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N91-28204

SHUTTLE DERIVED MANNED TRANSPORTATION SYSTEMS

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM
PENNSYLVANIA STATE UNIVERSITY
JUNE 1990

WAYNE L. ORDWAY
SYSTEMS ENGINEERING DIVISION
NASA JOHNSON SPACE CENTER
HOUSTON, TX

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Wayne L. Ordway
NASA Johnson Space Center
Houston, TX

Abstract

Shuttle derivatives have been under study by the National Aeronautics and Space Administration (NASA) for a number of years. With Space Station Freedom and the Lunar/Mars Initiative established as national objectives, the demand for access to Earth orbit is accelerating. These objectives have resulted in efforts to address additional launch requirements that must be met as we approach the turn of the century. Among the top level requirements are increased safety, higher reliability, lower cost, and the need for heavy lift launch capability. To satisfy these requirements, some of the largest technology demands will be placed upon the propulsion systems. This paper will present Shuttle derived manned concepts and will discuss the associated propulsion issues which arise from the top level requirements. These concepts are presented in terms of an overall architecture which can be achieved with modest up-front development.

Introduction

Space Shuttle derivative studies conducted over the past decade have primarily emphasized cargo vehicles. Shuttle Evolution assessments initiated in 1988 are attempting to address the corresponding issues for manned transportation systems. This paper will discuss some Shuttle derivatives with particular application to manned missions, though cargo delivery will be addressed in order to describe an architectural solution. Consideration of all three fundamental Shuttle hardware elements, the External Tank (ET), boosters, and Orbiter is essential to the evolution of an architecture which will meet long term requirements.

The primary goals for the next manned transportation system are to achieve increased reliability and safety, lower operational costs, and increased operational capability. As historically demonstrated throughout the aircraft and aerospace industry, such needs can be satisfied efficiently by introducing block upgrades to the elements of the system which have operational shortcomings. Shuttle operational experience has identified one of the prominent elements influencing reliability, safety, and cost to be the vehicle propulsion systems. The challenge of meeting the goals for the next generation systems will impose direct requirements upon the technologies and philosophy to be applied to development of new and/or modified propulsion systems. These requirements, to a large extent, will be imposed on both the manned and unmanned transportation system elements.

Launch Requirements

The civilian space requirements are formulated in the Civil Needs Data Base (reference 1) and are augmented by the requirements postulated in the Human Exploration Study performed by NASA in the Fall of 1989 (reference 2). Although preliminary, these sources enable determination of the fundamental launch requirements. The deliverables can be broadly categorized into the transportation of personnel, hardware, and propellant.

Extending human presence in space will require a considerable increase in the crew rotation capability beyond the present maximum of 70 crew members per year. This rate is based upon a Shuttle capability of 14 flights per year and 2 crew/5 passengers per flight. Projected requirements approach a rotation rate of 90 passengers per year in the 2010 time period with a Lunar/Mars initiative (figure 1). Increasing the crew capacity of the Shuttle to 10 (2 crew/8 passengers) is considered a viable option and becomes a basic requirement for the Shuttle derived system described in this report.

Requirements for cargo delivery must be examined for both hardware and propellant delivery since the two payload types can result in different delivery systems. For a typical Lunar mission, based on the requirements in reference 2, the total system mass in low Earth orbit (LEO) is on the order of 450K lbs for an aerobraked, fully fueled LOX/LH₂ transfer system. The capability for a direct launch, Lunar mission is highly desirable for an early Lunar program and would also enable reasonable means of initiating more aggressive missions (e.g. Mars). This goal establishes an upper, lift capability requirement of 450K lbs on the derived launch system. The Lunar mission LEO mass of 450K lbs breaks out into 300K lbs of required propellant and 150K lbs of hardware. These masses are representative of re-supply requirements for hardware and propellant for projected Lunar missions. Once the reusable, space based hardware is in place, however, propellant will become the dominant commodity. Consideration of these projected lift requirements has led to study of modular, heavy-lift transportation systems with payload capabilities up to 450K lbs.

Candidate Evolution Strategy

To address the goals of lower operational costs and increased capability for the next manned transportation system, an evolutionary strategy has been proposed which utilizes Shuttle derived hardware elements and draws upon the lessons of Shuttle operational experience (reference 3). The basic elements comprising the evolutionary architecture are: 1) an External Tank (ET) derived core stage, 2) a liquid rocket booster (LRB) system, and 3) a Block-II Orbiter lacking the main propulsion system.

