions can represent a very large share of over-all program costs if

based on today's method of operations. Therefore, for future operations, this manned round-trip transportation system must carry out routine operations at very low cost and the system must be versatile with great operational flexibility. Configuration changes from mission to mission should be limited to the integral cargo area with respect to restraints, cargo containers, personnel accommodations and packaging arrangements.

## B. SPACE SHUTTLE MISSION REQUIREMENTS

The major portion of the space exploration and application missions now defined involve placing either men, equipment, propellants, other consumables and instruments or some combination of these in low earth orbits. This is true not only for those missions which are conducted from low earth orbits but also for higher earth orbits, such as geosynchronous missions and from lunar and escape missions. For all these missions, low earth orbits serve either as a staging or buildup area or as parking orbits, while waiting to achieve the proper orbital conditions for continuation of a particular mission. Therefore, a versatile space shuttle system, that can transport effectively, a varying mix of personnel and cargo to low earth orbits and return, could be the keystone to the success and growth of future space flight developments for the exploration and exploitation of near and far space. Table II-1 summarizes the salient characteristics and requirements of six basic missions of major interest in NASA's future space program planning. These are further described as follows:

1. Space Station/Base Logistics Support. NASA is currently defining a large long-duration manned earth orbital space station that would be operational by the mid-1970's, which could evolve to a large space base in the late 1970's or early 1980's. These facilities will provide general purpose laboratories for the conduct and support of scientific and technological experiments, for earth applications and for the further exploration of space. The long term operation of a space station or space base will require a logistics system that is capable of routinely transporting large numbers to and from low earth orbit. For example, a 50-man space base would require on the order of 50 000 lbs. of consumables and equipment per quarter to sustain its operation. Perhaps the equivalent of its entire personnel complement would also be rotated during this same period, which would amount to about 20 000 pounds including men and support equipment. In addition to returning personnel to the earth surface base, return cargo

## MISSION CHARACTERISTICS

ORBITAL CHARACTERISTICS	SPACE STATION/ BASE LOGISTICS SUPPORT	PLACEMENT AND RETRIEVAL OF SATELLITES	DELIVERY OF PROPULSIVE STAGES & PAYLOAD	DELIVERY OF PROPELLANTS	SATELLITE SERVICE & MAINTENANCE	SHORT DURATION ORB. MISSION
ALTITUDE (N. MI.)	200 - 300	100 - 800	100 - 200	200 - 300	100 - 800	100 - 300
INCLINATION (DEG.)	28.5-90	28.5-SUN SYN.	28.5-55	28.5-55	28.5-SUN SYN.	28.5-90
ON-ORBIT ΔV (1000 FPS)	1 - 2	1 - 5	1 - 1.5	1 - 2	1 - 5	1 - 2
ON -ORBIT STAY TIME (DAYS)	7	7	7	7	7 - 15	7 - 30
CREW	2	2	2	2	2	2
PASSENGERS (MIN.)	ROTATE 50 MEN/QTR	2	2	2	4	10
ASCENT DISCRETIONARY PAYLOAD						
WEIGHT (1000 LBS.)	*70/QTR	10 - 50	25 - 50	50	5 - 15	25 - 50
VOLUME (1000 FT. <sup>3</sup> )		5 - 10	10	10	5 - 10	4 - 6
CRITICAL DIMEN. DIA. (FT.)	15	15	15	15	15	15
RETURN DISCRETIONARY PAYLOAD						
WEIGHT (1000 LBS.)	*45/QTR	10 - 50	--	--	15	50
VOLUME (1000 FT. <sup>3</sup> )	--	5 - 10	--	--	5 - 10	4 - 6

\* INCLUDE PASSENGERS

Table II-1

requirements consisting of tapes, film, equipment, and processing materials on the order of 25 000 lbs. or greater per quarter could exist for this long-duration orbital operation.

2. Placement and Retrieval of Satellites. Future space operations will entail the delivery and placement of satellites into low earth orbits as well as the retrieval of certain high priority, high cost satellites. These satellites could operate either in conjunction with a large manned orbital facility (space station/space base) or independently in other orbits. Although the weights of these modules or satellites may not be large, diameters on the order of 15 feet and associated lengths present relatively low density, large volume packaging requirements. A minimum of perhaps two persons may be required to conduct checkout, deployment or retrieval operations. Some satellites may require orbit-to-orbit positioning or retrieval, which may best be accomplished with the use of an on-orbit space tug operation, in conjunction with the space shuttle's delivery to a nominal low orbit.

3. Delivery of Propulsive Stages and Payloads for High Energy Missions. High velocity missions presently require large multi-stage launch vehicles to launch significant payloads from the ground base. The major portion of this energy is used to loft the payloads and propulsive stages to low earth orbits. A transportation system that had the payload and volume capability to deliver propulsive stages and payload to low earth orbits could provide an economical major support for these types of missions. In this use of a space shuttle, a high performance upper stage such as the Centaur could be carried into a low earth orbit together with a Venus or Mars probe which could weigh approximately 20 000 lbs. A second shuttle could then rendezvous with the first where the Centaur would be fueled and, after checkout, the probe would be launched. Also, a Centaur with propellants onboard and a payload of approximately 10 000 lbs. could be placed in orbit by a single shuttle launch. Similar operational techniques could be used to place large communication or navigation satellites into geosynchronous orbit. Studies show that the operational costs, for conducting these high velocity missions in this fashion, could be significantly reduced.

4. Delivery of Propellants. Large scale space operations will require that significant amounts of propellants be available to support these activities. The effective and efficient operation of a large manned earth orbital station or base will require propellants for the refueling of space tugs for orbit-to-orbit activities. An orbital propellant storage and operation facility could also be used to refuel other propulsive stages. These propulsive stages could be reusable, on-orbit space shuttles, capable of supporting high

earth orbit missions or lunar missions. Similarly, planetary injection stages could be launched into orbit unfueled and be subsequently loaded for the specific mission. This operational mode could be considered for both manned and unmanned high energy missions. The application of on-orbit reusable space tugs for the assembly of equipment and modules would similarly place demands for an on-orbit propellants depot or way-station.

5. Satellite Service and Maintenance. To achieve reliable and economic long-term space operations, automated satellites should be designed for varying degrees of maintenance and repair. Although they may operate in a highly automated mode, a capability to revisit satellites that had previously been positioned in orbits is highly desirable for purposes of inspection. With an on-orbit maintenance and repair facility, personnel, equipment, and instruments could be provided with a shirtsleeve environment whereby satellites could be brought into this controlled environment for service, maintenance and repair. The shuttle could serve as this facility at the location of the satellite or the satellite might be returned to the station where more extensive facilities would be available. Some satellites may require attention only on an infrequent basis, such as when they become inoperative or instruments require updating, while others may require revisits on a regular basis for such things as replenishment of expendables. As in the placement and retrieval operating mode, orbit-to-orbit activities may require the use of an on-orbit space tug type of system.

6. Short Duration Orbital Missions. Special purpose orbital missions of perhaps up to 30 days may be required to support unique missions for space system testing, earth viewing experimentation, and highly specialized sky viewing missions. Such missions may require as many as 10 persons to operate and calibrate instruments and to conduct other mission oriented functions. A large volume and payload capability would be desirable to transport these self contained mission modules to and from low earth orbits.

7. Space Rescue. Safety has always been considered as a prime goal in NASA programs. In past programs, safety has been achieved by preventive and remedial means when needed rather than an active systems operation. Space rescue, one aspect of safety, has not been practical with existing space vehicles due to the expense and operational difficulties of providing quick responses to likely emergencies. In some measure this has contributed to elaborate ground based backup support and costly spacecraft hardware designs.

The increase of manned activities in space will make these types of alternate solutions to ground based rescue even more complex and possibly impractical. On the other hand,

the space shuttle, with its systems and operational characteristics lends itself to a variety of ground based space rescue missions. Rescue operations might range all the way from "abandon ship" situations to the return of a severely ill person for earth based medical treatment. Manned systems in low earth orbits could be reached by a ground based shuttle within twenty-four hours or less from launch.

In addition the Space Shuttle in some instances could eliminate the need for space rescue by delivering, on a timely basis, replacement components for critical systems on other manned orbiting spacecraft.

8. Space Debris. The accumulation of space debris from expended hardware and inoperative satellites in near earth orbit has not presented a particular safety problem in the past. However, it may lead to future problems as space activities increase. The space shuttle will reduce this problem by not contributing to the increase of orbital debris by its inherent design and operational characteristics. The space shuttle may provide a capability to retrieve some existing debris. However, the extent of such retrieval missions will depend on the physical and orbital characteristics of the debris and also cost considerations.

9. Traffic Model. A nominal traffic model for the space shuttle is shown in Table II-2. This model is based upon current planning data for future missions and includes flights in support of a space station leading to a space base in 1980, the unmanned planetary program, the unmanned satellite program and the lunar program. This model shows less than 20 flights per year for the first three years followed by an increase to 60 flights per year with the initiation of an expanded lunar exploration program in 1978. The dominant missions are, as expected, support of the space base and the lunar program. While future events will, no doubt, require changes in this nominal traffic model, it is representative of current projected plans.

### C. DESIRED SYSTEM CHARACTERISTICS

1. Operating Costs. The goal of the lowest possible costs for recurring space shuttle operations will be achieved by incorporating design and operational features so as to:

- a. Maximize reusability of all parts of the system.
- b. Minimize the expendables.
- c. Maintain long-life flight systems readily and minimize vehicle refurbishment and associated operations between flights. (Accessibility, component replacement capability,

TABLE II-2 NOMINAL SPACE SHUTTLE TRAFFIC MODEL

PROGRAM	75	76	77	78	79	80	81	82	83	84	85
<u>Space Station</u> 12 Men, Rotate Entire Crew Per Qtr.	7	7	7	7	7						
<u>Space Base</u> 50 Men Rotate Entire Crew Per Qtr. (10 Men/ Flight)						23	23	23	23	23	23
<u>Unmanned Planetary</u>	7	1	8	3	4	6	5	2	7	5	3
<u>Unmanned Satellites</u>	2	2	2	2	2	2	2	2	2	2	2
<u>Lunar Program</u> 6 Man Orbital Station and 6 Man Base				48	48	34	34	34	34	34	34
<u>Total Space Shuttle Flights/Year</u>	16	10	17	60	61	65	64	61	66	64	62

systems onboard checkout and fault isolation typify desired design features). In the case of operations, procedures must be radically changed by minimizing the ground support equipment currently used for extensive integration, checkout and support operations to assure flight success with hardware used only once.

d. Minimize the ground support operations for both the flight vehicle ground turnaround operation (landing through pre-launch phase) and also for the inflight mission operations.

2. Operational Performance. System operational characteristics for the total mission are:

a. Airline type operations, i.e., airline passenger safety criteria with a shirtsleeve environment compatible with that of the Space Station and with 3g maximum flight loads; the ability to vary the mix of cargo and passengers both up and down, direct cargo and passenger loading and unloading; and a safe intact mission abort capability.

b. Autonomous flight system supported by minimal ground operations during mission, i.e., the pilot will be able to carry out the flight without ground aids; adaptive flight control system with onboard nav-guidance; and an onboard systems checkout, monitoring and related display console.

c. Minimal ground turnaround time and work.

d. Large and flexible payload capability to and from orbit.

e. Intra Vehicular Activities (IVA) personnel transfer; IVA-predominant cargo transfer mode.

f. Return to earth opportunities at least once every 24 hours.

g. Two-man flight crew with one man operational capability.

h. Vehicle should be self-sustaining for a period up to seven days. Missions in excess of seven days will be at the expense of the discretionary payload.

### III. SYSTEM CONCEPTS

#### A. BASIC CONCEPTS

Vehicle concepts that have been studied for low-cost, round-trip earth orbit transportation can be grouped in three generic classes:

1. Expendable launch vehicles of minimum-cost design, plus advanced reusable spacecraft.

2. Partially reusable vehicles, in which part of the launch vehicle hardware is expended.

3. Fully reusable vehicles.

In the following paragraphs, a vehicle configuration representative of each of the above three classes is described in summary form.

#### B. COMMON FEATURES

Features, common to the basic concepts of interest, are noted in this section. Reusable elements of all systems are configured for lifting entry and runway landings. The entry vehicles are designed and sized, where possible, for maximum use of radiative type thermal protection systems to minimize refurbishment costs and re-cycle activities.

Payload compartments are located on the vehicle c.g. to accommodate varied mixes of cargo and passengers. Configuration changes from mission to mission were limited to the integral cargo area with respect to restraints, cargo containers, personnel accommodations, and packaging arrangement. It is anticipated that special purpose cargo modules will be developed to accommodate these diverse cargo requirements. Provisions will be included to allow docking with the space base or large experiment modules, and for transfer of people and cargo without EVA, or for discharge of large satellites or other cargoes on orbit. "Swing nose" concepts are being examined which allow ready access to the interior payload compartment, on the ground and in orbit, in a fashion similar to current large transport aircraft.

All reusable vehicle elements include redundancies to preclude catastrophic results from single failures. Spacecraft and reusable stages are designed for a safe intact abort with payload in the event of major failures, and therefore do not require escape provisions for passengers or portions of the vehicle.

Flight subsystems are designed to minimize dependence upon ground facilities and operations. This is reflected in the guidance and control systems design for autonomous operation during ascent and return, and in provisions for on-board checkout of subsystems and malfunction detection.

#### C. VEHICLE SIZING

All vehicles studied were sized to the following nominal conditions:

1. 50 000 lbs. cargo and passengers, up and down.
2. Flight crews of two.
3. 10 000 cu. ft. internal payload volume.
4. 270 nmi orbit, 55° inclination.
5. Seven day mission duration.

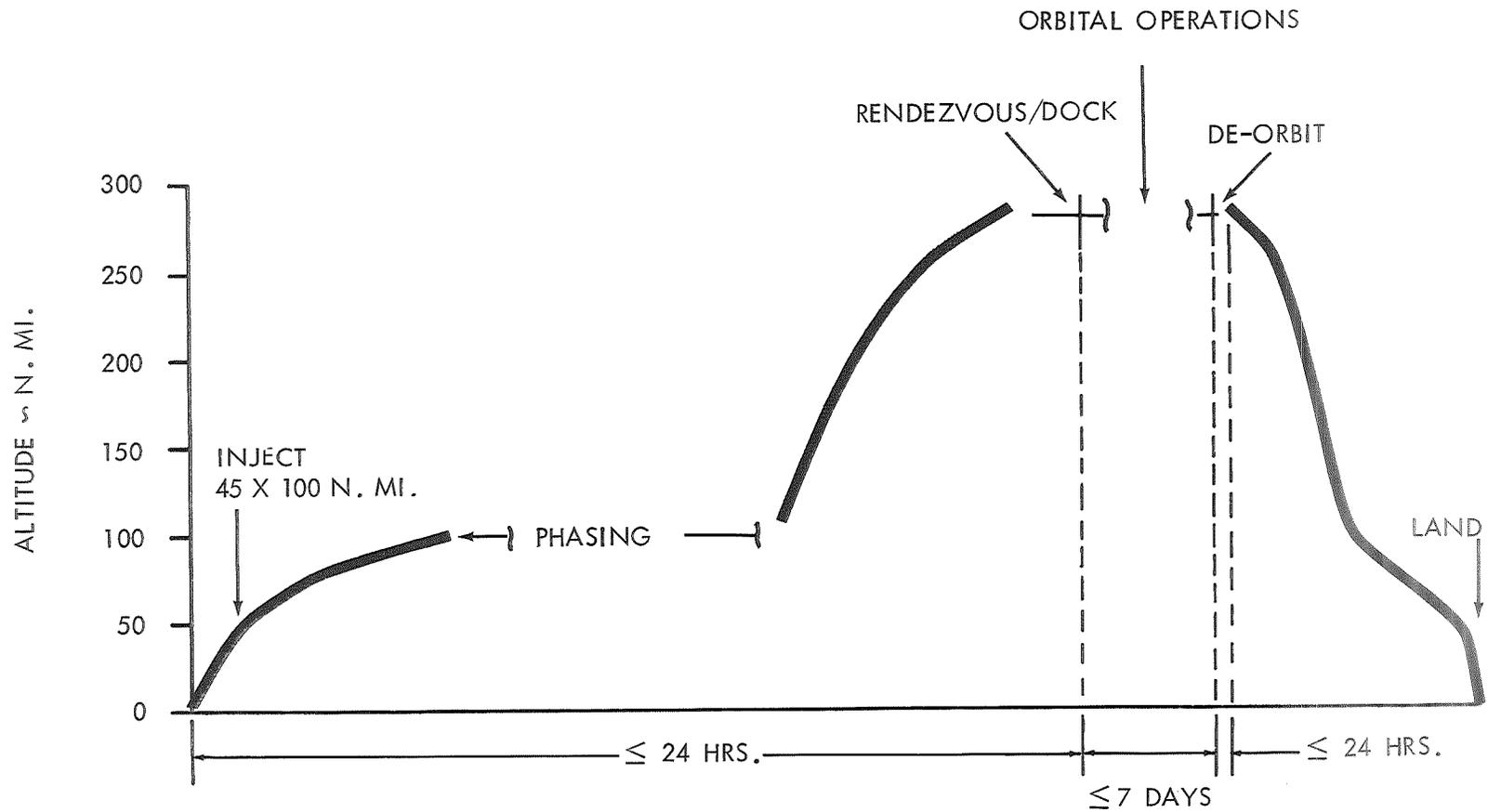
#### D. MISSION PROFILE

A mission profile, typical of all three classes of vehicle concepts is shown in Figure III-1. Staging of the expendable launch vehicle configuration is performance optimized. Staging of expendable tanks for the stage-and-one-half configuration occurs late in the ascent phase, at velocities of 15 000-20 000 fps. The fully reusable systems stage at approximately 160 000 ft. and 6000-9000 fps; the boost stage(s) then re-enter and cruise 150-200 miles back to the launch site. The on-orbit, de-orbit, reentry, and terminal landing phases are very similar for the orbital elements of all three classes.