A core stage consisting of a modified ET with an integrated main propulsion system has been previously studied (references 4,5). Figure 2 illustrates a candidate concept which is configured with three Space Shuttle Main Engines (SSME) and an optional propulsion return module. Standard SSMEs, to be operated at 100 percent thrust levels,

were baselined in this design in consideration of the planned improvements and the extensive operating experience and reliability which will have been achieved by the time the evolved systems become operational. To provide capability for the orbital insertion and maneuvering requirements typical of propellant delivery missions, provision is also made for a separate orbital maneuvering/reaction control system. The derivative concepts under consideration are intended to remain flexible to the incorporation of new, low cost propulsion systems which become available.

Based upon studies performed in 1988-89 (references 6,7), a new LOX/LH2 liquid rocket booster (LRB) system is a favored candidate for the evolution architecture. With the LRB concept shown in figure 3, the system's payload capability to LEO can be extended to 65-70K lbs. Among the many desirable attributes of this system are common propellant and engine systems, potential redundancy for engine out, abort options, environmentally clean exhaust, improved ground processing and safety, and growth potential. Additionally, the LRB has considerable synergism with heavy-lift launch vehicle concepts and with alternate access options such as the Personnel Launch System (PLS). The low cost, reliable propulsion systems developed for the LRBs may also have application to long-term evolution concepts of a "Shuttle-II" system incorporating fly-back boosters.

To address the requirement for increased crew capacity, a "Block-II" Orbiter is proposed with an enlarged crew compartment designed to accommodate a crew of ten. Removal of the main propulsion system from the Orbiter, enabled with a core stage concept, is the next major modification which offers several advantages. First, it separates the launch function from the spacecraft, with an associated reduction in vehicle complexity. Second, it provides the potential for increased operational capability. The available volume from removal of the propulsion system could house additional orbital maneuvering system propellant and the Orbiter weight reduction could translate into down payload capability. Additional enhancements which have been defined in recent Shuttle Evolution studies are included in the "Block-II" concept. These enhancements address a variety of vehicle subsystems and are designed to achieve the top level transportation system goals. The "Block-II" Orbiter concept is illustrated in figure 4.

The complete, Shuttle derived launch vehicle concept is depicted in figure 5 along with the estimated performance capability which results from enhancement weight changes. Performance capability for the derived Orbiter concept, however, is not considered the primary goal. If it is assumed that cargo delivery will be performed to a large extent by unmanned launch systems, performance capability can be traded for increased margins enabling the "Block-II" Orbiter to emphasize enhanced crew capability and on-orbit operations.

The described modifications to the Shuttle elements produce a manned transportation system which offers flexible architecture options. Elements from this system can be used to provide alternate access with a Personnel Launch System as well as substantial heavy-lift payload delivery with cargo and propellant launch vehicles. Modular, heavy-lift launch vehicle concepts incorporating a stretched core stage and 6-8 LRBs can be configured to meet a single launch Lunar mission cargo

requirement of 450K lbs. This vehicle can satisfy Lunar mission needs with minimum required on-orbit assembly and check-out and also provides reasonable capability for initiation of a Mars program. The overall evolution strategy requires no technology breakthroughs and is capable of meeting a wide range of requirements well into the next century. An illustration of the fundamental architecture is presented in figure 6.

System Requirements

Achieving the top level goals of increased reliability and safety, and lower operational costs for the next space transportation systems will require that an integrated systems engineering approach be employed throughout the design. The fundamental requirements placed upon the vehicle subsystems must be derived to optimize the overall system goals. With the substantial cost which will be associated with future systems and payloads, the reliability expectations for unmanned cargo vehicles have become as demanding as for the manned vehicles. In order to assess how the requirements for these vehicles differ, the subject of man rating must be addressed.

A man-rated system is defined to be one for which all elements are designed with the highest possible reliability, including the required escape system or safe haven. The philosophy applied to these systems emphasizes simple designs whenever possible and the use of only proven technology. Where application of new technologies appears beneficial, technology development programs should precede in order to evaluate reliability. A basic set of guidelines has been established which constitute design criteria for the man-rating of space systems (reference 8). The design emphasis prescribed for the system generally dictates the extent to which these guidelines are applied (figure 7). A summary of the man rating design guidelines is presented in figure 8.