#### E. EXPENDABLE VEHICLE PLUS REUSABLE SPACECRAFT

The configuration which represents this category consists of (1) a large solid first stage, (2) low-cost pump-fed second-stage, and (3) a reusable, lifting entry spacecraft, with an integrated payload compartment of 10 000 cu. ft. Several body shapes and decoupled (or semi-decoupled) landing modes are currently under consideration. A parabolic shaped spacecraft is illustrated in Figure III-2 as a representative concept in this class. Integrated electronics equipments is an integral part of the reusable spacecraft, providing substantial savings on these expensive elements. Semi-ballistic entry vehicles have been examined for lower cargo weights, but become impractical for return payloads in the 50 000 lb. class.

# TYPICAL MISSION PROFILE



ASCENT TO ORBIT MISSION PROFILE

Figure III-1



## F. PARTIALLY REUSABLE VEHICLES

The 1-1/2 stage (drop-tank) concept is an integral launch and reentry vehicle that aims at reducing recurring costs by incorporating all expensive items in the reusable core vehicle and containing the first-stage fuel in low-cost, expendable tanks. This concept is depicted in Figure III-3.

Some of the major design alternatives for this concept are illustrated, including (1) the basic body shape for the reusable core, (2) parallel vs. inclined arrangement of the expendable tanks, and (3) the possible use of a second set of drop tanks, to reduce the internal volume, and size, of the reusable core vehicle.

A typical vehicle is powered by four to eight high-performance, hydrogen-oxygen rocket engines with up to four million pounds of total thrust. High pressure bell and aerospike engines are design alternatives. The expendable propellant tanks are to be of simple and low-cost design and construction, within the weight constraints essential to acceptable payload performance.

## G. FULLY REUSABLE SYSTEMS

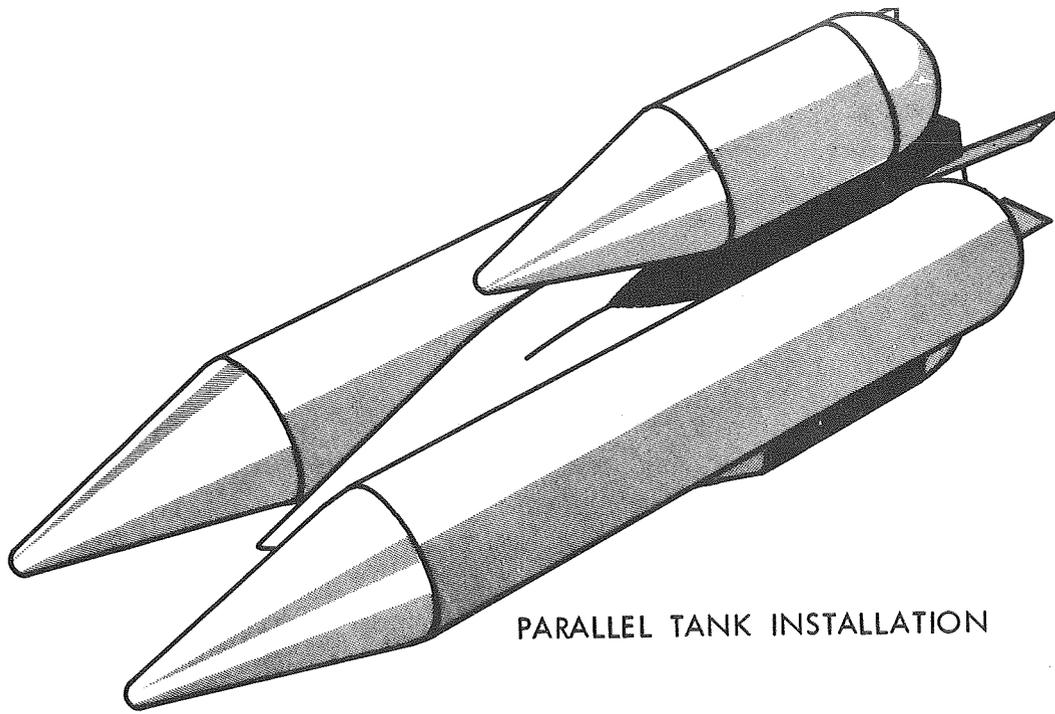
Over the past several years many varied concepts for a fully reusable round trip, low earth orbit transportation system have been studied. The study results have narrowed the field of reusable concepts to those involving boost stages with a vertical take off mode and a horizontal aircraft type terminal landing mode. The results also indicate the desirability of using an all rocket boost engine system as opposed to combining air breathing engines with rockets to boost. At this time there is no preferred concept. However, five concepts which hold the greatest promise are listed below. These typical configurations are depicted in Figure III-4.

1. Triamese Concept - a parallel stage arrangement with parallel stage thrusting and propellant cross feed wherein the first stage is divided into two identical elements as similar as possible to the orbital second stage.

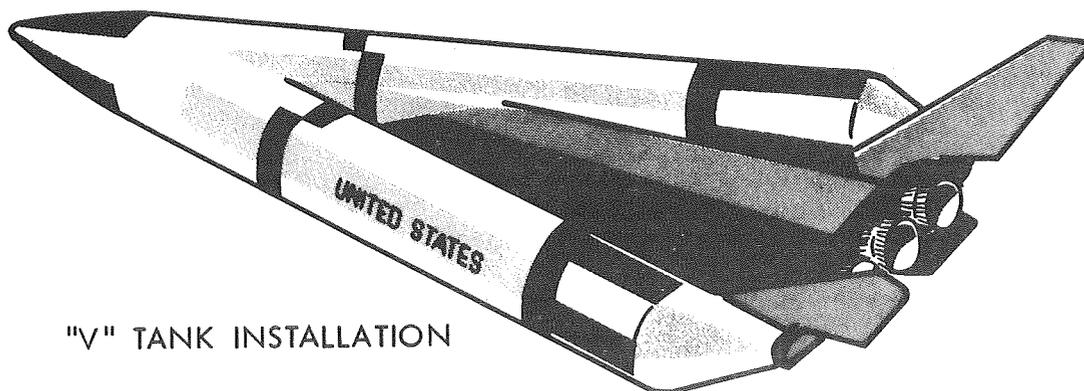
2. Parallel/Parallel Concept - a parallel stage arrangement with parallel stage thrusting and propellant cross feed resulting in two similar but different size stages.

3. Parallel Stage/Sequential Burn - a parallel stage arrangement with sequential stage thrusting.

# STAGE AND A HALF CONCEPT (DROP TANK)



PARALLEL TANK INSTALLATION



"V" TANK INSTALLATION

Figure III-3

# FULLY REUSABLE CONCEPT

[TWO-STAGE]