One of the foremost criteria unique to man-rated systems is the requirement for a crew escape system. Design studies being conducted within NASA are evaluating several approaches for ensuring crew safety in the next manned space vehicles. Crew escape options under consideration range from basic ejection concepts to intricate crew escape modules designed to survive the most catastrophic failure. Implicit in the requirement for crew escape provisions is a corresponding requirement for fault detection capability. Accurate and reliable means for sensing and isolating critical hazards is fundamental to crew safety and abort flexibility and is an essential requirement applicable to all critical systems for man-rated vehicles.

With regard to vehicle propulsion systems, an issue which arises specifically from man-rating considerations is the requirements on engine throttling capability imposed for ascent g-limiting and abort criteria. Engine throttling requirements need to be evaluated and set from a vehicle-level assessment of capability versus system complexity. Imposing throttling constraints based upon propulsion system considerations alone may not properly address the top level goals for the vehicle. Another issue with implications to engine throttling is the desire for engine-out capability. This approach to improving overall reliability will introduce a minimum throttle-up requirement upon the propulsion system. Fundamental to the engine-out design

philosophy is an assumed low probability of catastrophic engine failure. This places a basic requirement on the engine design to emphasize benign failure modes, in which other elements are not damaged by a failure, to the greatest extent possible. Approaches to engine design which minimize the potential for catastrophic failures have been identified from evaluation of historical engine failures (reference 9). In consideration of these many critical functions to be performed through propulsion system throttling, minimizing the failure potential of the throttling function in itself will be of utmost importance.

The remaining propulsion issues address the top-level goals of high reliability and low cost and are considered to be equally as important for unmanned systems as for manned systems. Ensuring high reliability for the next transportation systems may favor new approaches to propulsion system design. An example of one such approach is integrated system designs with sharing of components (reference 10). New and innovative design approaches need to be studied to substantiate their benefit potential. Regardless of the design approach, however, there are common propulsion requirements which can be discussed. The system and its components will be required to be fault tolerant. Another basic requirement will be the need for a comprehensive test program designed to verify functional reliability and establish system failure limits. The system's limitations and safety margins should be determined through off-limits testing including tests-to-failure to demonstrate the failure modes and effects. The capability for on-board, automated check-out and verification is also a desirable provision of future propulsion systems. In general, a requirement for some degree of propulsion system health monitoring and control will need to be specified.

In consideration of the lessons learned through Shuttle operational experience, a clear requirement for future propulsion systems will be improved maintainability and minimized hazardous operations. As shown in figure 9, the Shuttle's main propulsion system is responsible for a significant percentage of the Shuttle's operational processing time. Emphasis placed upon simplicity and accessibility during the design process can translate directly to reduced propulsion system operational costs. A summary of the issues and requirements identified for next generation propulsion systems is presented in figure 10.

Conclusion

An architectural strategy which utilizes Shuttle derived elements and a new LRB system appears a viable approach to achieving the goals of higher reliability, lower operational costs, and increased capability for the next manned transportation system. Evolution with a "Block-II" system offers the potential benefits of reduced risk and lower up-front development costs. The foreseen requirements for vehicle propulsion systems predominantly address the need for fault tolerance and health monitoring capability. High reliability is an expectation for both manned and unmanned systems. Specific requirements for propulsion throttling capability may arise for manned vehicles and will need to be derived on the basis of the vehicle requirements.