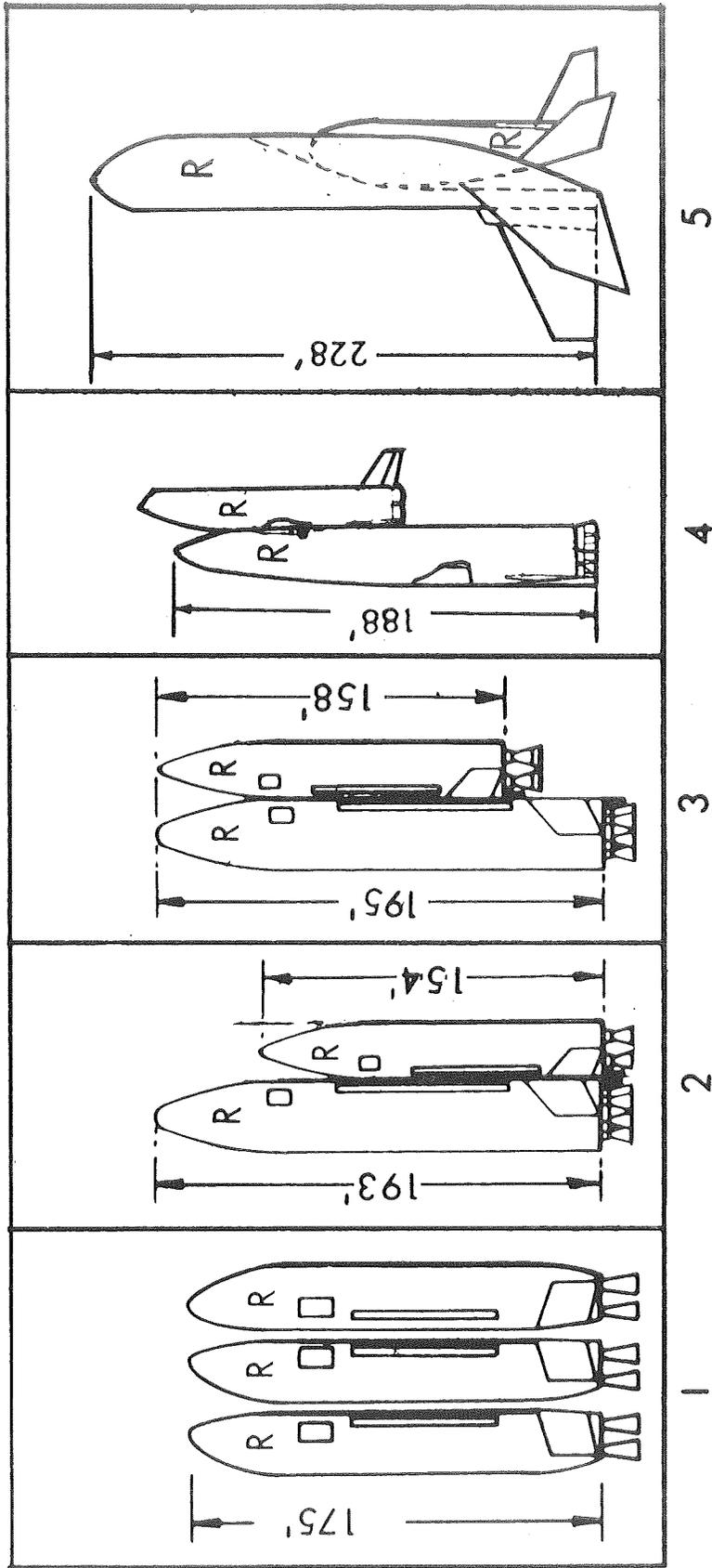


Figure III-4

4. MSC Concept - parallel stage arrangement with sequential stage thrusting and using fixed wings and a high angle of attack reentry mode.

5. LaRC Concept - Tandem stage arrangement with sequential stage thrusting and using fixed geometry lifting planform shape.

Each of the above concepts attempt to achieve unique economy in development and operations by capitalizing on concept characteristics such as stage and engine arrangement, aerodynamic shape, terminal landing requirements, sequential or parallel thrusting, cargo arrangement, and reentry mode and thermal protection systems. Within this framework however the final configuration design will be selected having the best combination of trade-off features and resulting in the greatest overall savings to program cost without reduction in safety.

## H. CONCEPTS SUMMARY AND COMPARISON

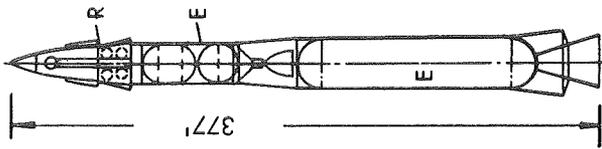
### 1. Vehicle Sizes and Weights.

a. Basic dimensions, weights, and thrust levels for three representative concepts have been summarized in Figure III-5. The spacecraft/stage weights at orbit insertion range from 150 000 - 300 000 lbs. Lift-off weights for the  $1\frac{1}{2}$  stage and fully reusable vehicles are on the order of 3-4 million pounds, for 50 000 lbs. payload and 10 000 cu. ft. payload volume.

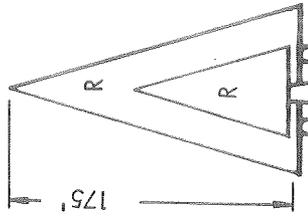
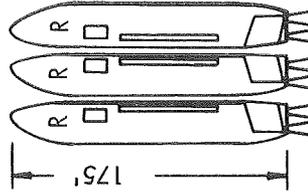
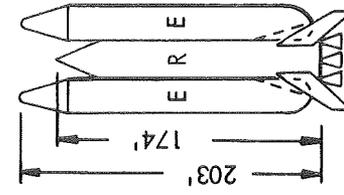
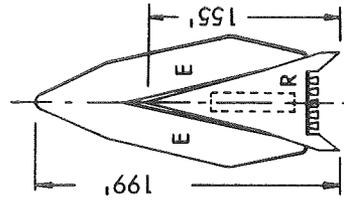
b. As an indication of weight sensitivities for highly reusable vehicles, a 1000 lb. increase in inert weight of the orbital stage would require on the order of 15 000 - 20 000 lbs. increase in total vehicle weight.

2. Operational Modes. Some basic operational aspects of the three classes of vehicles are compared in Table III-1. It will be noted that aircraft-type operations are adopted for the lifting entry reusable elements of each vehicle, from launch, abort, entry/landing, and recycle for subsequent flights. The opportunity to take advantage of these features is, of course, progressively greater with increased degree of vehicle recovery and reuse.

# SPACE TRANSPORTATION SYSTEM CONFIGURATION CONCEPTS



50,000 LBS. OF UP  
AND DOWN DIS-  
CRETIONARY CARGO  
INCLUDING CREW  
AND PASSENGERS TO  
A 270 N. MI. 55°  
ORBIT



E - EXPENDABLE  
R - REUSABLE

## SUMMARY DESCRIPTION

TOTAL LAUNCH WT.	7.13 M LBS.	2.92 M LBS.	3.64 M LBS.
TOTAL LAUNCH THRUST	9.75 M	3.65 M	5.50 M
1ST STG. WT.	5.21 M	2.39 M	1.30 M (x2)
1ST STG. PROP. WT.	--	2.30 M	1.05 M (x2)
2ND STG. WT.	1.63 M	0.474	0.98 M
2ND STG. PROP. WT.	--	0.264	0.74 M
3RD STG. (SPACECRAFT) WT.	0.24 M	N/A	N/A
3RD STG. PROP. WT.	0.13 M	N/A	N/A
S/C (ORBITER) LANDING WT.	0.16 M	0.26 M	0.28 M
S/C L/D (HYP.)	1.7	2	2

Figure III-5

# OPERATIONAL MODES

CONCEPT ITEM	REUSABLE SPACECRAFT PLUS NEW EXPENDABLE LAUNCH VEHICLE	1 1/2 STAGE	FULLY REUSABLE
LAUNCH	SIMILAR TO SATURN/APOLLO	VERTICAL LAUNCH - AIRCRAFT TYPE LAUNCH ACTIVITIES	
LAUNCH AZIMUTH RESTRICTIONS	SIMILAR TO SATURN/APOLLO	LIMITED BY DISPOSAL OF EXPENDABLE DROP TANKS	NO EXPENDED HARDWARE
ABORT	SIMILAR TO APOLLO, EXCEPT MUST REACH LAND FOR AN AIRCRAFT TYPE LANDING	INTACT ABORT OF COMPLETE STAGE, INCLUDING PAYLOAD NO DEPENDENCE UPON ROCKET-TYPE "ESCAPE" DEVICES	
STAGING	SIMILAR TO SATURN/APOLLO	REQUIRES JETTISON AND DISPOSAL OF DROP TANKS, FOR ABORT DURING ASCENT.	
RE-ENTRY	LIFTING RE-ENTRY	STAGING OF LARGE, DEPLETED TANKS. TANKS NOT UNDER ACTIVE CONTROL.	PARALLEL STAGING OF TWO OR THREE LARGE VEHICLES. STAGES RETURN TO LAUNCH SITE
TERMINAL LANDING	AIRCRAFT TYPE APPROACH AND LANDING GO-AROUND CAPABILITY PROVIDED		
REFURBISHMENT	REFURBISH SPACECRAFT, AND MATE WITH NEW LAUNCH VEHICLE	REPLACE TIP TANKS	
		REFUEL AND MINIMUM REFURBISHMENT, ONLY	
		NO REPLACEMENT OF ABLATIVES REQUIRED	

Table III-1

### 3. Technical Risk and Technology Requirements.

a. Critical subsystems and design requirements are summarized in Table III-2 for the three representative vehicle concepts. Requirements for (1) reusable, thermal protective systems, and (2) provisions for terminal approach and landing apply to all three concepts. In addition, the  $1\frac{1}{2}$  stage and fully reusable concepts require development and integration of large, high-performance, reusable, hydrogen-oxygen rocket engines.

b. New integrated electronics requirements arise in two areas; (1) on board checkout and malfunction detection and display systems, and (2) provisions for highly autonomous flight operations during ascent, on-orbit, and return phases.