References

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EVOLVING REQUIREMENTS

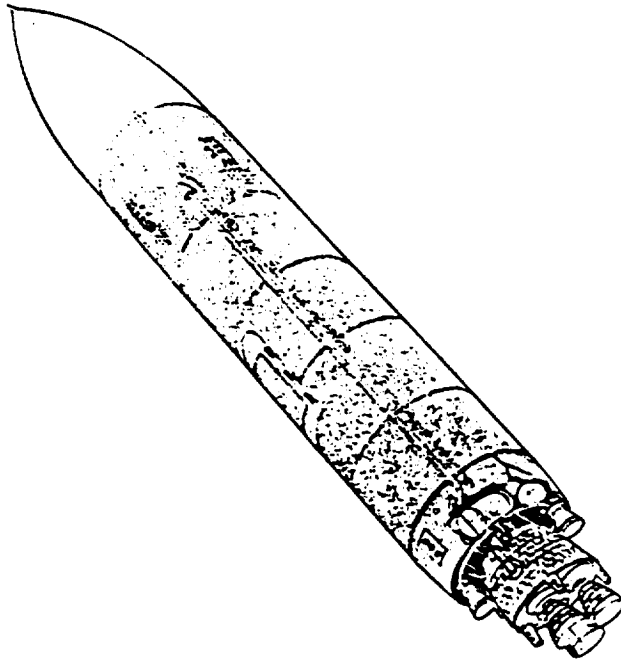
- EXPANDED HUMAN
PRESENCE IN SPACE
- ORDER MAGNITUDE
INCREASE IN LIFT
CAPABILITY
- PROPELLANT
(BULK) DELIVERY
- DOWN PAYLOAD

Figure 1

CORE STAGE

(EXTERNAL TANK DERIVATIVE)

- BENEFITS
 - IN - LINE PROPULSION
 - ENABLES SIMPLER ORBITER
 - SEPARATES LAUNCH PROPULSION FROM SPACECRAFT
 - ENABLES MODULAR LAUNCH SYSTEM



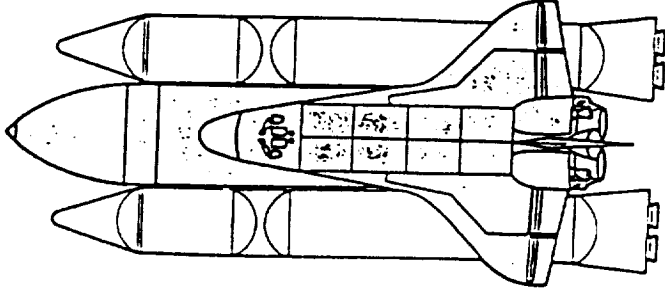
	CORE STAGE WEIGHT SUMMARY		
	EXPENDABLE 3 SSME P/A	WITH P/A MODULE	WITH ORBITAL INSERTION CAPABILITY
BASELINE ET (ET-41)	66588	66588	66588
AL-LJ ET	-8000	-8000	-8000
ENGINES, STRUCTURE FEED LINES, ETC	32000	32000	32000
DELTA WEIGHT FOR THRUST LOADS	7710	7710	7710
AFT SKIRT	6360	6360	6360
SUBSYSTEMS, INCL AVIONICS, TVC	8929	8929	8929
OMS/RCS	..	-	8684
P/A MODULE	..	9929	9929
SUBTOTAL	113587	123516	132200
10% MARGIN **	116687	127609	136293

**APPLIED TO NEW HARDWARE ONLY

Figure 2

LIQUID ROCKET BOOSTER

- BENEFITS
 - ENHANCED SAFETY
 - SHUT DOWN CAPABILITY
 - ADDITIONAL ABORT MODES
 - PRE-LIFT-OFF PERFORMANCE VERIFICATION
 - ENVIRONMENTALLY CLEAN
 - EFFICIENT LAUNCH OPERATIONS



Features

- LH2/LO2 propellants
- 2219 aluminum tankage
- New low-cost, pump-fed engines
- 4 engines per booster
- Expendable (engines may be recovered)
- Existing technologies

	LRB
Length (ft)	178
Diameter (ft)	18
Booster dry weight (lb)	122,000
Booster gross weight (lb)	821,000

Figure 3

ENGINELESS ORBITER

ORBITER WEIGHT SUMMARY

	WEIGHT, Lbs
OV 103, STS-37*	228000.00
TOP 10 ENHANCEMENTS	
ELECTROMECHANICAL ACT.	-5000.00
ADV. FUEL CELLS	..
INTEGRATED OMS/RCS.	-1580.00
OMS POD REDESIGN	
IMPROVED VERNIERS	..
IMPROVED AVIONICS	-1500.00
INCREASED CREW	1350.00
AUTOMATED ORBITER	..
COMPOSITE FLAP, ELEVONS, OMS POD	-1508.00
ADVANCED TPS	-1580.00
EXTENDED NOSE GEAR	..
INTEGRATED THERMAL CONTROL SYSTEM	TBD
BLOCK-II SSME	750.00

LESS PROPULSION SYSTEM	218972.00
	-40800.00

TOTAL	178172.00
PLUS CREW ESCAPE MODULE	15000.00

*TRANSATLANTIC ABORT CONDITION	193172.00

- BENEFITS
- INCORPORATES "TOP 10" ENHANCEMENTS
- MUCH SIMPLER, LIGHTER
- QUICKER TURNAROUND AT KSC

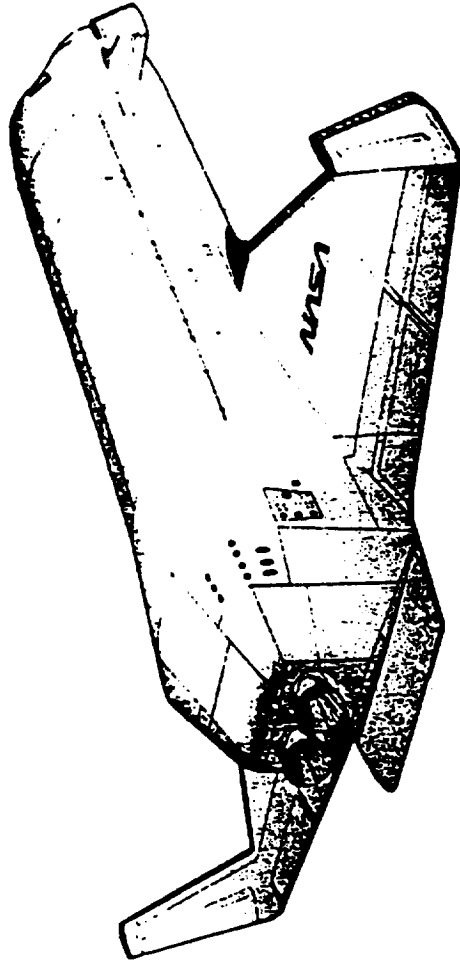


Figure 4

INTEGRATED LAUNCH STACK

PERFORMANCE IMPACTS DUE TO WEIGHT CHANGES

PAYLOAD, LBS

NSTS BASELINE 65000

BLOCK II ORBITER (WITH CEM) 37840

ET CORE STAGE -70705

LRB 20000

.....

NET PAYLOAD 52135 (67135 WITHOUT CEM)

MARGIN ENHANCEMENT (CANDIDATES LIST)

LOWER DYNAMIC PRESSURE
STANDARD I-LOAD -5000

100% SSME -4000

.....

PERFORMANCE TRADED FOR
MARGINS, LOWER COST -9000

NET PAYLOAD 43135 (58135 WITHOUT CEM)