### 4. Costs.

a. Approach. Because of the lack of detailed engineering and operational definition of the three basic system concepts, the approach to the cost analysis has been to estimate a most probable or nominal value and then to employ parametric curves to illustrate the potential ranges within which possible real values may lie. Therefore, only first approximations of concept costs, trade-offs and sensitivities are presented. Three parameters of primary interest are:

(1) Refurbishment, treated as a function of first unit cost; a range of 0.1% to 10.0% of the first unit cost has been investigated;

(2) Recurring costs per flight, including launch, flight operations, recovery, checkout, refurbishment and ground turnaround operations (Ranges for these costs are noted on the bar chart in Figure III-6);

(3) Equivalent number of system reuses, for which a range of from 25 to 1000 has been investigated. A design life of 100 to 300 flights has been determined to be adequate for the traffic models studied.

#### b. Cost Assumptions.

(1) While emphasis in the definition and development of the space shuttle is on reducing the recurring cost of transportation to and from earth orbit, there can be significant cost reductions by the adoption of an "aircraft like" approach in the design and development phases, i.e., by accomplishing qualification testing in flight and by using limited life development subsystems.

# TECHNICAL RISK AND TECHNOLOGY REQUIREMENTS

CONCEPT ITEM	REUSABLE SPACECRAFT PLUS NEW EXPENDABLE LAUNCH VEHICLE	1 1/2 STAGE	FULLY REUSABLE
TECHNOLOGY STATUS AND REQUIREMENTS	<p>LAUNCH VEHICLE IS CURRENT STATE-OF-THE-ART.</p> <p>NEW DEVELOPMENTS REQUIRED FOR REUSABLE SPACECRAFT, INCLUDING THERMAL PROTECTION AND APPROACH/LANDING PROVISIONS.</p>	<p style="text-align: center;">COMPARABLE OVER-ALL RISK</p> <p>PROPULSION INTEGRATION MORE DIFFICULT.</p> <p>LARGE ENGINE WTS. IN BASE ADD TO DIFFICULTIES IN CONFIGURATION/BALANCE</p> <p>ENTRY HEATING DUE TO HIGHER WING-LOADINGS IMPOSES SOMEWHAT GREATER DEMAND UPON TPS.</p> <p>LOW-COST TANK DEVELOPMENT.</p>	<p>FULLY REUSABLE MORE SENSITIVE TO UNCERTAINTIES IN REUSABLE DESIGN FEATURES.</p> <p>UNCERTAINTY IN ABILITY OR DESIRABILITY OF COMMON STAGE DESIGN FOR BOOSTER AND ORBITER ELEMENTS.</p>

Table III-2

## TECHNICAL RISK AND TECHNOLOGY REQUIREMENTS (CONT.)

CONCEPT ITEM	REUSABLE SPACECRAFT PLUS NEW EXPENDABLE LAUNCH VEHICLE	1 1/2 STAGE	FULLY REUSABLE
DEVELOPMENT AND TEST APPROACH	MUST USE ROCKET TEST AND DEVELOPMENT APPROACH	"AIRCRAFT" APPROACH FOR CORE WITH TANKS	"AIRCRAFT" APPROACH FOR ALL ELEMENTS
NEW TECHNOLOGY REQUIREMENTS  ENGINES	DEVELOPMENT OF LOW COST PUMP-FED LIQUID ROCKET ENGINES REQUIRED  DEVELOPMENT OF LARGE SOLID STAGE REQUIRED  TECHNOLOGY FOR BOTH AT HAND	REQUIRES DEVELOPMENT OF HIGH-PERFORMANCE HYDROGEN- OXYGEN ENGINE IN 500K - MILLION LB. THRUST CLASS. LONG-LIFE, REUSABLE THROTTLING. MUST BE ADAPTABLE TO BOOST AND UPPER STAGE USE.	
THERMAL PROTECTION SYSTEM	REUSABLE, ALL RADIATIVE THERMAL PROTECTION SYSTEM REQUIRED (2000 TO 2500 °F) MINIMUM REFURBISHMENT.		
CONFIGURATION DEVELOPMENT	REQUIRES AERODYNAMIC AND THERMODYNAMIC CHARACTERISTICS COMPATIBLE WITH ENTIRE ASCENT, ENTRY, AND LANDING PHASES OF FLIGHT.		
ASTRONICS SYSTEMS	<ul style="list-style-type: none"> <li>● INTEGRATED INTO REUSABLE SPACECRAFT</li> <li>● ON-BOARD CHECKOUT</li> </ul>	PARALLEL STAGING OF LARGE BODIES.  <ul style="list-style-type: none"> <li>● AUTONOMOUS OPERATION DURING ASCENT AND RETURN</li> <li>● ON-BOARD CHECKOUT AND MALFUNCTION DETECTION</li> </ul>	

Table III-2 (Cont'd)



(2) In the operational phase of the program, costs will be sizably reduced by hardware reuse (particularly of high cost elements), and by land recovery of the vehicles. Additionally, a significant reduction in launch and flight operations costs can be achieved by implementing the operational features discussed earlier, including such uses of self-checkout subsystems; eliminating of repetitive, redundant tests and checkouts; and by providing easily maintainable subsystems.

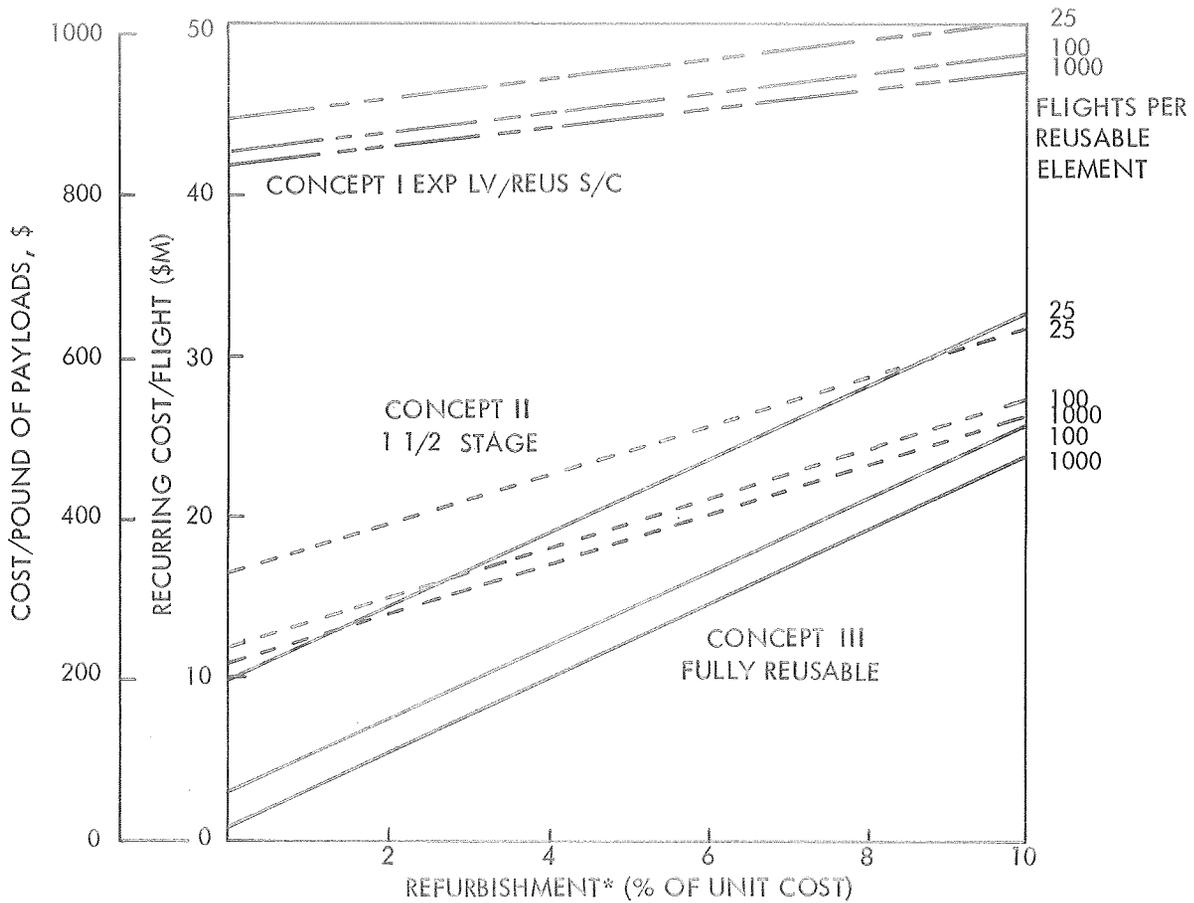
c. Parametric Analysis. This analysis was conducted to indicate the major trade-offs between vehicle life and refurbishment rate as they affect recurring costs. The results of this analysis are summarized in Figure III-7. Vehicle reuse is a proportionately more significant parameter for the  $1\frac{1}{2}$  stage and reusable concepts than for the expendable launch vehicle/reusable spacecraft. For refurbishment rates of 10% or less, the fully reusable concept offers the greatest promise for the range of reuse rates examined. It is significant that to achieve payload costs less than \$50/lb., the fully reusable vehicle is virtually mandatory, unless costs of expendable tankage can be reduced to values significantly lower than the \$75/lb. used in this analysis.

To be economically competitive with the fully reusable concept, the expendable tankage cost for the  $1\frac{1}{2}$  stage concept must be under \$20/lb. as shown in Figure III-8A. If refurbishment rates of under 1% are accomplished, then other items making up the operations costs begin to dominate the recurring costs.

d. Concept Comparison. Concept cost comparisons are shown in Figure III-8B and Figure III-9A. Because of the stated lack of detailed definition of the vehicles and operations, costs are necessarily preliminary. However, these preliminary estimates clearly show that for programs requiring 50 to 100 flights or more, the more reusable system concepts can produce significant overall savings. Figure III-8A also demonstrates the return to be gained from non-recurring investments in terms of payload delivery cost savings. Figure III-6, presented previously, provides insight into the makeup of the recurring costs shown in Figure III-8A. Results from the examination of two reuse rates (100 and 1000 flights) are shown in Figure III-7 and the dramatic effect of drop (tip) tank cost per pound assumptions is illustrated in Figure III-9B and Figure III-10.

The discussions of the program cost comparisons and sensitivity analyses conducted for the three generic

# RECURRING COST COMPARISON



ASSUMPTIONS	I EXPENDABLE LV REUSABLE SPACECRAFT	II STAGE & ONE HALF	III FULLY REUSABLE
ENTRY VEHICLE	\$67M	\$137M	\$225M
EXPENDABLE ITEMS/LAUNCH	\$40M (L.V.)	\$10M (TANKS)	-0-
LAUNCH & FLIGHT OPERATIONS, PROPELLANTS	\$2.2M	\$0.8M	\$0.8M
COST OF EXPENDABLE TANKS/LB.	-	\$75.00	-