Aggressive SSV Evolution Option

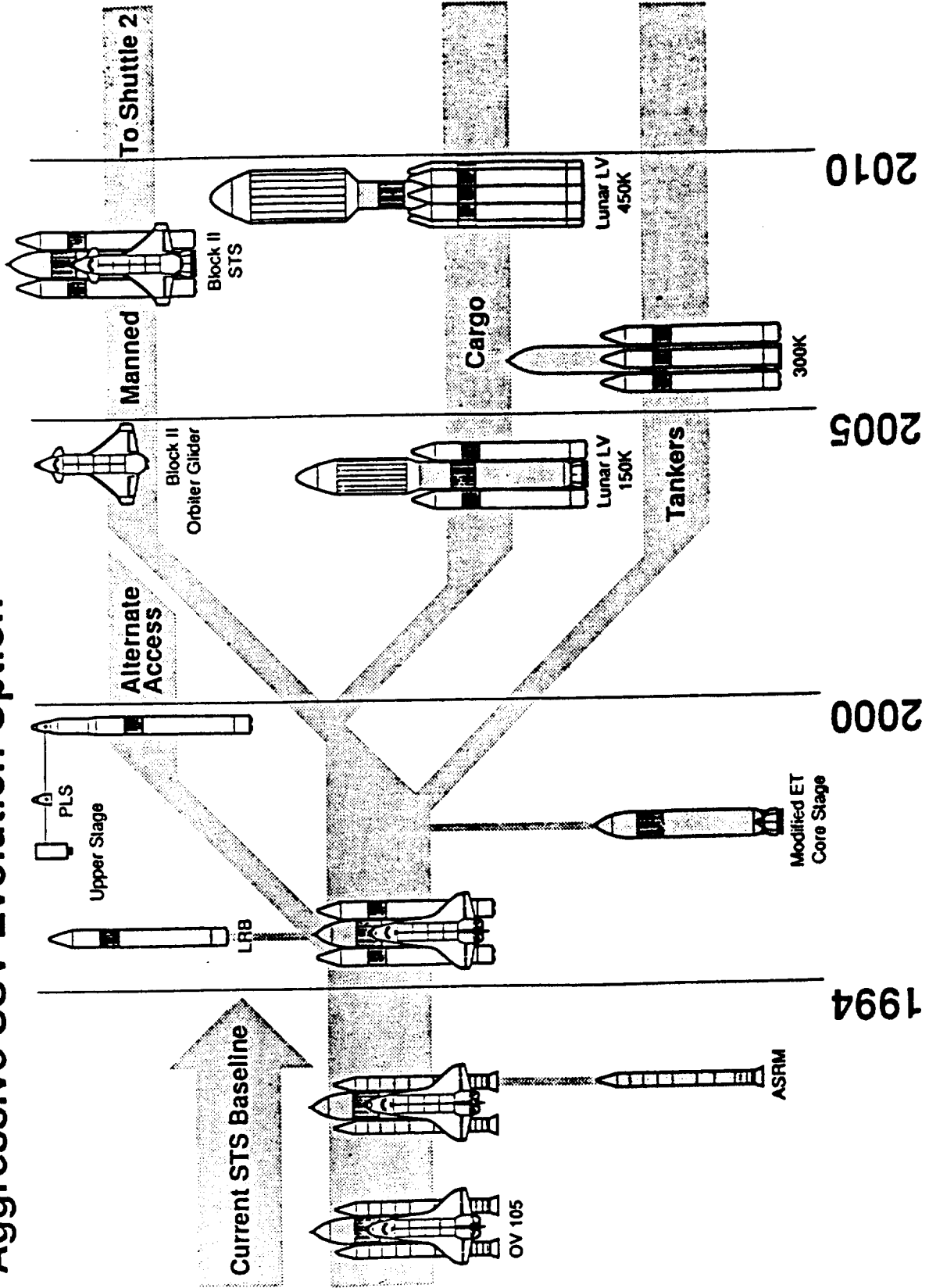


Figure 6

MISSION RISK LOGIC DIAGRAM

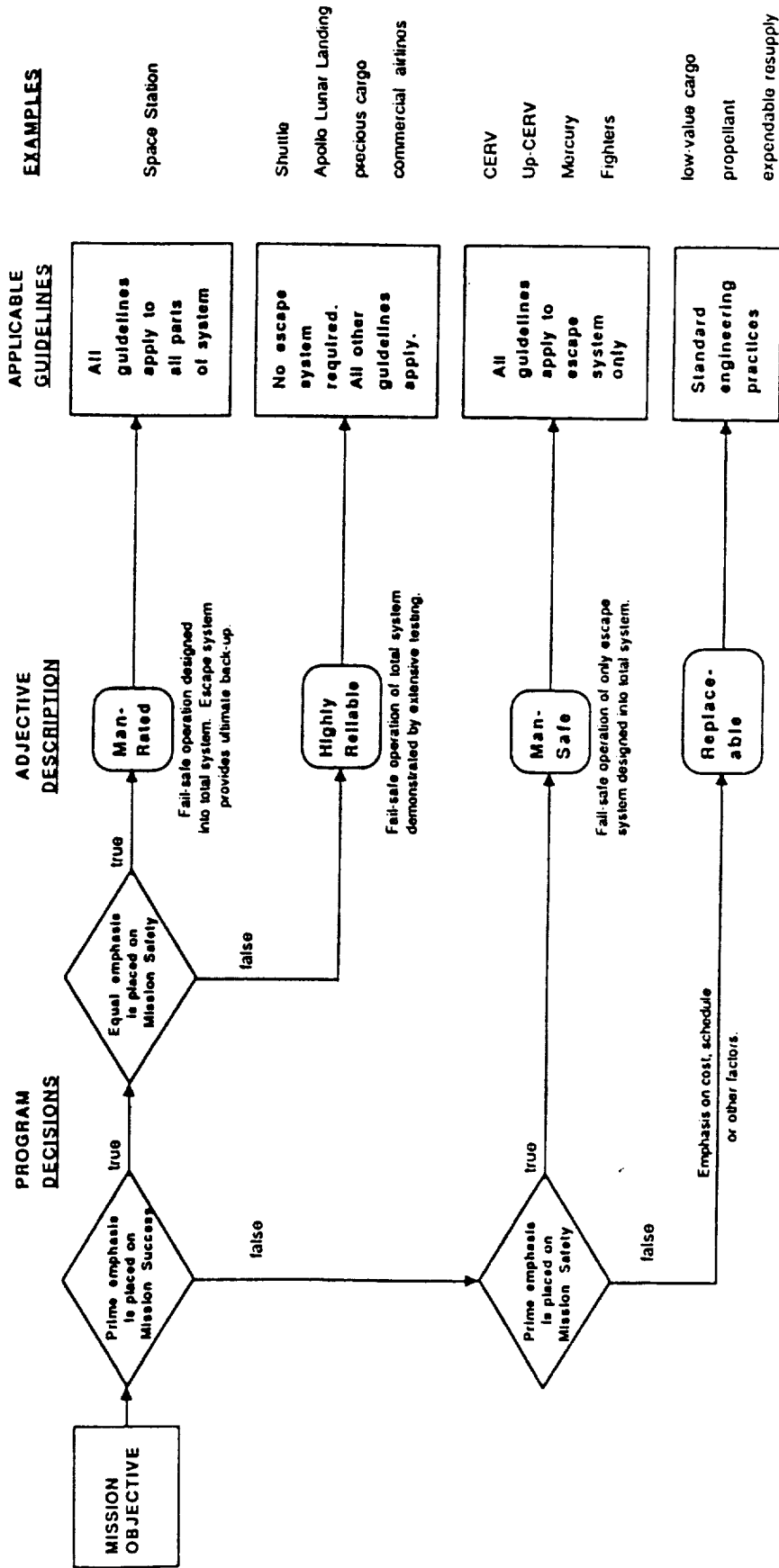
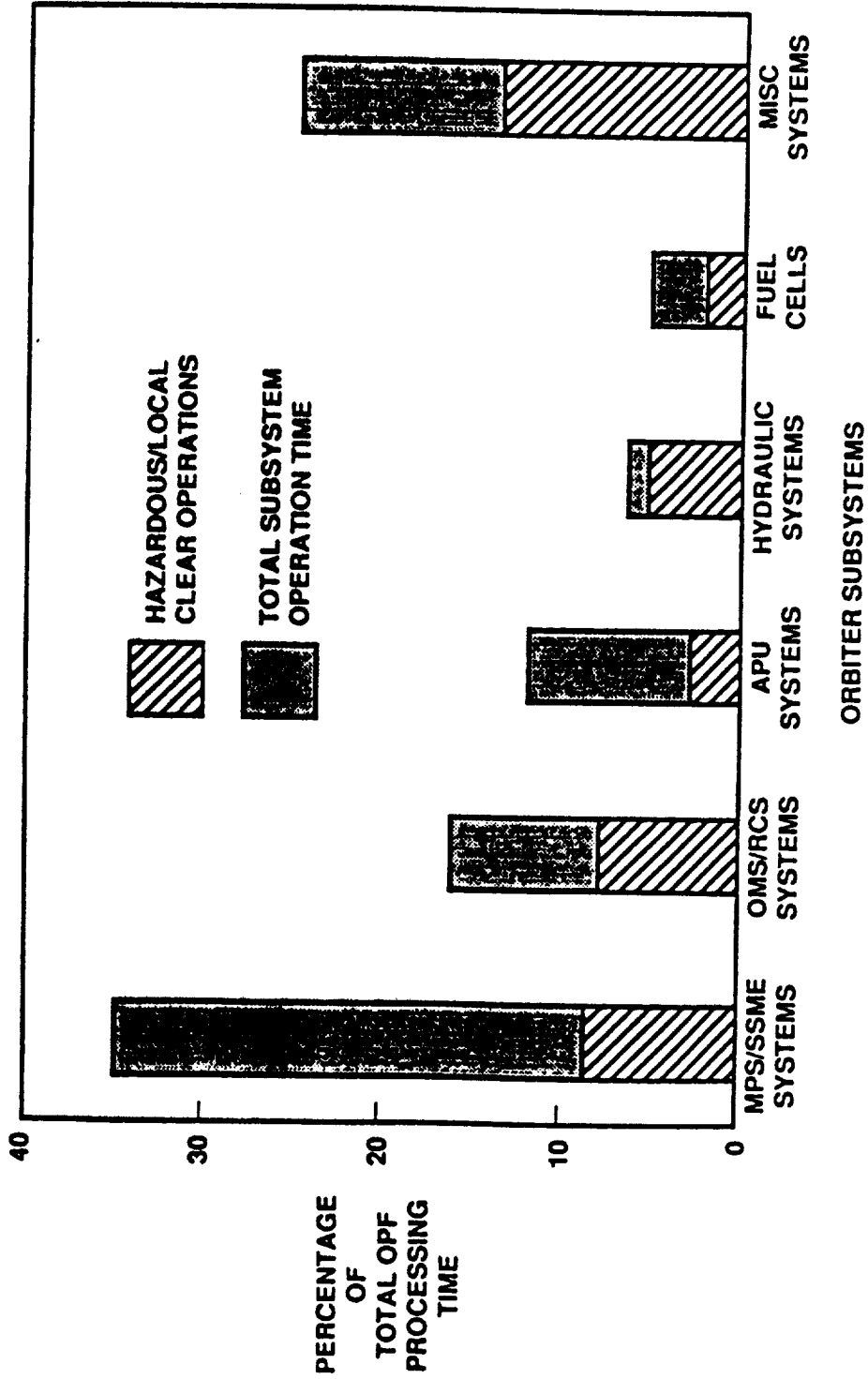