\* INCLUDES LABOR AND HARDWARE TO RECONDITION REUSABLE ELEMENTS

Figure III-7

**TRADEOFF BETWEEN DEVELOPMENT AND OPERATIONAL COSTS**

**TOTAL CONCEPT COST COMPARISON [NOMINAL COST VALUES]**

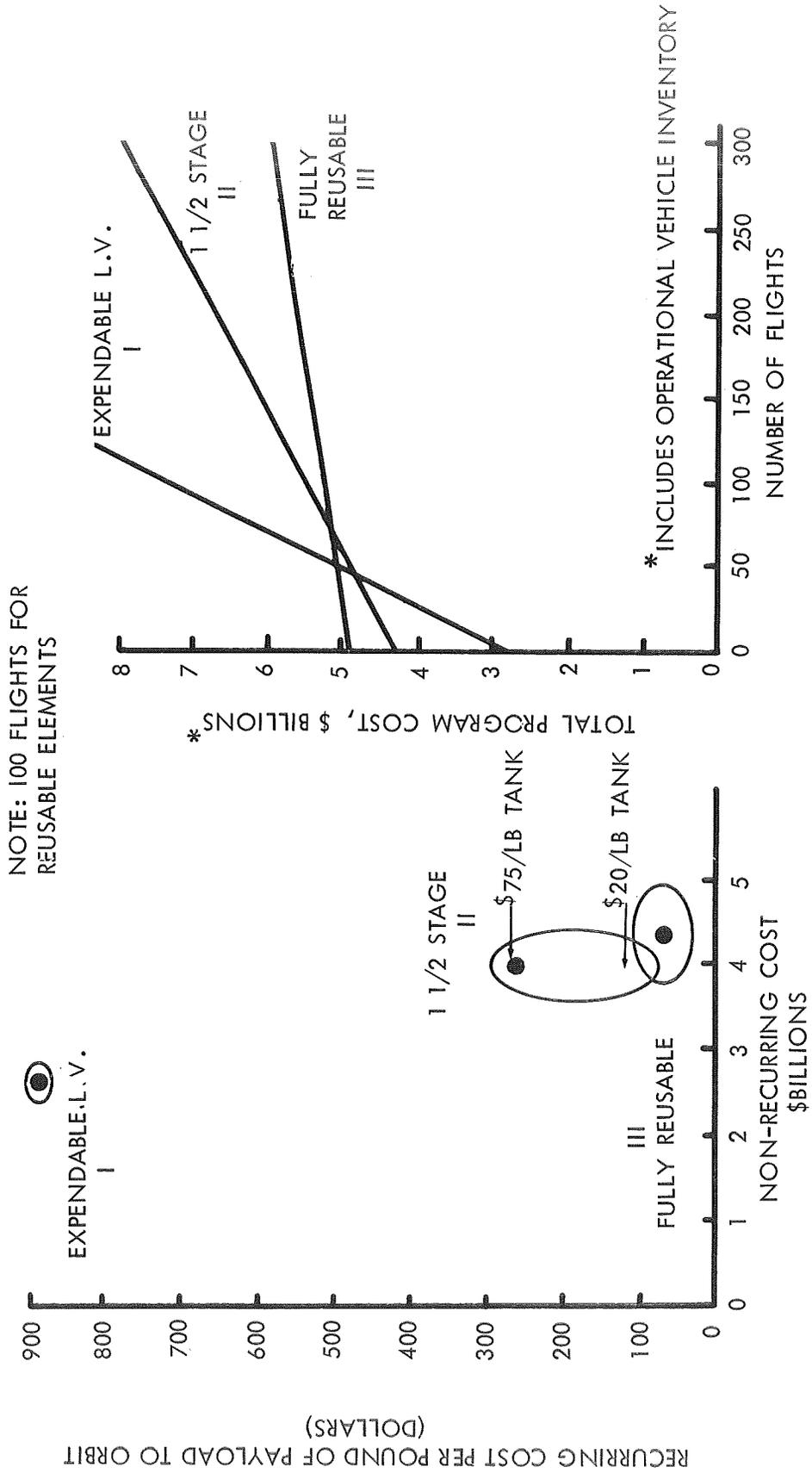


Figure III-8A

Figure III-8B

# TOTAL CONCEPT COST COMPARISON (NOMINAL COST VALUES)

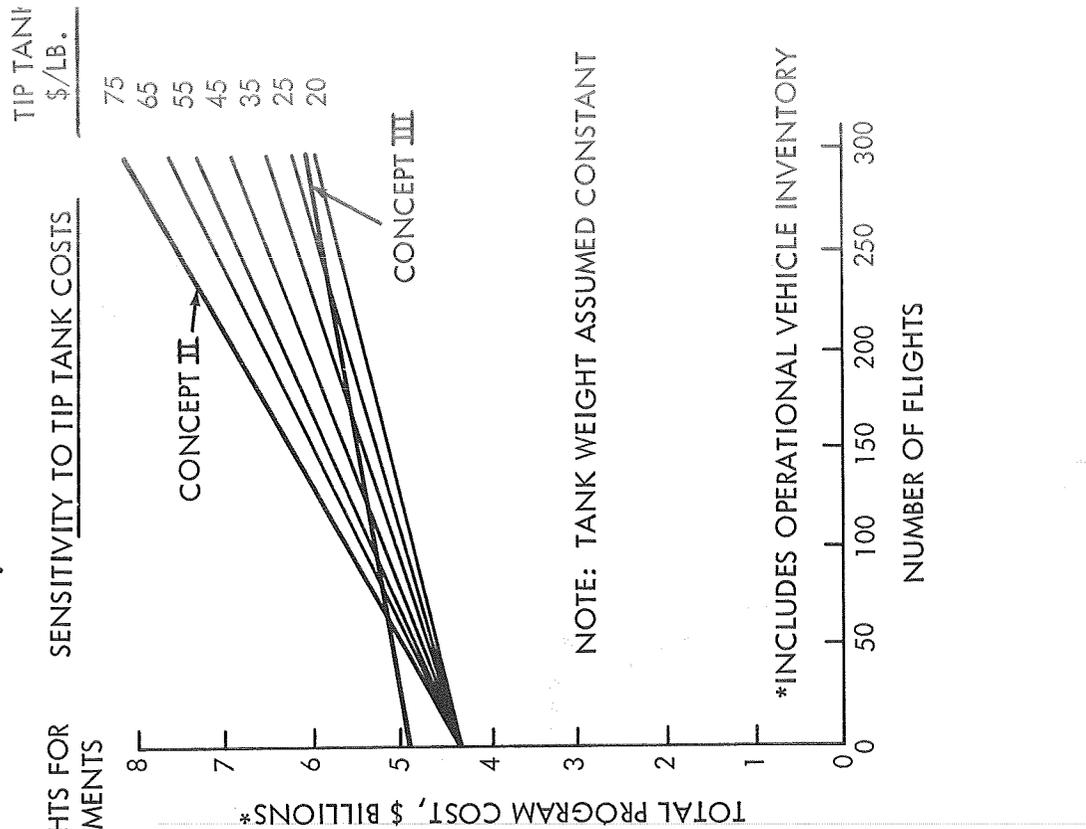


Figure III-9B

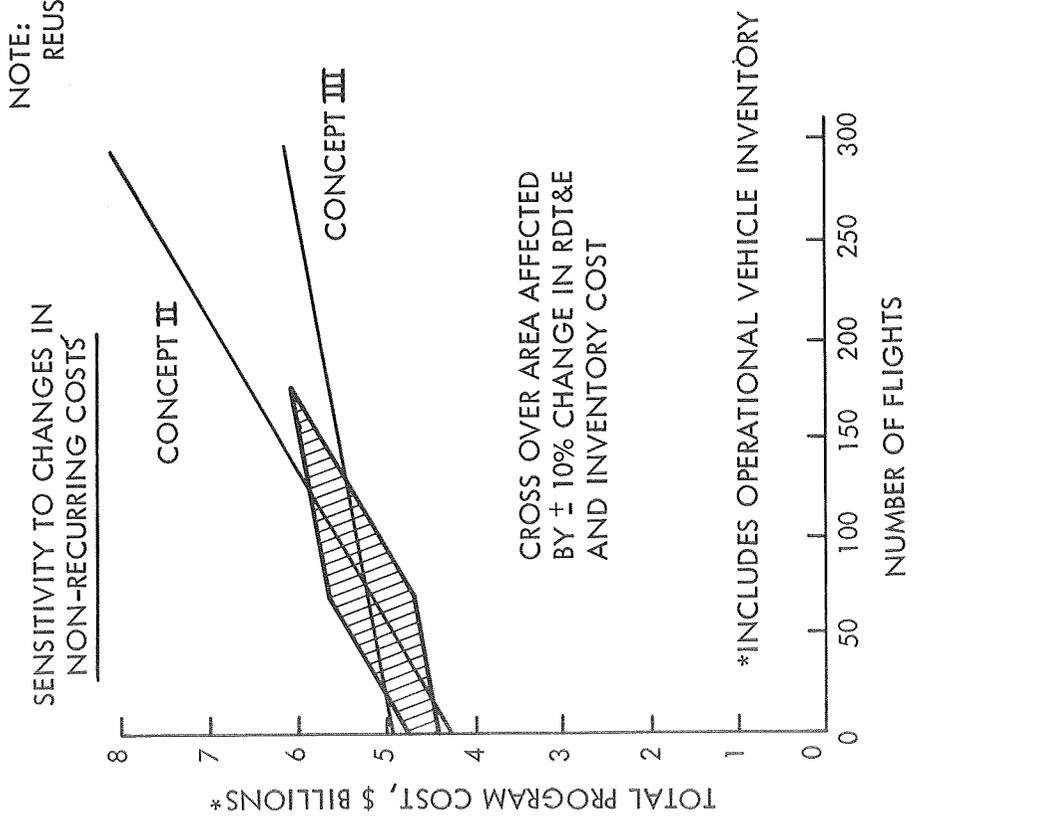


Figure III-9A

# RECURRING COST COMPARISON

## EFFECTS OF TIP TANK COST

### AT 100 FLIGHTS/VEHICLE

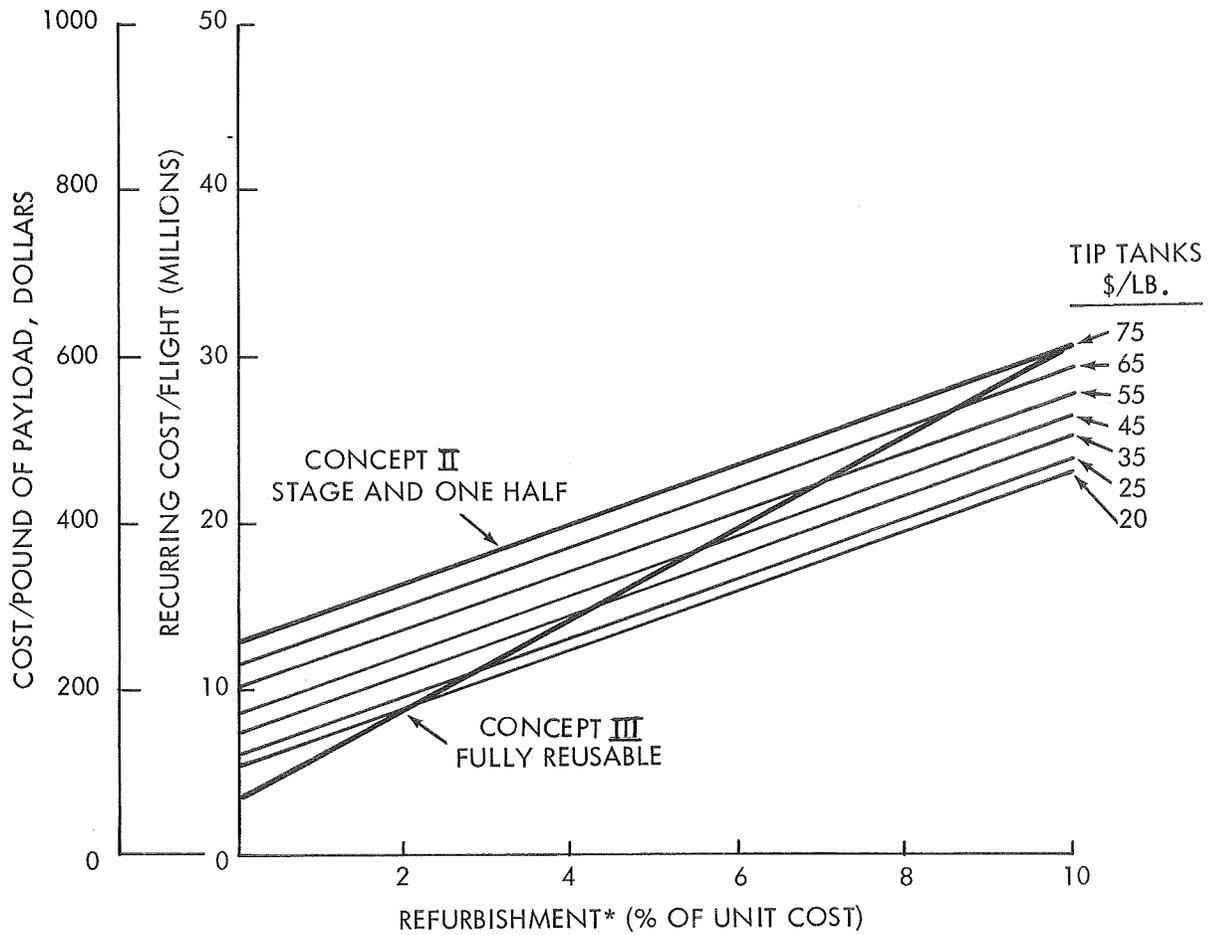


Figure III-10

\* INCLUDES LABOR AND HARDWARE TO RECONDITION REUSABLE ELEMENTS

classes of vehicles have thus demonstrated that the significant tradeoffs lie in the areas of refurbishment and operations costs, and point to a need for greater effort in these areas.

## I. PROGRAM PLANS

The three generic vehicle classes, (I: expendable launch vehicle with advanced reusable spacecraft; II: partially reusable; and III: fully reusable systems), cover a broad spectrum of development and operational features and associated complexities. Certain significant development considerations are common for all concepts, such as over-all configuration, airframe design, and thermal protection systems for the reusable vehicles. Advanced, high performance, high thrust rocket engine systems are required for Classes II and III. To exploit the advantages of competitive development in certain of the advanced systems, parallel or concurrent developments will be employed. For example, parallel development of the rocket engine systems through preliminary flight rating tests would provide redundancy in this most critical area. Vehicle configuration, flight control systems and thermal protection systems should be demonstrated, evaluated and optimized by parallel programs of analysis and demonstrations.

1. Development Consideration. An aircraft development approach, capitalizing on the configuration features of a stable and controllable lifting planform with appropriate propulsion system capability, will be employed where appropriate for the selected concept(s). The number of flight test vehicles and associated costs can be sharply reduced and the flight test hours can be increased greatly via flight test vehicle recovery and reuse. An incrementally difficult flight test program will be employed, increasing the flight regime with respect to speed and altitude as the flight vehicle is proven out in repetitive flight operations. Modifications and corrections for malfunctions, benign failures, and/or performance deficiencies would be accounted for during this flight test phase.

a. Concepts Comparison. Although the reusable entry element is common to all class concepts, there is a significant difference in their respective abilities to exploit aircraft development techniques over the entire design environment. The entry element in Class I can only be subjected to orbital entry conditions after being boosted into low orbit by a full-scale expendable launch system. The Triamese concept, representative of Class III, fully reusable systems, allows incremental flight test steps from subsonic to hypersonic velocities and the associated altitude envelopes. This could

be accomplished by conducting extensive flight tests progressively thru the speed range with one of the boost elements. The flight test program would culminate with full-spectrum ground to orbit flights of the total system.