Figure 7

DESIGN GUIDELINES FOR MAN-RATING SPACE SYSTEMS

- 1) ENVIRONMENTAL CONDITIONS FOR OPERATIONS
- 2) CREW ESCAPE SYSTEM
- 3) FAILURE TOLERANCE : Primary structure, pressure vessels and thermal protection systems should be designed for zero tolerance for any failure or malfunction that would jeopardize crew safety.
 - Design of all other critical systems should ensure:
 - a) No single failure results in a critical hazard.
 - b) No two failures result in a catastrophic event.
- 4) HAZARD DETECTION AND SAFING
 - Vehicle Diagnostic Systems
 - Fire Suppression Capability
- 5) STRUCTURAL / MATERIALS CRITERIA
- 6) REDUNDANCY
 - Appropriate functional redundancy on all critical systems (i.e. fail-safe, fail-operational/fail-safe, etc.)
- 7) DISPLAYS AND CONTROLS
 - System status monitoring and failure alerts

ORBITER PROCESSING TIME BY SUBSYSTEM



SOURCE: Rockwell International

MPS/SSME SUBSYSTEMS REQUIRE MOST OF THE ATTENTION

Figure 9

PROPULSION ISSUES AND REQUIREMENTS

- o PROPELLANT CANDIDATES (Safety, Reliability, Cost, Commonality)
- o SYSTEMS APPROACH TO PROPULSION DESIGN
- o FAULT TOLERANCE
 - Design for Benign Failure Modes / Failure Containment (Eliminate gears, provide lubrication, etc.)
 - Engine-Out Capability
- o ONBOARD CHECK OUT AND VERIFICATION CAPABILITY
 - Propulsion System Verification at Operational Conditions
- o HEALTH MONITORING AND CONTROL
 - Accurate Hazard Detection and Real-time Diagnostic Capability
 - Highly Reliable/Redundant Systems
 - Technology Development Program
- o THROTTLING CAPABILITY
 - Needs To Address System Requirements (G-Limiting, Q-Control, Engine-Out)
 - High Reliability (Implications to Abort Capability)
- o COMPREHENSIVE TEST AND VERIFICATION PROGRAM
 - Establish True Propulsion Failure Limits (Off-Limits Testing and Test-to-Failure)
 - Verify Failure Modes and Effects
- o OPERATIONALLY EFFICIENT (Low Cost, High Reliability and Maintainability)
 - Design for Simplicity and Accessibility; Implement Nondestructive Evaluations
 - Quality Assurance

Figure 10

**SHUTTLE DERIVATIVES - UNMANNED
AND
BOOSTER PROPULSION - LIQUIDS/HYBRIDS**