It appears that a minimal program would consist of two or three orbital flights to properly evaluate full-scale entry temperature distributions, abort envelope, and guidance and control schemes. In the case of Class I, these high-speed tests, coupled with the desire to investigate and demonstrate the vehicle in the low speed landing regime, indicate that a subscale vehicle may be needed to preclude the high costs and potential program delays associated with flight test investigations using a prototype spacecraft and the required launch system.

b. Pacing Item. The pacing item in Class I is the reusable spacecraft system. It should be noted, however, that the weight and size of the expendable launch vehicle could influence operational availability, especially if the initial operational requirements are to provide the high launch rates under consideration. The impact of the related production rate and supporting logistics is significant for the launch rates contemplated.

At this time, it is difficult to distinguish any significant difference in development time between Classes II and III. The pacing item is the rocket engine system. Therefore, these preliminary considerations indicate that Classes II and III could reach Initial Operational Capability (IOC) in about five or six years, with the major uncertainty being related to the rocket engine system. Class I could be available approximately one year earlier. However, Class I spacecraft development and launch vehicle size, coupled with the high launch rates could affect this date.

2. Facilities and Operations. The operational concept for the space shuttle is characterized by high flight frequencies and greatly reduced ground turnaround times, as compared to present systems.

A range of facility and ground operations alternatives for checkout, launch, recover, and refurbishment can be considered for the three system concepts. These alternatives range from providing new facilities to modifications of existing facilities at KSC and ETR. But to insure maximum operational efficiency and cost economy for repetitive operations, it is mandatory to exploit aircraft/airline type development and operations approaches wherever possible (see Fig. III-11).

# LAUNCH-RECOVERY REFURBISHMENT FACILITY

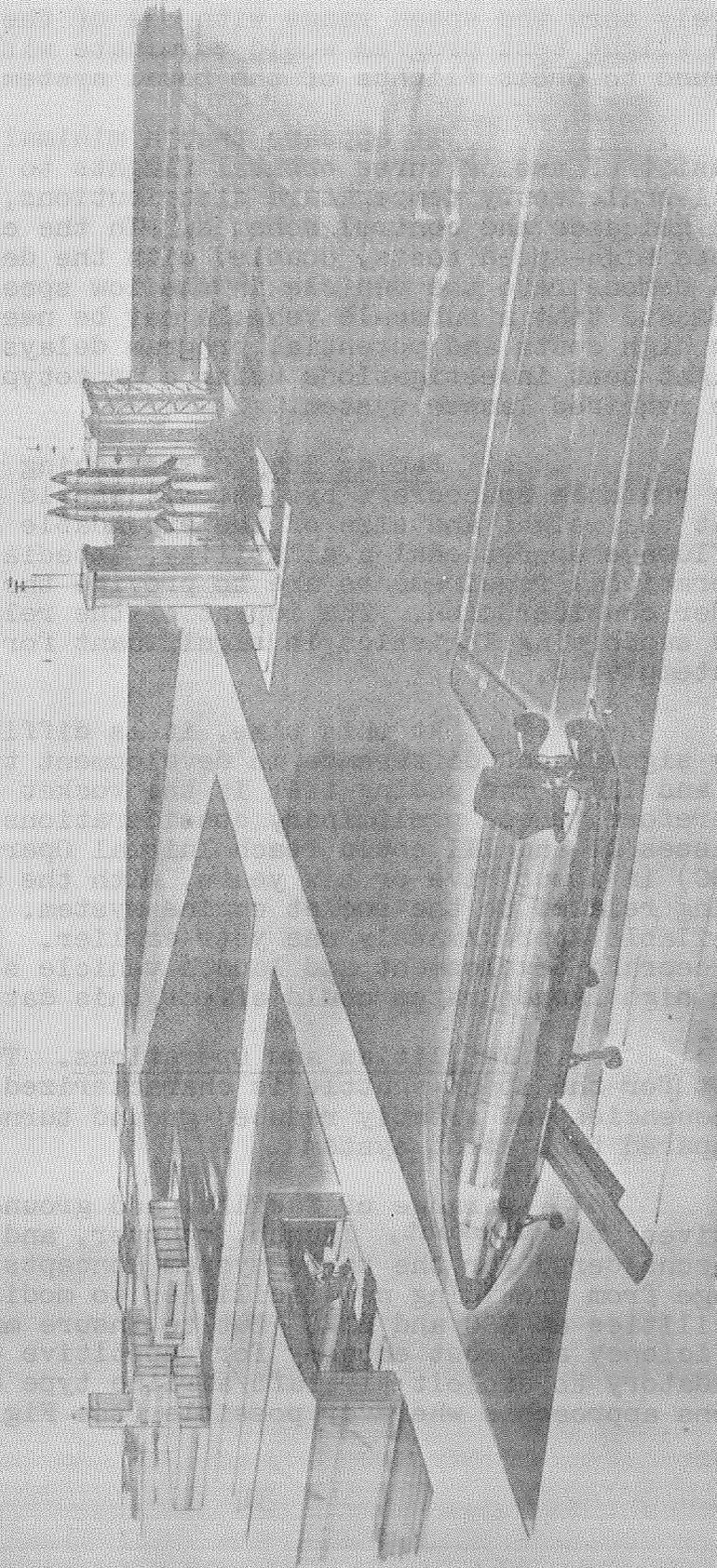


Figure III-11

In the case of Class I, a Saturn V/Titan III vertical assembly and transfer technique would be recommended.

In the case of Classes II and III, the individual elements would be transported to the launch pad for "erection" post-refurbishment activity or, alternatively, an integration/transfer operation would be employed. Additional study is needed to optimize the hangar-to-launch mode for Classes II and III. Preliminary studies for the Class II and III systems indicate that launch could take place from ETR and recovery could be accomplished at the skid strip at ETR, with appropriate ground control and approach equipment installed. Existing or new hangars in the area would be employed for the post-recovery operations and the vehicle would then be moved to the launch area located nearby, with actual locations being determined by noise, safety, and hazards separation distance requirements. Final cockpit checks using the on board, autonomous capability would be accomplished at the launch area to exercise and evaluate the flight readiness of the vehicle systems.

It should be noted that no critical or major new manufacturing or subsystem development facilities are anticipated. Engine, airframe, and electronics subsystem development can be accomplished within current national facilities or modifications thereto.

#### IV. CONCLUSION

A wide spectrum of space mission opportunities and scientific/applications transportation needs have been identified for the period of the mid-1970's and beyond. In a broad sense, the envelopes of payload performance and other critical mission-related requirements for this mission spectrum bracket a sizable number of common one-way and round-trip space shuttle performance requirements and operational modes. The attainment of a space shuttle system, which can operate on demand at annual costs an order or two of magnitude lower than current systems should not be considered solely in terms of probability but more in terms of essentiality to the effective growth of future space operations. The ability to exploit space based opportunities as they occur or naturally evolve is of vital national interest.

##### A. PREFERRED CONCEPT(S)

1. Fully reusable or near fully reusable system concepts offer the maximum potential for a low operating cost, versatile space shuttle system that can readily satisfy the vast majority of future space transportation requirements. The broad one-way and round-trip payload weight and integral volume requirements and maximum system reuse considerations favor large lifting planform configurations, re-entering at low wing loadings and capable of controlled runway landings at fixed sites.

2. Areas requiring major emphasis and considerably increased R&D are:

a. Reusable, high performance hydrogen/oxygen rocket engines.

b. Attitude control propulsion systems.

c. Reusable thermal protection systems with minimum refurbishment requirements.

d. On board electronic systems dealing with computer supported information processing and display, such as **checkout**, fault isolation, flight path energy management and control, nav-guidance, etc., and including consideration of the direct incorporation of logic functions of test and monitoring into subsystem major components.

e. Long-life and efficient primary structural systems.

f. Configuration definition; vehicle and subsystems synthesis to attain a stable and controllable configuration for the total flight regime.

## B. THE FUTURE

The development of a space shuttle can establish for the United States, world leadership in the field of aerospace transportation. The reusable space shuttle would provide a wide range of capability in space operations --- a capability that is the keystone to the success and growth of future space flight developments for the exploration and beneficial uses of near and far space. Program definition and system specifications for the reusable space shuttle can be accomplished within eighteen months.

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